Energy Use and Environmental Impact from Hotels on the Adriatic Coast in Croatia - Current Status and Future Possibilities for HVAC Systems

Doctoral Thesis

by

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Division of Applied Thermodynamics and Refrigeration
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ABSTRACT

This thesis analyses a specific type of energy usage system, "energy usage in hotels", and how this system behaves. In order to evaluate the current state of energy use in hotels, an energy audit questionnaire was developed and conducted among 31,5% of hotels on the Adriatic coast. The energy audit was used as a tool to set a benchmark for energy consumption in hotels and to identify opportunities for increased energy efficiency measures in HVAC systems. The analysis has shown that the average energy consumption in hotels on the Adriatic coast is in the range of 159 to 180 kWh/m^2 and 162 to 225 kWh/m^2 for seasonal and non seasonal hotels respectively. In order to establish a relationship between different independent variables in the hotels (total floor area and number of rooms) and dependent variables, such as electricity and oil consumption, mathematical statistical methods, such as correlation and regression analysis, were implemented.

The objective of this thesis was also to develop - from an energy, environmental and economical points of view - a methodology for the design and retrofit of HVAC systems in the hotels on the Adriatic coast. The methodology named HOTECO is based on a system thinking approach. With respect to the technological aspects, the first step was to analyse conventional HVAC system designs and to compare it with the three most promising alternative HVAC systems utilizing renewable energy sources for a typical hotel. Computer modelling in TRNSYS was used to assess energy consumption. TRNSYS software has been used for simulations for a number of years, is internationally recognized, and has been validated and verified.

It was concluded that energy and environmental savings in hotels on the Adriatic coast could be achieved using readily available technologies. The HOTECO methodology also demonstrated a framework that supports decision making regarding system selection and operational strategies to limit environmental impact from HVAC systems in hotels. Four scenarios for energy consumption in hotels on the Adriatic coast with regards to current state of energy systems and improved retrofit solutions utilizing renewable energy source were given.

Keywords: HVAC systems, hotels, energy performance, energy efficiency, environmental savings, energy audit, system approach, sustainable energy systems

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Vlasta Zanki

Zagreb, August 2006

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1. INTRODUCTION

1.1. Background of the thesis

This subchapter is aimed to explain the relationship between energy consumption and the tourism sector. Trends in tourism and energy consumption in buildings will be explained. This should give a clear picture with respect to the environmental impacts of energy consumption in the hotel sector and what are the current EU standards that the Croatian government will have to comply with. This chapter will also indicate the main end-users and the influencing factors of energy consumption in hotels.

1.1.1. Energy use in buildings and environmental impact of buildings

Over the last twenty years, there have been significant changes in human attitude towards the environment. Two major environmental impacts that became threats to the world climate and ecosystems were highlighted, namely: global warming and ozone depletion. With respect to global warming, the building sector (residential and tertiary) is responsible for 40% of total CO_2 emissions during its life cycle in the EU and world (Eicker 2003). Energy usage breakdown in Croatia is shown in Figure 1.1.

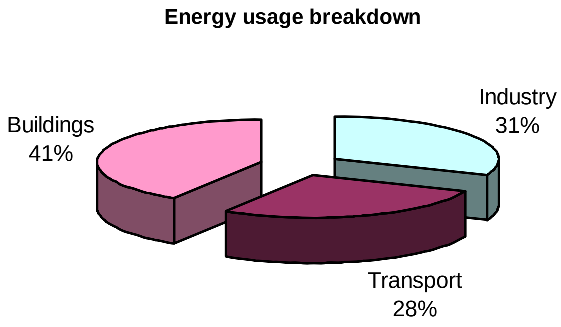

Figure 1.1. Energy usage breakdown in Croatia (EIHP 2005)

Energy end-use in different types of buildings varies however, the biggest consumers are thermal systems such as: heating, domestic hot water, cooling and ventilation systems. Energy consumption for thermal systems varies depending on building, and goes from 65% in the EU service sector (EC 2001a) (Figure 1.11.) to 80-85% in households (EIHP 2005), while in hotel sector, depending of the source (CADDET 1997, REST 2005) ranges from 61 - 70% (Figure 1.16. - Figure 1.17.). Refrigeration, air conditioning and heat pump applications represent one of the most important energy consumption sectors in present day society. It is estimated that as an average share in electricity use is between 10-20 % for the developed countries (UNEP 2003). For these reasons, this thesis focuses on energy consumption in thermal systems (HVAC&R and DHW[1]) and the environmental impacts of these in hotels.

In 2002, households accounted for 31,1% and the service sector 10,5% of Croatia's final energy demand of 232,22 PJ. These sectors were responsible for 14,7% of the total CO_2 emissions, 21,4 million tons (UNDP2005).

[1] HVAC&R and DHW – Heating, ventilation, air conditioning, refrigeration and domestic hot water

The total energy consumption in old houses is approximately 300 kWh/m^2, 180 kWh/m^2 for houses built according to standards dating from 1987 and 155 kWh/m^2 for houses that will be built according to new 2005 standards (that is in line with EU Directive Energy Performance in Buildings). The average energy consumption for building heating in Croatia, depends on its efficiency; 230 kWh/m^2 for poorly insulated buildings, 120 kWh/m^2 for average new housing and 20 kWh/m^2 for "zero" energy houses. The area of highest potential for energy savings is with heating systems (EIHP 2005).

Due to the threat of global warming, the world community committed itself to reduce green house gasses under Kyoto Protocol, adopted on December 10, 1997 (Billiard, 2005). As a consequence of this commitment the EU adopted a number of regulations and directives, among which, EU Directive 2002/91/EC on the energy performance of buildings. This directive deals with energy efficiency and environmental impact caused by energy consumption in buildings.

In accordance with EU Directive 2002/91/EC, which Member States need to incorporate into their national legislation, energy performance standards will apply to all new buildings built from January 2006. Particularly for larger buildings (over 1000 m^2), a full feasibility assessment of alternative heating and energy supply systems must be made before construction begins. The goal is this EU commitments to the Kyoto protocol is to reduce greenhouse gas emissions to 8% below 1990 levels by 2008-2012. Further on, existing buildings larger than 1000 m^2 will also be subject to energy performance improvements when they undergo major refurbishment or renovation (EC 2002).

The first part of the Directive 91/2002 deals with building physics and was incorporated into bylaw by the Croatian government in 2005. It is now in force as of July 1st 2006. Adoption of full Directive text is expected by the end of 2006.

The second important environmental impact, ozone depletion, is caused by refrigerant (CFCs[2] and HCFCs[3]) emissions from air-conditioning and refrigeration equipment. These units provide the basic needs of cooling or heating within buildings and for food preservation. These two refrigerant families also exert global warming effects. HFCs were developed in order to replace CFCs and HCFCs since they have no ozone-depleting potential. However, they do have direct global-warming effects.

The main regulations addressing ozone depleting substances (ODS) is the Montreal Protocol adopted in 1987 and the EU response to Protocol; European Regulation on Ozone-Depleting Substances No. 2037/2000 of June 29th, 2000. (Billiard, 2005). It comprises of the following key measures:

- CFCs, a total ban on use for maintenance and servicing of equipment as of January 1st, 2001;
- HCFCs, a total ban on production as of January 1st, 2025; a ban on use of virgin HCFCs in maintenance and servicing of equipment as of January 1st, 2010; a ban on the use of HCFCs for the production of new equipment from January 1st, 1996 to January 1st, 2004 depending on application (EC 2000).

According to the new Croatian bylaw on Ozone depleting substances, import of CFCs is banned from January 1st, 2006, while servicing with recycled and reclaimed CFCs is allowed till 2010. HCFCs were banned for new installation from 20 October 2005, while servicing will be allowed till end of 2015 (MZOPU 2005a).

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[2] CFCs - Chlorofluorocarbons

[3] HCFCs - Hydrochlorofluorocarbons

Atmospheric emissions from refrigerant gases arise in several ways: poor plant sealing or operation, incorrect or negligent refrigerant handling, insufficient plant maintenance, etc. In industrialized countries, actions aimed to reduce energy consumption and emissions have led to measures that cover all phases in the life cycle of refrigeration equipment (IIR 2002):

- during the design phase, features enabling refrigerating systems and component performance to be enhanced. Focus should be also on optimising plant containment and reducing the refrigerant charge;
- during installation and commissioning, application of stringent plant acceptance procedures, taking into account measurements of the energy consumption for the plant;
- during maintenance and servicing, application of stringent operating procedures
- during disposal of equipment, recovery of the refrigerant, and recycling or reclaiming whenever possible

Very few substances have properties appropriate for a refrigerant. Figure 1.2. shows some of the substances that have been used as refrigerants and how their application has varied over time. There is no ideal refrigerant, however. Selection of a refrigerant is a compromise between many factors including ease of manufacture, cost, toxicity, flammability, environmental impact, corrosiveness and thermodynamic properties as well as energy efficiency. A key characteristic is the pressure/temperature relationship. In general, for energy efficiency it is desirable that the refrigerant's critical point (temperature above which the refrigerant cannot condense) is high compared to the heat extraction and rejection temperatures.

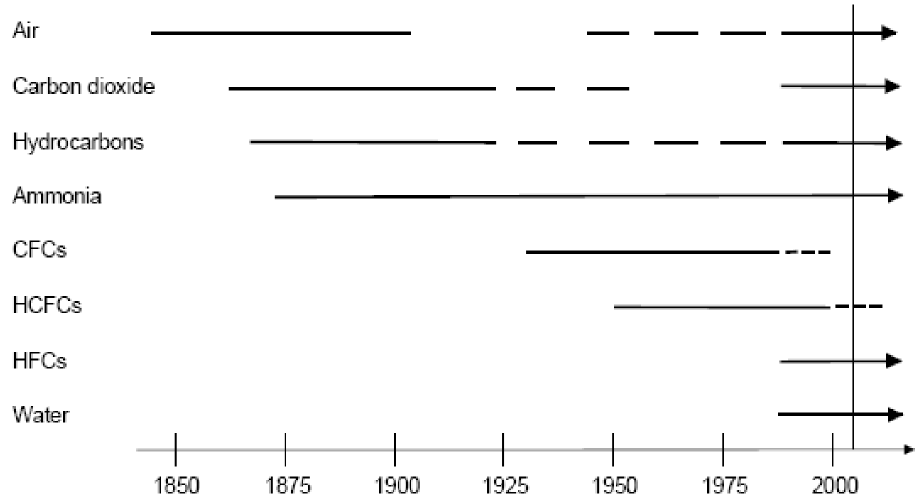

Figure 1.2. Typical refrigerants and their historical use (IIR 2003)

Although HFCs[4] are non-ozone depleting substances and are the most viable alternative for CFCs and HCFCs, they are still greenhouse gases, along with carbon dioxide, methane, nitrous oxide, PFCs[5] and SF_6[6]. The breakdown of the warming impact of GHG[7] emissions on a global scale is shown in Figure 1.3. and Figure 1.4. In 1997, carbon dioxide emissions were 89% of the total while PFCs, SF_6 and HFCs were only 1%, only half of which are HFCs for refrigerants, foam blowing applications, etc. The projected share in 2030 of HFC end-use emissions on the warming impact rise to approximately 2%, as the process of substitution of HFCs for ODS[8] is completed.

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[4] HFCs - Hydrofluorocarbons

[5] PFCs - Perfluorocarbons

[6] SF_6 – Sulphur Hexafluoride

[7] GHG – Greenhouse gases

[8] ODS – Ozone depleting substances

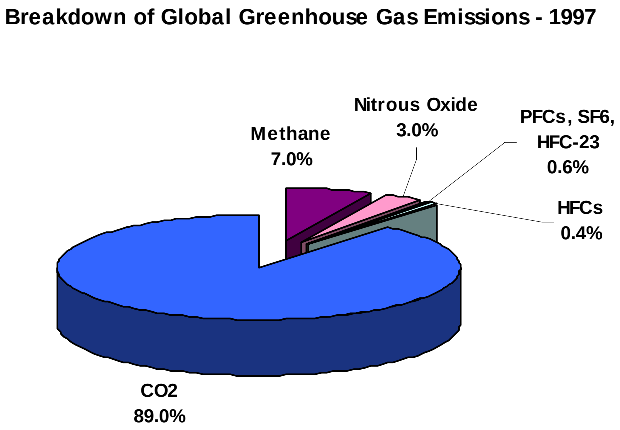

Figure 1.3. Breakdown of global Greenhouse gas Emissions in 1997, (Arthur D. Little 2002)

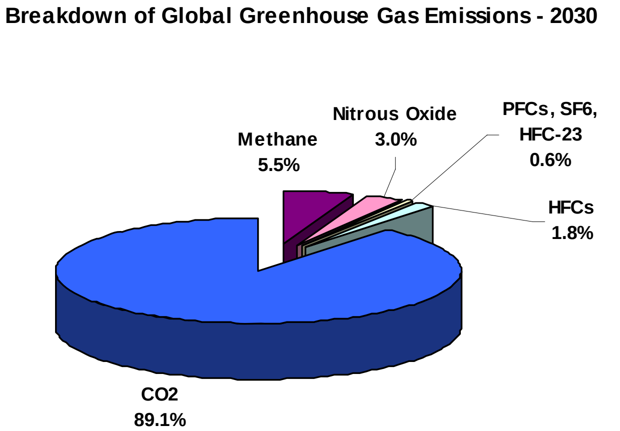

Figure 1.4. Breakdown of global Greenhouse gas Emissions in 2030, estimation (Arthur D. Little 2002)

Studies have shown that in the seven years between 1990 and 1997, when the CFC phase-out took effect in the developed countries, the warming impact of ODS emissions fell by more than 50%. By 2030, ODS releases to the atmosphere globally should be down to negligible proportions. The warming impact of projected HFC emissions in 2030 is only 12% of the warming impact of CFC emissions in 1990 (Arthur D. Little 2002).

There is a significant amount of substances contained in existing equipment, chemical stockpiles, foams and other products not yet released to the atmosphere called *banks*. Observations of atmospheric concentrations, combined with production and use pattern data, can indicate the significance of these banks, but not their exact sizes. The most accurate estimates of emissions from CFC-11 and CFC-12 are derived from observations of atmospheric concentrations. These emissions are larger than estimated releases based on current production, indicating that a substantial fraction of these emissions come from banks built up through past production. Observations of atmospheric concentrations show that global emissions of HFC-134a are presently smaller than reported production, implying that this bank is growing. The total global amount of HFC-134a currently in the atmosphere is believed to be nearly equal to the amount in banks (IPCC 2005).

It is estimated that 2221 x 10^6 kW of cooling capacity for air-cooled air conditioners and heat pumps is installed worldwide. Refrigerant charge quantities vary proportionally to the capacity. Assuming an average charge of 0.25 kg per kW of capacity, those 2221 million kW of installed cooling capacity represent and installed bank of approximately 548.000 metric-tones of HCFC-22 in the world (UNEP 2003).

Banks of CFCs, HCFCs, HFCs and PFCs were estimated at about 21 GtCO_2-eq in 2002. In a Business-As-Usual (BAU) scenario, banks are projected to decline to about 18 GtCO_2-eq in 2015. In 2002, CFC, HCFC and HFC banks were about 16, 4 and 1 GtCO_2-eq (direct GWP weighted), respectively (see Figure 1.5.). In 2015, the banks will be about 8, 5 and 5 GtCO_2-eq, respectively, in the BAU scenario (IPCC 2005).

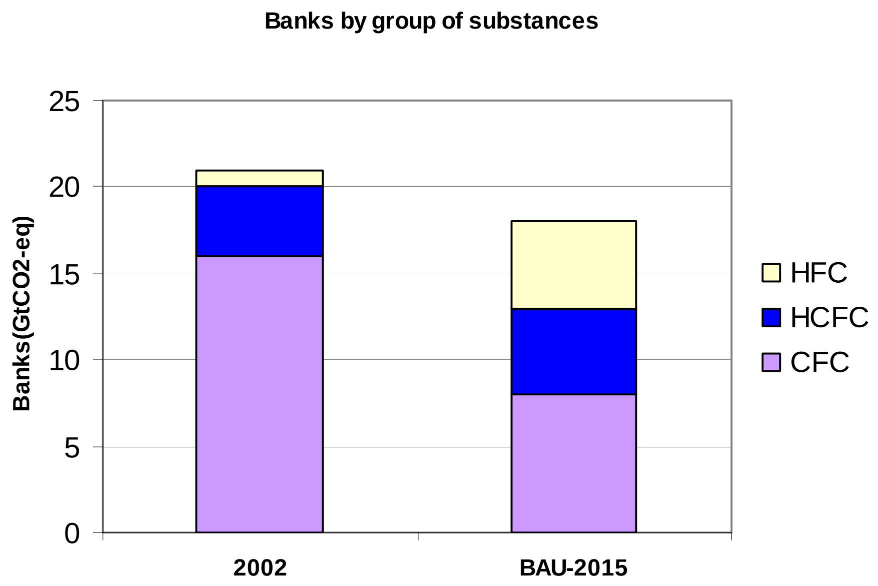

Figure 1.5. Banks by group of substances (IPCC 2005)

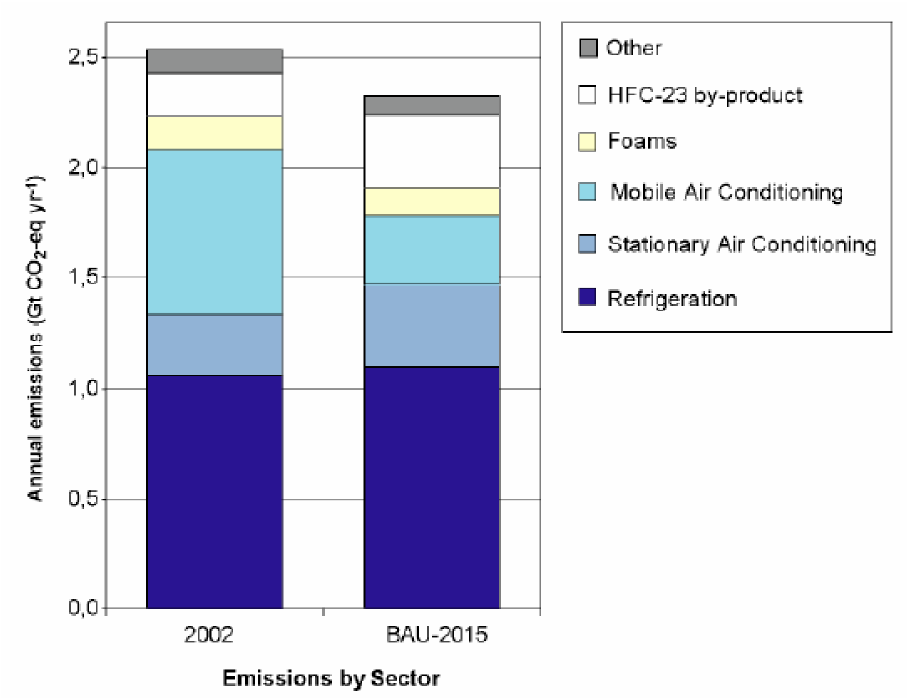

Figure 1.6. Annual emissions, related to the use of CFCs, HCFCs and HFCs per sector. (IPCC 2005)

CFC banks associated with refrigeration, stationary air-conditioning (SAC) and mobile air-conditioning (MAC) equipment are projected to decrease from about 6 to 1 $GtCO_2$-eq over the period of 2002 to 2015, mainly due to atmospheric release and partly due to end-of-life recovery and destruction (IPCC 2005).

HFC banks have started to build up and are projected to reach about 5 $GtCO_2$-eq in 2015. Of these, HFCs banked in foams represent only 0.6 $GtCO_2$-eq. Figure 1.6. shows the relative contribution of each sectors to global direct greenhouse gas (GHG) emissions that are related to the use of ODSs and their substitutes. Refrigeration applications, together with SAC and MAC, contribute to the bulk of global direct GHG emissions in line with the higher emission rates associated with refrigerant banks (IPCC2005).

In refrigeration applications, direct GHG emissions can be reduced by 10% to 30%. For the refrigeration sector as a whole, the Mitigation Scenario shows an overall direct emission reduction of about 490 $MtCO_2$-eq per year by 2015, with about 400 $MtCO_2$-eq per year predicted for commercial refrigeration. Specific costs are in the range of 10 to 300 US$/$tCO_2$-eq. Improved system energy efficiency can also significantly reduce indirect GHG emissions (IPCC2005).

Table 1.1. provides an estimate of the direct and indirect CO_2 emissions linked with each of the market sub-segments. The data shows that indirect CO_2 emissions represent a much larger global warming impact than the direct HFC emissions. Under the Business-as-usual Scenario the indirect CO_2 contribution is 84% of the total equivalent warming impact (TEWI) for refrigeration and air-conditioning. Air-conditioning and chillers represent 6% of direct emissions (MCG 1998).

Table 1.1. EU Emissions in 2010, Business-as-Usual Scenario, Comparison of direct and indirect emissions, refrigeration and air conditioning (MCG 1998)

Market Segment	Global Warming Emission, Mtonnes CO_2			% of GW impact related to energy use
	Direct HFC Emissions	Indirect CO_2 Emissions	Total Global Warming Impact	
Supermarket Refrigeration	9	23	32	72%
Mobile air-conditioning	8,9	14	22,9	61%
Industrial Refrigeration	3,4	25	28,4	88%
Air-conditioning, DX systems	2,6	10	12,6	79%
Small Commercial Distributed	1,8	12	13,8	87%
Domestic Refrigeration	0,8	30	30,8	97%
Transport Refrigeration	0,7	6	6,7	90%
Air-conditioning, chillers	0,7	12	12,7	94%
Other Small Hermetic	0,3	12	12,3	98%
TOTAL EMISSIONS	**28,2**	**144**	**172,2**	**84%**

Although the intention of the EU is to decrease the need for heating and cooling of buildings by using passive technologies, improved insulation and energy efficiency technologies, the air-conditioner world market is still expanding and the sales have been estimated at about 39.7 millions of units in 2000, among which 29,9 millions are room air conditioners (RAC) and 9,8 millions are Central air conditioners (CAC) (CENERG 2005).

Europe is responsible for only 6% of installed air conditioning equipment worldwide. However, the air conditioning market in Europe is expanding quickly in recent years (Figure 1.7. and Figure 1.8.), and room air conditioners are more widespread in the tertiary sector. Market research shows that only 27% of the European tertiary sector and 5% of the residential sector are equipped with room air conditioners. (CENERG 2005). Therefore, it can be concluded that the market is far away from saturated.

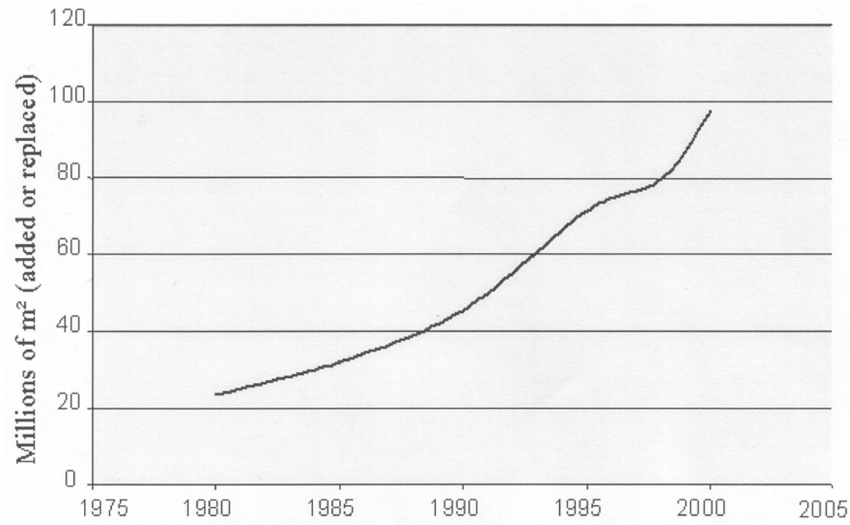

Figure 1.7. Annual additional building floor area conditioned by CAC form 1980 to 2000, for EU (CENERG 2005)

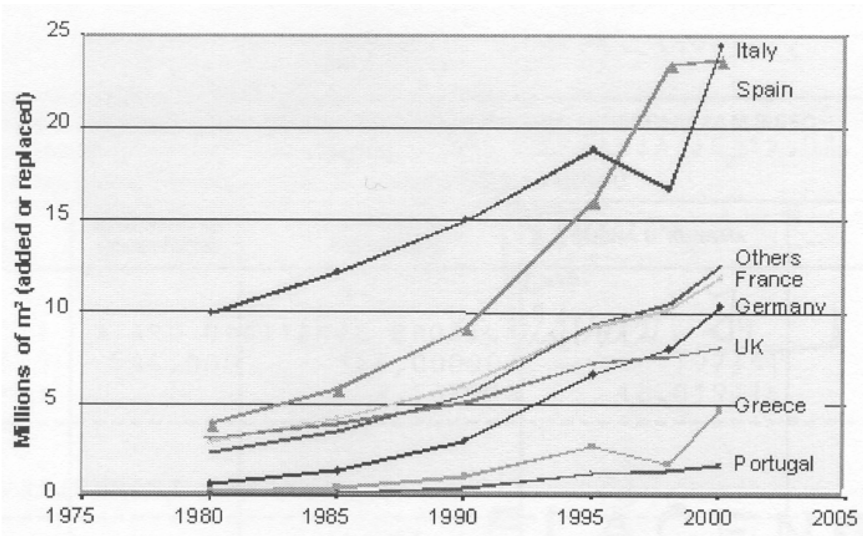

Figure 1.8. Annual additional building floor area conditioned by CAC from 1980 to 2000 by countries (CENERG 2005)

One can see from the Figure 1.8. that Spain and Italy, being Mediterranean countries, represent more than 50% of the EU market.

Most specialists are of the opinion that vapour-compression systems are likely to be the dominating trend over the next 20 years (IIR 2002). The challenge remains to develop vapour-compression systems that are environmentally friendly, energy-efficient, robust and sustainable, cost-effective and safe for users. Bearing in mind these challenges, some of the objectives that the International Institute of Refrigeration set for the next 20 years, with 2000 as a baseline are:

- to reduce energy consumption by 30% to 50%
- to halve refrigerant leakage
- to improve LCCP (Life Cycle Climate Performance) by 30% to 50%
- to reduce the refrigerant charge by 30% to 50% (IIR 2002)

However, defining quantitative objectives is useful only if reliable benchmarks are defined and validated. In this research, benchmarks for existing hotels were established. By doing so, validating proposed advanced technologies was possible.

Technologies using vapour-compression systems that can meet the objectives stated above and proposed by IIR are:

- sustainable building that can be achieved only if energy efficiency is taken into account right from the beginning of the design process.
- heat pumps (IIR 2002).

Presently about 130 million heat pumps with a thermal output of 1300 TWh/yr are in operation worldwide, reducing CO_2 emissions by about 0,13 Gt/yr (Halozan, 2004). Heat pump technology is considered to be one of the key players for energy conservation and CO_2 reduction. Considering a 30% market penetration of the building sector in the coming years, using currently available technologies, potential savings in worldwide CO_2 emissions are estimated at 6%. This 6% is among the largest contributions to CO_2 reduction a single currently available technology can offer.

One of the technologies that can also contribute to CO_2 emission savings on the Adriatic coast in the heating season is assumed to be heat pump technology. The same system will be used in the cooling season which will additionally decrease investment costs.

Improving the energy efficiency of refrigeration systems is not difficult and should be encouraged because of its environmental benefits (IIR 2003). Therefore, all components in vapour compression systems (compressor, condenser, expansion device, evaporator, and interconnecting piping) should be optimized and efficient.
In order to combat global warming, the main strategies are; reduction of energy consumption, reduction of refrigerant emissions, research and development on new refrigerants and not-in-kind (NIK) technologies, new developments in the cold chain and new developments in air-conditioning and heating systems (IIR 2002).

Promising technologies that will play important roles in ensuring sustainable development using non-vapour-compression systems are:

- Absorption and adsorption cooling systems, which quite often are fuel fired. Low energy efficiency is still the major drawback of this technology
- Solar refrigeration and cooling should be given priority
- Trigeneration (combined cooling, heat and power) has considerable benefits from and energy standpoint. The development of high-performance absorption plants will enhance the benefits such system (IIR 2002).

However, the vapour compression cycle is thought to remain the most important technology. For the long term, there remains only five important refrigerant options for the vapour compression cycle for the refrigeration and A/C sectors, listed alphabetically (UNEP 2003):

- ammonia (R717)
- carbon dioxide (R744)
- hydrocarbons and blends (HCs, e.g. HC-290, HC-600, Hc-600a etc.)
- hydrofluorocarbons (HFCs, HFC-blends)
- water (R718)

General solution strategies for air-conditioning and sustainable buildings according to ASHRAE/IESNA (IIR 2002) are:

- consider energy efficiency from the outset of the building design process;
- seek the active participation from members of the design teams including architects, engineers and builders;
- consider building attributes such as function, form, orientation, window/wall ratio and HVAC system types early in the design process;
- minimise heating and cooling loads by analysing the external and internal loads for both peak and partial load conditions;
- consider how to reclaim, redistribute and store energy for later use;
- transporting energy from production and availability sources to locations of demand should be considered instead of purchasing additional energy;
- never reject waste energy at temperatures usable for space conditioning without calculating the benefits of energy recovery ore reuse;
- make use of heat pumps to upgrade waste heat to the temperature level required for further use;
- maintaining good indoor air quality (IAQ) by introducing the outside air flow recommended by standards. The energy cost for greater quantities can be disproportionate;
- apply new concepts such as low-temperature heating and high-temperature cooling;
- use design solutions that are easily understood by building occupants.

Principles of design for building envelope according to ASHRAE/IESNA are:

- the building design should attempt to offset gains and losses of heat, light and moisture between the interior and exterior of the building, among interior spaces and over time;
- in energy design, the desired goal should be to produce a controlled membrane that allows or prevents heat, light and moisture flow so as to achieve a balance between internal and external loads. Thus the envelope becomes an integral part of the building's environmental conditioning system;
- traditional building components must be used – insulation, caulking, weather stripping and solar shading devices;
- thermal conductivity should be controlled through the use of insulation, thermal mass and/or phase-change thermal storage at levels that minimise net heating and cooling.

Principles of design for air-conditioning systems according to ASHRAE/IESNA:

- Major heat-generating equipment (computer centres, kitchen areas, etc.) should, when practical, be located where it can offset heat losses;
- The supply of zone cooling and heating should be sequenced to prevent the simultaneous operation of heating and cooling systems for the same space;
- Controls should be provided to allow systems to operate in an occupied and unoccupied mode (IIR 2002).

Ammonia and the hydrocarbons (HCs) used as halocarbon substitutes have atmospheric lifetimes ranging from days to months, and the direct and indirect radiative forcing associated with their use is very likely to have a negligible effect on global climate. Changes in energy-related emissions associated with their use may also need to be considered (IPCC 2005). Although ammonia, hydrocarbons and natural working fluids are suggested for future application, they cannot be used safely in all applications and circumstances. The risks to be managed generally increase with increasing charge and proximity to people. The cost of safety measures required for highly flammable or toxic refrigerants, which may involve system redesign, might be more effectively invested in improved HFC systems (Arthur D. Little 2002).

Observations and model calculations suggest that the global average amount of ozone depletion has now approximately stabilized. Although considerable variability in ozone is expected from year to year, including polar regions where depletion is more significant, the ozone layer is expected to begin recovering in the coming decades due to declining ODS concentrations, assuming full compliance with the Montreal Protocol (IPCC 2005).

Figure 1.9. shows sectoral reduction potentials for direct emissions of CFCs, HCFCs and HFCs in 2015 as compared to the BAU (business as usual) projections. The overall reduction potential is about half (1,2 $GtCO_2$-eq per year) of the BAU direct GHG emissions. Direct GHG emissions of residential and commercial air-conditioning and heating equipment (SAC) can be reduced by about 200 $MtCO_2$-eq per year by 2015 relative to the BAU scenario. Specific costs range from –3 to 170 US$/ tCO_2-eq. When combined with improvements in system energy efficiencies, which reduce indirect GHG emissions, in many cases, net financial benefits accrue.

Sectoral Emissions Reduction Potentials 2015

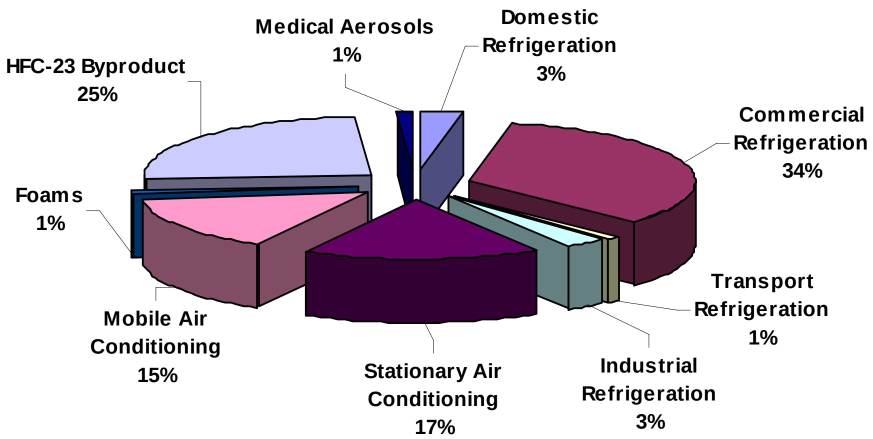

Figure 1.9. Sectoral reduction potentials for direct emissions of CFCs, HCFCs and HFCs in 2015 as compared to the BAU projections (IPCC2005)

Opportunities elaborated in International Panel for Climate Change report (IPCC 2005) to reduce direct GHG (i.e., refrigerant) emissions can be found in:

- more efficient recovery of refrigerant at end-of-life (in the Mitigation Scenario assumed to be 50% and 80% for developing and developed countries, respectively);
- refrigerant charge reduction (up to 20%);
- better containment and
- the use of refrigerants with reduced or negligible GWPs[9] in suitable applications.

Improving the integrity of the building envelope (reduced heat gain or loss) can have a significant impact on indirect emissions. HFC mixtures and hydrocarbons (HCs) (for small systems) are used as alternatives for HCFC-22 in developed countries. For

[9] GWP – Global warming potential

those applications where HCs can be safely applied, the energy efficiency is comparable to fluorocarbon refrigerants. Future technical developments could reduce refrigerant charge, expanding the applicability of HCs.

Due to the actions undertaken worldwide as a commitment to the Montreal Protocol, changes in HVAC&R sectors over the last few years are impressive and a broad range of options enabling the use of non-ozone-depleting substances in now available. Refrigeration equipment and refrigerants needed in buildings for the tourism sector are rapidly evolving in order to comply with regulations on ozone-depleting substances (ODS) and regulations or draft regulations on climate change. Although HCFCs are forbidden in new installations from 1996-2004, depending on applications, and will be banned for servicing from 2010. On the global scale 85-90% of air-cooled air conditioners produced in 2000 were still using HCFC-22 as a refrigerant (EC 2000, IIR 2002). A significant shift to non-ODS alternatives has been observed in Europe and Japan. A shift of approximately 5% has been seen in the US (UNEP 2003). Unfortunately, in recent years the majority of installed refrigeration equipment in Croatia uses HCFC refrigerants. The questionnaire which was conducted for the purposes of this research has shown that 90% of refrigeration equipment in hotels are charged with HCFC-22 (see details in Chapter 3). However, HCFCs are banned for new installation in Croatia with a new bylaw from October 20th, 2005, while servicing will be allowed until 2015 (MZOPU 2005a).

GWP, TEWI, LCCP and COP

Global Warming Potential (GWP) is the measure of how greenhouse gases impact on global warming. It is defined as being radiative forcing caused by a substance over a specific period. GWP is expressed with respect to the radiative forcing exerted by the same quantity of CO_2, used as reference gas. This definition enables comparison of various gases with variable atmospheric lifetimes. GWPs are calculated for specific time horizons (20,100 or 500 years). The 100-year time horizon is the most widely used. Figure 1.10. shows the GWP of the most commonly used refrigerants (IIR 2002).

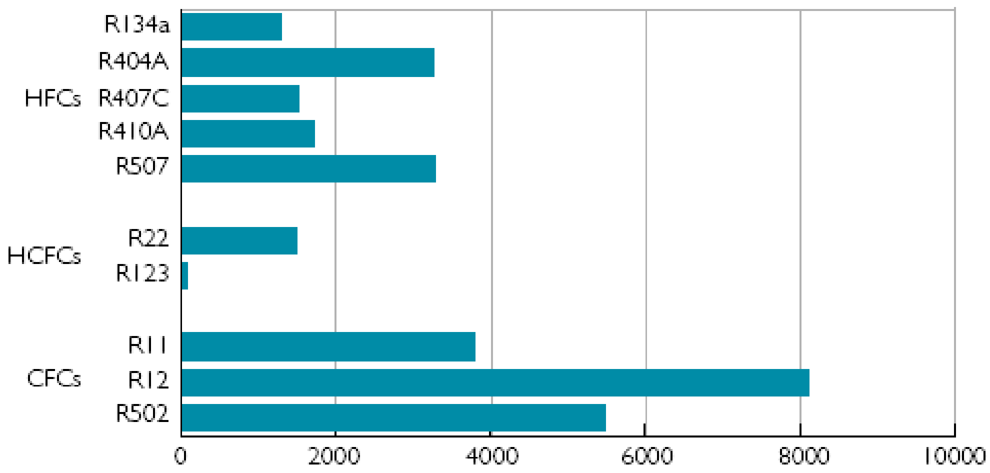

Figure 1.10. Global Warming Potential (100 yr) of several HFCs, HCFCs and CFCs (IIR 2002)

However, the use of GWP measurements has its limitations; GWP measurements provide information on the properties of a gas, but do not make it possible to quantify the overall greenhouse effect of a refrigerating plant using the refrigerant in question (IIR 2002).

The atmospheric lifetimes range from about a year to two decades for most HFCs and HCFCs; decades to centuries for some HFCs and most halons and CFCs, and 1000 to 50,000 years for PFCs. Direct GWP for halocarbons range from 5 to over 10,000 years (IPCC 2005).

Total Equivalent Warming Impact (TEWI) is a concept introduced in 1989. It takes into account, not only direct, but also indirect emissions of greenhouse gases attributed to refrigerating plant. The mean values concerning direct and indirect emissions have been estimated as follows:

- direct emissions (leaks) of refrigerants contained in refrigerating installations account for about 20% of the overall impact of the refrigeration sector on global warming.
- Indirect CO_2 emissions generated by the production of (essentially electrical) energy required to operate refrigeration equipment accounts for about 80% of the overall impact of the refrigeration sector on global warming (IIR 2002).

The TEWI calculation of a refrigeration system is based on the following relation (Arias 2005):

$$TEWI = \left(M_{losses} \cdot N + M_{ref} \cdot (1-\kappa)\right) \cdot GWP_{ref} + RC \cdot E \cdot N \qquad (1.1)$$

Where M_{losses} is the refrigerant leakage, N is the lifetime of the refrigeration system, M_{ref} is the refrigerant charge, κ is the recycling factor, GWP_{ref} is the Global Warming Potential of the refrigerant, RC is the Regional Conversion Factor, which is the emission of CO_2 per unit of energy delivered, and E is the annual energy consumption of the equipment.

The first part of equation (1.1) is the direct impact, which takes into consideration the refrigerant leakage during the lifetime of the system and refrigerant losses at the end of the system's life. The second part of the equation is the indirect impact, which takes into account the energy used during the lifetime of the refrigeration system and the CO_2 emissions from the production of electricity. The CO_2 emission from electricity generation is calculated with a Regional Conversion Factor RC, which is the emission of CO_2 per unit of energy delivered in kg CO_2/kWh (Arias 2005).

The regional conversion factor varies from country to country due to the efficiency of power plants and the regional fuel mix. The average of CO_2 emissions from a carbon power plant is about 1.11 [kgCO_2/kWh], from and oil power plant is about 0.77 [kgCO_2/kWh], from a gas power plant is about 0.55 [kgCO_2/kWh] and from nuclear and hydroelectric power plants is 0.00 [kgCO_2/kWh] (Arias 2005). The regional conversion factor for Croatia in 2002 was quite low, 0,302 [kgCO_2/kWh] due to high ratio of hydro power in total electric power production.

Life Cycle Climate Performance (LCCP) is a concept that emerged more recently and enables a more comprehensive evaluation. It covers all emissions throughout the life cycle of the installation, including emissions occurring during the manufacturing of various chemical installation components, as well as emissions occurring during scrapping or recycling of its components (IIR 2002).

The energy efficiency of refrigeration and air-conditioning plants is measured using the coefficient of performance (COP). This COP describes the relationship between the refrigeration capacity provided by the plan and the energy consumed by the compressor. The COP of a typical commercial vapour-compression refrigeration plant, operating with a temperature lift of about 40 K between condenser and evaporator, is roughly three. The COP of a refrigeration plant using absorption technology for a conventional systems is often about 0.7. However it is possible to reach a COP equal to 1.5 with new advanced multi-effect systems (IIR 2002). Comparing theoretical COP values, the COP of R410A (HFC) is approximately 6% less than that of HCFC-22. (Arthur D. Little 2002).

Today's chiller uses, on average, 35% less electricity than chillers produced just two decades ago and the best chiller today use half the electricity of the average 1976 chiller. Building owners can typically expect a three to five year payback on investment by replacing an old CFC chiller for any location that cool for more than 3 months a year (UNEP 2004).

If one considers a refrigeration plant running on electricity, it is important to bear in mind that the efficiency of most electric power plants using fossil fuels such as coal, oil and natural gas is, at best, 40%. However new combined gas-vapour plants can reach up to 60% (IIR 2002).

The refrigeration and air-conditioning sectors consume about 15% of all electricity consumed worldwide. Therefore the importance of achieving optimal energy efficiency for refrigerating and air-conditioning plants is significant. Beyond the positive impact on the earth's energy resources, by improving the energy efficiency of installations positive effects are achieved on the indirect emissions of CO_2, which is a severe by-product of the refrigeration sector on the greenhouse and global warming effects (IIR 2002).

1.1.2. Energy use in tertiary buildings

Since 1/3 of the energy used in non-industrial buildings is used in tertiary buildings (schools, hospitals, offices, hotels, restaurants, shops), which accounts for 1/4 of the non-industrial buildings. It is then obvious that hotels and other tourist facilities accounts for a big part of the overall energy consumption (ECBCS 2002).

For the tertiary sector, Figure 1.11., the importance of space heating is obvious since it accounts for 52% of the total consumption. This is somewhat lower than in households (57%), while energy consumption for lighting and other equipment is 14% and 16% respectively (EC 2001a).

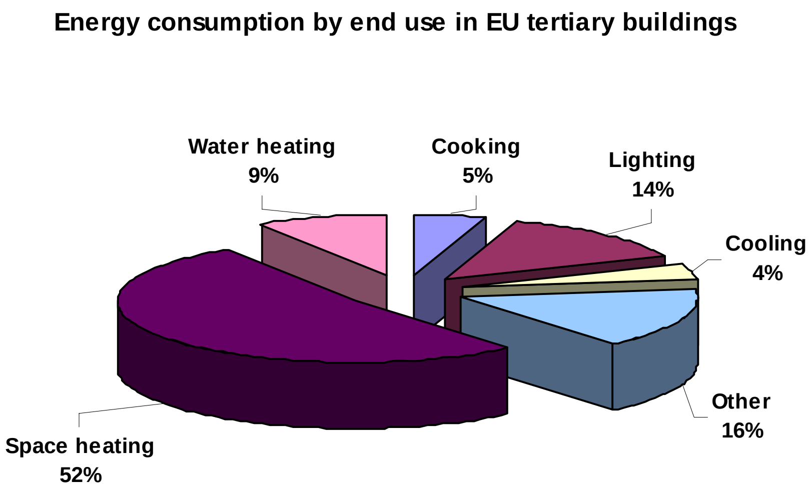

Figure 1.11. Energy consumption in the tertiary sector in EU (EC 2001a)

The share of central air conditioning equipment within the tertiary sector is illustrated in Figure 1.12. where the office sector is dominating but hotels still represent approximately 8 to 22%, depending on the country.

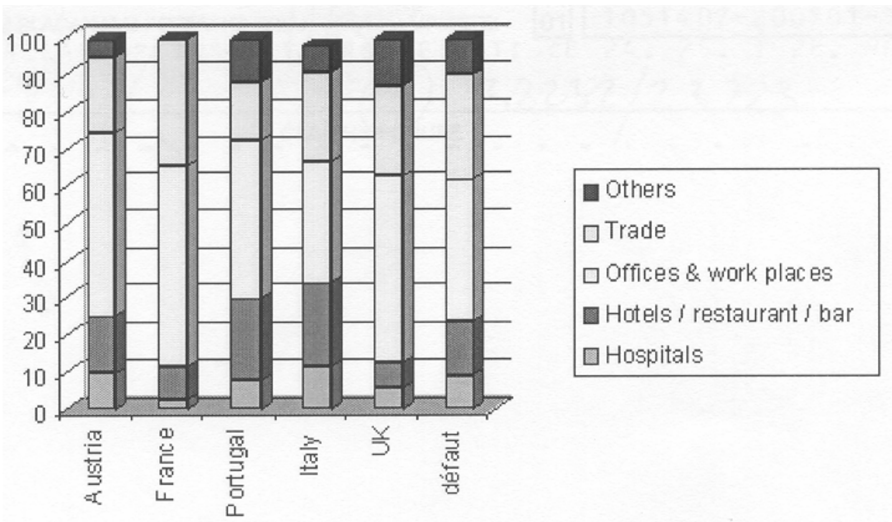

Figure 1.12. Share of CAC installed by tertiary sector for six countries (CENERG 2005)

Depending of the type of air conditioning equipment, divided in 5 groups as; room air conditioning (RAC), chillers, split units, roof top units and variable volume systems, research has shown that 90% of hotels in the EU are equipped with room air conditioning units and chillers. (Figure 1.13. and Figure 1.14)

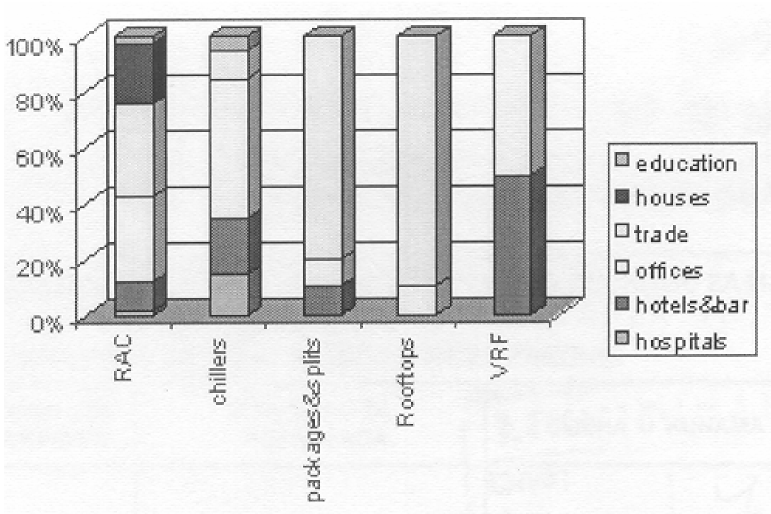

Figure 1.13. Share of installed equipment by sector (CENERG 2005)

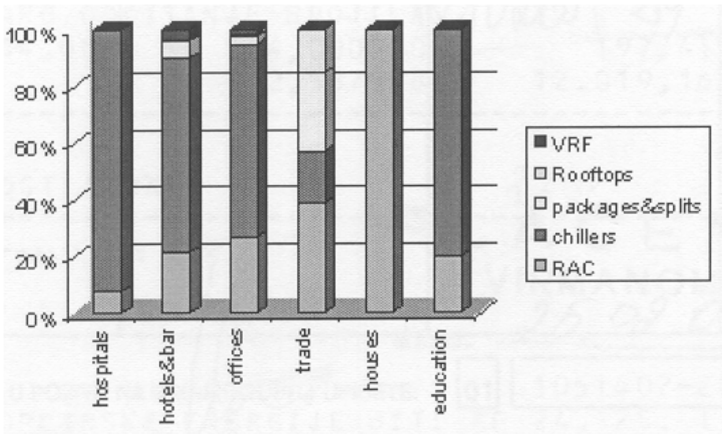

Figure 1.14. Share of installed equipment by type (CENERG 2005)

Market and sector research has shown that cooled floor space will continue to grow. From the Figure 1.15. one can see that predicted growth rate for the hotel sector in the next 15 years is approximately 40%.

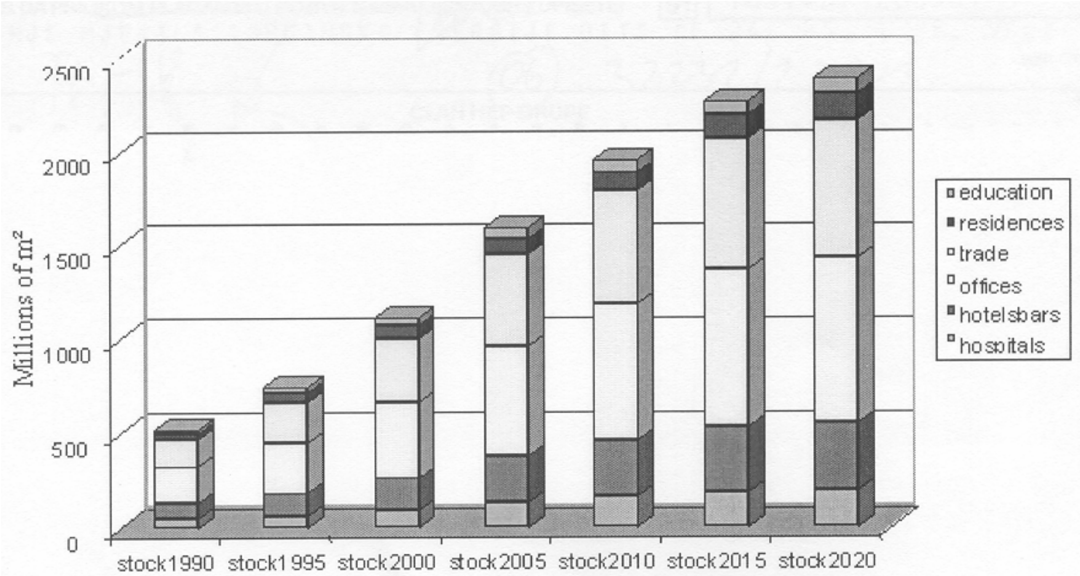

Figure 1.15. Estimated growth of cooled floor area by sector by 2020 (CENERG 2005)

Estimated average number of equivalent operating hours for air conditioning equipment at full load, by climatic zone is given in Table 1.2.

Table 1.2. Average number of operating hours for air conditioning equipment (CENERG 2005)

Country	City	Trades	Offices	Hotels	Residences
Austria	Salzburg	177	193	235	74
Austria	Vienna	134	147	176	55
France	Carpentras	1414	1307	595	547
France	Limoges	790	726	314	212
France	Trappes	752	625	262	156
Germany	Middle	431	383	236	168
Germany	North	199	187	115	87
Greece	Athens	984	729	1530	741
Greece	Theso	859	891	1175	480
Italy	Cagliari	1265	993	898	822
Italy	Milano	1017	727	726	615
Italy	Napoli	1366	966	1097	833
Portugal	Lisbon	1226	931	413	611
Spain	Murcia	2157	1402	1870	1049
Spain	Oviedo	678	300	382	143
UK	London	230	276	331	94
Average		1019	803	768	519

In much of the developed world, air conditioning has become almost a necessity. In the U.S. more than 90% of newly constructed housing units are centrally air-conditioned. Two thirds of all dwelling units in the U.S. have central air conditioning and another one-third have one or more room air conditioners. Virtually all-commercial building space in the U.S. is air-conditioned (Arthur D. Little 2002).

1.1.3. Energy consumption in hotels

The world Summit on Sustainable Development in Johannesburg 2002, acknowledged tourism as one of the major energy-consuming sectors and requested states to integrate energy efficiency into tourism related polices. Other sections in the WSSD plans for implementation are dedicated to sustainable tourism, energy conservation and emission control, and the special need for effective conservation and management of natural resources in Small Island Developing States (UNEP 2003).

The tourism industry has grown rapidly to become one of the largest business sectors in the world economy, employing in excess of 200 million people worldwide in 2002. The industry's rapid growth, however, has placed a heavy burden on local economies, cultures and environments. With current energy sources, carbon emissions are quite high. According to the European Environmental Agency (EEA) tourism is responsible for 5-7% of total emissions in Europe. It is estimated that 90% of the energy consumption in tourism today is spent on transportation (UNEP 2003).

Over the last decade the growth of electricity consumption in many hotels has been in the range of 25-30%. This increase may be attributes to the growing number of facilities, more demanding standards of accommodation (TV-sets, mini-bars and air conditioning units in all rooms), as well as development of the operating equipment (electric heating and cooking, cold rooms, elevators and escalators, accounting, computing and control equipment). On the other hand, the shift to more efficient equipment and lighting has recently been observed in many world regions. In spite of this, it is estimated that the energy demand may further increase by 10-25% in the coming years (Bohdanowicz 2003).

European hotels consume approximately 39TWh/year (CHOSE 2001). Depending on the source of energy (hydro-, wind-, nuclear-, oil-, or coal based) hotels can be responsible for the annual generation of up to 160 kg of carbon dioxide per square meter of area, which is equivalent to 10 tons of CO_2 per bedroom (Bohdanowicz, Martinac 2003). Energy consumption in hotels compared with total energy consumption in the country is given in Table 1.3. If one compare energy consumption in the hotel sector in Croatia (see Chapter 3 for details) and total energy consumption of the country, it can be seen that this sector has a share of 1,14% of the total electricity consumption in the country and 0,43% of the total energy consumption. It has been expected that due to tourism growth energy consumption in 7 coastal counties could grow by 7.5% per year (Hrastnik, Franković 2001), which means that energy demand in the region will be doubled by 2010.

Table 1.3. Energy consumption in hotels

	Number of hotels	Energy consumption in hotels	Total energy consumption in the country	Ratio of energy consumption in hotels over total energy consumption
USA in 2000		55,6 TWh (Bohdanowicz 2003)	28 413 TWh (Bohdanowicz 2003)	0,19%
EU in 2000	197 000 (Bohdanowicz 2003)	39 TWh (CHOSE 2001)	16 406 TWh (Bohdanowicz 2003)	0,23%
Sweden in 2001	1976	3,2 TWh (for heating and cooling) (Bohdanowicz 2003)	398 TWh (Bohdanowicz 2003)	---
Croatia in 2002	393 (coastal region 90% of total number of hotels)	180,23 GWh (electricity) 445,1 GWh (total energy)	15,81 TWh electricity 104,5 TWh total en (MGRP 2004)	1,14% 0,43%

Energy consumption in hotels accounts for between 3% and 6% of the total running costs (IMPIVA 1994). The magnitude of energy costs are second only to that of the staff (CHOSE 2001). An interesting parallel with another energy intensive area is supermarkets, where energy consumption accounts for 1% of the total turnover. Since the profit is 3% of the turnover, a 50% reduction of energy consumption gives a 15% increase in profit. Electricity consumption in large supermarkets in the US and in France is estimated to be 4%, while in Sweden it's 3% of the national electricity use (Arias 2005).

Analysis of energy costs in 49 hotels on the Adriatic coast in 1997, has shown that electricity, heating oil and water costs contribute each with approximately 32%, while gas costs are approximately 3% (Kurek 2002).

A study conducted amongst 20 hotels in the region of Rijeka city, owned by Liburnija Riviera Hotels (LRH) showed that the ratio of energy costs over total costs was changing from 1982 to 2001 in the range of 2,94% (1989) to 6,51 % (2001). In the years from 1998-2001 there was a continuous increase in energy costs. With regard to water cost there is also an increase from 0,85% of the total cost in 1989 to 2,79% in 2001 (Holjevac 2003). Energy costs per guest nights we in the range of 1,6 - 2,3 EUR/guest night (12-17 KN/guest night) (Holjevac 2002).

Construction costs for HVAC and electrical systems for one guest room are in the range of 10-12% and 11-13% respectively, while for public areas are in the range from 16-18% and 8-10% (Bohdanowicz 2003).

Table 1.4. Typical parameters regarding energy consumption in different types of hotels (IMPIVA 1994)

Efficiency rating	Good	Fair	Poor	V.Poor
A) Large hotels (more than 150 rooms) with air conditioning, laundry & indoor swimming pool				
Electricity (kWh/m² year)	<165	165-200	200-250	>250
Fuel (kWh/m² year)	<200	200-240	240-300	>300
Total (kWh/m² year)	<365	365-440	440-550	>550
Water (kWh/m² year)	<220	230-280	280-320	>320
B) Medium-sized hotels (50-150 rooms) without laundry, with heating & air conditioning in some areas				
Electricity (kWh/m² year)	<70	70-90	90-120	>120
Fuel (kWh/m² year)	<190	190-230	230-260	>260
Total (kWh/m² year)	<260	260-320	320-380	>380
Water (kWh/m² year)	<160	160-185	185-220	>220
C) Small hotels (4-50 rooms) without laundry, with heating & air conditioning in some areas				
Electricity (kWh/m² year)	<60	60-80	80-100	>100
Fuel (kWh/m² year)	<180	180-210	210-240	>240
Total (kWh/m² year)	<240	240-290	290-340	>340
Water (kWh/m² year)	<120	120-140	140-160	>160

There are a number of factors that influence the energy consumption in hotels, and some of them are: hotel size, category, services offered, occupancy, operational hours, shape and location of the building, climate, age of the building, energy efficiency of energy systems, as well as of energy management of the hotel. Therefore it is difficult to make standard classifications of energy consumption in hotels. However, it is possible to establish a typical model indicating the main areas of energy consumption as it is shown in Table 1.4. Typical values of energy consumption in Mediterranean country hotels, where Croatia belongs, are presented in Table 1.5.

Table 1.5. Average yearly energy use intensity for hotel buildings in kWh/m² (Bohdanowicz 2003, CHOSE 2001)

	Greece	**Cyprus**	**Portugal**	**Italy**
Energy consumption in kWh/m²	72-519	103-370	99-444.6	249-436
Average energy consumption in kWh/m²	289,9	272,6	296,4	364,4

There are numerous researches which have shown that the source of approximately 50% of the energy consumption in hotels is due to thermal comfort. Figure 1.16. illustrates the main energy end-uses within a hotel and their share in total energy consumption. However this data can vary depending on hotel category and seasonal operation.

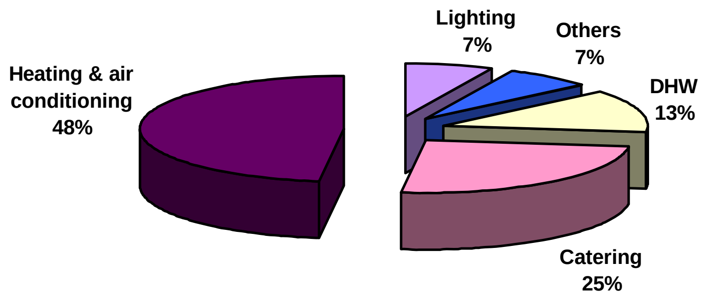

Figure 1.16. Energy consumption by end-users in a hotel (CADDET 1997)

The European research project REST (Renewable energy and sustainable tourism) gave a more detailed energy end-user breakdown which is shown in Figure 1.17.

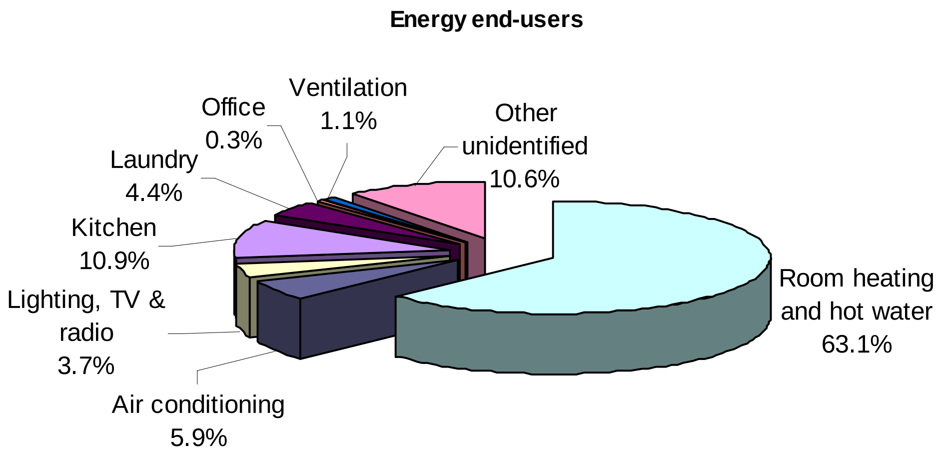

Figure 1.17. Energy consumption by end-users in a hotel (REST 2005)

Table 1.6. illustrates the estimated distribution of energy consumption for each activity or service. The type of hotel analysed is a 3-star establishment located in the climatic zone of Southern Europe with, 120 rooms, a total area of 5000m^2, open year-round, with 50 000 guests per year and with three elevators in the building. In order to compare the different energy consumption ratios, hotels with and without restaurant and air conditioning are considered (IMPIVA 1994).

Table 1.6. Distribution of energy consumption for each activity or service (IMPIVA 1994)

Concept	With air conditioning throughout With Restaurant 40 000 servings/yr	With air conditioning throughout Without Restaurant -	With air conditioning only in common areas With Restaurant 40 000 servings/yr	With air conditioning only in common areas Without Restaurant -
Heating	12%	13%	13.7%	16%
Air conditioning	10.6%	12%	8.6%	10%
Lighting	11.8%	13.3%	10.6%	12.4%
DHW	34.3%	38.7%	38.7%	45%
Equipment	19.5%	22%	14%	16.3%
Kitchen	12.5%	-	14.1%	
Total	**(171 kWh/m2)**	**(150 kWh/m2)**	**(150 kWh/m2)**	**(128 kWh/m2)**

This research will give answers to what is the average energy consumption in hotels on the Adriatic coast, depending on hotel category and seasonal/whole year operation.

Although "Tourism strategy till 2010" (document adopted by Croatia government in November 2003) stated that the tourism sector should contribute to the preservation of natural resources and operate according to ecological standards and principles (MINT 2003a). There were no actions following these statements in last 3 years that could be an example of good practice among the hotel industry in Croatia. According to national strategy, the unfavourable structure of commercial accommodation capacity should be changed while guest occupancy from the current 35% should increase to at least 50-55% in short term and 60% in the long term.

Recent years have seen a rise in the number of air-conditioning systems on the Adriatic coast and especially in hotels which are undergoing the process of new categorization; an evident increase in quality of tourist products. As a consequence to increase of number of installed cooling systems, the energy consumption will further grow.

1.1.4. Energy in Croatia

Achieved gross electricity consumption in 2003 amounted to 15,5618 TWh. Total primary energy supply in 2003 increased by 5,2% compared to the supply realised in the previous year with a total of 395,94 PJ (110 TWh) (MGRP 2004).

Figure 1.18. shows the individual energy share in the total consumption. In 2003, liquid fuels accounted for the largest share. It is estimated that the share of liquid fuels will gradually decrease till 2030. The next largest share in 2003, was that of natural gas, slightly above 25%. However, increase is estimated for the future. Due to hydrological conditions, hydropower share has decreased, and this trend is expected to continue as well. Imported electricity participated with 3,5%. Future development of the power system in the Republic of Croatia is expected to meet the domestic demand with domestic production.

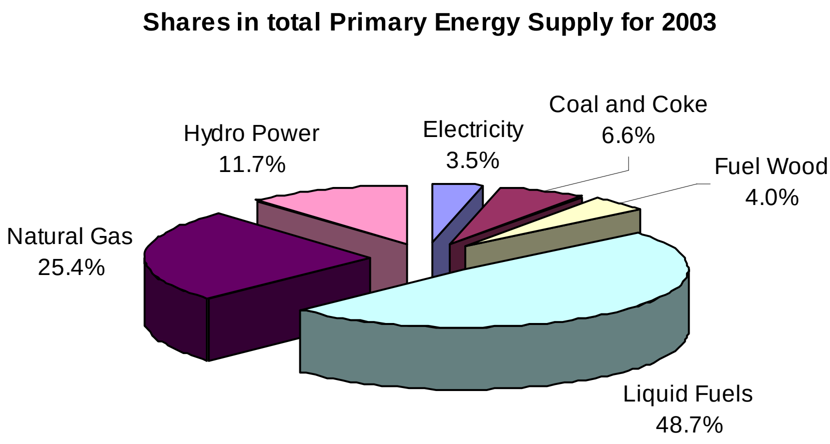

Figure 1.18. Shares in total primary energy supply in Croatia for 2003 (MGRP 2004)

In 2003, domestic primary energy production met 46,4 % of domestic energy needs. The decreasing trend in self-supply is recorded and expected to continue in the future so that by 2030 it might just exceed 20 percent.

In 2003 the total energy supply per capita amounted to 2129 kg of oil equivalent. Compared to the matching category in the European Union it was 46,6% lower, while electricity demand per capita in Croatia is 51,8% lower compared to the European average (EU15) (MGRP 2004).

In the last six years gross electricity consumption and net electricity consumption increased by an average annual rate of 3% and 3,3% respectively. On the other hand, primary energy production in 2003 continued along a decreasing trend. Final energy demand structure for 2003 is shown in the Figure 1.19. Other sectors (including households, services, agriculture and building construction) participated with the largest share with 48,5%, which increased compared to the previous year by 8%. Demand for all forms of energy show an increase, except electricity demand which remained at the same level.

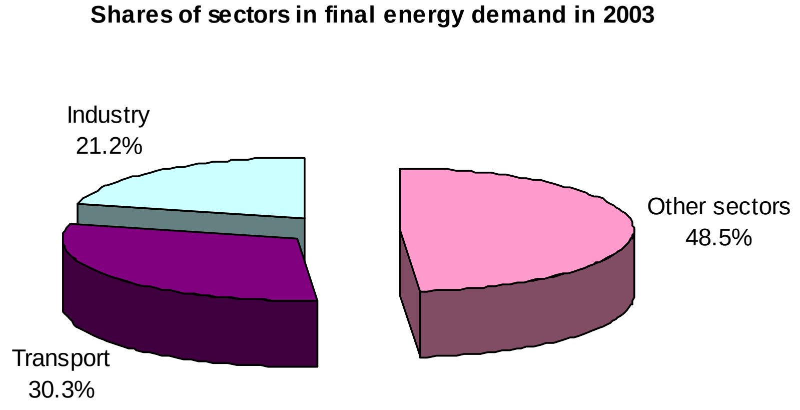

Figure 1.19. Shares of Sectors in Final Energy Demand in Croatia for 2003 (MGRP 2004)

Figure 1.20. presents data on final energy demand in sub-sectors for the 2003. In 2003 all sub-sectors have recorded a increase in energy demand. The construction sector saw the largest increase of 28,9%, while important increases were also recorded in household and service sectors - 8,2 and 6,6 % respectively (Table 1.7.).

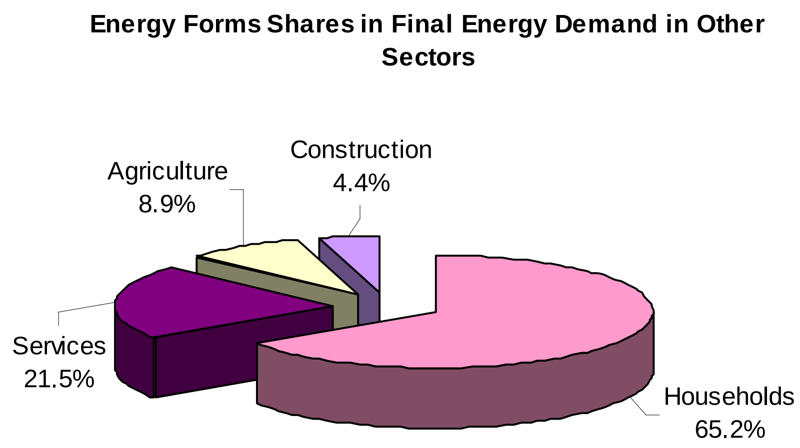

Figure 1.20. Energy forms shares in final Energy demand in other sectors for 2003 (MGRP 2004)

Table 1.7. Final energy demand in other sectors by sub-sectors (MGRP 2004)

	1998.	1999.	2000.	2001.	2002.	2003.	2003./02.	1998.-03.
	PJ						%	
Households	66,14	71,05	69,63	69,70	72,32	78,27	8,2	3,4
Services	19,44	19,95	19,73	22,71	24,28	25,88	6,6	5,9
Agriculture	11,90	11,80	12,09	11,36	10,54	10,67	1,2	-2,2
Construction	4,72	4,36	4,08	4,19	4,11	5,29	28,9	2,3
Total – other sectors	**102,20**	**107,16**	**105,53**	**107,96**	**111,25**	**120,11**	**8,0**	**3,3**

Statistics for the service sector, to which to hotels belong, show that electricity, gas and extra light fuel oil consumption in 2003 increased by 7,3%, 4,7% and 2,2% respectively compared to 2002. (MGRP 2004).

Although Croatia has signed the Kyoto Protocol, it has still not been ratified by Parliament. As a candidate country for the EU, ratification might occur soon. Once it comes into force, Croatia will be obliged to reduce greenhouse gas emissions by 5% in the period from 2008 to 2012, compared to 1990 levels, the reference year. Observing greenhouse gas CO_2 separately from the other gasses, and accordingly distributing proportional Kyoto obligations, CO_2 emissions in 2003 have already exceeded the Kyoto limit. The foreseen difficulties in meeting the Kyoto Protocol are a consequence of a very low CO_2 emission in the reference year when compared to other members of the appendix and UNFCCC Convention. A low emission rate is the result of a considerable share of hydro power and natural gas in the electricity generation network, large imports of electricity (from the neighbouring countries where Croatia invested in power production as part of the previous state), generation of electricity and thermal energy in cogeneration facilities, small number of energy intensive industry facilities and low energy consumption per capita (MGRP 2004).

Croatia as a South European, Mediterranean country has a high potential for solar energy, but unfortunately in energy summary balance for 2003, the ratio of solar and wind energy was 0%. Biomass, with 381,1 thousand toe (3,363 TWh) and hydro energy in amount of 424,4 thousand toe (4,936 TWh), contribute 9,6% an 10,7% in the total primary energy production and with 4,2% and 4,7% of total energy consumption in Croatia. In February 2005, the first wind power station with a capacity of 5 MW was connected to the grid, but increases in solar energy utilization are still slow (MGRP 2004).

According to the EU's Renewables Directive 2001/77/EC of September 27th 2001 on the promotion of electricity produced from renewable energy sources in the internal electricity market, the EU should double the share of overall renewable energy production from 6% to 12% by 2010. It also aims to increase the share of electricity produced from renewable energy sources (RES) in the EU to 22,1% by 2010 (up from 15.2% in 2001), (EC 2001b).

Another EU directive that is aimed to decrease the environmental impact of energy consumption is Directive 2006/32/EC on energy end-use efficiency and energy services. This directive has for objective to increase end-use energy efficiency. One of these measures is to develop the market for energy services, thus making energy efficiency an integral part of the internal market for energy. The directive covers retail supply and distribution of extensive net-bound energy carriers, such as electricity and natural gas, together with other important energy types, such as district heating, heating fuel, coal and lignite, forestry and agricultural energy products and transport fuels. The directive includes a target of 1% cumulative savings at Member State level as a means of measuring energy efficiency improvements and reaching sufficient market demand for energy services (EC 2006).

In a few years to come Croatia will have to set targets that will comply with these directives. One of the areas that might contribute to fulfilling these targets will be service sector where the hotel industry belongs.

1.1.5. Trends in number of tourism accommodation capacities and quality of services

Tourist arrivals growth

International tourism is one of the most expanding fields of the world economy. Europe, and particularly the Mediterranean, still remains the most important tourist destination and major tourist market (HGK 2004).

World's and European average annual growth rate in international tourist arrivals for the period of 1995-2002 is 3,6% and 3,1% respectively (WTO 2005a). However, Croatia is ranked among 30 countries that grew at a rate double to that of the world average in the same period. Croatia had a net increase of 5.459.000 tourist arrivals in year 2002 compared to 1995 that represents an annual growth of 24,7%. There have been 6,944 million international tourist arrivals in 2002 which represents 1% and 1,73% of the world's and Europe's international tourist arrivals. Regarding the sub-regional distribution of tourist arrivals in Europe; Western Europe leads with 35% market share, followed by Southern Europe with 33% (WTO 2005 a).

Southern Europe had the lowest increase in tourist arrivals and managed to rise by 1,5% (WTO 2005a) in 2002 compared to 2001, while Croatia increased by 6% in the same period (HGK 2003). The World Tourism Organization predicts a 3% annual growth rate for the Mediterranean region by 2020, where Croatia is emphasized as one of the countries with the highest growth rates in terms of international tourist arrivals (8.4%) (HGK 2004). In Table 1.8. one can see real and estimated annual growth rates by 2020 in international arrivals among other countries with a developed tourist industry in the Mediterranean region.

Table 1.8. Croatia vs. competitor countries 1990 – 2020. (HGK 2004, HGK 2005)

	International arrivals in millions						
Country	1990.	1995.	2000.	2002.	2004.	2020.	Estimated annual growth rates in %
Spain	34,1	38,8	48,0	51,7	53,6	73,9	2,6
Italy	26,7	31,1	41,2	39,8	39,5	52,5	2,1
Greece	8,9	10,1	12,5	14,2	14,1	17,1	2,1
Turkey	4,8	7,1	9,6	12,8	17,5	27,0	5,5
Croatia	**7,0**	**1,3**	**5,8**	**6,9**	**9,4**	**10,0**	**8,4**

The year 2003 recorded 7% more tourists and 4% more overnight stays in comparison with the previous years (HGK 2004). While in the year 2004 tourist arrival growth was 6% with a total 9,4 million tourists, which confirmed estimated trends (HGK 2005).

The Croatian National Bank's preliminary figures for 2003 show that international tourism generated 22.5% of Croatian GDP. International tourism accounted for a 42.8% share of total exports of goods and services, and for 74.0% of total exported services. The per capita income from tourism in 2003 amounted to USD 1,436 (HGK 2004).

Accommodation facilities

Worldwide capacity of hotels and similar establishments reached 17,4 million rooms in 2001, that is almost 5 million more than in 1990 (37% more). The biggest share, 38% of the world total, can be found in Europe with about 6,6 million rooms (Figure 1.21. and Figure 1.22.), of which 2,4 million were in Southern Europe. Hotel capacity in the world grew on average by 3,1 % a year between 1990 and 2000, except for Europe where average growth was 2% (WTO 2005 a).

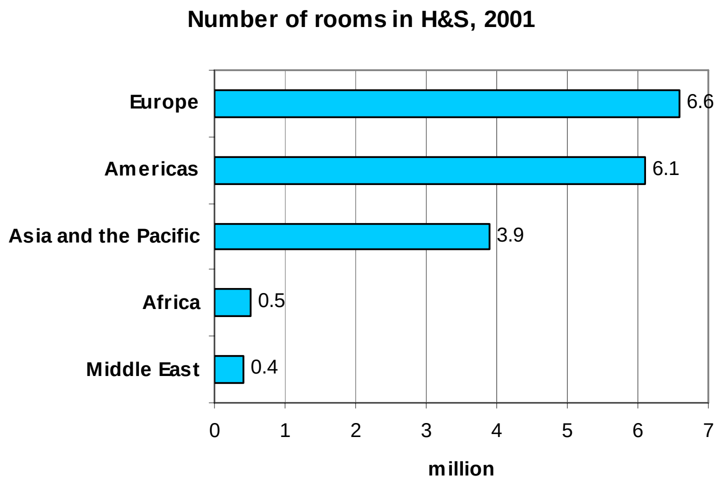

Figure 1.21. Number of rooms in hotels and similar establishments in 2001 (WTO 2005a)

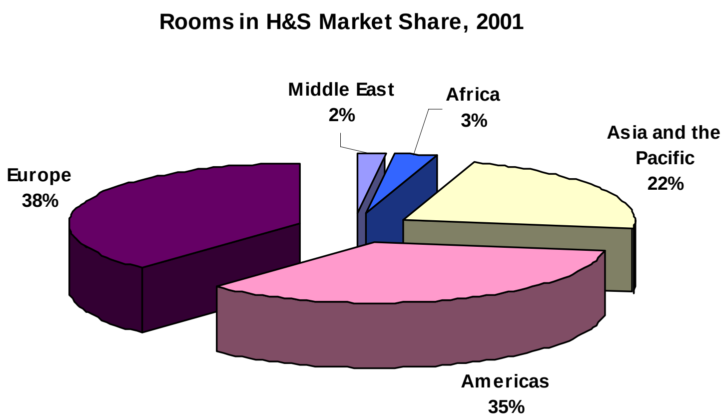

Figure 1.22. Market share of rooms in hotels and similar establishments in 2001 (WTO 2005a)

In Croatia, tourists prevailingly stay at hotels. Around 34% and 35% of them stayed at hotels in 2003 and 2004 respectively, accounting for 28% of overnight stays. Second to hotels are camps, with 21% of total tourists and 27% of overnight stays, followed by private accommodation (19% and 24% respectively) and marinas (8% and 2% respectively). In 2003. Croatia had 782,651 beds, 96,607 (12.3%) of which were in hotels, 195,514 (25.0%) in camps, 317,850 (40.6%) in private accommodation and

55,057 (7.0%) in marinas (HGK 2004). In 2004, there was a growth of 3% in the total number of beds amongst which are 3473 new beds in hotels (HGK 2005).

Accommodation quality shows an improving trend. Currently, the majority of facilities have three stars (43% in 2003 and 53% in 2004), and 8% (year 2003) and 13% (year 2004) are four or five-star hotels. Most beds are in small, family-run hotels and B&Bs, which ensure personalised services and are tailored to guests' needs. Boutique hotels are an increasing trend - hotels with personalised quality services. Trends in the hotel industry are towards specialised services in areas such as sports, wellness, conferences, and also amenities for gourmets, singles, naturists etc. Hotels and restaurants employ 85,000 people (HGK 2005), and it is estimated that the whole tourism sector directly employs 140,000 people and an additional 175,000 indirectly (HGK 2004).

However, the Croatian tourism industries main problem is with regards to a low total occupancy rate of 15% or approximately 54 days per year. The hotels, are the prominent part of the accommodation sector and achieved an occupancy rate of 28% or 103 days per year, while all others types (camps, marines, private accommodation) had an occupancy rate of 12% or average 43 day per year (Blažićević 2002).

1.2. Motivation of Thesis

Since 1995, when the tourism industry in Croatia started to recover and tourist arrivals started to grow, numerous hotels have undergone major renovations and energy system retrofits. Unfortunately, during renovations, emphasis was on tourism competitiveness (fulfilments of conditions for hotel category) and not on sustainability and energy efficiency. It was important to "revive" the tourist industry at minimal costs since many people in the coastal regions were living off tourism before the 90's. There was no awareness amongst decision makers about future energy consumption, environmental impacts of energy consumption and the cost of energy during operational periods. Renewable energy sources played a negligible role within the potential energy system retrofits. At that time there were no government subsidies or funds available that could support the installation of renewable energy sources, especially solar collectors for domestic hot water (DHW). There was even one case recorded in the Dubrovnik region, that during renovation solar collectors were replaced with oil boiler. Owners and hotel management did not recognize possibilities for energy savings and furthermore, there were no regulations or bylaws that could force them to think about sustainability and energy efficient systems. However, in recent years Croatia experienced several electricity blackouts in August on the Adriatic coast (Vodice, Dubrovnik, island Murter,) due to too high electricity consumption for air-conditioning systems on the hottest days.

A survey done among Croatian hotels on the coast, which will be explained in more detail in Chapter 3, has shown that 88,2 % of installed chillers with approximately 12 MW of capacity operate with HCFC refrigerants (these are the results for 51 hotels out of 75 with cooling systems that gave information about the type of refrigerants). The share of equipment installed between 1992-1999 is 51,8%, while 35,2% of equipment was installed during 2000-2003. The remaining 13% was installed before 1990. In total 88% of HCFC-equipment was installed from 1996-2003 when HCFCs were banned in the EU for new installations. But not in Croatia where these chillers were cheaper than chillers with environmentally acceptable HFC refrigerants. HCFCs are banned for new installations in Croatia with a new bylaw from October 21st 2005, while servicing will be allowed till 2015 (MZOPU 2005a). In next 10 years hotels will be forced either to replace their chillers or to retrofit the refrigerant from HCFC to HFC. There are also a number of hotels that have not been privatized and modernized yet (approximately 12% by August 2006) (HFP 2006), but they will be in the coming years and will consequently lead to their renovation. These are the two opportunities that might direct the hotel industry to search other options for energy efficient technologies, renewable energy sources and environmental savings needed, in order to comply with the Kyoto protocol and EU directives. During this next period HVAC system retrofits should be done the "right way" e.g. following sustainable principles, designing energy efficient HVAC systems with higher portions of renewable energy sources. Data collected and analysed in this research as well as the developed methodology could be of grate help to designers and decision makers in hotel management.

Academic research in Croatia on HVAC system retrofitting, optimization and energy efficiency has never been a priority and little research has been conducted. Most of today's research is focused on systems for electricity supply on islands where tourism is the most important industry and biggest energy consumer during the summer months. There is no exact data about energy consumption, or status of heating and cooling systems and utilization of renewable energy sources. Energy utilization for HVAC systems in the hotel industry and energy, environmental and economical optimization of retrofitting options is hardly investigated. It is therefore the **main purpose** of this thesis to evaluate the current state of energy consumption in hotels on the Adriatic coast and to develop a methodology for HVAC system design with regards to energy consumption, environmental impact and cost of installation and operation. The methodology is named HOTECO.

From the very beginning, it was clear that this project had to be interdisciplinary. The project was therefore designed with energy-engineering as well as environmental and economic perspective in mind. *Hence the focus of the thesis was shifted from an energy audit scheme that was conducted among 31,5% of hotels on the Adriatic coast (current state of energy consumption and systems) towards HVAC system options that were proposed, modelled and analyzed as energy efficient options for the hotel sector in Croatia.*

This thesis can be considered as a contribution to an overall theory about energy efficient solutions and simulation methodology for HVAC system retrofitting options optimization in the building sector especially in the highly energy intensive hotel area. Survey among hotels will be a valuable data base for further research in building and service sectors as well as for energy planning and policy making at the governmental level.

The hotel energy system can be viewed and analysed from five different perspectives (Figure 1.23.):

- The **energy perspective** is concerned with real-time behaviour of the equipment according to the needs influenced by hourly weather data. The **mathematical-engineering perspective** uses mathematical models to represent the physical behaviour within the building envelope and the response from the HVAC systems in order to provide required thermal comfort.
- The **environmental perspective** which analyzes the environmental impact (local level) of the energy utilization in hotels.
- The **policy perspective** which is concentrated on Croatia's fulfilment of the Kyoto Protocol, Montreal Protocol, and EU directives (EU SAVE directive 93/76/EEC, Directives 2037/2000, 2002/91/EC, 2006/32/EC), Croatian energy strategy and Croatian tourism strategy (environmental perspective on state level).

- The **economic perspective** focuses on the economical savings through the operational period of installed energy efficient systems.
- The **tourism perspective** which analyses growing trends in tourist arrivals and growing needs for quality accommodation facilities that will put a pressure on energy system as well as the environment.

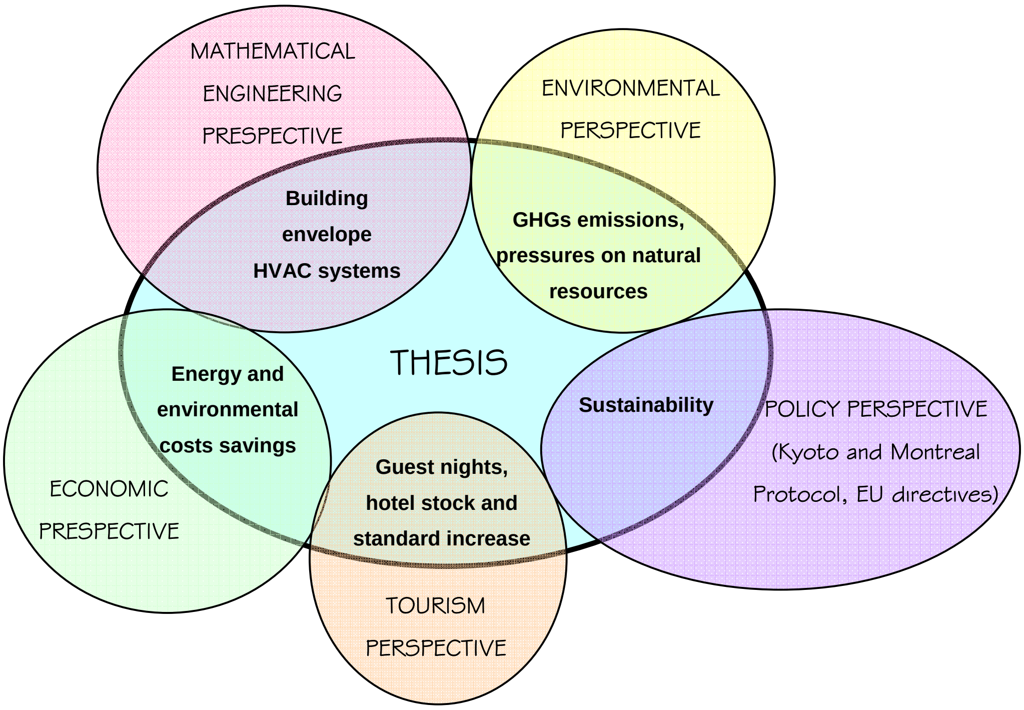

Figure 1.23. Perspective of the thesis

1.3. Research questions

As pointed out before, this thesis is focused on an *engineering perspective*, but it also takes into account environmental, economical, tourism and policy aspects.

The main research question can be formulated as follows:

"What would be the methodology for the design and retrofit of HVAC systems in the hotel industry on the Adriatic coast that would be in line with world and EU energy and environmental policies and that would result with minimal energy use, minimal environmental impact, reasonable costs and sustainable development and growth of the tourism industry in Croatia?"

The broader research questions that were used for the information gathering and analysis are the following:

1. **Energy consumption in the Croatian hotel industry**
   a. What is the average energy consumption in Croatian hotels?
   b. What is the energy efficiency status of the hotel sector?
   c. What is the share of energy sources in the total energy consumption?
   d. What is the current state of renewable energy sources utilization in hotels?
   e. Why is it important to study energy usage in hotels independently from energy usage in buildings?
2. **HVAC systems in hotels**
   a. What is the present state of HVAC systems in hotels?
   b. What are the important issues relevant to energy utilization?
   c. What problems are connected with retrofitting existing systems?
3. **Technical standards**
   a. What impacts do EU standards have on the development of sustainable HVAC systems in hotels?
   b. What kind of actions should the Croatian government introduce in order remove barriers for energy efficiency in hotels on the Adriatic coast?

4. **HVAC design**
    a. What would be the options for sustainable HVAC systems for hotels on the Adriatic coast?
    b. What are the factors that influence energy utilization in hotels?
    c. How building envelopes can decrease energy consumption?
5. **Future perspective**
    a. What could be future environmental emissions in the hotel sector with current state of energy sources utilization?
    b. What could be future environmental emissions with introduction of solar energy for DHW and heating and energy efficient HVAC systems?
6. **Environmental impacts**
    a. What environmental impact does the energy consumption in hotels yield?

1.4. Thesis outline

The thesis is divided into three main parts, plus conclusions and appendices. Four main parts comprise of 9 chapters, see also Figure 1.24.

<u>Part I : Introduction and Previous work</u>

Part I provides the relevant background for the thesis. In some areas, it even may provide more background information than might be considered necessary. However, due to the interdisciplinary nature of the thesis, this additional information is considered to be essential. Chapter 2 reviews past and current developments in the area of the hotel auditing scheme and HVAC systems in hotel. Modelling and simulation approach with regard to energy performance in buildings is presented.

Part II: Energy audit scheme in hotels

This part defines the necessity for energy audit research among hotels in Croatia. Energy audits were conducted among 31,5% of hotels, which after analysis, gave relevant data for future work and development of optimization retrofit methodology that is elaborated in Part III. Benchmarks for hotels on the Adriatic coast are also established. Regression analysis as a statistical method was used to define influencing parameters for electricity and heating oil consumption in hotels.

Part III: HVAC system analysis

This Part comprises 3 chapters. Chapter 4 discuses system thinking approach with regards to building (hotel) and HVAC systems as a part of that system. In this chapter, the research question is explained. Chapter 5 gives models for four HVAC systems and energy simulation results obtained with dynamic simulations in the TRNSYS programme using hourly data for temperature and solar radiation for two hotels in the Split region. Chapter 6 analyzes the simulation results from an energy and economical point of view.

Part IV: Environmental analysis, HOTECO methodology and conclusions

Chapter 7 gives environmental analysis of energy consumption in hotels and discusses four scenarios of energy consumption in hotels on the Adriatic coast with regard to current state of the systems and energy efficient retrofit solutions with different shares of renewable energy sources. These scenarios will give contribution to energy planning in the coastal regions. In Chapter 8 HOTECO methodology for sustainable HVAC design is presented. Chapter 9 contains the general methodology conclusions for the design of energy efficient retrofit solutions in hotels, as well as conclusions in energy consumption predictions relevant for the Croatian energy authorities. The chapter also contains conclusions about possible improvements for the sustainable development of the hotel industry relevant for tourism authorities.

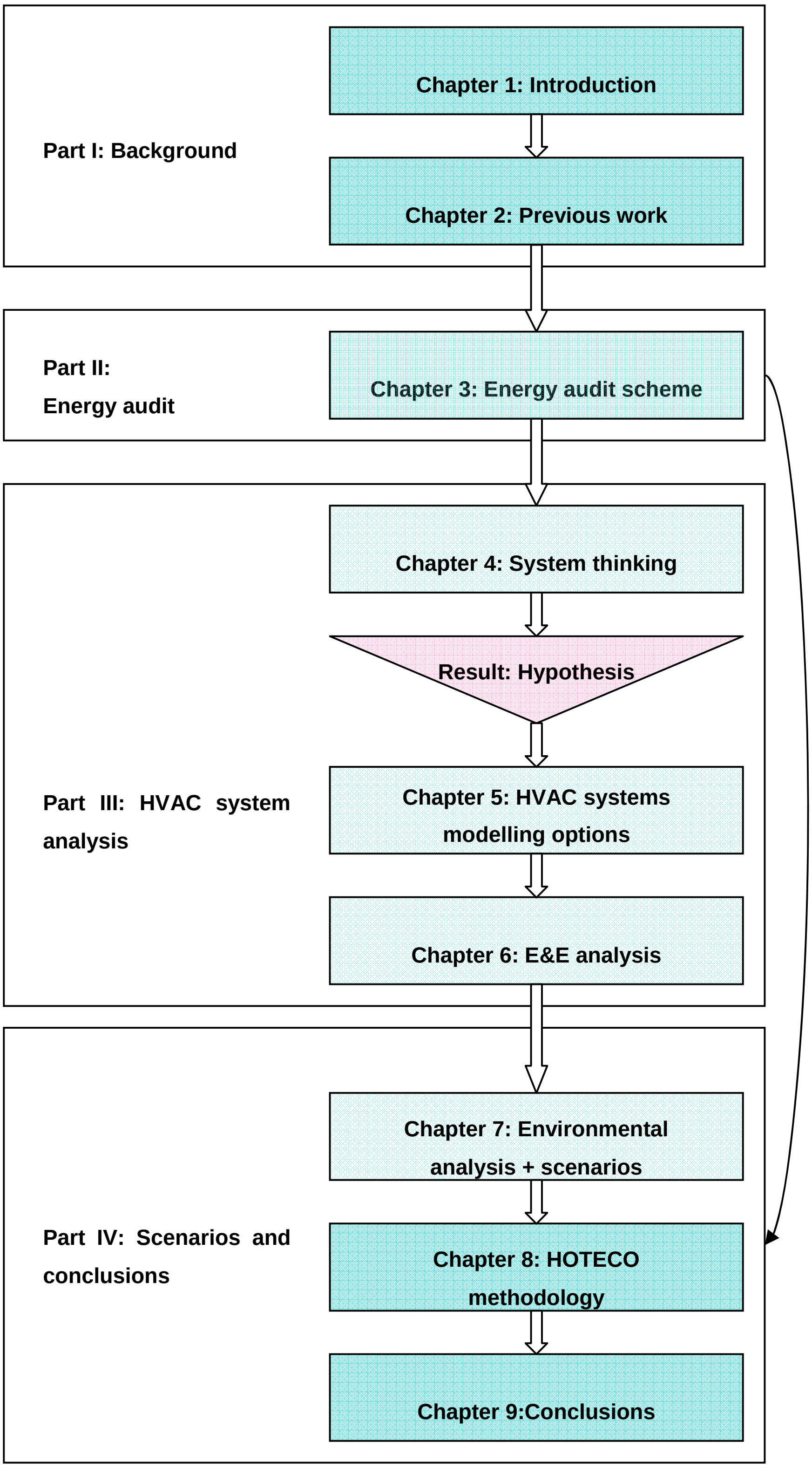

Figure 1.24. Thesis outline

2. PREVIOUS WORK

This chapter presents a brief overview of the most relevant publications. The first section discusses the important background literature that is directly related to the topic of this thesis, i.e. literature that discusses methods of retrofit for HVAC systems in hotel buildings. The second section discusses the relevant literature in the area of energy consumption analysis and HVAC systems in hotels, while the third part discuses HVAC systems modelling in buildings.

2.1. TOBUS and XENIOS methodology

There is very little research conducted that combined energy consumption in hotels and methodology for optimization of HVAC systems that utilize renewable energy sources. Energy consumption with regards to HVAC systems is very much dependant on climatic conditions and location of hotel. Croatian institutes and Universities have not done any detailed research in this field.

A team of European researchers from Greece, Italy, France and Spain under auspices of the European research program ALTENER, developed a methodology named XENIOS, for assessing refurbishment scenarios and the potential application of renewable energy sources (RES) and rational use of energy (RUE) in hotels. The XENOIS methodology is addressed to hoteliers, technical managers, engineers and architects interested in renovating and refurbishing a hotel. The tool supports the user during decision-making process to set priorities, while deciding on a retrofit strategy through a technical and economical assessment of selected interventions.

XENOIS methodology is based on existing European methodologies for apartment (EPIQR) and office buildings (TOBUS) (Dascalaki, Balaras 2004).

The main objective of the TOBUS project was to develop an evaluation tool for the assessment of retrofitting needs in office buildings for European countries and to estimate the cost of meeting these needs in compliance with improved energy performance and indoor environment. The tool encompasses an integral approach, where all problems are treated globally but also taking into account their interdependence (Caccavelli, Gugerli 2002).

TOBUS assists the user with two main tasks 1) *Diagnosis*: Evaluation of the general state of the office building with respect to deterioration, functional obsolescence, energy consumption and indoor environmental quality (IEQ), 2) *Actions*: Definition of retrofitting actions and their corresponding costs to improve the office building condition; the buildings energy performance and IEQ.

The TOBUS methodology aims at offering the surveyor a tool to select office building upgrade solutions with respect to multiple criteria (Wittchen, Brandt 2002),. One of the key elements for reaching this goal is the building survey, which is necessary in order to assess and determine the:

- physical condition of the building
- necessary work needed to bring the building back to it's initial state
- extent of the different types of work
- budget for the works.

The overall approach of TOBUS regarding energy is a first estimate of a building's loads (heating, cooling and lighting), energy consumption and assessment of energy savings resulting from different interventions for space heating and cooling, hot water production, lighting, equipment and elevators, and for water conservation.

TOBUS and afterwards XENIOS are not designed to be either a simulation tool or detailed energy audit tool.

The XENIOS methodology and software permits the user to perform a preliminary hotel audit and make a first assessment of cost-effective energy efficient renovation practices, technologies and systems.

The hypothesis on which TOBUS and afterwards XENIOS developments are based is that the interaction between the expert and his environment is the main engine of awareness and of the evolution of the experts cognitive operational tools toward a better equilibrium. This also assumes that the evolution of the initial knowledge structure, which results from this interaction, goes towards a better structure, which allows the expert to better explain processes or events, and improves his reasoning and action potential (Flourentzou, Roulet 2002).

2.2. HVAC systems in hotels

Although significant amounts of research have been conducted in the area of; various HVAC system components, HVAC system behaviour in buildings, and implementation of renewable energy sources in the buildings, there were few studies found during the literature survey for HVAC systems in hotels. With regards to hotels and tourism accommodation facilities, authors are mostly dealing with energy consumption patterns and identification of main energy consumers.

The project that aimed at the systematic implementation of conditions for future massive application of renewable energy sources (RES) in the tourism industry is named "HOTRES" (Karagiorgas, 2003). Under the work plan of the project, five renewable energy technologies are promoted (solar thermal, solar passive, solar PV, biomass and geothermal energy). The market reaction has been friendly to three of the five RETs with the following shares: 66% for solar thermal, 10% geothermal (geothermal heat pumps) and 24% for PV units. The study has shown the shortest payback period to be solar thermal and it varies from 1,7 years in Greece up to 19 years in France, while for the solar PV it varies from 6 year in Spain up to 43 years in Greece. It is obvious that country conditions, government subsidies, electricity price and energy source variety influence payback periods in different Mediterranean countries. No preferences were given to biomass and bioclimatic systems in all hotels surveyed by this study. At the end, one of the conclusions was that hoteliers are business oriented and need commercialized solutions, therefore don't accept easily "new technology" project, often of the R&D type.

There are small numbers of researches for different HVAC systems options for hotels. One of them is a study of the life cycle energy cost analysis of heat pump application for hotel swimming pools in the subtropical climate of Hong Kong. The authors (Lam, Chan 2001) were investigating possibilities for heat pump installations for swimming pool heating systems that would allow them to operate year round. Heat pump energy consumption over a life of ten years was compared with electric condensing and non condensing boilers. It was concluded that financial savings with heat pump installation might be as high as 75%.

The other study from the authors (Yu, Chan, 2005) deals with HVAC system components in hotels and presents the operating efficiency of air-cooled chillers in three existing hotels and investigates the extend to which the annual electricity consumption can decrease by improving their efficiency. Authors investigated how chiller efficiency can be enhanced by restoring chiller sequencing and using a floating condensing temperature control.

The papers from (Khemiri, Hasairi 2005) present results and analysis from the data collected during the energy audits of a hotel located in the centre of the Mediterranean country Tunis during the years 1987, 1996 and 2002. Two energy conservation measures were carried out to investigate the energy savings after two energy audits. The objective of the work was to obtain a quantified energy savings, utilizing proposed energy efficient technologies.

There are number of case studies in the Mediterranean countries that demonstrated cost benefits for energy efficient technologies described in a research report done under the EU THERMIE Programme Action (IMPIVA 1994).

Case study 1. The Ritz Hotel, Piccadilly, London, UK. Energy efficient space heating and hot water system, with four gas fired low pressure hot water boilers were installed instead of three inefficient steam boilers. Thermal efficiency was greatly improved due to better boiler performance and lower heat losses from piping and heat exchangers, while high maintenance costs have been reduced. The execution of the project has had immediate benefits in term of a reduction in gas consumption of 40% as well as improved reliability and maintenance (IMPIVA 1994).

Case study 2. Hotel Belroy Palace, Benidorm, Alicate, Spain. The main goal of the project was to install a solar collector system for space cooling, heating and for sanitary hot water for the hotel building. The new solar system consists of 328 m^2 of high efficient solar collectors and a heat storage volume of 36 m^3. During the summer time hot water is supplied to the LiBr-H_2O absorption chiller and after used for sanitary hot water. In winter time heat is used for space heating and sanitary hot water. After three years of system operation energy savings are 90% of the energy required for hot sanitary water, 80% of energy required for space heating in winter and 60% of cooling energy during the summer time. This savings represents a reduction in fuel consumption of 61 tons per year and a reduction of electricity used in the compressors of 110 MWh per year (IMPIVA 1994).

There are number of demonstration projects in hotels worldwide, described in CADDET publications (CADDET 1997), where it was shown that implementing energy efficient technologies and renewable energy sources can save energy and improve energy performance of the hotel. Heat recovery and pre-filter coils were installed in Kalastajatorppa hotel in Helsinki where heat was recovered from exhaust air. The average amount of recovered heat was 1,272 MWh per year while the simple payback period was 3.1 years.

Next example is an integrated piping system used in a motel HVAC design in the USA. The system is similar to four pipe fan coil system that are widespread in Europe but not in the USA, that gave a 2,9 year simple payback period (CADDET 1997).

Further on, a cogeneration system that combines fuel cells with gas engines was installed in Meguro Gajo-En hotel (total floor area 40.411 m^2) in Japan. The waste heat from the cogeneration system consisted of two 200 kW gas engine generators and a 50 kW phosphoric acid fuel cell was used to power an absorption refrigeration unit and for the hot water supply. The emphasis of this project was to demonstrate the technical aspects of the system, thus neglecting the economic (CADDET 1997).

The status of solar collector installations in Greece is presented by author Karagiorgas. There are over 100 hotels utilizing central solar thermal systems in Greece. The total surface area of these systems is 28,820 m^2 and the total volume of the storage tanks is 1172760 lit. Average system size is 257 m^2 per hotel while 41,4 % is installed on Crete (Karagiorgas, 2003).

Solar technology is already widely used in the hospitality business requiring a constant supply of hot water. Water heating for such business accounts, on average, for approximately 12% of the total energy costs (20% of energy use), hence, solar water heaters can lower fuel and electricity bills (UNEPTIE 2003)

Since hotel are large energy consumers, individual energy planning becomes increasingly important due to several supply options competing and (or complementing each other and the high uncertainty associated with growing fuel prices. Mavrotas et al (2003) present a linear programming model for energy planning in hotels under uncertainty in fuel costs on the case study of hotel in Greece.

A group of authors from Hong Kong (Deng, Burnett, 2000, 2002a) report in several journals about their study of energy use in 16 hotels during the mid 90's. The overview indicates that the energy use situation in Hong Kong is very much diversified. The total energy use in a hotel is dominated by electricity, with the greatest portion for air conditioning because of sub-tropical climate. With detailed multiple variable regression analysis it was concluded that a number of hotel operating parameters, as well as climatic conditions, can affect electricity, diesel and gas use in a hotel building. Regression analysis has indicated that outdoor air temperature and the number of guests are significant factors affecting electricity use in the hotel, while outdoor air temperature and number of meals are significant factors affecting diesel use. In order to achieve both operating cost savings and environmental protection it is recommended that an energy management programme be established and energy conservation measures implemented.

Author (Deng 2003) continues with a study of energy consumption patterns for hotels in Hong Kong with a survey of energy and water use in 36 quality hotels. He indicates that no clear consumption patterns and obvious underlying factors that may be used to explain energy and water use can be easily identified. However, the regression analysis also indicates that, while some correlations are weak, a few strong energy and water use performance explanatory indicators do exist.

The same authors (Deng, Burnett, 2002b) investigated water use for hotels in Hong Kong. A study in 17 leading hotels showed a diversified water use. After a detailed regression analysis, it was indicated that monthly laundry load, number of guests and the number of food covers may collectively influence the monthly total water use in a hotel.

Authors (Noren, Pyrko 1998) presented a typical electricity load shapes for hotels in Sweden (Figure 2.1.). The load shapes are presented as a non-dimensional normalised load, where the typical load shapes give a reasonable approximation compared to measured ones. Simple linear regression with daily mean load as main variable, and outdoor dry-bulb temperature as independent variable, was applied. R^2 values were generally poor, that brought to conclusion that there was no general rule to predict how electricity consumption depends on outdoor temperature for Swedish hotels. Electricity load in Swedish hotels is influenced by heating system, since some hotels do use electricity for direct heating or heat pumps. Nonetheless, a typical daily load shape can be developed for hotels with reasonable accuracy, and typical daytime standard deviations are approximately 8-10% of the mean values. Authors have also concluded that knowledge of electricity patterns and electricity consumption indicators are necessary for development of new tools for energy auditors and for identification of operational and maintenance problems.

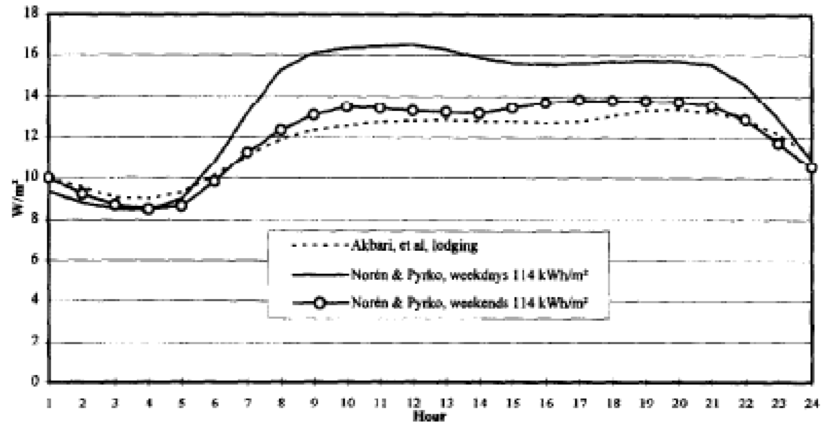

Figure 2.1. Load shape for Swedish hotels compared to USA hotels (Noren, Pyrko 1998)

A multiple regression analysis was also used in this research in order to analyse data collected with questionnaires and to establish a relationship between electricity and heating oil consumption and various parameters for hotels on the Adriatic coast. The regression analysis results are presented in Chapter 3.

A comprehensive research about energy audit scheme in hotels is done by Phdungsilp (2002). The questionnaire consists of eleven parts: general information about hotel, envelope, lighting, cooling plant, heating plant, service hot water, ductwork, pipework, energy sources consumption, environmental audit and thermal comfort and indoor climate data sheet. The environmental awareness among European hoteliers was studied by author Bohdanowicz (2003). A survey questionnaire was developed comprising of twenty-two multiple-choice questions. The same survey was conducted among hotels in Dubrovnik region in Croatia (Bohdanowicz, Zanki Alujević, Martinac 2004). The results were compared with Swedish and Polish hotels and have been presented in Chapter 3.

2.3. Modelling and simulations in buildings

It is generally believed that computer simulations are a powerful and flexible energy analysis tool for buildings. There are number of research papers published in journals such as Energy & Buildings and Building & Environment dealing with simulations in buildings. Some of the researchers use existing software such as TRNSYS, DOE-2, BLAST or others, or develop their own methodologies and software tools. It is found that integration of energy performance analysis into the building design process is a key development area nowadays (Hui, 1996). Ideally, energy analysis should be carried out at the design stage, during construction, and throughout the life of a building so that the performance can be monitored and improvements can be made, if required. Furthermore, practice should switch from studying isolated components and optimisation of subsystem and focus on building with all installations as a system.

An example that demonstrate systematic methods of modelling and analysis of integrated domestic, HVAC applications is the work by Sakellari (2005). In this work the reference system boundaries enclose the building as a construction and as a dynamic function, a comfort-providing system based on a heat pump, a low-temperature hydronic heat distribution system and controls in a residential application. Several models have been developed in the computational tool of TRNSYS and EES. These tools have been employed because they allow co-solving; hence the integrated system as well as the interaction between the different parts of the system could be studied.

Another recent study in residential buildings is about energy efficiency in dwellings in Riga, Latvia, done by author Blumberga A. (2001). The objective of the study was to develop evaluation method for technical, economical and environmental evaluation of energy efficiency in typical residential building. Different software tools developed outside Latvia could not be used since they do not contain data with specific conditions for the country. Therefore, a quasi-static one zone optimization computer model named "Maja" was developed. The evaluation criteria were reduction of CO_2 emissions and the costs of these reductions.

A group of authors (Tang, Kim 2004; Clark, Tang 2004; Born, Clark, Johnstone 2004) at University of Strathclyde under guidance of Professor Clark have published a number of papers in the area of integrated building performance simulation. Simulations in ESP-r system environment are proposed in order to support sustainable design of buildings. ESP-r system has been the subject of sustained development since 1974. The aim has bee to permit an emulation of building performance in a manner that a) corresponds to the reality, b) supports early-through-detailed design stage application and c) enables integrated performance assessments in which no single issue is unduly prominent (Hensen, Clarke 2000, Clarke 2002).

Most studies have been done in the field of energy system modelling in residential buildings. However, buildings within the service sector such as hotels, supermarkets, commercial buildings, schools and hospitals are specific with regard to energy consumption and therefore should be studied separately. These buildings require systematic studies and modelling of typical heating, ventilation, air conditioning and refrigeration systems.

A special type of energy system, namely energy use in supermarkets has been investigated by author Arias (Arias 2005) through modelling, simulation and field studies. A user-friendly computer program, CyberMart, which calculates the total energy performance of a supermarket, is presented. CyberMart opens up perspectives for designers and engineers in the field by providing innovative opportunities for assessment and testing of new energy efficient measures but also for evaluation of different already-installed system designs and components.

The XENIOS methodology for cost-effective energy efficient retrofit in hotels, mentioned before, considers building as a group of several discreet macro-elements corresponding to discreet building elements or spaces with different uses and operation schedules, such as hotel rooms, restaurants, lobby and bars, swimming pool, kitchen, technical premises and systems. Each macro-element consists of various elements which may vary according to the space use. HOTECO methodology that is developed in this thesis recognizes the building as a one element without zoning, since emphasise is on the HVAC system supply rather than energy utilization in rooms. Four HVAC systems, existing and proposed, were modelled, simulated and optimized for the same building using TRNSYS software tool. Simulations in the HOTECO methodology were made for a typical meteorological year; therefore hourly values of temperature and solar radiation are taken into account for yearly energy consumption estimation and system comparisons.

It would be impossible to check this hypothesis through fully controlled experiments since a hotel is dynamic building with many inflows and outflows that are dependant of guest occupancy, behaviour of tourists and climate conditions. However, data obtained through the simulation process were validated using measured and collected data for energy consumption of simulated hotel.

3. ENERGY AUDIT SCHEME IN HOTELS

This chapter will present the methodology used and results obtained from walk through audits conducted amongst hotels on the Adriatic coast. The results, presented in kWh/m^2, will give a base to help establish an energy benchmark for hotels on the Adriatic coast in Croatia. The regression analysis was implemented using a number of parameters that can predict the energy consumption. At the end, the regression equations that foresee the energy and oil consumption patterns are given.

3.1. The energy audit methodology

A detailed survey was developed and conducted among hotels on the Adriatic coast aiming to assess the energy consumption and establish a benchmark for different types of hotels in 5 coastal regions. The survey also aimed to get information about the utilization of renewable energy sources, types of cooling, heating and domestic hot water systems, refrigerants used as working fluids and consequently to assess the environmental impact of energy consumption in hotels.

In 2003 there were 97329 registered hotel beds in Croatia. 89,3% of these beds and 90% of the hotels are placed in 7 coastal counties (MINT 2003b) . These counties are: Dubrovnik-Neretva, Split-Dalmatia, Šibenik-Knin, Zadar, Primorsko-goranska, Lika-Senj, and Istria. Since there were only 8 registered hotels in the Lika-Senj county, among which 3 were in the coastal region on the island Pag, these hotels were added to the group of Primorsko-goranska. Similarly, 11 hotels in the Šibenik-Knin county were added to the Zadar county. Finally, the coastal area was divided into 5 regions namely: Dubrovnik (Dubrovnik-Neretva county), Istria, Rijeka (Primorsko-goranska and Lika-Senj counties), Split (Split-Dalmatia county) and Zadar (Zadar and Šibenik-Knin counties). According to official statistics from the Ministry of Tourism, a total of 393 hotels were registered in the coastal region in 2002 and were distributed as such; 65 hotels (17%) in Dubrovnik region, 122 (31%) in Istria, 87 (22%) in the Rijeka region, 84 (21%) in the Split region and 35 (9%) in the Zadar region (Figure 3.1.).

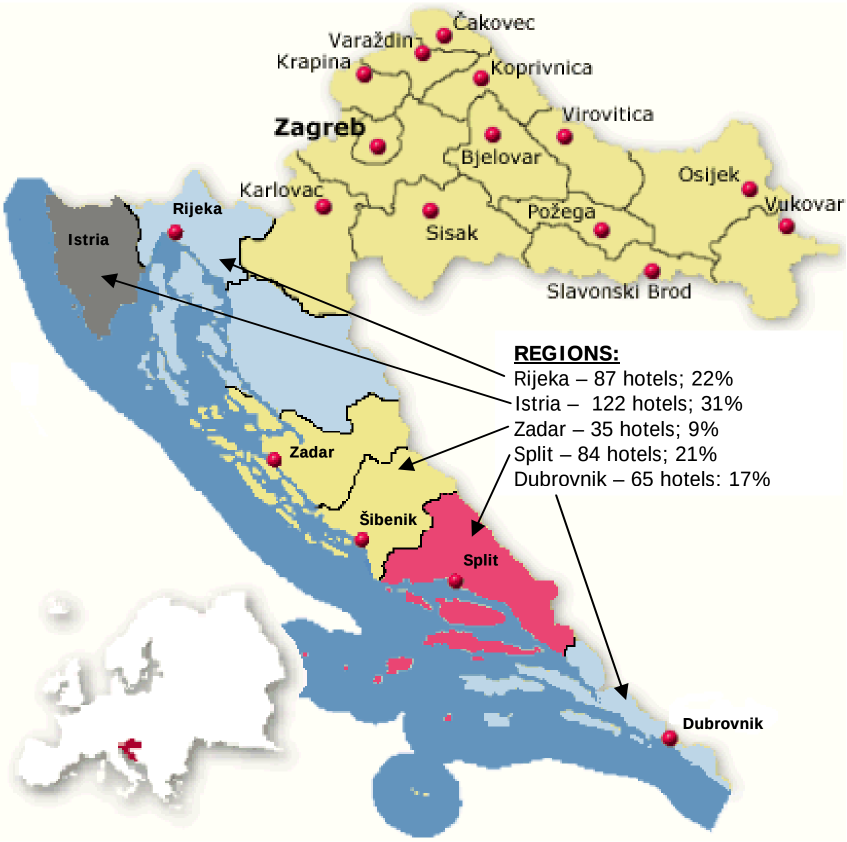

Figure 3.1. Five coastal regions on the Adriatic coast

Hotel buildings are specific, compared to others in the service sector. They have different operating schedules (seasonal , non-seasonal), various levels of service that influence the hotel's category, diverse facilities within the building (as restaurants, swimming pools, conference halls, laundry, etc.) with specific technical facilities, variability of occupancy levels throughout the year or season and inconsistency in guest's perception of thermal comfort and indoor climate. From the other side, there are some factors such as climatic conditions; location of hotel and year of construction that additionally influence the energy consumption regardless of previously mentioned parameters. Year of construction determines the building standards that were in force during design and construction and consequently, quality of thermal insulation, if used at all. For the purpose of energy audits in this research, hotels were divided according to the following parameters

- place
- location (mainland, islands)
- category
- operating schedule
- number of beds
- number of rooms
- heating facilities
- cooling facilities
- restaurants
- swimming pools

An energy and environmental audit questionnaire was developed (based on a comprehensive literature review) (Phdungsilp 2002, Bohdanowicz 2003) comprising of 6 parts with approximately 140 multiple choice questions. (Appendix I). Six main parts of the questionnaire are as follows:

1. ***General information about hotel building***
   - hotel info
   - category
   - location
   - building characteristics (number of floors, area, fenestration area, number of rooms, number of beds, roof)
   - restaurants (area, number of meals)
   - additional facilities (fitness, sauna, shops)

- swimming pool (area, sea/fresh water)
- laundry
- elevators

2. ***Energy consumption***
   - electricity consumption (monthly data)
   - fossil fuels consumption (monthly data)
   - water consumption (monthly data)
3. **Cooling system**
   - air cooling
   - water cooling
4. **Heating system**
5. **Domestic hot water system (DHW)**
6. **Environmental awareness**

The questionnaires were conducted on site with the people responsible for the technical systems in the hotels. Hotels were questioned in May-June 2003 and in March 2004. Since the aim of this thesis is to establish a benchmark for different hotel categories, with emphasize on hotels with a higher level of technical services (heating, cooling systems, restaurants, swimming pools), 50% of 3, 4, and 5 stars were targeted. Time for the energy audit, financial obstacles, as well as low levels of support from hotel management were the main reasons why not all targeted hotels with 3, 4 and 5 stars were visited. However, in the end, 124 hotels answered the energy and environmental audit questionnaire which represents 31,5% of the total number of hotels (393) in the 5 coastal regions with a response rate of 85%. Among the audited hotels, 95 (76,6%) are with 3,4 or 5 stars, this represents 43% of the total number of hotels within these categories in coastal regions. Numbers and percentages of audited hotels in different regions are presented in Table 3.1. Hotels with 2 and 1 stars are mainly 2 star hotels, since there are not many 1 star hotels, also they were not interesting from energy point of view.

Table 3.1. Number of surveyed and total number of hotels for 5 coastal regions

		Number of surveyed hotels (A)/total number of hotels (total)/ percentage of surveyed hotels											
	category	5* and 4*			3*			2* and 1*			5*,4*,3*,2*,1*		
	REGION	A	total	%	A	total	%	A	total	%	A	total	%
1	Dubrovnik	3	8	37,5%	16	28	57,14%	5	29	17,24%	24	65	36,92%
2	Istria	5	7	71,43%	20	70	28,57%	0	45	0%	25	122	20,49%
3	Rijeka	5	5	100%	18	34	52,94%	9	48	18,75%	32	87	36,78%
4	Split	0	3	0%	20	45	44,44%	9	36	25%	29	84	34,52%
5	Zadar	2	2	100%	6	19	31,58%	6	14	42,86%	14	35	40,00%
	Total	15	25	60%	80	196	40,82%	29	172	16,86%	124	393	31,55%

It can be seen from Table 3.1 that 50% of hotels in the 5 coastal regions are 3 stars, 44% are 2 and 1 star hotels, while only 6% are high quality hotels with 4 and 5* stars. According to the Ministry of tourism, one of the aims within the document "Tourism strategy till year 2010" (MINT 2003a), is to improve quality of existing hotel stock and increase the number hotels with 5 and 4 stars. The ratio of 5 and 4 star hotels goes from 3,57% in the Split region to 12,31% in the Dubrovnik region, while ratio of 3* hotels differ from 39,08% in the Rijeka region to 57,38% in Istria (MINT 2003b). Increased ratio of high quality hotel will lead to an increase in energy consumption in the coastal region.

According to the operation schedule, hotels in Croatia can be divided into 2 main groups: seasonal and non seasonal. Seasonal hotels differ regarding the operation schedule, since some of the hotels start their operation in March, some in April, and others in May, and stay open either till the end of September or October. However, the majority of seasonal hotels operate for 6 months, from April till end of September. For non seasonal hotel operations we consider year round functioning (12 months).

Seasonal hotels in coastal regions are represented by 64,63% (254 hotels) while non seasonal represent 35,37% (139 hotels). Distribution of hotels depends on operating schedule in 5 regions is given in Figure 3.2., where, for example, it can be seen that in Istria only 12,3% of hotels operates all year around. Rijeka and Dubrovnik are regions with the highest number of hotels with year round operation, with ratios of 58,62% and 44,62% respectively.

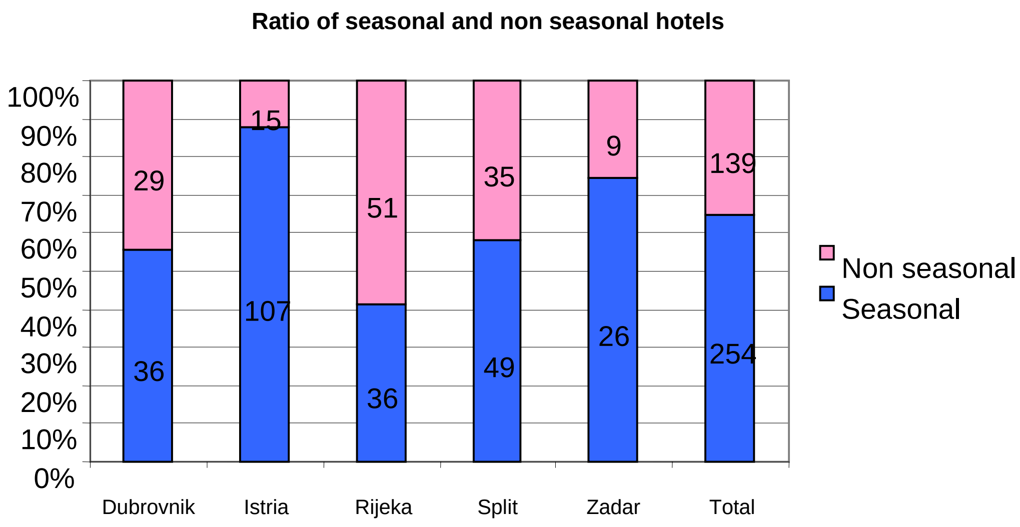

Figure 3.2. Number and ratio of seasonal and non seasonal hotels in 5 regions

Bearing in mind regional distribution (5 regions), hotel category (3 groups) and operating schedule, hotels in this study were divided into 30 groups, what was necessary for detailed analysis of the energy consumption and breakdown of energy end-users in hotels.

3.2. The energy audit results

To be able to analyze all collected data effectively, as well as to easily access different groups of data, a database in Microsoft Access was designed (see Figure 3.3.).

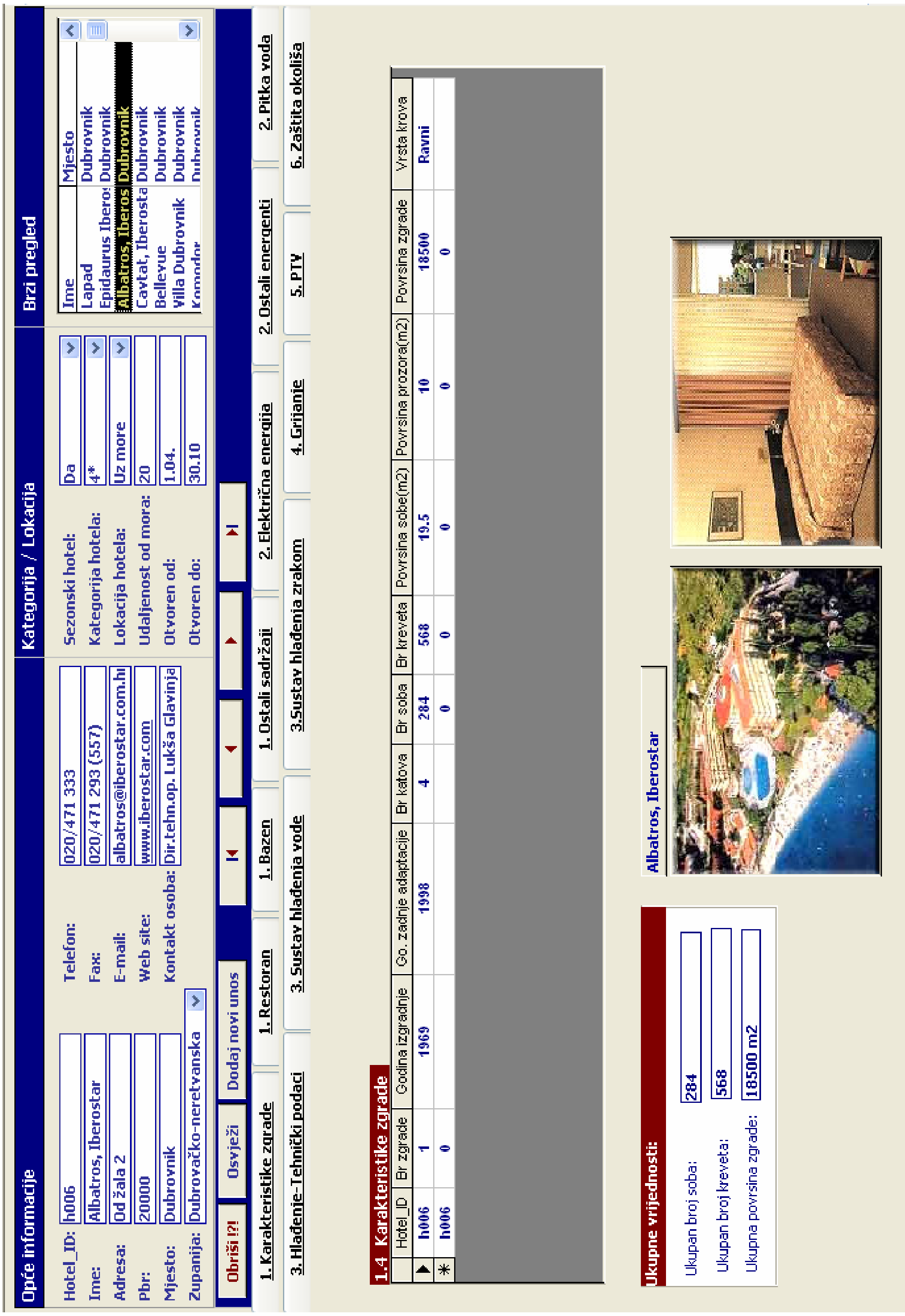

Figure 3.3. Graphical interface of hotel's database

3.2.1. Building and facility characteristics

3.2.1.1. Floor area of the hotels

First part of questionnaire gave data about floor area (FA) of hotels which is valuable information for total hotel stock floor area estimation that is used later on to estimate the total energy consumption in hotels. According to the number of rooms and typical floor space for the room of different categories an average area of facilities in hotels (restaurants, conference halls, reception, halls, sport facilities, service area, etc) was estimated. Analysis showed that in 4* and 5* hotels for each room belongs a hotel floor area of 63,72 m^2, in 3* and 2* hotels belonging floor area is 55,93 m^2 and 44,54m^2 respectively (Table 3.2.). These are reasonable results, since according to official standards for hotels, increased room floor area corresponds to higher hotel standard. If one excludes room floor space from total floor area of the hotel, estimated floor space for additional facilities would be 8554,32 m^2 for 5 and 4 stars hotels, 6534,59 m^2 and 3065,32 m^2 for 3* and 2* hotels respectively.

Table 3.2. Gross floor area of the hotel that belongs to one hotel room or bed

Hotel category	m^2/room	m^2/bed	additional floor area if rooms are excluded, m^2
5* and 4*	63,72	36,53	8554,32
3*	55,93	28,46	6534,59
2*	44,54	22,55	3065,32

According to hotel's categorization standard, minimal floor area of room for existing and new hotels is given in Table 3.3.

Table 3.3. Minimal floor area of the room (MINT 2004a)

Hotel category	Existing hotels m^2/room	New hotels m^2/room
5*	24	32
4*	21,5	26
3*	17,5	21
2*	15	-

124 hotels that were surveyed in this study are presented by approximately 900.000 m^2. Average floor area in Dubrovnik region was 7770 m^2 (147 rooms), in Istria region was 10727 m^2 (220 rooms), while in Rijeka and Split regions average floor area of the hotel was 8837 m^2 (147 rooms) and 8090 m^2 (161 rooms) respectively.

According to data obtain from the hotel survey (Table 3.2. and Table 3.3.), total floor area of hotel stock in 5 coastal regions was estimated to approximately 3.000.000 m^2, where 840.000 m^2 (28%) belongs to non seasonal hotels, while 2.160.000 m^2 (72%) belongs to seasonal hotels.

Croatia is a country with more than a thousand islands, where more than 60 are inhabited. These islands are very popular tourist resorts, where the hotel and accommodation sector represents one of the most important industries. According to results presented in Table 3.2. - Table 3.3., it is estimated that 79% of total hotel floor area is placed on the mainland, while the remainder, 21%, is placed on islands. With regards to operation schedule of these hotels, analysis showed that 80% of hotel floor area on the mainland operated in seasonal regime while 20% operates during the whole year. Situation on the islands is different, 43% of hotel floor area is operated in seasonal regime, while 57% operates during the whole year. (Figure 3.4.)

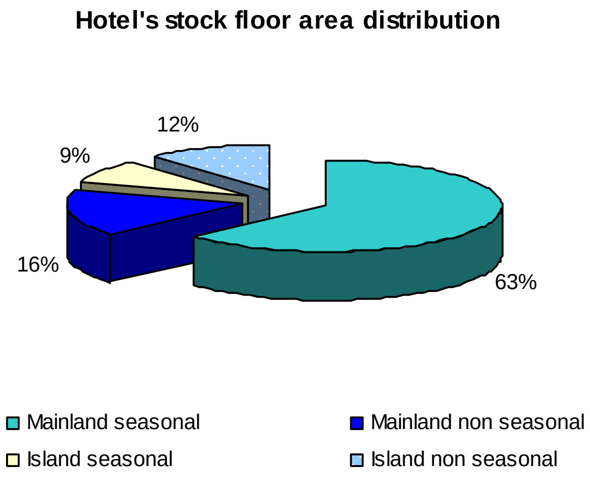

Figure 3.4. Hotel's stock floor area distribution

3.2.1.2. Age of the hotels

To be able to analyse the potential for energy consumption savings for heating and cooling systems by improving building envelope, it is important to collect data about the year of construction. Data from surveyed hotels has shown that 50% of buildings were built during a 20 years period, from 1961-1980, when tourism industry recorded its highest growth rate in the Mediterranean. Further on, 16% of the buildings were built before 1930, which is proof of a long tourism tradition on the Adriatic coast. During the period of 1931-1950 and 1951-1960 only 12% of the hotel buildings were built, while 16% growth is recorded from 1981-1990 and only 6% in the period of 1991-2002, see Figure 3.5.

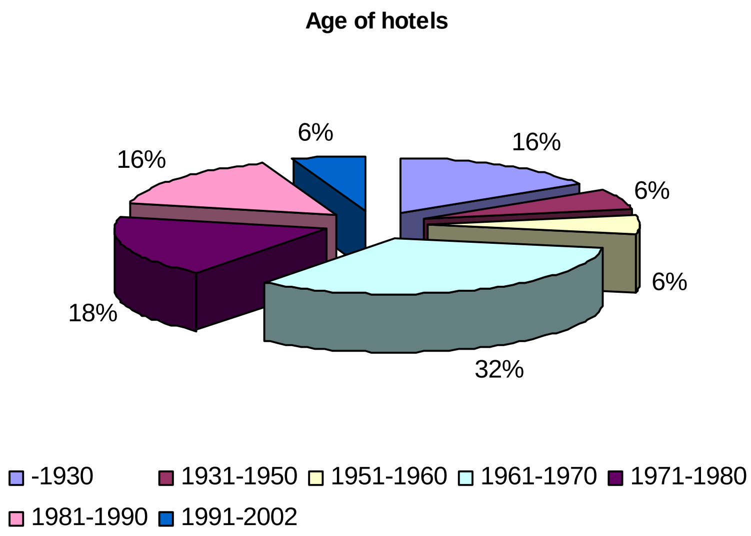

Figure 3.5. Age of surveyed hotel's stock

The majority of hotels are built without thermal insulation, implying that the potential for energy savings during the heating and cooling season are significant.

3.2.1.3. Restaurants

Although one might think that a restaurant is a necessary facility of all hotels, there are still 4% of hotels (out of 393 registered hotels in 2003) that do not have one. However, the majority of hotels do have restaurants either as a facility within the building or as a facility in another hotel building within the same tourist complex. Restaurants are high energy density end users with an approximate consumption of 10,6% to 25% of the total energy consumption in a hotel (see Figure 1.16. and Figure 1.17.). Energy audits in hotels on the Adriatic coast has shown that electricity and gas are the main energy sources for food preparation, while hot water needed for dish washing is distributed from a central system for domestic hot water, mostly powered by heating oil. Furthermore, food preparation demands high intensity of water consumption (both cold and hot). Even though the majority of hotels with 3 stars do not have air-conditioning in the rooms, some of them declared to have cooling in the restaurant, while kitchens are equipped with at least an exhaust ventilation system.

World experience has shown that energy consumption for one meal is in the range of 1-2 kWh, while the average water consumption of 60°C is 4,5 litres. Additional energy consumption for dishwashing and food preservation is 0,2-0,3 kWh and 0,1-0,3 kWh per meal, respectively (Bohdanowicz 2003).

3.2.1.4. Swimming pools

According to new regulation for a hotel categorisation, all hotels with 4 and 5 stars should have a swimming pool but analysis of existing hotel stock showed that only 64% (16) of these hotels in the 5 coastal regions have swimming pools. However, there are some hotels with 3 or 2 stars that do have a swimming pool within their facilities. There is a total of 92 swimming pools registered within 393 hotels in the coastal region. Water used for swimming pools can be either tap water or seawater, and depending on time of pool and hotel operation, water can be heated or not.

3.2.1.5. Additional facilities

In some regions, such as Dubrovnik and Opatija (region of Rijeka), there is a specific type of tourism - conference tourism - that is developed throughout the year. Typically hotels with 4 and 5 stars are the ones that have conference halls and therefore conferences are held within their premises. These conference halls are mostly air-conditioned, as to offer thermal comfort and indoor climate for a large number of people during the whole year.

Survey has shown that 50% of hotels do have laundry facilities, which are a big consumers of electricity (washing, drying, ironing) and hot water (60-80°C). World experience shows that energy consumption per 1 kg of clothes is 2-3 kWh.

3.2.2. Energy consumption in hotels

The main purpose for energy and environmental audits in hotels was to collect data about energy consumption and to identify energy resource diversity. In this research, energy performance of hotels is evaluated in terms of Energy Use Intensity (EUI), (Deng, Burnett, 2002a) which is defined as the site energy consumption per unit of gross floor area. Units chosen in this study are kWh/m^2. Descriptive statistics was used to determine mean values for electricity and oil consumption. Therefore, energy resources were analysed separately, and at the end of this paragraph, analysis was made for the total energy consumption in hotels depending on operational schedule, category and region. Energy resources widely used in hotels on Adriatic coast are: electricity, heating oil and gas.

3.2.2.1. Analysis of electricity consumption

It is expected that electricity consumption in hotels depends on hotel's category which basically gives a picture about services offered in the hotel. Electricity is used to power all building service systems such as lighting, TV, elevators, cooking devices, electrical appliances, laundry and HVAC systems (mostly ventilation, cooling and hot water pumps, rarely heating systems).

Energy billing information of monthly electricity consumption was obtained from 86 hotels out of 124 which give a 70% response rate. Hotels that did not provide electricity consumption data do not have an established energy management programme or energy monitoring programme. In these cases billing information stays in the administration sector, while technical staff is not interested in their evaluation and are not aware of the importance of monitoring the behaviour of the technical systems.

Collected data was analysed with regard to electricity consumption (kWh) per square meter, per room and per bed for 24 categories depending on the location (4 regions: Dubrovnik, Istria, Rijeka, Split), operating schedule (seasonal and non seasonal hotels) and number of stars (5*- 4*, 3* and 2*). Surveyed hotels from the Zadar region did not provided adequate data; therefore this region is excluded from this analysis. However, climate conditions are similar to region of Split which leads to the conclusion that results might be similar.

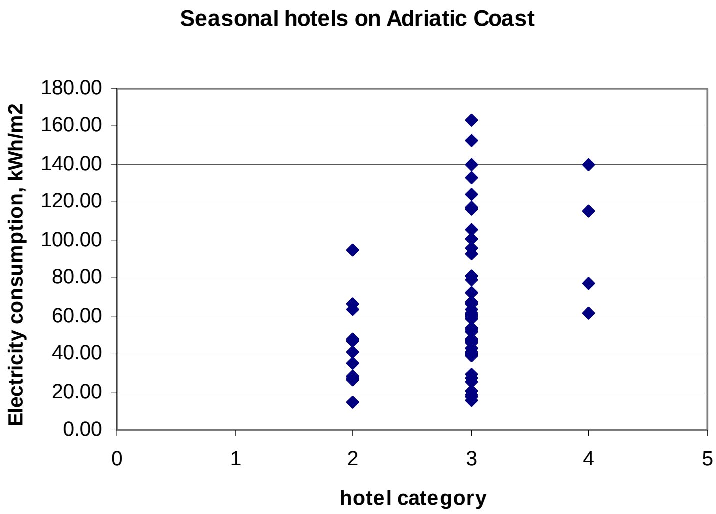

Figure 3.6. Electricity consumption for seasonal hotels on the Adriatic coast by hotel category

On Figure 3.6. and Figure 3.7. data for electricity consumption is presented by hotel category for all surveyed hotels. It can be seen that electricity consumption varies a lot for the same hotel category, it goes from 15,42 – 163,6 kWh/m² and from 29,15 – 148,88 kWh/m² for seasonal and non seasonal 3 stars hotels respectively.

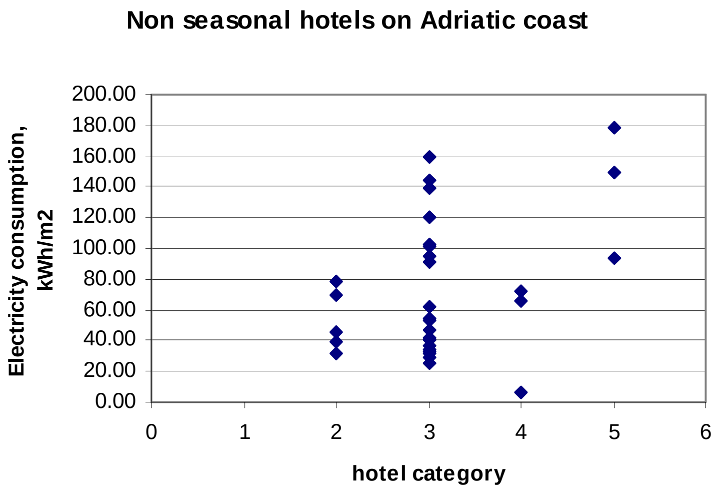

Figure 3.7. Electricity consumption for non seasonal hotels on the Adriatic coast by hotel category

In Table 3.4. the average electricity consumption is given for different hotel categories, together with the number of surveyed hotels for each category. Since there are not many hotels with, for example 5 stars, only one or two hotels were surveyed in a specific group. However, at the end of the table, average electricity consumption for all hotels with the corresponding number of hotel samples is given. Data presented in Table 3.4. is within expected ranges of electricity consumption for different hotel categories, and therefore it is proof that hotels in a higher category consume more electricity, while seasonal hotels consume less electricity than non seasonal. Although operating time for seasonal hotels is only 6 months, compared to whole year operation (12 months), electricity consumption is only 17% lower than 5 and 4 stars hotels, 25% lower for 3 stars hotels and 6% lower for 2 stars hotels. Reason for this is in low occupancy rate during the period of October-March. According to official statistics from the Ministry of tourism (MINT 2004b), only 14,04% and 14,78% of overnights are registered in hotels in the period from January – March (4,58% and 4,73%) and October – December (9,47% and 10,05%) in years 2002 and 2003 respectively. This data is taking into account the total number of overnight stays in hotels in Croatia, but bearing in mind that 95% of overnights occur in coastal regions, percentages stated above present realistic data for coastal hotels as well.

One exception is presented in Table 3.4. for higher electricity consumption in seasonal hotels (127,51 kWh/m^2) compared to non seasonal are 5 and 4 stars hotels (90,99 kWh/m^2) in Istria. The reason for this is a bigger floor area reported for one surveyed non seasonal hotel compared to seasonal hotels. If one compares electricity consumption per room, it can be seen that for non seasonal hotels consumption are higher (7285,12 kWh/room), compared to seasonal hotels (6317,38 kWh/room).

According to data for electricity consumption per one hotel's room in kWh/room (Table 3.4.), estimates for total electricity consumption were made for all hotels in five coastal regions (Table 3.5.). Estimated total electricity consumption is 180,23 GWh, this represents 5,5% of total electricity consumption in the service sector in 2002.

Table 3.4. Average electricity consumption in kWh for different hotel categories

			Seasonal hotels				Non seasonal hotels			
		No hotels	No hotels	kWh/m2	kWh/room	kWh/ bed	No hotels	kWh/m2	kWh/room	kWh/ bed
Dubrovnik	5* - 4*	3	1	**77,45**	5045,18	2522,59	2	**125,44**	10453,83	5226,91
Dubrovnik	3*	15	11	**74,96**	3055,66	1544,28	4	**113,27**	5082,70	2343,49
Dubrovnik	2*	3	3	**50,62**	2351,76	1175,88	0			
Surveyed/ response	**24**	**21**	**15**				**6**			
Istria	5* - 4*	3	2	**127,51**	6317,38	3320,60	1	**90,99**	7285,12	3917,78
Istria	3*	10	10	**60,19**	2980,78	1539,57	0			
Istria	2*	0	0				0			
Surveyed/ response	**25**	**13**	**12**				**1**			
Rijeka	5*- 4*	4	1	**61,34**	3627,81	1813,90	3	**102,78**	7198,21	3819,64
Rijeka	3*	18	5	**61,10**	2704,44	1359,20	13	**54,18**	3858,27	2031,40
Rijeka	2*	8	3	**41,22**	1863,53	875,47	5	**50,47**	2674,30	1352,75
Surveyed/ response	**32**	**30**	**9**				**21**			
Split	5* - 4*	0	0				0			
Split	3*	15	12	**65,01**	3859,68	1943,87	3	**96,64**	6732,16	3166,82
Split	2*	7	6	**44,11**	1898,56	950,10	1	**45,88**	1101,20	550,60
Surveyed/ response	**29**	**22**	**18**				**4**			
		No hotels	No hotels	kWh/m2	kWh/room	kWh/ bed	No hotels	kWh/m2	kWh/room	kWh/ bed
Croatia	5* - 4*	10	4	**88,77**	4996,79	2552,36	6	**106,40**	8312,39	4321,44
Croatia	3*	58	38	**65,31**	3150,14	1596,73	20	**88,03**	5224,38	2513,90
Croatia	2*	18	12	**45,31**	2037,95	1000,49	6	**48,18**	1887,75	951,67
Surveyed/ response	**124**	**86**	**54**				**32**			

Table 3.5. Electricity consumption in kWh in five costal regions (estimation)

kWh	5* and 4*	3*	2* and 1*	Total
Dubrovnik	11.027.775	13.690.090	4.959.166	29.677.032
Istria	9.928.824	38.510.189	17.142.913	65.581.926
Rijeka	4.444.155	18.890.740	10.819.267	34.154.162
Split	1.413.638	23.023.649	7.577.031	32.014.318
Zadar	1.941.694	14.036.498	2.837.839	18.816.031
Total, kWh	28.756.086	108.151.166	43.336.216	180.243.469

The breakdown of electricity consumption (Figure 3.8.) in the hotel sector is as follows: 16% in Dubrovnik region, 37% in Istria, 19% in Rijeka region, 18% in Split region and 10% in Zadar region. These data corresponds to the ratio of hotels in different regions (17% - D, 31% - I, 22% - R, 21% - S, 9% - Z, Figure 3.1.).

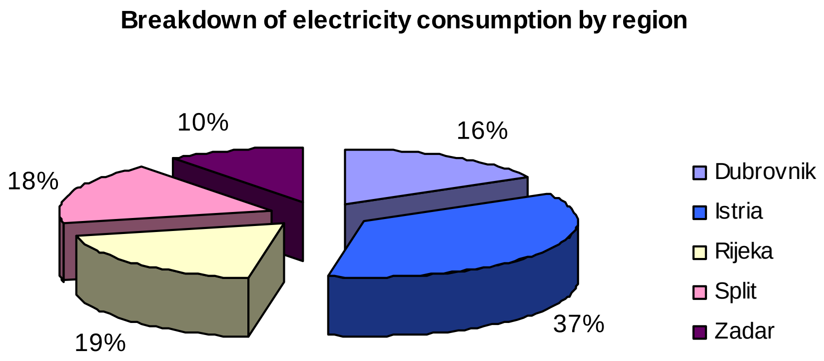

Figure 3.8. Breakdown of electricity consumption by region

Although high quality hotels with 5 and 4 stars represent only 6% of total hotel stock they consume 16% of the electricity (Figure 3.9.). Hotels with 3 and 2 stars, which represent 50% and 44% of total hotel stock, consume 60% and 24% of electricity respectively. This data is reasonable since hotels with 5 and 4 stars consume more than double of the electricity consumed in hotels with 2 stars (Table 3.4.)

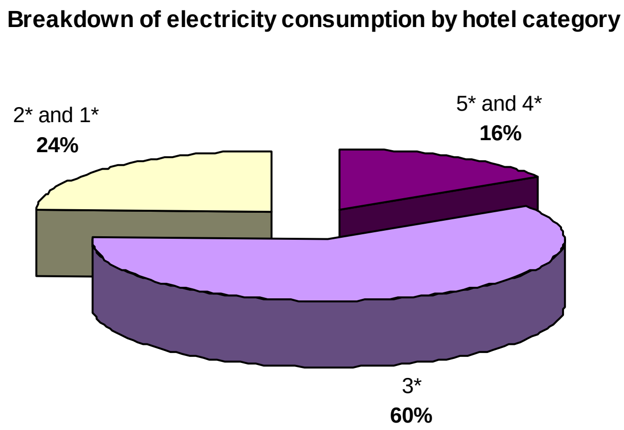

Figure 3.9. Breakdown of electricity consumption by hotel category

In Figure 3.10. and Figure 3.11. the breakdown of electricity consumption in GWh based on the data from Table 3.5. by hotel category and operational schedule for different regions is given. It can be seen that seasonal hotels in Istria consumes 60.78 GWh, this is almost the same amount of energy as all seasonal hotels in the other 4 regions. Rijeka and Dubrovnik regions have a long tourist tradition all year round (with the help of congress tourism), that is the reason why non seasonal hotels in these regions consume more energy than seasonal ones. Analysis of electricity consumption has shown that seasonal hotels utilize 64% of the total electricity consumption in 5 coastal regions while non seasonal ones consume 36%. This is estimated data based on the electricity consumption in hotels in 2002, but ratio of energy consumption in seasonal and non seasonal hotels might be changed in years to come, since the strategy for Croatian tourism is aimed at extending the tourist season and to improve tourist services in existing hotels. The breakdown of electricity consumption by hotels category in five regions is given in Appendix II.

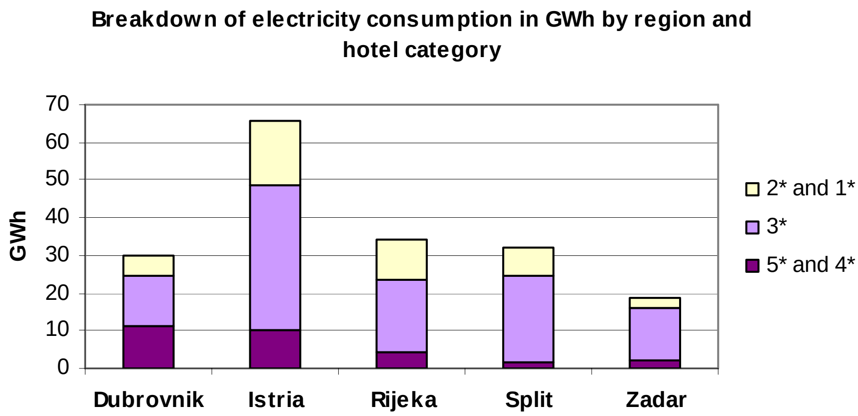

Figure 3.10. Breakdown of electricity consumption in GWh by region and hotel category

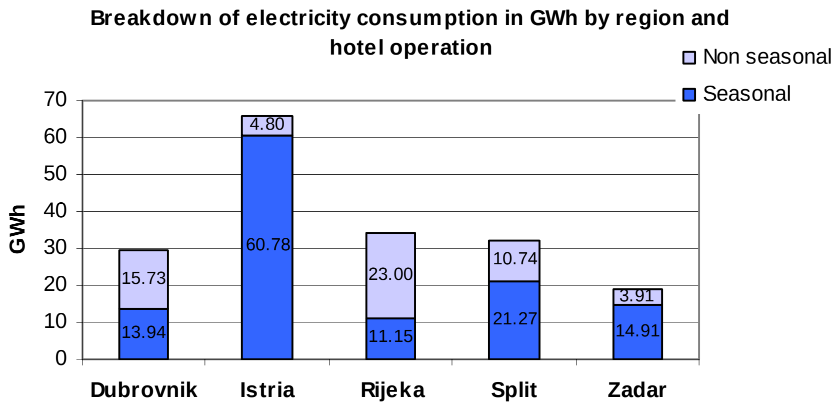

Figure 3.11. Breakdown of electricity consumption in GWh by region and hotel operational schedule

Analysis has also shown that hotels on the mainland are responsible for 81% (146 GWh) of total electricity consumption, while 19% (34,2 GWh) belongs to hotels on islands. Although the ratio of hotel facilities on islands is 21%, the reason for lower electricity consumption is due to a lower level of offered services (only one 4 stars hotel was registered on the island Rab, while the rest of the hotel stock is in 3 and 2 stars hotels).

3.2.2.2. Analysis of heating oil consumption

Heating oil is used in hotels for domestic hot water heating and for space heating. Energy consumption for domestic hot water depends, to some extent, on the hotel's category due to the different water consumptions. On the other hand, energy consumption for space heating should be the same, expressed in kWh/m^2, since heating demand depends of the climate. There are three major factors that influence energy consumption for different hotel categories: building envelope conditions, energy efficiency of heating system and water consumption.

Billing information for yearly oil consumption was obtained from 74 hotels out of 124, which is a 60% response rate. During the survey it was realised that due to weak energy management and quarterly oil purchases, only 25% of hotels did have recorded monthly oil consumption. The other 35% could provide only yearly oil consumption. Combined heating systems such as heat pumps and solar collectors were found in 14 hotels. That is why results of only 60 hotels (out of 74 who gave information about heating oil consumption) were presented in Table 3.6.

Collected data was analysed with regard to oil consumption in litres per square meter, per room and per bed for 24 categories depending of location (4 regions: Dubrovnik, Istria, Rijeka, Split), operation schedule (seasonal and non seasonal hotel) and number of stars (5*- 4*, 3* and 2*). Surveyed hotels from the Zadar region did not provide adequate data; therefore this region is excluded from this analysis. However, climate conditions are similar to the Split region which leads to conclude that results might be similar.

On Figure 3.12. and Figure 3.13. data for heating oil consumption is presented by hotel category for all surveyed hotels. It can be seen that heating oil consumption varies a lot for the same hotel category and it goes from 1,24 – 26,69 l/m² and from 0,81 – 52,94 l/m² for seasonal and non seasonal 3 stars hotels respectively.

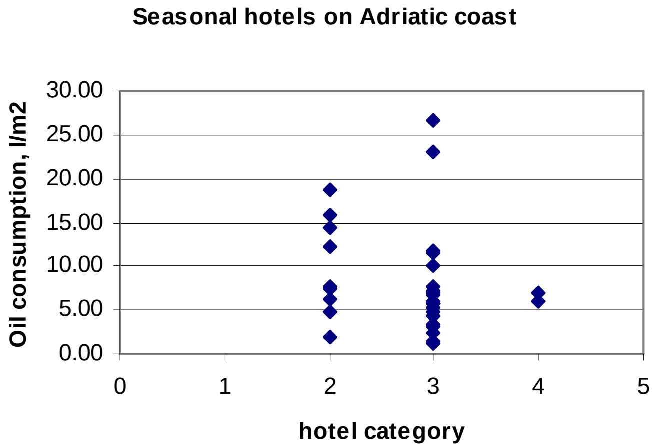

Figure 3.12. Heating oil consumption for seasonal hotels on the Adriatic coast by hotel category

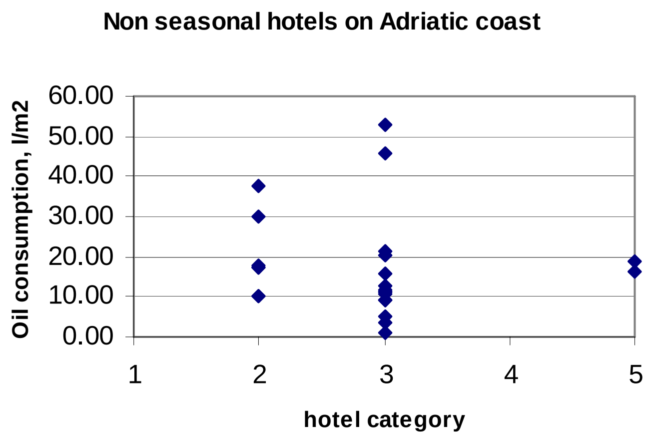

Figure 3.13. Heating oil consumption for non seasonal hotels on the Adriatic coast by hotel category

In Table 3.6. the average heating oil consumption is given for different hotel categories, together with the number of surveyed hotels for each category. Since there are not many hotels with 5 stars, in some cases only one or two, they were surveyed in a specific group. However, at the end of the table an average heating oil consumption for all hotels with corresponding number of hotel samples is given. One can see that oil consumption for hotels with year round operation in litres per room is highest for hotels with 5 and 4 stars (Croatia average 928,85 l/room and year), then something lower is for hotels with 3 stars (819,08 l/room and year) while the lowest is for 2 stars hotels (782,44 l/room and year). Reasons for this distribution is that hotels with higher standards have a higher hot water consumption (due to guest's water consumption, meal preparation and higher floor area for cleaning), bigger floor area per room and bigger area of common facilities that are heated spaces. These are the average values for all hotels. However as it was expected due to different climatic conditions and highest heating demand, the north Adriatic coast (region of Rijeka) has the highest oil consumption per room in the range of 1061 - 1188 l/room per year for all hotels. On the other hand hotels in the southern part of the Adriatic coast (region of Split and Dubrovnik), where heating demand is lower, consume less heating oil per room and differs from 503 – 709 l/room per year.

It can be seen that oil consumption per square meter of hotel is lower for the 5 and 4 star non seasonal hotels with an amount of 11,54 l/m² compared to the consumption in 3 and 2 stars in the order of 13,44 l/m² and 22,55 l/m² respectively. One of the reasons for higher oil consumption for 2 stars hotels is due to the lack of individual regulation of indoor temperature for the room. A second reason might be due to the fact that lower quality hotels have higher ratios of heated areas compared to the total floor area of the hotel. As it was elaborated in subchapter 3.2.1.1. (Table 3.2. and Table 3.3.). as hotel category increases, floor area of additional (not heated) facilities also increases.

Table 3.6. Average oil consumption in litres for different hotel categories

			Seasonal hotels (heating +DHW)				Non seasonal hotels (heating + DHW)			
		No hotels	No hotels	l/m2	l/room	l/ bed	No hotels	l/m2	l/room	l/ bed
Dubrovnik	5* - 4*	2	1	6,07	395,25	197,62	1	5,42	709,37	354,68
Dubrovnik	3*	9	7	6,93	263,47	134,15	2	15,04	637,36	305,89
Dubrovnik	2*	3	3	11,79	535,76	267,88	0			
Surveyed/ response	**24**	**14**	**11**				**3**			
Istria	5*- 4*	0	0				0			
Istria	3*	4	4	11,85	721,78	366,81	0			
Istria	2*	0	0				0			
Surveyed/ response	**25**	**4**	**4**				**0**			
Rijeka	5* - 4*	3	1	6,89	407,78	203,89	2	17,66	1148,33	592,18
Rijeka	3*	15	5	7,56	334,97	168,27	10	16,37	1188,81	623,83
Rijeka	2*	5	0				5	20,00	1061,50	533,76
Surveyed/ response	**32**	**23**	**6**				**17**			
Split	5* - 4*	0	0				0			
Split	3*	10	6	4,95	283,94	136,64	4	8,90	631,08	291,46
Split	2*	9	7	8,30	309,59	157,93	2	25,10	503,37	254,58
Surveyed/ response	**29**	**19**	**13**				**6**			
		No hotels	No hotels	l/m2	l/room	l/ bed	No hotels	l/m2	l/room	l/ bed
Croatia	5*- 4*	7	2	6,48	401,51	200,76	3	11,54	928,85	473,43
Croatia	3*	46	22	7,82	401,04	201,47	16	13,44	819,08	407,06
Croatia	2*	21	10	10,04	422,67	212,90	7	22,55	782,44	394,17
Surveyed/ response	**124**	**60**	**34**				**26**			

With respect to oil consumption in seasonal hotels, it can be seen from the Table 3.6. that consumption per room is similar in all types of hotels (app. 400l/room), but it differs as a consumption per square meter (from 6,48 l/m^2 for 5 star hotels to 10,04 l/m^2 for 2 star hotels) . These differences might be explained with the same arguments as for non seasonal hotels.

According to average oil consumption per one hotel's room in l/room (Table 3.6.), estimation for total oil consumption was made for all hotels in the five coastal regions (Table 3.7.). Estimated total oil consumption is 22,23 x 10^6 litres, that represents 229,5 GWh of energy with 0,22% in total energy consumption in service sector.

Table 3.7. Oil consumption in litres in five costal regions (estimation)

litres	5* and 4*	3*	2* and 1*	Total
Dubrovnik	884.769	1.371.682	1.114.342	3.370.793
Istria	1.418.738	4.291.983	203.6321	7.747.042
Rijeka	555.072	3.707.092	2.856.718	7.118.882
Split	119.211	1.588.190	1.083.380	2.790.782
Zadar	158.800	689.382	356.672	1.204.854
Total, litres	3.136.591	11.648.329	7.447.433	22.232.353

Breakdown of oil consumption (Figure 3.14.) in the hotel sector is as follows: 15% in the Dubrovnik region, 35% in Istria, 32% in the Rijeka region, 13% in the Split region and 5% in the Zadar region. This data does not completely correspond to the ratio of hotels in different regions (17% - D, 31% - I, 22% - R, 21% - S, 9% - Z, Figure 3.1.). The reason for that is a higher number of non seasonal hotels in the Rijeka region where there is a higher need for space heating compared to the regions of Dubrovnik, Split and Zadar where lower oil consumption compared to the ratio of hotels is estimated.

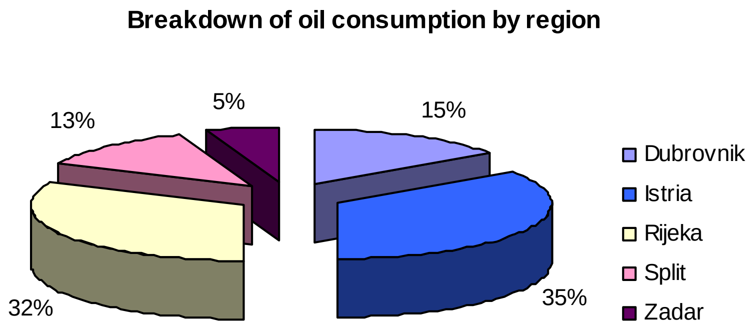

Figure 3.14. Breakdown of heating oil consumption by region

Although high quality hotels with 5 and 4 stars represent only 6% of total hotels stock they consume 14% of the oil (Figure 3.15.). Hotels with 3 and 2 stars, which represent 50% and 44% of total hotel stock, consume 53% and 33% of oil respectively.

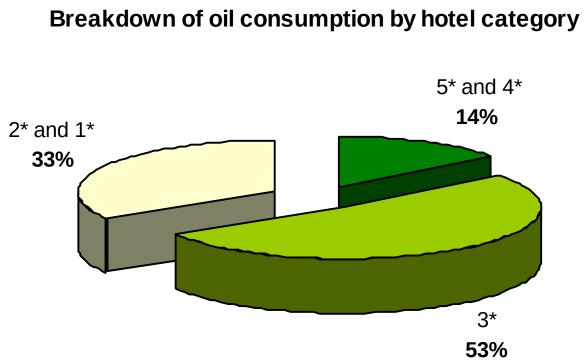

Figure 3.15. Breakdown of electricity consumption by hotel category

In Figure 3.16. and Figure 3.17. the breakdown of oil consumption in litres by hotels category and operational schedule for different regions based on the data from Table 3.7. is given. It can be seen that seasonal hotels in Istria and Rijeka consume 67% of the total oil consumption. Furthermore, it can be seen that non seasonal hotels in the Rijeka region consume 53% of the total oil consumption in non seasonal hotels.

Analysis of oil consumption has shown that seasonal hotels utilize 55% of total oil consumption in the 5 coastal regions, while non seasonal consumes 45%. This is estimated data based on heating oil consumption in hotels in 2002. However the ratio of oil consumption in seasonal and non seasonal hotels might be changed in years to come.

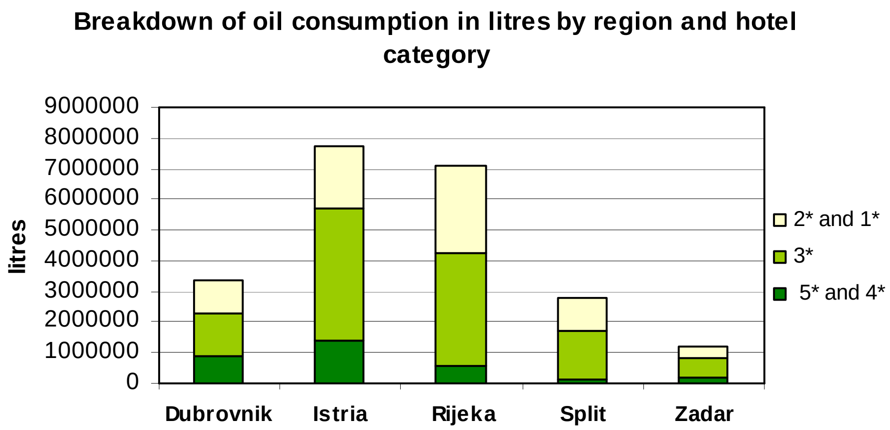

Figure 3.16. Breakdown of oil consumption in litres by region and hotel category

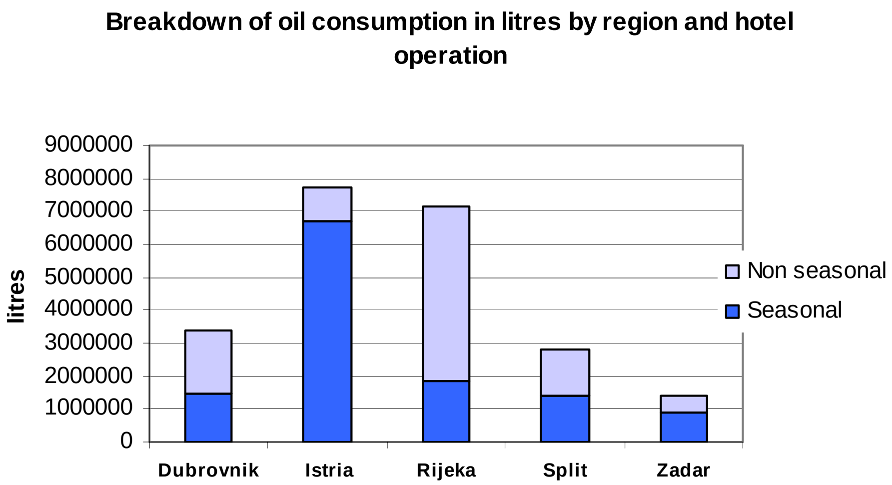

Figure 3.17. Breakdown of oil consumption in litres by region and hotel operational schedule

The breakdown of oil consumption by hotels category in five regions is also given in Appendix II.

3.2.2.3. Analysis of gas consumption

The use of gas in the form of a propane-butane mixture is usually for cooking, while only a few hotels do have a heating and domestic hot water powered by LPG. These hotels are excluded when calculating the average consumption of gas, given in Table 3.8.

Table 3.8. Average gas consumption in kg for different hotel categories

			Seasonal hotels				Non seasonal hotels			
		No hotels	No hotels	kg/m2	kg/room	kg/ bed	No hotels	kg/m2	kg/room	kg/ bed
Dubrovnik	5* - 4*	2	1	0,11	7,39	3,70	1	0,33	43,35	21,68
Dubrovnik	3*	10	7	0,56	22,32	11,80	2	0,45	20,74	9,52
Dubrovnik	2*	2	2	0,47	22,35	11,18	0			
Surveyed/ response	**24**	**13**	**10**				**3**			
Istria	5* - 4*	3	2	0,25	22,49	11,35	1	0,14	11,34	6,10
Istria	3*	9	7	1,05	59,50	31,16	2	1,24	64,54	34,77
Istria	2*	0	0				0			
Surveyed/ response	**25**	**12**	**9**				**3**			
Rijeka	5* - 4*	3	1	0,59	35,01	17,51	2	0,60	40,04	21,61
Rijeka	3*	17	4	0,39	17,70	8,37	13	0,60	28,08	13,77
Rijeka	2*	5	1	1,51	134,62	67,31	4	0,42	20,51	10,36
Surveyed/ response	**32**	**25**	**6**				**19**			
Split	5* - 4*	0	0				0			
Split	3*	9	7	0,33	19,21	9,63	2	1,35	98,00	43,37
Split	2*	3	1	0,36	2,67	0,83	2	0,81	16,20	8,19
Surveyed/ response	**29**	**12**	**8**				**4**			
		No hotels	No hotels	kg/m2	kg/room	kg/ bed	No hotels	kg/m2	kg/room	kg/ bed
Croatia	5* - 4*	8	4	0,32	21,63	10,85	4	0,36	31,58	16,46
Croatia	3*	44	25	0,58	29,68	15,24	19	0,91	52,84	25,36
Croatia	2*	10	4	0,78	53,21	26,44	6	0,62	18,35	9,28
Surveyed/ response	**124**	**62**	**33**				**29**			

Billing information for yearly gas consumption was obtained from 62 hotels out of 124, a 50% response rate. During the survey it was realised that due to weak energy management and quarterly gas purchase, only 20% of hotels do have recorded monthly gas consumption, although these are not believed to be real amounts of consumed gas per month. The other 30% could only give yearly total gas consumption.

Collected data were analysed with regard to gas consumption in kg per square meter, per room and per bed for 24 categories depending on location (4 regions: Dubrovnik, Istria, Rijeka, Split), operating schedule (seasonal and non seasonal hotel) and number of stars (5*- 4*, 3* and 2*). Surveyed hotels from Zadar region did not provide adequate data; therefore this region is excluded from this analysis.

From Table 3.8. it can be seen that there is no obvious pattern for gas consumption in different categories. Gas consumption per room varies from 11,34 kg to 98 kg for non seasonal hotels and form 7,39 to 134,62 kg/room for seasonal hotels. However, average data for Croatia shows that highest consumption is in the 3 star, non seasonal hotels. This might be explained by the number of prepared meals in these types of hotels that provides full service for their guests. Guests at 5 and 4 star hotels prefer to have at least one meal in 'a la cart' restaurant, outside of the hotel, what might be a reason why 5 and 4 stars seasonal hotels consumes the lowest amount of gas per room (21,63 kg/room). Basically gas consumption depends on number of cooking devices that are powered by gas and number of prepared meals. According to data for gas consumption per one hotel's room in kg/room (Table 3.8.), estimation for total gas consumption was made for all hotels in the five coastal regions (Table 3.9.). Estimated total gas consumption is 2714,5 tones, that represents 35,36 GWh of energy with 0,03% of total energy consumption in the service sector.

Table 3.9. Gas consumption in kg in five costal regions (estimation)

kg	5* and 4*	3*	2* and 1*	Total
Dubrovnik	41.318	441.346	83.483	566.148
Istria	30.576	479.911	629.490	1.139.977
Rijeka	23.476	169.356	195.290	388.122
Split	4.018	206.550	164.157	374.725
Zadar	8.353	139.820	97.344	245.515
Total, kg	107.741	1.436.983	1.169.764	2.714.488

Breakdown of gas consumption (Figure 3.18.) in the hotel sector is as follows: 21% in the Dubrovnik region, 42% in Istria, 14% in the Rijeka region, 14% in the Split region and 9% in the Zadar region. This data does not completely corresponds to the ratio of hotels in different region (17% - D, 31% - I, 22% - R, 21% - S, 9% - Z, Figure 3.1.). The reason for that should be investigated, taking into account number of guests, occupancy rate, number of meals prepared and cooking device diversity, which was not available in this study. However, the reason for higher gas consumption in the Istria region is due to a better access to the regional gas pipeline.

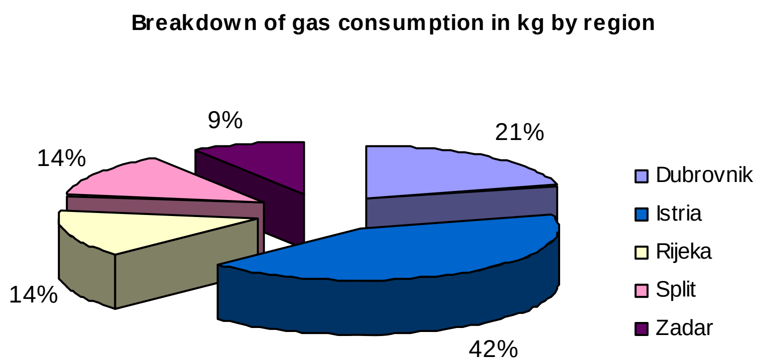

Figure 3.18. Breakdown of gas consumption by region

Although high quality hotels with 5 and 4 stars represent only 6% of total hotels stock they consume 4% of the gas (Figure 3.19.). Hotels with 3 and 2 stars that represent 50% and 44% of total hotel stock consume 53% and 43% of gas respectively.

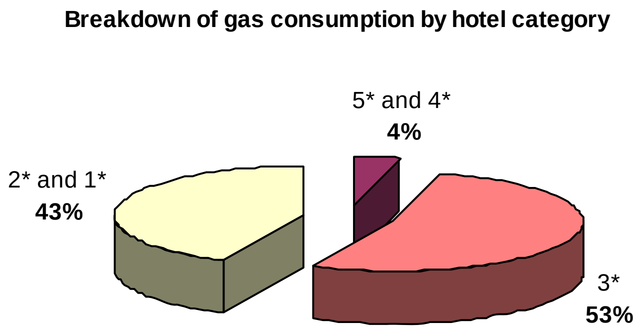

Figure 3.19. Breakdown of electricity consumption by hotel category

In Figure 3.20. and Figure 3.21. the breakdown of gas consumption in kilos, based on the date from Table 3.9. by hotel category and operational schedule for different regions is given. It can be seen that seasonal hotels on the Adriatic coast consumes 83% of the total gas consumption. Since gas consumption is strongly dependant on the number of guests and meals prepared, seasonal hotels that operates during the summer months when the hotel's occupancy goes from 20 to 100% have reasonably higher gas consumption. Furthermore it can be seen that hotels in the Istria region consume 42% of total gas consumption. This is estimated data based on gas consumption in hotels in 2002. However ratio of gas consumption in seasonal and non seasonal hotels might be changed in years to come, due to the fact that a regional pipeline will be extended to the regions of Rijeka, Zadar and Split.

The breakdown of gas consumption by hotels category in five regions is also given in Appendix II.

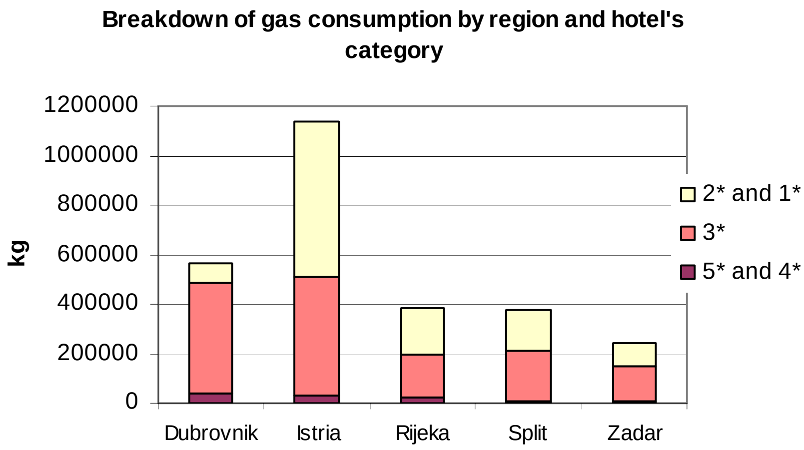

Figure 3.20. Breakdown of gas consumption in kg by region and hotel category

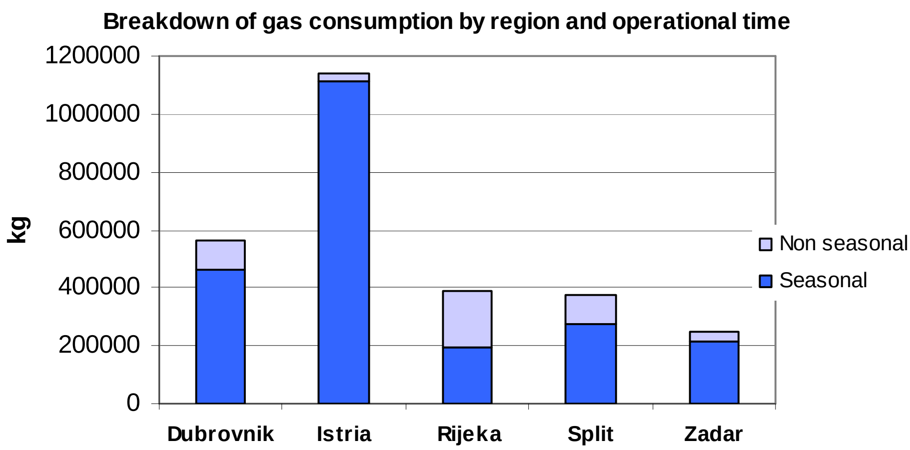

Figure 3.21. Breakdown of gas consumption in kg by region and hotel operational schedule

3.2.2.4. Analysis of total energy consumption

Data for electricity, oil and gas consumption collected during audits and analysed in subchapter's 3.2.2.1-3. were integrated and presented as a breakdown of energy resources for different hotel categories, operational schedules and regions in Tables 3.10-3.13. Net calorific value for conversion are as follows: for light heating oil H_d=42710 kJ/kg (MGRP 2004), while density was taken as 0,87 kg/dm^3 (Recknagel

2002), that gives H_d=37158 kJ/l, and gas used in hotels is a propane - butane mixture with calorific value H_d=46890 kJ/kg (MGRP 2004).

From Tables 3.10.-3.13. it can be seen that electricity consumption in seasonal hotels correspond to ratios from 30,74 – 54,83% depending of region and hotel category. Generally speaking, hotels with a higher quality have higher ratio of electricity consumption in the total breakdown of energy consumption (Figure 3.22.). The ratio of electricity consumption in non seasonal hotels goes from 21,57% to 54.22%. Heating oil consumption for seasonal and non seasonal hotels varies in the range of 37,81% - 60,68% and 43,31% -74,79% respectively, while higher ratios correspond to hotels in lower categories. With regards to gas consumption, it is in the range of 1,41% - 8,6% for seasonal and 0,82% - 8,28% for non seasonal hotels.

Table 3.10. Breakdown of energy consumption by fuel type for the Dubrovnik region

Dubrovnik Hotel category	5* and 4*		3*		2* and 1*		All hotels	
Operation schedule	Seasonal	Non seasonal	Seasonal	Non seasonal	Seasonal	Non seasonal	Seasonal	Non seasonal
% kWh, elec.	53.84%	54.22%	52.02%	38.44%	45.99%	21.57%	50.61%	38.08%
% kWh, oil	43.03%	43.31%	42.42%	55.31%	46.78%	74.79%	44.08%	57.80%
% kWh, gas	3.13%	2.47%	5.56%	6.25%	7.23%	3.63%	5.31%	4.12%
KWh/m² year	147.07	210.99	156.03	219.54	169.40	217.64	157.50	216.06

Table 3.11. Breakdown of energy consumption by fuel type for Istria

Istria Hotel category	5* and 4*		3*		2* and 1*		All hotels	
Operation schedule	Seasonal	Non seasonal	Seasonal	Non seasonal	Seasonal	Non seasonal	Seasonal	Non seasonal
% kWh, elec.	39.37%	38.81%	36.45%	N/A	N/A	N/A	37.91%	38.81%
% kWh, oil	58.79%	60.37%	55.73%	N/A	N/A	N/A	57.26%	60.37%
% kWh, gas	1.84%	0.82%	7.82%	N/A	N/A	N/A	4.83%	0.82%
KWh/m² year	327.02	234.47	195.29	N/A	N/A	N/A	261.15	234.47

Table 3.12. Breakdown of energy consumption by fuel type for the Rijeka region

Rijeka Hotel category	5* and 4*		3*		2* and 1*		All hotels	
Operation schedule	Seasonal	Non seasonal	Seasonal	Non seasonal	Seasonal	Non seasonal	Seasonal	Non seasonal
% kWh, elec.	N/A	39.56%	38.22%	33.76%	30.74%	30.24%	34.48%	34.52%
% kWh, oil	N/A	56.95%	57.82%	62.51%	60.68%	66.47%	59.25%	61.98%
% kWh, gas	N/A	3.48%	3.96%	3.73%	8.58%	3.29%	6.27%	3.50%
KWh/m² year	N/A	231.20	167.26	159.84	146.98	173.13	157.12	188.06

Table 3.13. Breakdown of energy consumption by fuel type for the Split region

Split Hotel category	5* and 4*		3*		2* and 1*		All hotels	
Operation schedule	Seasonal	Non seasonal	Seasonal	Non seasonal	Seasonal	Non seasonal	Seasonal	Non seasonal
% kWh, elec.	54.83%	N/A	53.79%	33.14%	40.84%	41.48%	49.82%	37.31%
% kWh, oil	43.76%	N/A	37.81%	58.97%	50.56%	50.24%	44.04%	54.60%
% kWh, gas	1.41%	N/A	8.40%	7.90%	8.60%	8.28%	6.14%	8.09%
KWh/m² year	67.83	N/A	124.27	172.58	195.52	96.87	129.21	134.73

Table 3.14. Breakdown of energy consumption by fuel type for Croatia (Adriatic coast)

Croatia Hotel category	5* and 4*		3*		2* and 1*		All hotels	
Operation schedule	Seasonal	Non seasonal	Seasonal	Non seasonal	Seasonal	Non seasonal	Seasonal	Non seasonal
% kWh, elec.	49.35%	44.20%	45.12%	46.22%	38.10%	31.10%	44.19%	40.50%
% kWh, oil	48.53%	53.54%	48.44%	47.17%	52.44%	63.83%	49.80%	54.85%
% kWh, gas	2.13%	2.26%	6.44%	6.62%	9.46%	5.07%	6.01%	4.65%
KWh/m² year	180.64	225.56	160.71	215.23	159.68	162.55	166	203

Data presented in Table 3.10. - Table 3.14. is the result from analysis of surveyed hotels, that is the reason why some groups of data are missing. As it was said in subchapter 3.1., (see Table 3.1.) not all hotel categories in different regions were surveyed and not all surveyed hotels gave sufficient data. However, for future work and utilization of presented data, approximations can be made with regards to similar climatic conditions. For the region of Split, data from the region of Dubrovnik can be taken, while for the region of Istria, data from the region of Rijeka will be a good approximation.

From Figure 3.22. it can be seen that hotels in a higher category utilize more electricity to provide services to their guests than hotels with lower standard. All hotels should provide a minimum amount of domestic hot water and all hotels should provide sufficient heating. From the other side, the ratio of gas consumption to total consumption is growing as the hotels' category lowers. Furthermore, the Dubrovnik and Split regions have a higher ratio of electricity consumption compared to the other energy sources (heating oil and gas) than the Rijeka and Istria regions. This might be explained with the higher heating demand due to lower average temperatures and lower intensity of solar radiation.

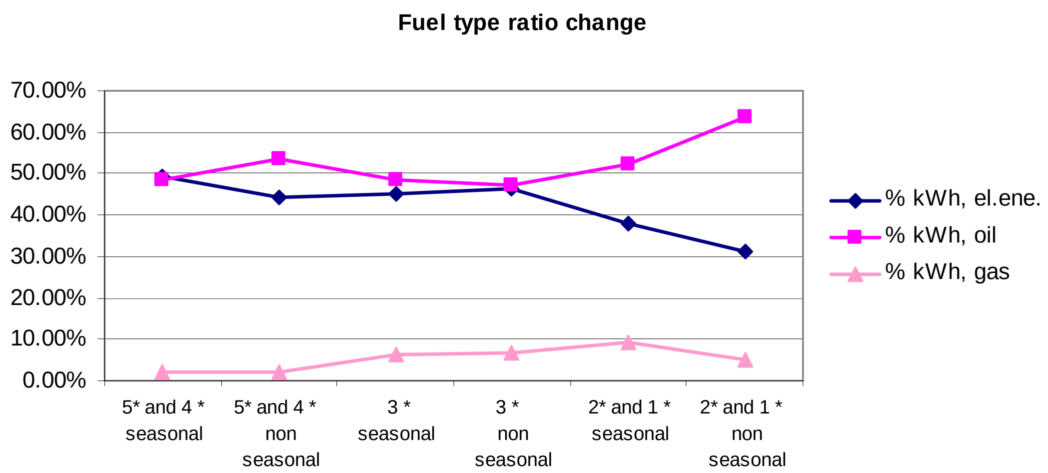

Figure 3.22. Changes is fuel type ratio for different hotel's categories on the Adriatic coast

3.2.2.5. Analysis of existing energy management in hotels

One of the observations from the survey was that energy management practice is on a low level or does not exist in many hotels. Energy management is considered to be a number of actions taken by the hotel's management at an energy resource and systems planning level with actions by the facility management on daily maintenance frequency. It was observed that personnel who take care of maintenance for the technical systems are not educated enough about the operational and financial effects of energy consumption in hotels. Only a few hotels collect energy data for their own analysis. The equipment performance, optimization of operating practices, regular adjustment of equipment, and replacement or modification of inefficient equipment and systems was not one duty and definitely not a priority for hotel management. Collection and analysis of energy data would help to identify areas for possible energy savings.

One of the main reasons for energy and water data collection and monitoring is to introduce energy management through data analysis and consequently the implementation of energy saving measures. World experience with respect to energy and water contributions in hotel's total costs shows ratios between 3 and 6% (Zanki 2002). Therefore energy saving actions and implementation of energy efficient measures can contribute to profit increase which is one of the best motivators for hotel owners.

A study conducted among 20 hotels in the region of Rijeka city owned by Liburnija Riviera Hotels (LRH), showed that the ratio of energy costs in total costs were changing from 1982 to 2001 in the range of 2,94% (1989) to 6,51 % (2001). In the years 1998-2001 there was a continuous increase in energy costs. With regards to water costs there is also increase from 0,85% of total costs in 1989 to 2,79% in 2001 (Holjevac 2003).

If one observes that energy costs are estimated as one fourth of total profit, the reasons to implement energy saving measures will be even more attractive.

3.2.3. Analysis of existing HVAC and DHW systems

3.2.3.1. Domestic hot water systems (DHW)

Domestic hot water installation is a precondition in hotel operations. Hot water should be available at any time and in required amounts. The energy audit has shown that 90% of hotels have combined systems for DHW and heating. In 90% of installations, fuel is light heating oil, while the other 10% utilizes electricity, solar collectors or LPG. It was recorded that only 6 out of 124 hotels do have solar thermal installations, that is negligible if one consider the sun potential on the Adriatic coast with more than 2000 sunshine hours throughout the year. Only 24% of hotels confirmed that they record water consumption, although there are no measurements for hot water.

3.2.3.2. Heating systems

98% of all surveyed hotel heating systems consist of a boiler, oil burner, hot water storage tank, hot water distribution lines and heating devices (radiators). In the case where cooling systems exist, fan coils are used for heating purposes as well. In only 2 hotels, out of 124 were solar collectors used for heating systems as well, while back up system is an oil boiler. Combined heating systems such as heat pumps, collectors and oil boilers are recorded in 10% of hotels.

The age of installed equipment can also give information towards possible points for energy efficiency improvements. 24,3% of boilers are older than 25-35 years, installed between 1970-1980 and 25,7% of boilers older than 15-25 years, installed between 1980-1990. The remaining 48,6% of the boilers were installed within the last 13 years.

3.2.3.3. Cooling systems

According to the official price list of hotels in 2003, 35% of hotels declared to have cooling systems. However it was not clearly stated which areas were cooled. As it was expected all hotels with 5 and 4 stars were in this group, but the rest were hotels with 3 stars and some with 2 stars. Cooling system are required for hotels with 5 and 4 stars in rooms and common facilities, while for existing 3 star hotels cooling is needed in common facilities only, but for new 3 star hotels, rooms should be cooled as well.

Energy auditing has shown that the systems approach does not exist. In many cases, hotel management implemented partial solutions, which makes cooling systems decentralized and hence less energy efficient.

Coefficient of performance (COP) for a cooling system depends on the temperature difference between condensing and evaporating temperatures, therefore for the same evaporation temperature systems with a lower condensing temperature will achieve better energy efficiency. That was the motivation behind asking about the type of condenser (air cooled, water cooled or seawater cooled condenser) in the energy audit questionnaire. Analysis has shown that 42 out of 124 hotels confirmed installation of centralized cooling systems, where 69% of condensers are cooled by air. 19% are chillers with water cooled condensers, while the rest, 12%, are chillers with seawater cooled condensers which are the most efficient. There were 33 out of 124 hotels who confirmed installation of decentralized cooling systems (mostly split units installed in restaurants and other common facilities)

Only one hotel confirmed the installation of an absorption cooling chiller powered by gas. An ice storage system that contributes to energy conservation was confirmed by 5 hotels. From these results it is obvious that potential for energy savings in cooling systems exists.

3.2.4. Analysis of water consumption

Water consumption in the hotel directly influence energy consumption, firstly due to the electricity consumed in pumping systems, and secondly due to the energy consumption for water heating. Water consumption in the hotel depends on number of guests, floor area and the number of facilities that utilize water (swimming pools, wellness centre, number of public showers on the beach and number of meals prepared in restaurant). Average water consumption obtained by questionnaire analysis for different hotel categories and regions is given in Table 3.15. Total number of hotels who provided data about water consumption was 80, that gives a 64,5% response rate. Yearly water consumption differs greatly from 0.18 m^3/m^2 (14,485 m^3/room) to 12,14 m^3/m^2 (355 m^3/room), however average water consumption is in the range of 1-3 m^3/m^2 (app. 70 - 170 m^3/room). It can be seen from the table that water consumption does not follow any pattern depending on hotel category since in the region of Rijeka water consumption in hotels in the lower category is higher than for higher category hotels while in the regions of Split and Istria (seasonal hotels) the situation is reversed. It was realised that water consumption depends on the presence of a swimming pool in the hotel which was also analysed and presented in Table 3.15.

In some places on the coast, especially on the islands, there is a lack of potable water. None of the islands possess water springs and therefore water is transported from the mainland through underwater pipelines or by ship. However, the pipeline capacities are limited and sometimes, in high tourist season, do not satisfy the needs, while ship transport is very costly and limited. There is a big issue with water management in the tourism industry since water consumption is a heavy burden on natural resources. With respect to water consumption in hotels of the world, it is estimated that – depending on the hotel standard – guests typically use between 90 and 150 litres of water per night. However, a recent report published by one hotel chain provides an average figure of 440 l/guest-night, while another chain reports an average figure of 224 l/guest-night (Bohdanowicz, Martinac 2003).

Table 3.15. Average water consumption in m^3 for different hotel categories

			Seasonal hotels				Non seasonal hotels			
		No hotels	No hotels	m^3/m2	m^3/room	m^3/ bed	No hotels	m^3/m2	m^3/room	m^3/ bed
Dubrovnik	5* and 4*	2	1	1.73	112.58	56.29	1	0.99	129.60	64.80
Dubrovnik	3*	16	12	2.53	102.87	51.83	4	2.70	121.77	56.67
Dubrovnik	2*	3	3	2.45	106.30	53.15	0			
Dubrovnik	With pool			2.73	97.15	49.43		0.99	129.60	64.80
Dubrovnik	No pool			2.25	109.54	54.63		2.70	121.77	56.67
Surv/ resp.	**24**	**21**	**16**	**2.46**	**104.12**	**52.36**	**5**	**2.36**	**123.34**	**58.29**
Istria	5* and 4*	3	2	2.03	181.10	91.33	1	4.09	327.53	176.14
Istria	3*	10	10	1.82	85.68	44.37				
Istria	2*	0								
Istria	With pool			1.29	80.53	40.71				
Istria	No pool			1.84	88.36	46.70				
Surv/ resp.	**25**	**13**	**12**	**1.86**	**92.05**	**48.34**	**1**	**4.09**	**327.53**	**176.14**
Rijeka	5* and 4*	4					4	1.71	111.54	58.22
Rijeka	3*	9	4	2.69	97.83	48.55	5	3.02	171.00	97.40
Rijeka	2*	4	3	2.89	126.57	68.54	1	2.40	150.10	75.05
Rijeka	With pool							1.86	117.40	62.81
Rijeka	No pool							2.50	148.20	81.35
Surveyed/ response	**32**	**17**	**7**	**2.77**	**110.15**	**57.12**	**10**	**2.43**	**145.12**	**79.49**
Split	5* and 4*	0								
Split	3*	13	10	5.32	212.68	101.31	3	0.87	68.57	33.87
Split	2*	7	6	1.74	76.22	38.17	1	9.75	233.90	116.95
Split	With pool			4.66	196.35	98.15		5.91	185.13	91.93
Split	No pool			2.10	94.97	47.59		1.75	126.81	57.18
Surveyed/ response	**29**	**20**	**16**	**3.98**	**161.51**	**77.63**	**4**	**3.83**	**155.97**	**74.56**
Zadar	5* and 4*	3	2	4.40	110.96	43.98	1	1.76	91.88	46.03
Zadar	3*	1	1	9.74	146.47	79.51				
Zadar	2*	5	5	2.02	59.15	29.74				
Zadar	With pool									
Zadar	No pool									
Surveyed/ response	**29**	**9**	**8**	**3.58**	**83.02**	**39.52**	**1**	**1.76**	**91.88**	**46.03**
		No hotels	No hotels	m^3/m2	m^3/room	m^3/ bed	No hotels	m^3/m2	m^3/room	m^3/ bed
Croatia	5* and 4*	12	5	2.72	134.88	63.87	7	2.14	165.14	86.30
Croatia	3*	49	37	4.42	129.11	65.12	12	2.20	120.45	62.64
Croatia	2*	19	17	2.28	92.06	47.40	2	6.07	192.00	96.00
Croatia	With pool			2.89	124.68	62.77		2.92	144.04	73.18
Croatia	No pool			2.06	97.62	49.64		2.32	132.26	65.06
Surveyed/ response	**124**	**80**	**59**				**21**			

Data about guest nights in hotels on the Adriatic coast were not available for all hotels, but results based on the analysis of 15 hotels from the region of Rijeka for 2002 show that, water consumption per guest and night vary based on hotel occupancy and it goes from 287 l/guest night (100% occupancy rate) to 800 l/guest night (13% occupancy rate).

The questionnaire has shown that water prices vary depending on region from 4,4-7 KN/m^3 (0,6 – 0,9 EUR/m^3) in the region of Split, 9 – 10 KN/m^3 (1,23 – 1,37 EUR/m^3) in the region of Dubrovnik, 7-19 KN/m^3 (0,9 –2,6 EUR/m^3) in the region of Rijeka to 11-17 KN/m^3 (1,5 – 2,3 EUR/m^3) in the region of Istria.

It has been shown (on the study conducted among 20 hotels in Rijeka region for period 1998-2003) that the ratio of water costs in total costs of energy resources varies form 32,4-39,3% while 24,7-32,2% goes to electricity, 28,7-40,2% to heating oil and 1,8-3,4% to gas costs (Elteh 2003). High water cost is a good enough incentive to promote water savings measures and introduce a water management system.

3.2.5. Results of environmental awareness audit

The last part of the energy audit was an environmental awareness set of questions that gave an overview about environmental and energy saving measures applied in hotels at the Adriatic coast. It has been shown that 40% of hotels do not "think" about energy consumption and they have not implemented any energy savings measures (not even energy consumption monitoring). The remaining 60% of the hotels tried to implement energy saving measures, but they are mainly related to energy efficient lighting. The exceptions are six hotels who have installed solar collectors.

At the same time as the energy audit was made, environmental awareness questionnaires were distributes to the hotel's management in the Dubrovnik region. The same questionnaire was distributed among hotels in Sweden and Poland and compared (Bohdanowicz, Zanki Alujević, Martinac 2004). Traditionally, and to some degree understandably – from a business perspective and in fear of negative publicity – the hotel industry has been reluctant to assume responsibility for any significant negative environmental impacts occurring during various stages (including construction, operation, maintenance, retrofitting, demolition) in the life-cycle of hotel facilities. Studies have shown that recently, however, attitudes have started to change. The environmental awareness survey among hoteliers in three countries, namely Sweden, Poland and Croatia showed that 81,5% in Poland, 82,7% in Sweden and 100% in Croatia of respondents believed environmental protection to be essential for the performance and further development of the tourism industry. Recognizing the problem is a necessary first step towards change and the implementation of more responsible practices and behaviours. The majority of respondents 83,3 % in Croatia believed that environmental impacts caused by hotels are moderate to significant. On the contrary only 26% of respondents in Croatia declared being involved with energy and water saving measures and some sort of waste management (sorting, recycling) (See Figure 3.23.) Among energy saving options, energy-efficient lighting received the most attention (76% in Sweden, 70.2% in Poland but only 23.3 in Croatia).

Many people insist that efficient equipment is prohibitively expensive; however they are often unaware of the fact that the running costs of inefficient apparatuses are frequently much higher than the initial cost of more efficient equipment. It is therefore important to evaluate the cost of equipment not only based on initial cost, but taking the entire life-cycle into consideration. This attitude will gradually become more common in the future and current figures related to the incorporation of energy-efficient equipment into the hotel market (20% for Croatia, 41.9% for Poland,

and 58.2% for Sweden) will undoubtedly increase (Bohdanowicz, Zanki Alujević, Martinac 2004).

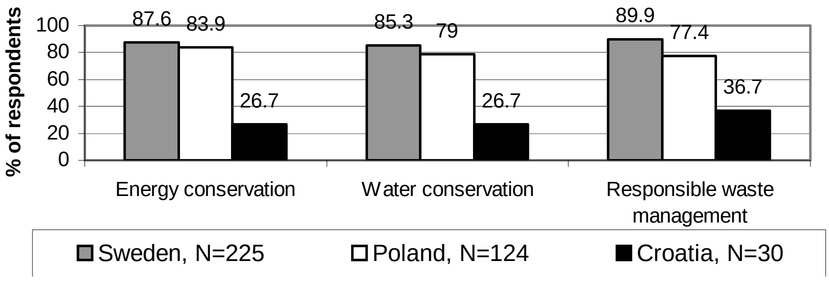

Figure 3.23. Environmental areas targeted, % respondents (Bohdanowicz et la 2004)

As a conclusion one can say, Croatian hoteliers generally seem to have a high level of environmental knowledge and concern for these issues. However, among the three countries investigated, concrete pro-ecological initiatives were found to be least likely implemented in Croatia. This may in part be due to the very recent revival of the Croatian tourism industry, following regional political and economic difficulties in the 1990s. It is reasonable to expect the situation in Croatia to improve as the industry continues to regain momentum (Bohdanowicz, Zanki Alujević, Martinac 2004).

The questionnaire also showed that:

- 100% of respondents believe that environmental protection is conditional for tourism development
- 83,3% of respondents believe that the environmental impact of hotel sector is significant
- 63,3% of employees are familiar with environmental actions
- 50% of respondents are involved in some of the actions that might contribute to environmental protection
- 26% of respondents are involved in actions for energy and water savings
- 23% of respondents are familiar with energy saving lighting measures

- 20% of respondents are familiar with the fact that energy efficient equipment, although with higher investments costs, brings savings after a short payback period
- 6,6% of respondents encourage their guests to save energy and water
- 30% of respondents sort waste

As a conclusion of the environmental awareness audit, it can be said that although it seems Croatian hoteliers are familiar with most of the environmental protection measures, they neglect their implementation. Therefore, it can be concluded that the potential for environmental and energy saving measures are significant.

3.3. The benchmark for hotels on the Adriatic coast

Benchmarking is creating a standard by which something can be measured or judged. It is a quantitative process that can help to compare a hotel's current performance against itself over a period of time and with other competitor's standards and to determine which improvements are needed (IBLF 2005). Benchmarks for hotels established in this study are: electricity consumption, heating oil consumption, energy and water consumption per square metre and per room. Results collected from the energy audit and analysed separately in chapters 3.2.2. and 3.2.4. are summarised and presented in Table 3.16. Benchmarks are given for different hotel categories (5&4 , 3 and 2&1 stars), for different operational schedules (seasonal and non seasonal hotels) and for four regions (Dubrovnik, Istria, Rijeka and Split) with the average for the whole Adriatic coast. The region of Zadar did not have good response rate, so it was omitted in this table, but benchmark for the region of Split could be used.

Table 3.16. Benchmarks for Croatian hotels on the Adriatic coast

	Hotel category	5* and 4*		3*		2* and 1*		All hotels	
	Operation schedule	Seasonal	Non seasonal	Seasonal	Non seasonal	Seasonal	Non seasonal	Seasonal	Non seasonal
Dubrovnik	Electricity, kWh/m²	79,18	114,4	81,15	84,39	77,9	47,02	79,45	82,27
	Other energy	67,82	96,6	74,85	135,61	91,1	170,98	77,55	133,73
	Total, kWh/m²	147	211	156	220	169	218	157	216
	Water, m³/m²	1,73	0,99	2,53	2,7	2,45	N/A		
Istria	Electricity, kWh/m²	128,74	90,81	71,08	N/A	N/A	N/A	98,94	90,81
	Other energy	198,26	143,19	123,92	N/A	N/A	N/A	162,06	143,19
	Total, kWh/m²	327	234	195	N/A	N/A	N/A	261	234
	Water, m³/m²	2,03	4,09	2,83	N/A	N/A	N/A		
Rijeka	Electricity, kWh/m²	N/A	91,38	63,83	54,02	45,19	52,31	54,13	64,9
	Other energy	N/A	139,62	103,17	105,98	101,81	120,69	102,87	123,1
	Total, kWh/m²	N/A	231	167	160	147	173	157	188
	Water, m³/m²	N/A	1,71	2,69	3,02	2,89	2,40		
Split	Electricity, kWh/m²	N/A	N/A	66,7	57,33	80,07	40,18	64,27	50,37
	Other energy	N/A	N/A	57,3	115,67	115,93	56,82	64,73	84,63
	Total, kWh/m²	N/A	N/A	124	173	196	97	129	135
	Water, m³/m²	N/A	N/A	5,32	0,87	1,74	9,75		
Croatia	Electricity, kWh/m²	89,32	99,89	72,64	99,37	60,96	50,69	73,35	82,21
	Other energy	91,68	126,11	88,36	115,63	99,04	112,31	92,65	120,79
	Total, kWh/m²	181	226	161	215	160	163	166	203
	Water, m³/m²	2,72	2,14	4,42	2,20	2,28	6,07		

The energy consumption pattern for hotel buildings on the Adriatic coast do not differ from other hotels in the Mediterranean region (See Table 1.5.) and it varies between 41-594 kWh/m². However, average energy and water consumption in general is lower as it can be seen from Table 3.16., where total energy consumption varies between 124-327 kWh/m² for seasonal hotels and 97-234 kWh/m² for non seasonal hotels. Lower values for energy consumption compared to other Mediterranean countries can be explained by specific climate conditions, lower occupancy rate (yearly average 28%) and lower ratio of air-conditioned rooms and hotel facilities. Graphical presentation of benchmark results are given in Figure 3.24.

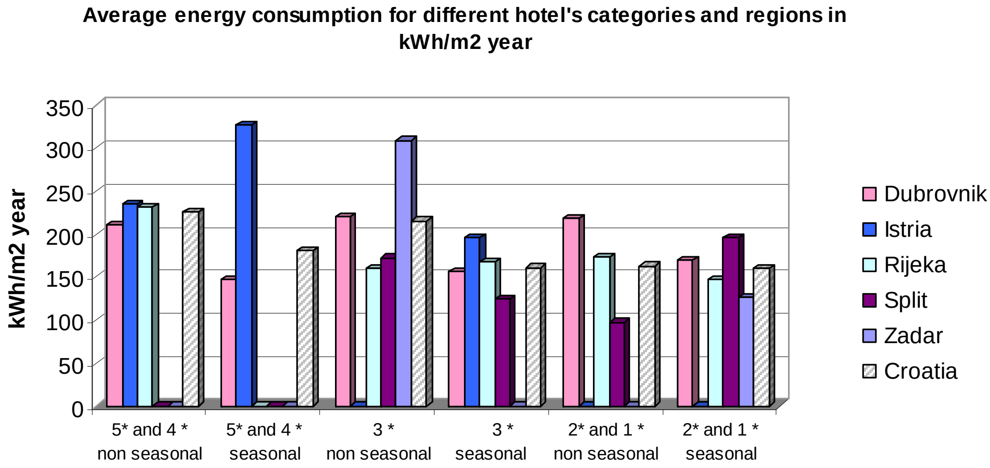

Figure 3.24. Average energy consumption for different hotel categories and regions in Croatia

In general, the use of benchmarks is good for the following reasons (IBLF 2005):

- Contributes to lower pollution and saving of water, waste, energy and non – renewable resources
- Helps managers to be more strategic in their planning and operations through product differentiation and cost savings
- Lowers utility costs by assessing the cost-saving techniques and technologies that will help to improve performance
- Keeps ahead of impending legislation and other regulatory penalties
- Improves staff awareness
- Reduces manpower and operating costs
- Helps control costs and manage risk through the identification of liabilities and weakness.

This is a first standard for hotels in Croatia based on data for energy and water consumption in year 2002 and it is expected that it will be of grate use for experts who intend to implement energy efficiency measures in the future.

3.4. Explanatory indicators (variables) for energy and water consumption –(Influencing variable analysis)

To analyse the data collected with the energy audit and to investigate how different variables (total floor area, number of rooms, size of the room, region) influence electricity, heating oil and water consumption, regression and correlation analysis was used.

Regression analysis is a statistical tool for the investigation of relationships between variables. "The goal of regression analysis is to determine the values of the parameters that minimize the sum of the squared residual values for the set of observations. This is known as a "least squares" regression fit." (Suryanarayana, Arici 2003)

In this research, linear regression with one independent and one dependant variable and multiple regression analysis with several (maximum five) independent variables (predictors) was used. A line in a two dimensional or two-variable space is defined by the equation:

$$y = a + b \cdot x \qquad (3.1.)$$

y variable can be expressed in terms of a constant (a) and a slope (b) times the x variable. The constant is also referred to as the intercept, and the slope as the regression coefficient, or B coefficient.

In the multivariate case, when there is more than one independent variable, the regression line cannot be visualized in the two dimensional space. In general then, multiple regression procedures will estimate a linear equation of the form:

$$y = a + b_1 \cdot x_1 + b_2 \cdot x_2 + \ldots + b_n \cdot x_n \tag{3.2.}$$

The regression coefficient (or B coefficient) represents the independent contributions of each independent variable to the prediction of the dependent variable.

The regression line expresses the best prediction of the dependent variable (y), given the independent variables (x). Usually there is substantial variation of the observed points around the fitted regression line. The deviation of a particular point from regression line is called the **residual value** (Statsoft 2005).

If there is no relationship between the x and y variables, then the ratio of the residual variability of the y variable to the original variance is equal to 1. If x and y are perfectly related then there is no residual variance and the ratio of variance would be 0. 1 minus this ratio is referred to as **R-square** or the **coefficient of determination**.

$$R^2 = \frac{\sum_{i=1}^{n} (\hat{y}_i - \bar{y})^2}{\sum_{i=1}^{n} (y_i - \bar{y})^2}, \quad 0 \le R^2 \le 1 \tag{3.3.}$$

Where variance by regression model (SSR) is given by equation (3.4.) and total variation (SS_{yy}) is presented by equation (3.5.).

$$SSR = \sum_{i=1}^{n} (\hat{y}_i - \bar{y})^2 \tag{3.4.}$$

$$SS_{yy} = \sum_{i=1}^{n} (y_i - \bar{y})^2 \tag{3.5.}$$

The R-square value is an indicator of how well the model fits the data (e.g. an R-square close to 1.0 indicated that we have accounted for almost all of the variability with the variables specified in the model) (Statsoft 2005).

In multiple regression, R can assume values between 0 and 1. To interpret the direction of the relationship between variables, one looks at the signs (plus or minus) of the regression or b coefficients. If a b coefficient is positive, then the relationship of this variable with the dependent variable is positive; if the coefficient is negative then the relationship is negative (e.g. the lower the occupancy rate the higher is energy consumption per guest night). If the *b* coefficient is equal to 0 then there is no relationship between the variables (Statsoft 2005).

According to Chadock scale there is a very strong correlation between variables if $0,64<R^2<1$ (See Table 3.17)

Table 3.17. Chadock scale for R^2 value (Horvat 2006)

R^2	$\lvert r \rvert$	Explanation
0	0	There is no relationship
0,00 – 0,25	0,00 – 0,50	Poor relationship
0,25 – 0,64	0,50 – 0,80	Media relationship
0,64 – 1	0,80 – 1	Strong relationship
1	1	Full relationship

3.4.1. Regression analysis for electricity consumption

As it was elaborated in subchapter 3.2.2.1. the electricity in hotels is used to power all building service systems as lighting, TV, elevators, cooling devices, electrical appliances, cooking devices, laundry and HVAC systems (mostly ventilation and cooling, rarely heat pump in heating season and hot water pumping system).

However, the electricity consumption in some of these services and systems are influenced by several factors that might be explanatory factors (predictors). For example, installed lighting power is in direct relation with total floor area, the number of TV's are dependant of the number of rooms, the number and frequency of elevator usage is dependant of size of the hotel (number of floors) and the number of rooms. The electricity used for cooling systems is related to the system capacity and the floor area that is cooled. The electricity used in restaurants and laundry depends of the number of guests. The energy that is used to power a ventilation systems depends of the floor area that is ventilated, while the energy for a hot water pumps depends on the domestic hot water consumption, which is influenced by the number of guests (showers), the number of rooms, the floor area (for cleaning purposes) and the number of meals (a food preparation and dish washing). One of the influencing factors for the electricity consumption is an energy efficiency of the installed devices and systems, which is dependent of systems year of installation and maintenance practice.

As a conclusion it can be said that there are several explanatory factors that might describe the electricity consumption in hotels. These are:

- total floor area - FA
- number of rooms – NR
- floor area per room - FAR
- guest nights - GN
- occupancy rate - OR
- number of meals
- cooling degree days
- percentage of the gross floor area that is mechanically cooled
- hotel category – additional services offered in hotel

The energy audit conducted in hotels on the Adriatic coast could not go into all equipment details that might additionally explain electricity consumption behaviour. Furthermore, information about guest nights, occupancy and meals prepared, was not available for this study.

The statistical Package for Social Sciences SPSS (ver. 11.5, SPSS Inc., Chicago, IL) and Microsoft Excel was uses for the statistical analysis. Entery regression analysis was used to determine correlation between set of predictors (FA- hotel floor area and NR

– number of rooms) and dependent variables as: electricity consumption (kWh) and oil consumption (litres). Regression analysis was made for different hotel categories and regions and at the end it was summarized for all hotels, separating seasonal and non seasonal hotels.

The Pearson product-moment correlation was used to determine the relationship between selected variables (FA and NR). Analysis has shown that predictors (FA and NR) are in strong correlation ($r = 0,75$; $p< 0,01$)

Descriptive statistical analysis in subchapter 3.2. has shown that there is a difference in electricity consumption with regards to regional location of hotel. Therefore, in order to explain electricity consumption as a dependent variable better, regression analysis was done for different regions separately. Hotel sample size for some of the regions and groups of hotels is lower than 15, which might not be statistically significant; however it is the only data available. Even in the case where questionnaires included all hotels in the regions and that response rate was 100%, hotel samples in some cases would not be greater than 15.

3.4.1.1. The regression analysis for electricity consumption for seasonal hotels

Regression analysis has shown that two predictors: floor area and number of rooms are statistically significant ($p<0,01$) for seasonal hotels on the Adriatic coast, while 29% ($R^2=0,29$) of dependent variable "electricity consumption" is explained by these two predictors . Table 3.18. presents results of multiple regressions for these two predictors, while the electricity consumption might be explained with the equation (3.6.).

$$(E_{FA\text{-}NR})_{CRO\text{-}S} = -0,271 \times FA + 2891,81 \times NR + 113583,62 \qquad [\text{kWh}]$$

$$R^2=0,29;\ p<0,01 \qquad (3.6.)$$

Table 3.18. Results of multiple regression analysis for electricity consumption for seasonal hotels

R^2=0,29	Unstandardized Coefficients		Standardized Coefficients
	B	Std. Error	Beta
Constant	113583,627	141402,622	
Floor area	-0,271	21,460	-0,003
Number of rooms	2891,810	1120,314	0,542*

Dependent Variable: Electricity consumption
* p<0,05
** p<0,01

Figure 3.25. - Figure 3.27. present surveyed results for the region of Rijeka and seasonal hotels. Regression fit line with R^2 values for relationship between electricity consumption, total floor area, and number of rooms was given with 95% mean prediction interval. It can be seen that R^2 values are 0,73 and 0,95 which give strong relationships between these predictors and the total electricity consumption. Total floor area and number of rooms are statistically significant predictors for seasonal hotels in the Rijeka region, since $p<0,01$ while for multiple regression analysis R^2=0,59. Total electricity consumption per square meter against total floor area gives no relationship.

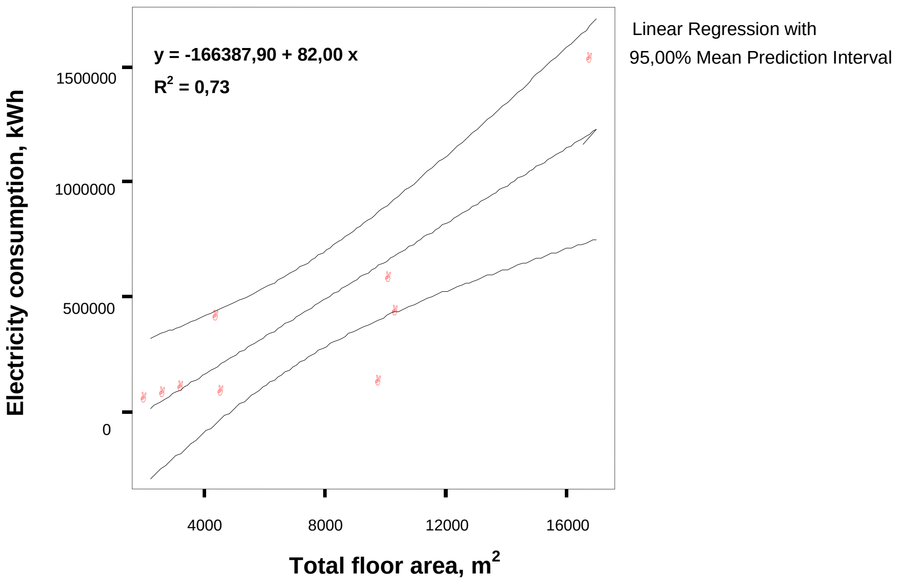

Figure 3.25. The annual electricity consumption for seasonal hotels in the Rijeka region against total floor area of the hotel

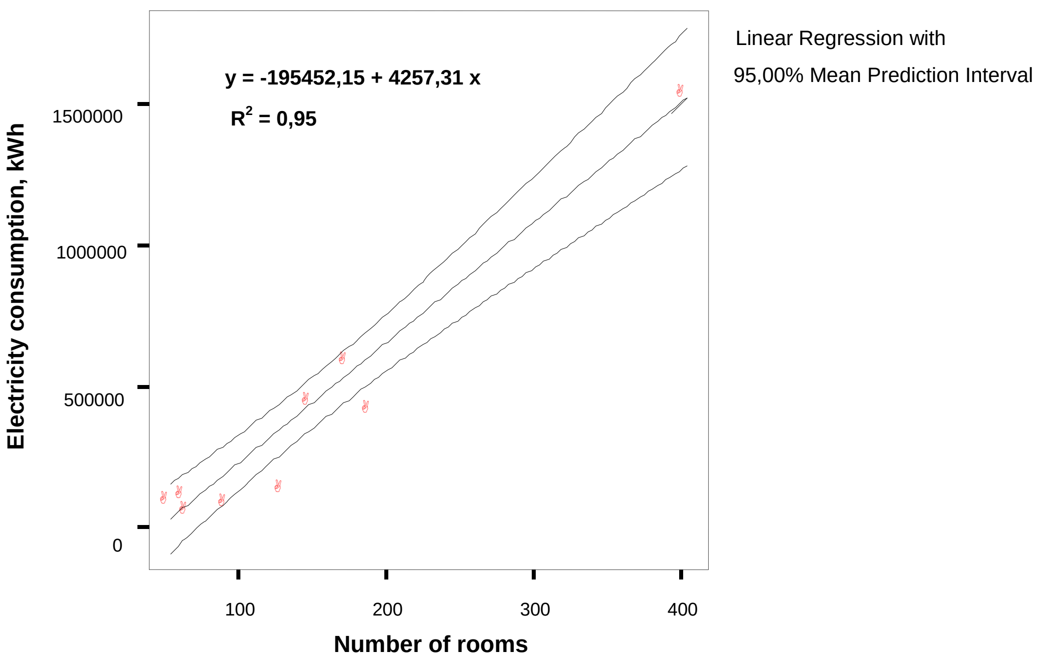

Figure 3.26. The annual electricity consumption for seasonal hotels in the Rijeka region against number of rooms

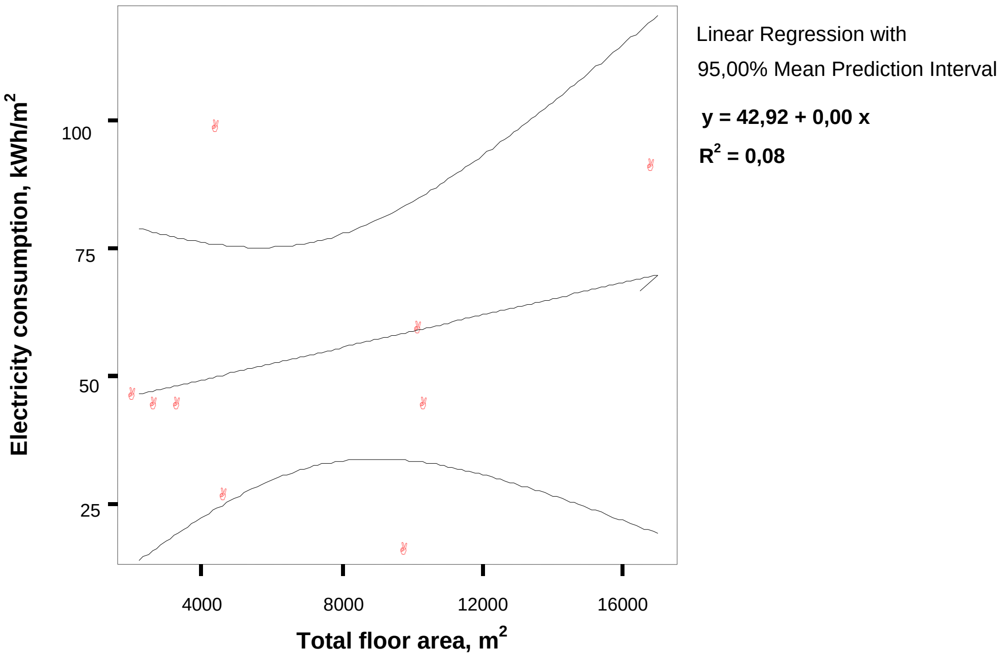

Figure 3.27. The annual electricity consumption per square meter for seasonal hotels in the Rijeka region against number of rooms

In the Table 3.19., results for 8 different groups of hotels from regression and correlation analysis are presented. It can be seen that R^2 values for total electricity consumption with independent variables (floor area, number of rooms, and product of these two variables) gives media or strong relationships, depending on region. Multiple regression analysis for Dubrovnik, Rijeka and Split regions show that these two predictors (total floor area and number of rooms) are statistical significant $p<0,01$, while for region of Istria, results are not statistically significant. Correlations for regions of Dubrovnik, Rijeka and groups of coastal hotels with 5&4 and 2 stars are strong and it can be concluded that electricity consumption could be predicted by knowing total floor area or number of rooms. However, one has to bear in mind that hotel samples for these groups of hotels are lower than 15.

Table 3.19. Regression analysis results - R^2 values for electricity consumption for seasonal hotels

R^2 value for electricity consumption in [kWh] – seasonal hotels								
Region (No of hotels)	Dubrovnik (12)	Istria (16)	Rijeka (9)	Split (18)	Croatia (57)	Croatia 5&4* (4)	Croatia 3* (40)	Croatia 2* (13)
Floor area, [m²]	**0.7316**	0.4364	**0.7318**	0.4887	0.4660	**0.6221**	0.4825	**0.6936**
Number of rooms	**0.6921**	0.1634	**0.949**	0.3626	0.3356	**0.8957**	0.5396	**0.7236**
m² * No. of rooms	**0.7398**	0.2659	**0.9474**	0.3733	0.3932	**0.7924**	0.5463	**0.7768**
R^2 value for normalized electricity consumption in kWh/m²								
Floor area, [m²]	0.0745	0.0001	0.0830	0.0974	0.0091	0.0431	0.1717	0.0397
Number of rooms	0.0139	0.0183	0.5011	0.1167	0.0047	0.2971	0.0692	0.002
m² * No. of rooms	0.0309	0.0003	0.2886	0.1145	0.0033	0.1549	0.0752	0.0035
R^2 value for normalized electricity consumption in kWh/room								
Floor area, [m²]	0.0005	0.0365	0.4884	0.0131	0.0167	0.4296	0.0791	0.0014
Number of rooms	0.0541	0.0297	0.4314	0.1132	0.0103	0.7678	0.1621	0.0332

Total electricity consumption per square meter against total floor area gives very weak relationship with R^2 values between 0,0001 to 0,1717. From the other side, the total electricity consumption per room against floor area and number of rooms gives mainly weak relationship, except for the region of Rijeka and a group of coastal hotels with 5&4 stars where a strong relationship is presented with R^2 values between 0,429 and 0,7678.

Regression equations (3.7.) – (3.14.) with media or strong relationships estimate electricity consumption according to floor area (FA) for different groups (regions) of seasonal hotels.

$$(E_{FA})_{D\text{-}S} = 60{,}751 \times FA + 51660 \quad [kWh], \quad R^2=0{,}7316 \quad (3.7.)$$

$$(E_{FA})_{I\text{-}S} = 92{,}631 \times FA - 23330\ 8 \quad [kWh], \quad R^2=0{,}4364 \quad (3.8.)$$

$$(E_{FA})_{R\text{-}S} = 82{,}005 \times FA - 166388 \quad [kWh], \quad R^2=0{,}7318 \quad (3.9.)$$

$$(E_{FA})_{S\text{-}S} = 34{,}816 \times FA + 159895 \quad [kWh], \quad R^2=0{,}4887 \quad (3.10.)$$

$(E_{FA})_{CRO\text{-}S} = 62{,}871 \times FA - 4306{,}3$ [kWh], R^2=0,466 (3.11.)

$(E_{FA})_{CRO5\&4\text{-}S} = 123{,}38 \times FA - 314062$ [kWh], R^2=0,6221 (3.12.)

$(E_{FA})_{CRO3\text{-}S} = 43{,}093 \times FA + 127107$ [kWh], R^2=0,4825 (3.13.)

$(E_{FA})_{CRO2\text{-}S} = 39{,}738 \times FA + 16142$ [kWh], R^2=0,6936 (3.14.)

Regression equations (3.15.) – (3.21.) estimate electricity consumption according to number of guests rooms (NR) for different groups (regions) of seasonal hotels.

$(E_{NR})_{D\text{-}S} = 3180{,}7 \times NR + 22533$ [kWh], R^2=0,6921 (3.15.)

$(E_{NR})_{R\text{-}S} = 4257{,}3 \times NR - 195452$ [kWh], R^2=0,949 (3.16.)

$(E_{NR})_{S\text{-}S} = 1890{,}7 \times NR + 161253$ [kWh], R^2=0,3626 (3.17.)

$(E_{NR})_{CRO\text{-}S} = 2956{,}4 \times NR + 39915$ [kWh], R^2=0,3356 (3.18.)

$(E_{NR})_{CRO5\&4\text{-}S} = 10883 \times NR - 0{,}6$ [kWh], R^2=0,8957 (3.19.)

$(E_{NR})_{CRO3\text{-}S} = 2444{,}8 \times NR + 72880$ [kWh], R^2=0,5396 (3.20.)

$(E_{NR})_{CRO2\text{-}S} = 1777{,}1 \times NR + 12704$ [kWh], R^2=0,7236 (3.21.)

Equations with $R^2>0{,}6$ (strong relationship) might be useful for electricity consumption prediction in the design phase of hotels. Also for future planning and scenarios for regional electricity consumption in the service sector.

3.4.1.2. The regression analysis for electricity consumption for non seasonal hotels

The same analysis performed on seasonal hotels, which represents 64% of total hotel stock on the Adriatic coast, has been made for non-seasonal ones. Regression analysis has shown that two predictors: floor area (FA) and number of rooms (NR) are statistically significant ($p<0,01$) for non seasonal hotels on the Adriatic coast. 46,5% ($R^2=0,465$) of the dependent variable "electricity consumption" is explained by these two predictors. Table 3.20. presents results of multiple regression analysis for these two predictors, while the electricity consumption might be explained by equation (3.22.).

$$(E_{FA\text{-}NR})_{CRO\text{-}NS} = 24,99 \times FA + 4227,3 \times NR - 163356,57 \quad \text{[kWh]},$$

$$R^2=0,465;\ p<0,01 \qquad (3.22.)$$

Table 3.20. Results of multiple regression analysis for electricity consumption for non seasonal hotels on Adriatic coast

$R^2=0,465$	Unstandardized Coefficients		Standardized Coefficients
	B	Std. Error	Beta
Constant	-163356,57	195406,83	
Floor area	24,99	18,102	0,267
Number of rooms	4227,3	1759,05	0,465*

Dependent Variable: Electricity consumption
* p<0,05
** p<0,01

Figure 3.28. - Figure 3.30. present surveyed results for all non-seasonal hotels on the Adriatic coast. Regression fit line with R^2 values for relationships between electricity consumption, total floor area, and number of rooms was given with 95% mean prediction interval. It can be seen that R^2 values are 0,36 and 0,43 which gives a media relationship between these variables and a total electricity consumption. Total floor area and number of rooms are statistically significant predictors for non-seasonal hotels on Adriatic coast, since $p<0,01$ while for multiple regression analysis $R^2=0,465$.

Total electricity consumption per square meter against the total floor area, as in the case of seasonal hotels, gives no relationship.

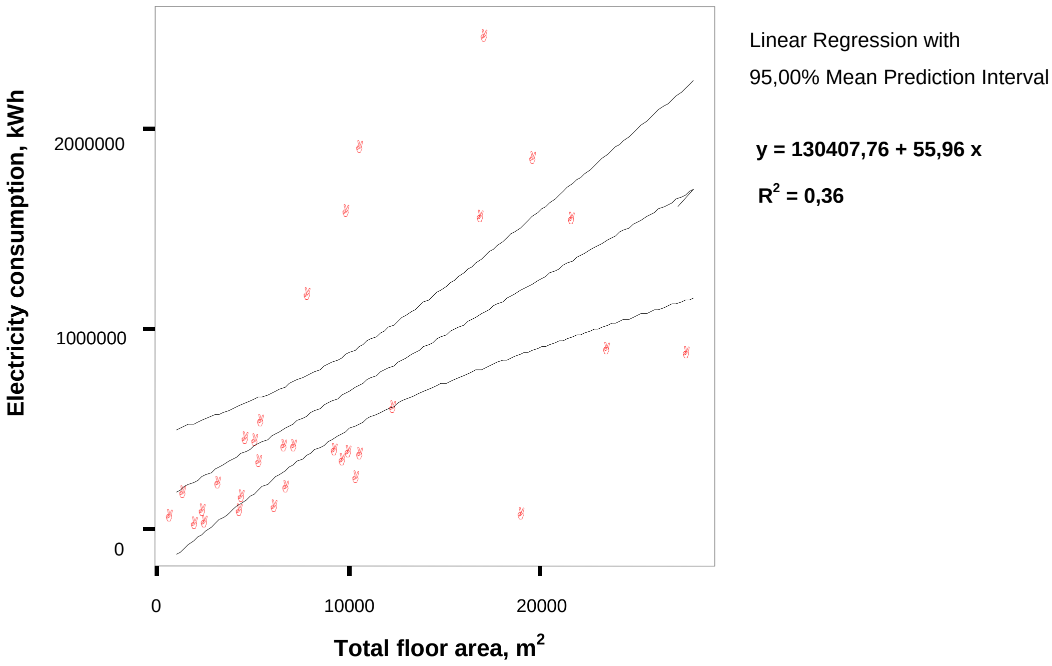

Figure 3.28. The annual electricity consumption for non-seasonal hotels in Croatia (Adriatic coast) against total floor area of the hotel

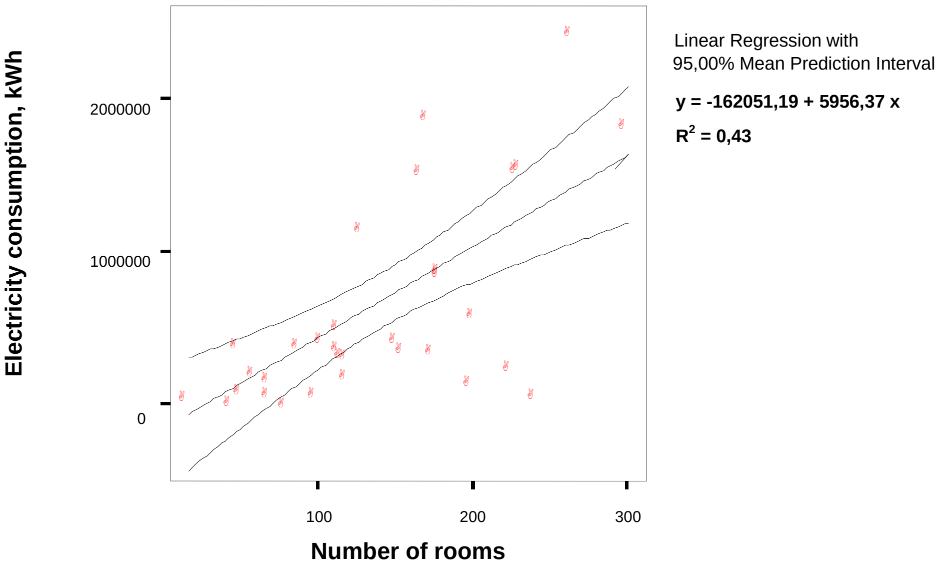

Figure 3.29. The annual electricity consumption for non-seasonal hotels in Croatia (Adriatic coast) against number of guest rooms

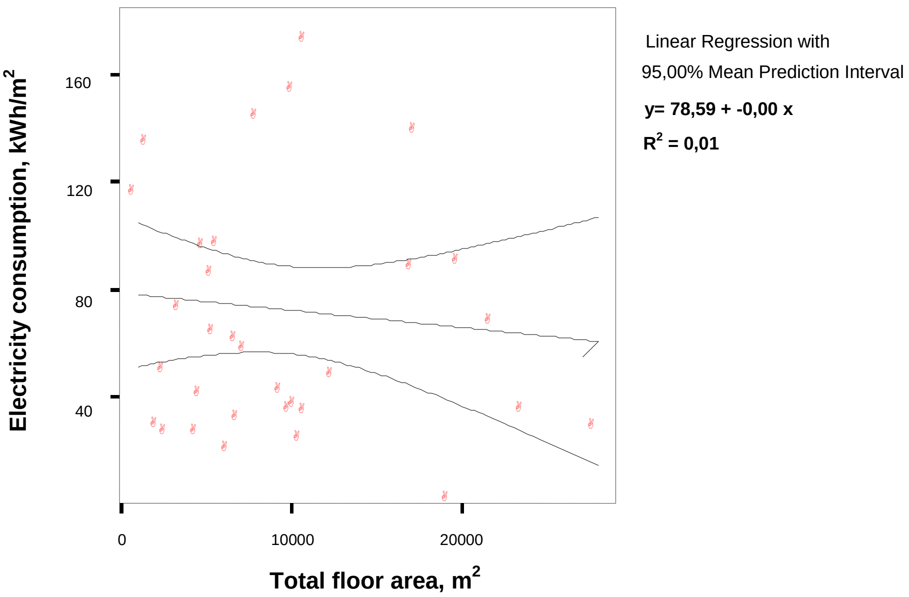

Figure 3.30. The annual electricity consumption per square meter for non-seasonal hotels in Croatia (Adriatic coast) against total floor area of the hotel

In the Table 3.21. results for 7 different groups of hotels from regression and correlation analysis are presented. It can be seen that R^2 values for the total electricity consumption for independent variables (floor area, number of rooms, and product of these two variables) gives media or strong relationships, depending on the region, but correlations are as strong as for seasonal hotels. Reason for that might be different occupancy rates throughout the year. For the region of Split and a group of coastal hotels with 2 stars, relationships are strong, however hotel sample is small and these correlations are not statistically significant.

Table 3.21. Regression analysis results - R^2 values for electricity consumption for non seasonal hotels

	R^2 value for electricity consumption in [kWh] – non seasonal hotels							
Region (No of hotels)	Dubrovnik (6)	Istria (0)	Rijeka (21)	Split (5)	Croatia (32)	Croatia 5&4* (6)	Croatia 3* (20)	Croatia 2* (6)
Floor area, [m²]	0.4709	-	0.5173	**0.8659**	0.3579	0.0049	0.3884	**0.6866**
Number of rooms	0.5528	-	0.5686	0.5934	0.4294	0.0014	**0.6436**	0.2783
m² * No. of rooms	0.6244	-	**0.6710**	**0.9684**	0.4468	0.0030	0.6297	0.5375
	R^2 value for normalized electricity consumption in [KWh/m²]							
Floor area, [m²]	0.0212	-	0.0136	0.1206	0.0100	0.2810	0.0380	0.0011
Number of rooms	0.3002	-	0.0005	0.1250	0.0128	0.1146	0.0261	0.0107
m² * No. of rooms	0.0015	-	0	0.0335	0	0.3251	0.0014	0.0222
	R^2 value for normalized electricity consumption in [kWh/room]							
Floor area, [m²]	0.4950	-	0.1334	0.0402	0.0931	0.0579	0.0726	0.0125
Number of rooms	0.1895	-	0.0203	0.0063	0.0162	0.1328	0.0248	0.1163

Total electricity consumption per square meter against total floor area gives a very weak relationship with R^2 value between 0 and 0,281. From the other side, total electricity consumption per room against floor area and number of rooms, gives mainly weak relationships, except for the region of Dubrovnik where a strong relationship is noted with R^2 value 0,495.

Regression equations (3.23.) – (3.27.) with media or strong relationships estimate electricity consumption according to floor area (FA) for different groups (regions) of non-seasonal hotels.

$(E_{FA})_{D\text{-}NS} = 71{,}401 \times FA + 423138$ [kWh], R^2=0,4709; (3.23.)

$(E_{FA})_{R\text{-}NS} = 49{,}714 \times FA + 76458$ [kWh], R^2=0,5173 (3.24.)

$(E_{FA})_{S\text{-}NS} = 141{,}23 \times FA - 207643$ [kWh], R^2=0,8659 (3.25.)

$(E_{FA})_{CRO\text{-}NS} = 55{,}964 \times FA + 130408$ [kWh], R^2=0,3579 (3.26.)

$(E_{FA})_{CRO3\text{-}NS} = 55{,}274 \times FA + 113561$ [kWh], R^2=0,3884 (3.27.)

Regression equations (3.28.) – (3.32.) estimate electricity consumption according to the number of guest rooms (NR) for different groups (regions) of seasonal hotels.

$(E_{NR})_{D\text{-}NS} = 10831 \times NR - 570645$ [kWh], R^2=0,5528 (3.28.)

$(E_{NR})_{R\text{-}NS} = 5481{,}1 \times NR - 169298$ [kWh], R^2=0,5686 (3.29.)

$(E_{NR})_{S\text{-}NS} = 7067 \times NR - 141326$ [kWh], R^2=0,5934 (3.30.)

$(E_{NR})_{CRO\text{-}NS} = 5956{,}4 \times NR - 162051$ [kWh], R^2=0,4294 (3.31.)

$(E_{NR})_{CRO3\text{-}NS} = 6754 \times NR - 285888$ [kWh], R^2=0,6436 (3.32.)

3.4.1.3. Multiple regression analysis for electricity consumption

Linear regression analysis has shown that there is a strong relationship between electricity consumption and total floor area and number of rooms. However, in order to establish a better correlation and relationship between assorted variables, multiple regression analysis with five predictors was applied.

During the energy audit, data about guest nights in all hotels was not available. But for this research, data about guest nights for 14 hotels belonging to a hotel chain in the Rijeka region was obtained and analysed. As a first step, linear regression analysis was done for variables connected with hotel dynamics (guest nights, occupancy and combination of these variables). Results for coefficient of determination are presented in Table 3.22. It can be seen that the total electricity consumption against guest nights gives a relationship with R^2 = 0,3665, while the product of guest nights and total floor area gives a better relationship with R^2 = 0,5111.

Table 3.22. Regression analysis results - R^2 values for electricity consumption for non-seasonal hotels (Liburnia Riviera hotels – Rijeka region)

R^2 value for electricity consumption in kWh for Liburnia hotels	
guest nights	0.3665
occupancy, %	0.0155
m^2 *guest night	0.5111
guest n *m^2/room	0.3973
m^2/room *%	0.1016

First of all, multiple regression analysis was done for independent variables that are constant during time: total floor area (FA), number of rooms (NR) and floor area per room (FAR). Floor area per room is an indicator that gives a relation of total floor area to number of rooms. Size of the rooms are mostly determined by standards of categorisation (see Table 3.2. and Table 3.3.) while FAR gives insight to the floor space belonging floor area to additional facilities, per one room. The regression equation presenting total electricity consumption is:

$$E_{FA-NR-RFA} = -14{,}85 \cdot FA + 6681{,}02 \cdot NR + 5137{,}19 \cdot FAR - 567073{,}53 \qquad (3.33.)$$

with the coefficient of determination being R^2 =0,797 this means there is a strong relationship between these variables and total electricity consumption.

Furthermore, it was investigated how the variables "guest nights" (GN) and "occupancy rate" (OR) influenced the total electricity consumption together with variables "total floor area" (FA) and "number of rooms" (NR). The regression equations (3.34.) - (3.35.) are as follows:

$$E_{FA-NR-GN} = 30{,}56 \cdot FA + 6166{,}5 \cdot NR - 11 \cdot GN - 58780{,}9 \tag{3.34.}$$

with the coefficient of determination, $R^2 = 0{,}836$ and

$$E_{FA-NR-GN-OC} = 27{,}56 \cdot FA + 12368{,}72 \cdot NR - 28{,}89 \cdot GN + 17792{,}2 \cdot OR - 867509{,}73 \tag{3.35.}$$

with the coefficient of determination, $R^2 = 0{,}885$.

Regression equations (3.34.) and (3.35.) include variables GN and OR give us better R-square values and promote a more accurate estimation of the total electricity consumption.

At the end, multiple regression analysis was performed with five possible indicators of electricity consumption (with data that was available for this study), three of them are constant during the life time of hotel (total floor area - FA, number of rooms - NR and floor area per room – FAR) and two of them constantly changing (guest nights – GN and occupancy rate – OR). The regression equation is:

$$E_{FA-NR-GN-OC} = 9{,}96 \cdot FA + 11762{,}1 \cdot NR - 22{,}81 \cdot GN + 11646{,}8 \cdot OC + 2688{,}74 \cdot RFA - 792849.86 \tag{3.36.}$$

with the coefficient of determination, $R^2=0{,}89$, which gives the best relationship and the best possible estimated total electricity consumption with available data. These indicators are relatively easy to collect from hotel management and therefore electricity consumption planning can easily be done using this formula.

3.4.2. Regression analysis for heating oil consumption

In this chapter regression analysis for heating oil consumption in hotels is elaborated in similar manner as for electricity consumption the previous chapter. As it was shown in subchapter 3.2.2.2. and 3.2.2.4. heating oil is the second most used energy resource in hotels. 90% of hotels utilize oil for heating and domestic hot water production.

Explanatory parameters for heating oil consumption with regard to space heating would be; size of the hotel (total floor area – FA and number of rooms – NR), and number of degree days in the heating season (if one compares hotels in different regions) and building characteristics as a U-value for building envelope. Heating demand is quite independent with regard to the number of guests since most hotels do not have automatic regulation that would provide individual room control of indoor temperature. With regards to domestic hot water consumption, explanatory indicators would be; number of guests – GN (that indicate sanitary water consumption and water consumption for cleaning) and number of meals prepared. If hotel facilities include a swimming pool with heated water, fresh water consumption for the pool would be one of the indicators for oil consumption.

As a conclusion it can be said that there are several explanatory indicators that might describe electricity consumption in hotels. These are:

- total floor area
- number of rooms
- floor area per room
- guest nights
- occupancy rate
- heating degree days
- percentage of floor area that is heated
- fresh water consumption

- fresh water consumption for the pools
- year of hotel construction
- year of boiler installation

Information about guest nights, occupancy and meals prepared, as mentioned before, was not available for this study. Therefore, regression and correlation analysis was made for different hotel categories and regions (that represent differences in degree days) and finally it was summarized for all hotels, separately for seasonal and non seasonal hotels for three explanatory variables: total floor area, number of rooms and product of these two variables (floor area x number of rooms).

Descriptive statistical analysis in subchapter 3.2. has shown that there is a difference in heating oil consumption with regards to regional location of hotel. Therefore, in order to better explain oil consumption as a dependent variable, regression analysis was done for different regions separately in the same manner as for the case of electricity consumption. Hotel samples for some of the regions and groups of hotels is lower than 15 which might not be statistically significant; however this is the only data available.

3.4.2.1. The regression analysis for heating oil consumption in seasonal hotels

Regression analysis has shown that two predictors: floor area and number of rooms are statistically significant ($p<0,01$) for seasonal hotels on the Adriatic coast, while 56,2% ($R^2=0,562$) of the dependent variable "heating oil consumption" is explained by these two predictors . Table 3.23. presents results of multiple regression for these two predictors, while the heating oil consumption might be explained with equation (3.37).

$$(O_{FA-NR})_{CRO-S} = 4{,}43 \times FA + 97{,}43 \times NR + 4488{,}7 \quad \text{[litres]},$$

$$R^2=0{,}562;\ p<0{,}01 \qquad (3.37.)$$

Table 3.23. Results of multiple regression analysis for oil consumption for seasonal hotels

R^2=0,562	Unstandardized Coefficients		Standardized Coefficients
	B	Std. Error	Beta
Constant	4488,68	10412,25	
Floor area	4,43	1,476	0,524**
Number of rooms	97,43	61,21	0,278

Dependent Variable: Heating oil consumption
* p<0,05
** p<0,01

Figure 3.31. - Figure 3.33. present surveyed results for seasonal 3 star hotels on the Adriatic coast. Regression fit line with R^2 values for relationship between heating oil consumption, total floor area, and number of rooms with 95% mean prediction interval is given. It can be seen that R^2 values are 0,55 and 0,59 which implies media relationship between these variables and the total heating oil consumption (See Table 3.24.).

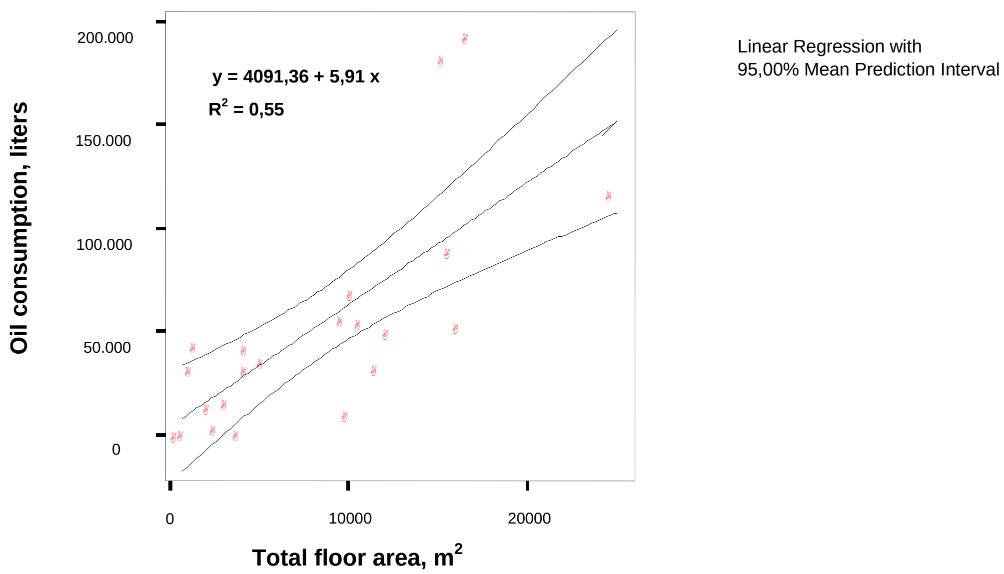

Figure 3.31. The annual heating oil consumption per square meter for seasonal 3 star hotels on the Adriatic coast against total floor area of the hotel

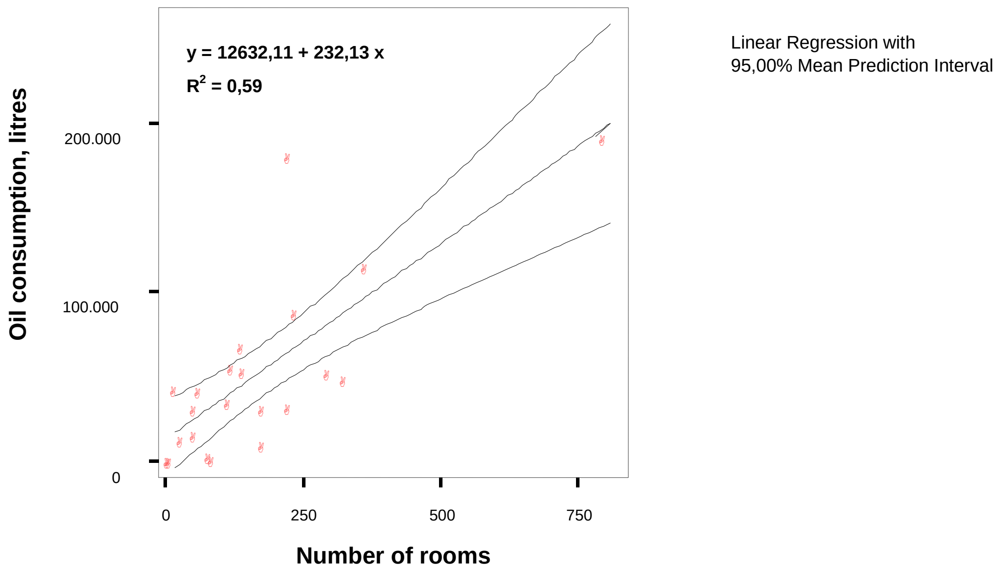

Figure 3.32. The annual heating oil consumption for seasonal 3 star hotels on the Adriatic coast against number of guest rooms

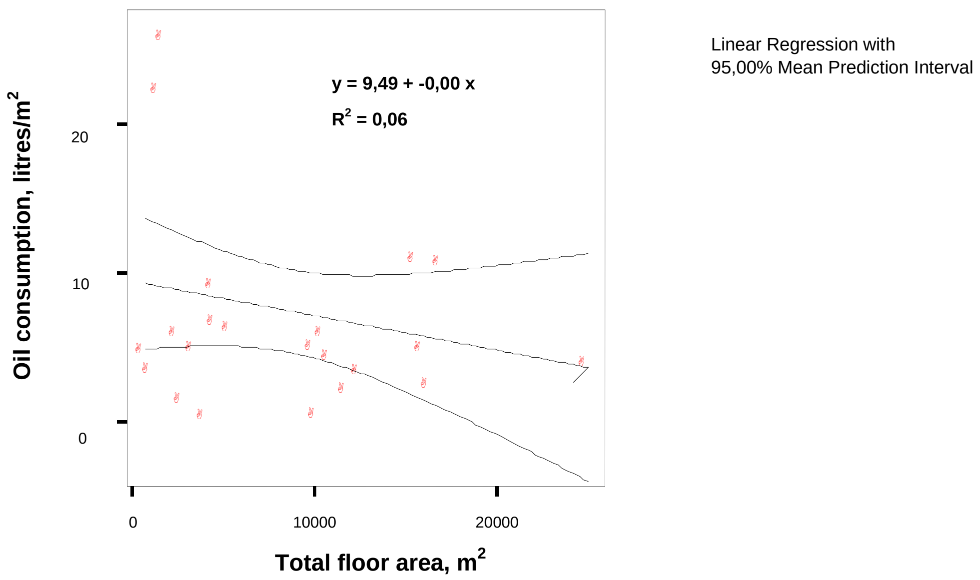

Figure 3.33. The annual oil consumption per square meter for seasonal 3 star hotels in on the Adriatic coast against total floor area of the hotel

In Table 3.24. results for 7 different groups of hotels from regression and correlation analysis are presented. It can be seen that the R^2 value for total heating oil consumption and independent variables (floor area, number of rooms, and product of these two variables) gives a media relationship, or in some cases strong relationship, depending on the region. The reason for this is that seasonal hotels use heating systems only during the April and October months if there is a need, while hot water is mostly used as domestic hot water throughout the season. Therefore oil consumption is influenced by number of guests and meals prepared.

Table 3.24. Regression analysis results - R^2 values for heating oil consumption for seasonal hotels

	R^2 value for heating oil consumption in [litres] – seasonal hotels						
Region (No of hotels)	Dubrovnik (12)	Istria (4)	Rijeka (6)	Split (11)	Croatia (33)	Croatia 3* (22)	Dubrovnik 3* (8)
Floor area, [m²]	0.4367	0.3551	**0.8744**	**0.7036**	0.5252	0.545	**0.652**
Number of rooms	0.3270	0.1733	**0.9203**	0.236	0.4307	0.585	**0.6764**
m² * No. of rooms	0.3045	0.3206	**0.9473**	**0.6465**	0.5146	0.6357	**0.659**
	R^2 value for normalized heating oil consumption in l/m²						
Floor area, [m²]	0.0173	**0.6915**	0.5482	0.1185	0.0464	0.0600	-
Year of hotel construction	0.1076	0.4855	0.2393	0.185	0.0125	0.0016	-
Year of boiler installation	0.0286	0.2976	0.0517	0.0799	0.015	0.0171	-
	R^2 value for normalized heating oil consumption in l/room						
Floor area, [m²]	0.018	0.6214	0.0256	0.0039	0.0022	0.0196	
Year of hotel construction	0	0.438	0.1054	0.358	0.0076	0.0019	
Year of boiler installation	0.01	0.3494	0.6364	0.0138	0.0098	0.0119	

It was expected that the relationship between year of boiler installation, which influences boiler efficiency, and total oil consumption would be stronger, however as it can be seen from Table 3.24. this relationship is very weak except for the region of Istria.

Total heating oil consumption according to total floor area might be estimated by following the regression equations:

$$(O_{FA})_{R\text{-}S} = 12{,}029 \times FA - 36303 \quad [l], \quad R^2=0{,}8744 \qquad (3.38.)$$

$$(O_{FA})_{S\text{-}S} = 4{,}085 \times FA + 12045 \quad [l], \quad R^2=0{,}7036 \qquad (3.39.)$$

$$(O_{FA})_{D3\text{-}S} = 3{,}095 \times FA + 9204{,}6 \quad [l], \quad R^2=0{,}652 \qquad (3.40.)$$

$$(O_{FA})_{CRO3\text{-}S} = 5{,}91 \times FA + 4091{,}36 \quad [l], \quad R^2=0{,}55 \qquad (3.41.)$$

These equations might be useful for heating oil consumption prediction in the design phase of a hotel and for future planning and scenarios for heating oil consumption in service sector.

Regression analysis of total heating oil consumption according to the number of rooms gives a strong relationship only for the region of Rijeka and 3 star hotels in the region of Dubrovnik. Regression equations are as follows:

$$(O_{NR})_{R\text{-}S} = 218{,}27 \times NR + 20518 \quad [l], \quad R^2=0{,}9203 \qquad (3.42.)$$

$$(O_{NR})_{D3\text{-}S} = 146{,}59 \times NR + 7311{,}6 \quad [l], \quad R^2=0{,}6764 \qquad (3.43.)$$

$$(O_{NR})_{CRO3\text{-}S} = 232{,}13 \times NR + 12632{,}1 \quad [l], \quad R^2=0{,}59 \qquad (3.44.)$$

3.4.2.2. The regression analysis for heating oil consumption for non-seasonal hotels

Regression analysis results for 4 groups of non-seasonal hotels (depending of availability of data) are presented in Table 3.25. From the coefficient of determination it can be seen that there is no strong relationship between total oil consumption and explanatory factors.

It was expected that the relationship between total floor area and number of rooms would have a stronger relationship with the total oil consumption due to fact that non-seasonal hotels require heating from October till April.

Table 3.25. Regression analysis results - R^2 values for heating oil consumption for non-seasonal hotels

	R^2 value for heating oil consumption in [litres] – non seasonal hotels					
Region (No of hotels)	Dubrovnik	Istria	Rijeka (18)	Split (6)	Croatia (24)	Rijeka 3* (11)
Floor area, [m²]			0.4232	0.0139	0.3271	0.2966
Number of rooms			0.3788	0.0060	0.2595	0.2418
m² * No. of rooms				0.0082	0.1847	0.2954
	R^2 value for normalized heating oil consumption in l/m²					
Floor area, [m²]			0.1043	0.2789	0.0709	
Year of hotel construction			0.0164	0.0308	0.0541	
Year of boiler installation			0.0323	0.2102	0	
	R^2 value for normalized heating oil consumption in l/room					
Floor area, [m²]			0.0113		0.0192	
Year of hotel construction			0.0421	0.1541	0.178	
Year of boiler installation			**0.6841**	0.1585	0.1134	

3.4.2.3. Multiple regression analysis for heating oil consumption

Linear regression analysis has shown that there is no strong relationship between heating oil consumption and total floor area and number of rooms for non-seasonal hotels. Therefore, similar to the electricity consumption case, multiple regression will include several explanatory variables that will help estimate oil consumption.

The same data for guest nights as the electricity consumption analysis from 14 hotels belonging to hotel chain in the Rijeka region were used. As a first step linear regression analysis was done for variables connected with hotel dynamics (guest nights, occupancy and combination of these variables). Results for the coefficient of determination are presented in Table 3.26. It can be seen that total heating oil consumption against guest nights gives a relationship with R^2 = 0,7483, and hence a strong relationship.

Table 3.26. Regression analysis results - R^2 values for heating oil consumption for non-seasonal hotels (Liburnia Riviera hotels – Rijeka region)

R^2 value for heating oil consumption in litres for Liburnia hotels	
guest nights	0.7483
occupancy, %	-
m^2 *guest night	0.3755
guest n *m^2/room	0.5136
m^2/room *%	0.058

First of all, multiple regression analysis was done for independent variables that are constant during time: total floor area (FA), number of rooms (NR) and floor area per room (FAR). The regression equation estimating total heating oil consumption is:

$$O_{FA-NR-RFA} = -2{,}2 \cdot FA + 1430{,}9 \cdot NR + 743{,}12 \cdot FAR - 60966{,}3 \qquad (3.45.)$$

with the coefficient of determination being R^2 =0,49 which do not give a very strong relationship between these variables and total oil consumption. This confirms that with constant building variables it is not possible to predict oil consumption.

Furthermore, it was investigated how variables such as; “guest nights” (GN) and “occupancy rate” (OR) influence the total oil consumption together with other variables; “total floor area” (FA) and “number of rooms” (NR). The regression equations (3.46.) - (3.47.) present this:

$$O_{FA-NR-GN} = 2{,}53 \cdot FA - 1485{,}25 \cdot NR + 6{,}79 \cdot GN - 15434{,}5 \qquad (3.46.)$$

with the coefficient of determination, $R^2 = 0{,}837$ and

$$O_{FA-NR-GN-OC} = 1{,}94 \cdot FA - 432{,}6 \cdot NR + 3{,}97 \cdot GN + 2336{,}48 \cdot OR - 125205 \qquad (3.47.)$$

with the coefficient of determination, $R^2 = 0{,}852$.

Regression equations (3.46.) and (3.47.) give better R-square values and gives more accurate estimates of total oil consumption since the variables GN and OR are included.

At the end multiple regression analysis was performed with five possible indicators of oil consumption (with data that was available for this study). Three of them are constant during the life time of hotel (total floor area - FA, number of rooms - NR, floor area per room – FAR) and two of them are constantly changing (guest nights – GN and occupancy rate – OR). The regression equation for heating oil consumption is:

$$O_{FA-NR-FAR-GN-OC} = 13{,}06 \cdot FA - 189{,}64 \cdot NR + 0{,}674 \cdot GN + 5702{,}51 \cdot OC - 1471{,}73 \cdot RFA - 167723{,}6 \qquad (3.48.)$$

with the coefficient of determination R^2=0,882 which gives the best relationship and the best possible estimation of total oil consumption with available data.

3.4.3. Case study hotel D1 (Dubrovnik region)- regression analysis

The case study was used to compare the relationship between electricity consumption and number of guests per month for seasonal hotels in the Dubrovnik region. On Figure 3.34. one can see the typical guest load curve. The regression fit line is presented with a polynomic line with R-square coefficient of 0,954 and 0,885 for years 2003 and 2004 respectively.

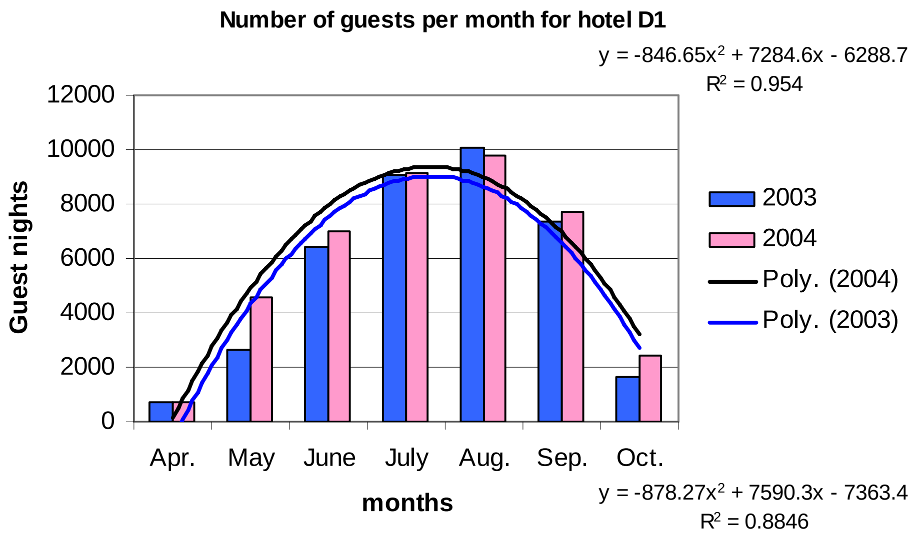

Figure 3.34. The guest load profile for hotel D1 in Dubrovnik region for years 2003 and 2004

Occupancy rate during the period of April - August goes from 7% to 100%. From Figure 3.35. one can see that as occupancy rate increase, electricity consumption per guest night is decreasing. At the same time electricity consumption per square meter is growing. However, weather occupancy rate is at a minimum or not, there is still significant amount of energy being used to operate hotels facilities.

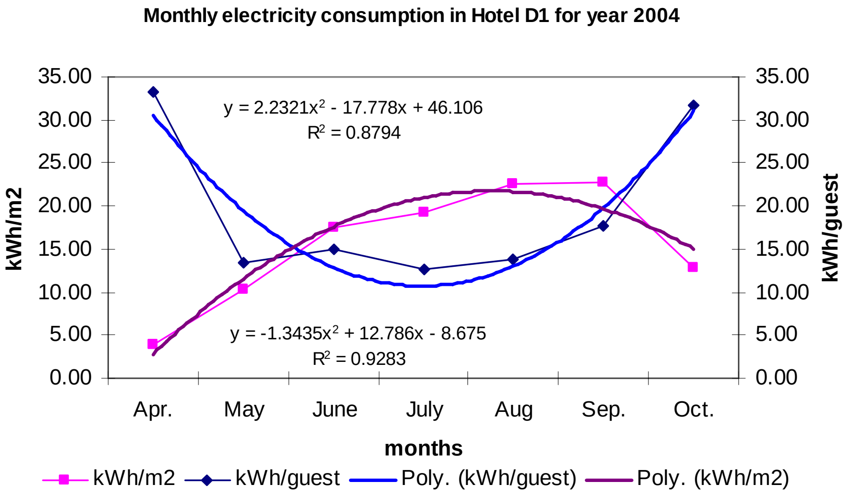

Figure 3.35. The electricity consumption per square meter and guest for years 2003 and 2004 (hotel D1)

4. THE PROBLEM DEFINITION AND PROBLEM SOLVING METHODOLOGY - SYSTEM THINKING IN HOTELS

Based on the energy audit results presented in the previous chapter, this chapter will set a thesis hypothesis and present a problem solving methodology. A systems Thinking Approach was used as an integrated approach to problems related with energy usage in hotels. An emphasise is given to HVAC&R and DHW systems that account for approximately 60-70% of the total energy consumption in hotels.

4.1. Introduction

Chapter 1 indicated that the aim of this research is to tackle energy performance in hotels from five different perspectives and to give future scenarios. These perspectives are; mathematical–engineering, environmental, tourism, policy and economic. Therefore, during the evaluation of the current state of energy performance in hotels and the development of algorithms for energy efficient system design and retrofit, a systems thinking approach should be implemented, taking into account all of these perspectives.

This study is about one specific type of energy usage systems, "energy usage in hotels", and how this system behaves. A hotel building is a specific type of energy usage system when compared to other systems in the service sector such as supermarkets, schools or hospitals. All of these systems are different with regards to behavioural patterns of people, occupancy factor, level of thermal comfort and indoor air quality. Therefore, the type of systems required to operate the building, and consequently their energy use intensity expressed in kWh/(m^2year), is different. Thus, energy use intensity is a measure that is comparable only within the same type of systems (buildings) with similar standards and local climate, and it is also dependant on energy utilization systems within the buildings. Mechanical systems in hotels or in any building must work in line with the building layout, orientation, envelope, lighting strategies, electrical equipment and site characteristics to reduce dependence on energy derived from fossil fuels, and to increase the use of passive energy and renewable energy sources.

The energy system related to any building might be divided in two main parts: *energy production system* and *energy usage system* (Lundqvist 2006). Energy production systems are typically large scale and are supplied with primary energy (fossil fuels, renewable energy sources such as wind, hydro, biomass and geothermal). The outputs from energy production systems are electricity and heat (energy carriers), that should be maximized with regard to input of primary energy (efficiency). This thesis is focused on energy usage systems in hotels and solutions for minimizing required inputs (energy carriers and fossil fuels) with increased utilization of free energy (solar, passive and seawater energy). Emphasis is also given on increased efficiency of energy transformation systems for HVAC (heating, ventilation and air conditioning) and DHW (domestic hot water) systems (Figure 4.1.). Catering (C), lighting (L) and other electrical systems were not considered in this study.

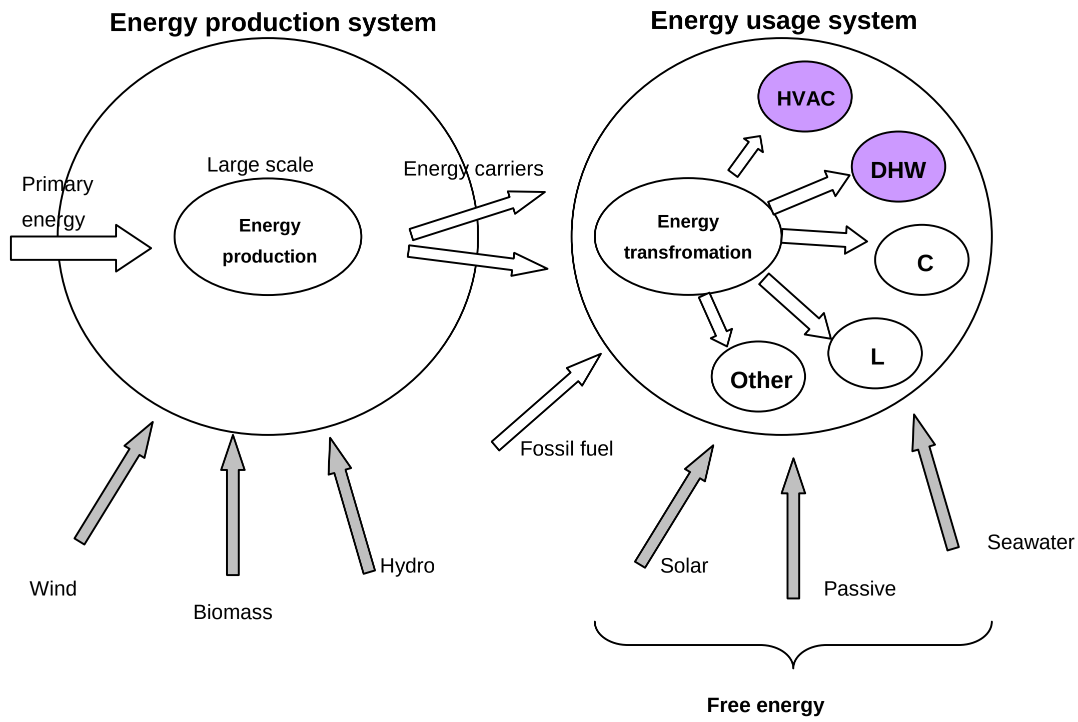

Figure 4.1. Schematic view of energy production and energy usage systems

If one looks at the project development phases of a building consisting of; schematic design, design development, contract documentation and construction it can be seen that the most expensive actions are during system erection and operation (Figure 4.2.). Therefore if possible, energy efficiency actions should be taken early, during the design phase, especially if new hotel facilities or major renovations are considered. However, bearing in mind increasing energy prices and current regulations about energy saving measures, retrofitting an existing system might be an economically feasible option too. At the beginning of the design process it is cheap to test new ideas while the impact on life cycle costs (LCC) and Life Cycle Climate Performance (LCCP) are huge. Different tools to test new ideas exist and one of them is using a computer simulation environment, such as TRNSYS, used in this thesis. TRNSYS gives opportunities to model different HVAC systems and to test their performance according to building requirements for cooling and heating calculated with real climatic data (Test Reference Year – TRY or Typical Meteorological Year - TMY). Therefore a number of desired options might be simulated and compared under the same conditions.

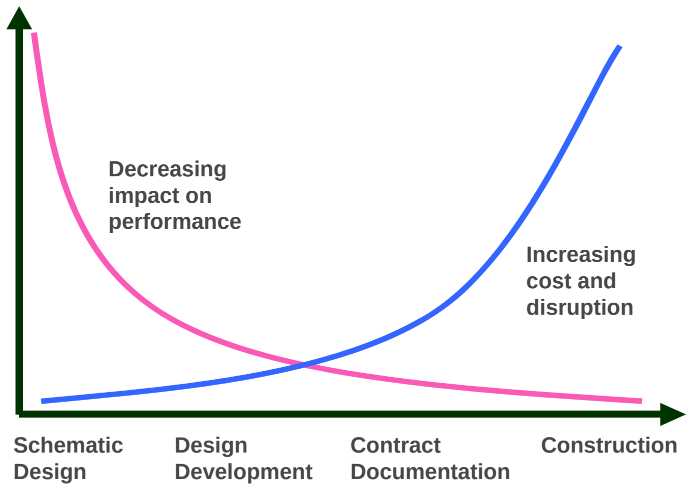

Figure 4.2. Impact on performance vs cost of disruption (Jongeling 2003)

Furthermore, there is a new regulation, EU directive 91/2002 Energy Performance in Buildings, that gives guidelines for the application of minimum requirements on the energy performance of new buildings and existing buildings that are subject to major renovations. For new buildings with a total useful floor area over 1000 m^2, member states (as well as Croatia since the process of harmonisation with the EU has started) shall ensure that the technical, environmental and economic feasibility of alternative systems such as: decentralised energy supply systems based on renewable energy, CHP, district or block heating or cooling (if available) and heat pumps are considered, and are taken into account before beginning construction. Major renovations of existing buildings above 1000 m^2 should be regarded as an opportunity to apply cost-effective measures which enhance energy performance (EC 2002). A majority of hotels on the Adriatic coast are buildings with total floor area greater than 1000 m^2 (average total floor space depending on the region is between 7700 and 10700 m^2). Therefore, any major renovation should be considered as an opportunity to implement energy efficient measures. Since all buildings will have an impact on long-term energy consumption, new buildings should therefore meet minimum energy performance requirements tailored to the local climate. The application of alternative energy supply systems is generally not explored to its full potential and therefore the technical, environmental and economic feasibility of alternative energy supply systems should be highlighted and considered for different types of buildings.

4.2. Traditional "mindset" in hotels on the Adriatic coast

The energy audits have shown that HVAC&R&DHW[10] systems in hotels are not considered as an integrated system, but rather as a collection of several independent units. There are even cases where heating and DHW systems are separated, although they utilize the same energy source and both require hot water storage. One of the reasons for this is the absence of an integrated systems approach during the design phase.

Further on, it was recorded that during the lifetime of a hotel, the number of services and requirements change. For example, a hotel that was originally meant to be seasonal currently operates during the whole year and vice versa. With regards to cooling and air-conditioning system installations, it was noticed that they are new, since cooling was not originally a requirement for hotels with higher category (4 and 5 stars). During the years, category standards have changed, guest standard has increased while the climate has, to some extent, also changed. The situation in hotels

[10] HVAC&R&DHW systems – Heating Ventilation Air-conditioning & Refrigeration & Domestic Hot Water systems

on the Adriatic coast has significantly changed after the war (subsequent to 1995), when the majority of hotels underwent major renovations in order to comply with the new categorization regulations. Major changes were done in rooms' interior, while heating and DHW systems remained the same. As a consequence to increased hotel category requirements, thermal comfort criteria also rose, leading to an increase in energy consumption. There are also a number of hotels with 3 stars that have installed cooling systems in recent years, although it is not a requirement for that category. The process of major refurbishment should be considered as a golden opportunity to apply a systems thinking approach with an implementation of energy efficient technologies and renewable energy sources.

With regards to cooling systems, the questionnaires have shown that all cooling systems installed in surveyed hotels are not older than 14 year with the exception of two systems that are 27 years old (utilizing R22). However, the majority of there systems were installed in the last 6 years. It was also realised that cooling systems were considered as separate units without attempts to utilize rejected heat from the condenser for domestic hot water heating. There were only two hotels, out of 75 who declared possession of a cooling system with condenser heat recovery for swimming pool water heating. Only 5 hotels out of 42 who confirmed installation of centralized cooling system have cold water thermal storage. With regards to cooling systems in 3 star hotels, it was realised that systems were installed without traces of systems thinking since split systems are installed in different facilities and in various places, mainly depending of available financing.

The energy audit was used as a tool to identify opportunities for increased energy efficiency measures and to set a benchmark for energy and water consumption in hotels. An energy audit doesn't make much sense if there's no reference values for energy consumption. Furthermore, TRNSYS as a simulation tool was used to evaluate existing systems, energy consumption for cooling systems and for efficient analysis of energy saving possibilities with introduction of the systems thinking approach.

There are three levels of energy efficiency that were considered in this research:

- Energy efficiency on demand side (building envelope)
- Energy efficiency on energy utilization side (HVAC&R&DHW systems)
- Energy efficiency of power supply systems (electricity, gas, heating oil, renewable energy sources)

Therefore it is necessary to look at the building (hotel) as a system with components such as: building envelope, heating, cooling, ventilation, refrigeration system, domestic hot water, and fuels that power these systems. World experiences presented in chapter 1 show that approximately 60-70% of total energy in hotels is utilized in HVAC&R&DHW systems, therefore improvement of these will contribute to an overall increase in hotel energy efficiency, which is the focus of this research.

The methodology used in this research consists of identifying the systems and the important questions related to them as for example, the system's efficiency measures and actor perspective (Soft System Methods -SSM by Checkland). It is then necessary to change to an engineering/science perspective where the system is defined in a classical way (as thermodynamic systems) in order to model the systems in TRNSYS. Therefore there is a need to explain the system thinking approach used in this thesis and for systems modelling.

4.3. The need for system thinking approach

According to (Checkland 2002) the "approach" is a way of going about tackling a problem, while a particular "approach" may be relevant to more than one subject. Systems approach is further on explained as:

> *"A systems approach : an approach to a problem which takes a broad view, which tries to take all aspects into account, which concentrates on interaction between the different parts of the problem."*

System thinking is goal-oriented and gives answer to the question:

> *"How can we provide an efficient means to meet the following objective….?"* (Checkland 2002)

As it was elaborated in Chapter 3, a hotel is a complex building with numerous energy systems and parameters that influence energy consumption behaviours. The goal (intention) of this research is to establish algorithms for HVAC&R&DHW systems design that will consequently lead to minimal energy consumption and minimal environmental impact during the lifetime of the hotel. According to the Croatian tourism strategy till 2010 (MINT 2003a), new hotel capacity will grow 3% per year while existing accommodation facilities should improve in quality, therefore emphasis in this research is given to existing hotel facilities and energy efficient retrofit possibilities.

Soft system methodology given by Checkland presents a schematic view when "Thinking about desirable and feasible change". (Figure 4.3.)

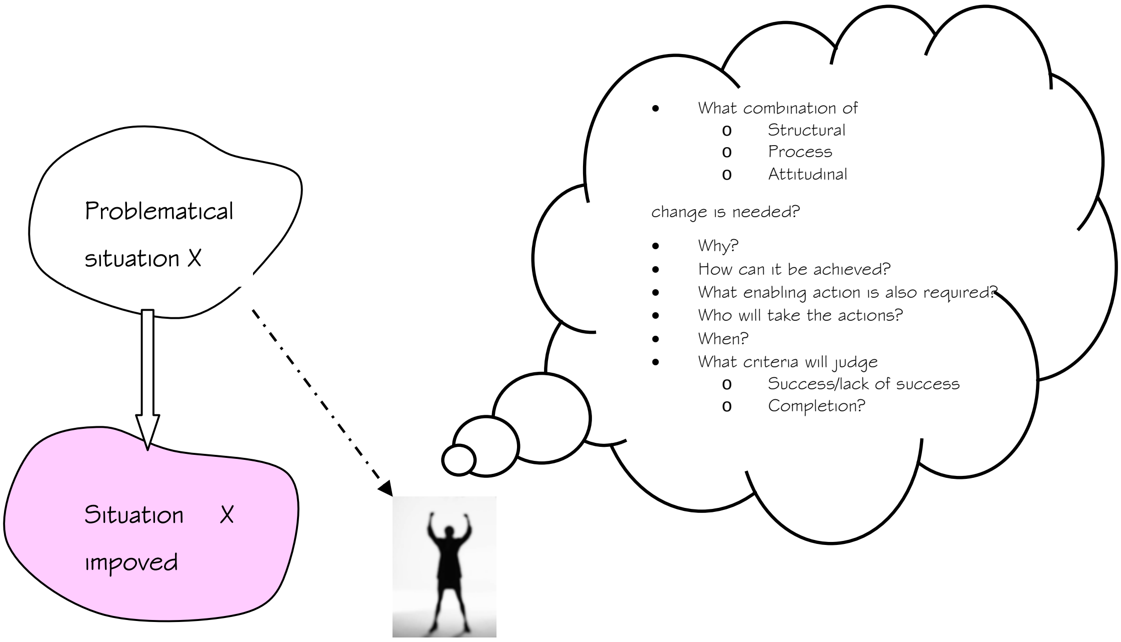

Figure 4.3. Thinking about desirable and feasible change (Checkland 2002)

First of all, it is necessary to detect problematical situation X, which, for the case of hotels, would be high consumption of energy resources and low efficiency of HVAC&R&DHW systems, but also low awareness within the hotel industry and consequently lack of focus on these issues. The energy audits gave the current state of energy consumption and energy management from a planning and operational point of view. It was concluded that energy management in many hotels does not exist or it is at a minimum. The awareness of energy consumption in many cases is neglected. Therefore, for the case of hotels on the Adriatic coast, identification of problematic situations and introduction of energy management should be a priority. The energy audits have shown that there is a lack of renewable energy utilization and environmental actions aiming to save energy.

In order to answer the question; "*what* combination of structural, process and attitudinal *change is needed* in HVAC&R&DHW systems?", it is necessary to closely analyze the current state of energy consumption due to the operation of systems that provide thermal comfort, indoor climate and domestic hot water. Measurements made in hotels gave information about energy consumption for hot water production (space heating and domestic hot water). However, information about energy that is needed to power air-conditioning, cooling and ventilation systems was generally not available, since it would require specific measurements within many hotels which was not possible to arrange for this study. Therefore, to be able to estimate energy consumption due to HVAC system operation, modelling and simulation of these systems was done with a help of TRNSYS simulation environment. Results from these simulations gave realistic data on how much energy is used to power HVAC systems. Verification of this data was done using measured data for heating and DHW obtained in hotels.

Furthermore, to give an answer to question: "*what* changes in existing systems are needed and *why?*", modelling and simulation of advanced HVAC systems is performed. A comparison of energy efficient HVAC systems that utilize renewable energy sources with existing ones, shows which systems are feasible for retrofit and what potential energy and environmental savings can be expected. Design and modelling of energy efficient systems also gave answer to the question: "*how can* new improvements be achieved?".

In order to ensure successful improvements by implementing energy efficient technologies in hotels, it is necessary to change the attitude of hotel management, which is mainly focused on improving services for the guests, without special attention to the energy consumption. Therefore hotel management should take actions in the sense of technically educating the staff and change their attitudes towards energy management, energy savings and the significance of the cost of energy.

When changes are needed? If hotel management wants to comply with EU regulations regarding energy performance in buildings, and to contribute to energy savings on a regional/state level, all while protecting the environment, which is a precondition for a successful tourist industry, actions should be taken now. One of the measures that can be taken with minimal investment and will yield positive economic benefits for each hotel, is the introduction of energy management routines (energy monitoring, recording and regular maintenance). Energy management and energy audits for each hotel will indicate the current state of energy consumption, define the energy efficiency of exiting systems and will highlight which systems require improvements. Furthermore, each major renovation of a hotel which leads to improvements in services and a rise in hotel category should consider retrofitting existing, non-efficient HVAC&R&DHW systems.

At the end of the discussion related to Figure 4.3., one can say that the criteria for successful completion of changes and actions taken for the case of hotels would be improved system operation, lowered energy costs and minimized environmental emission from hotels.

One could say that system thinking should contain: "*….his purpose, the system (s) selected, components, structure, the means by which the system retains its integrity and the coherency principle which makes it defensible to describe the system as a system.*" (Checkland 2002)

4.4. Systems definition

First of all, before starting a system thinking analysis and subsequently modelling the systems, it is necessary to define the system and its boundaries.

> *"Any analysis of energy efficiency or capacity requires a system and systems boundary; heat and work only exist at a system boundary."* (Johansson 2003)

There are several definitions that define a *system*. One given by Churchman, states….

> *"…..a system is a set of parts coordinated to accomplish a set of goals."* (Churchman 1968)

Another useful definition is given by Kotas….

> *"A system is an identifiable collection of matter whose behaviour is the subject of study. For identification, the system is enclosed by a system boundary, which may be purely imaginary or may coincide with a real boundary"* (Kotas 1995)

Churchman's definition is focused on the purpose of the system: Building a hotel for tourist accommodation, installing HVAC & DHW systems to provide thermal comfort, indoor climate and domestic hot water for hotel's guests. According to Churchman it is not important how these goals are accomplished.

Kotas' definition has its roots in engineering sciences (thermodynamics) and gives no room for a discussion on the purpose of the system. He recognizes system boundaries that define the number of components and behaviour between system and environment. In the case of this research, the hotel as a building construction with installations covering HVAC&R and DHW systems are taken as a system. Among other factors, such as number of guests, the building envelope defines energy consumption for HVAC&R systems and is an undividable system component.

4.5. The Modelling Process

"A model is an abstraction, a set of assumptions about some aspects of the world, either real or imaginary, intended to clarify our view of an object, process, or problem by retaining only characteristics essential to the purpose we have in mind." (Miser, Quade 1985)

The modelling process aims to accomplish the objective of the research by means of possible alternatives and criteria. A model is therefore made up of factors and components relevant to the problem. Factors that influence models are usually numerous and their interrelations so complex that mental models are inadequate to handle the large number of factors and their relations.

The purpose of this research is to define promising energy efficient alternatives for existing HVAC&R&DHW systems; however, the possible alternatives are quite numerous. For this research a manageable number of three, most promising, alternatives were identified. These alternatives are:

- H: solar heating with LPG boiler as a back up; C: seawater cooling – (SWC-SH)
- H: heat pump with seawater as a heat source; C: seawater cooled chiller (HPS)
- H: solar heating with LPG boiler as a back up; C: solar absorption chiller (ACS)

- DHW systems – solar collectors with LPG boiler as a back up system – for all three alternative systems

Prior to modelling of these three alternatives, a *screening process* taking into account availability of renewable energy sources and cost of systems was undertaken. The criteria for screening include security in supply, ecology and construction costs. For example biomass boilers are not suggested, since a biomass supply network to the coastal region is not yet established. Furthermore; although considered as an energy efficient measure, cold thermal storage is not considered. The reason for this is that the majority of hotels have 3 stars and hence do not require full air-conditioned premises, while costs of installation are also high. Cold thermal storage is economically viable only if the cooling capacity is above 1MW (Skelin 2006).

Design cases include a scenario (e.g. about the economic future) and set technical assumptions (Figure 4.4.). The technical assumptions are merely assumed values – explicitly stated – for the most uncertain factors in the system (Miser, Quade 1985).

During the system analysis procedure iteration is needed. Sometimes intermediate results or a preliminary version of the final results may force the analyst to alter initial assumptions, revise earlier work or collect more data. Figure 4.4. shows typical iterations and feedback loops in a systems analysis study. For example in this thesis during the modelling of DHW systems, several iterations with variation on the number of solar collectors that would meet optimal operation regarding energy and economical constrains, were done.

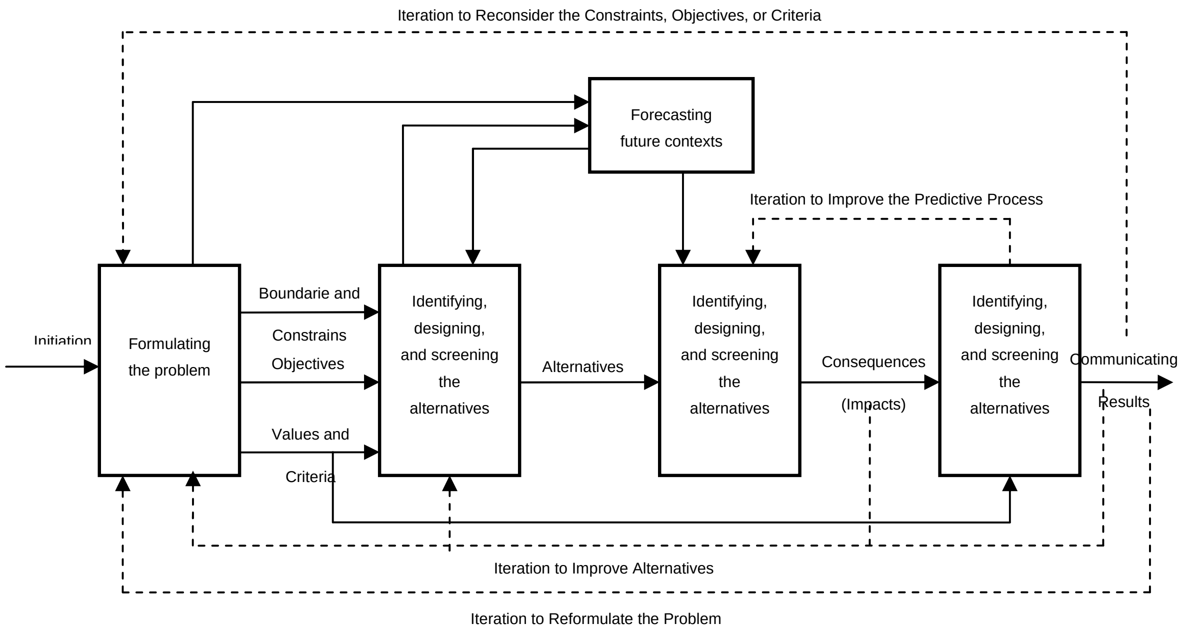

Figure 4.4. The system analysis procedure with iteration loops (Miser, Quade 1985)

In this research, a problem solving procedure is presented in Figure 4.5. The analysis starts with indications about the current state of energy performance in the hotel (results obtain in the Chapter 3 during analysis of energy audit in hotels) and formulation of problems that are presented as room for improvement in the building's energy performance. After setting objectives, a conceptual model of possible alternatives is formed. A physical model is built involving engineering science which will be a basis for the computational model further on. Computer simulations gave problem solving options that, with the help of the iterative improvement process, gave final results. Alternatives are ranked and compared with conventional systems.

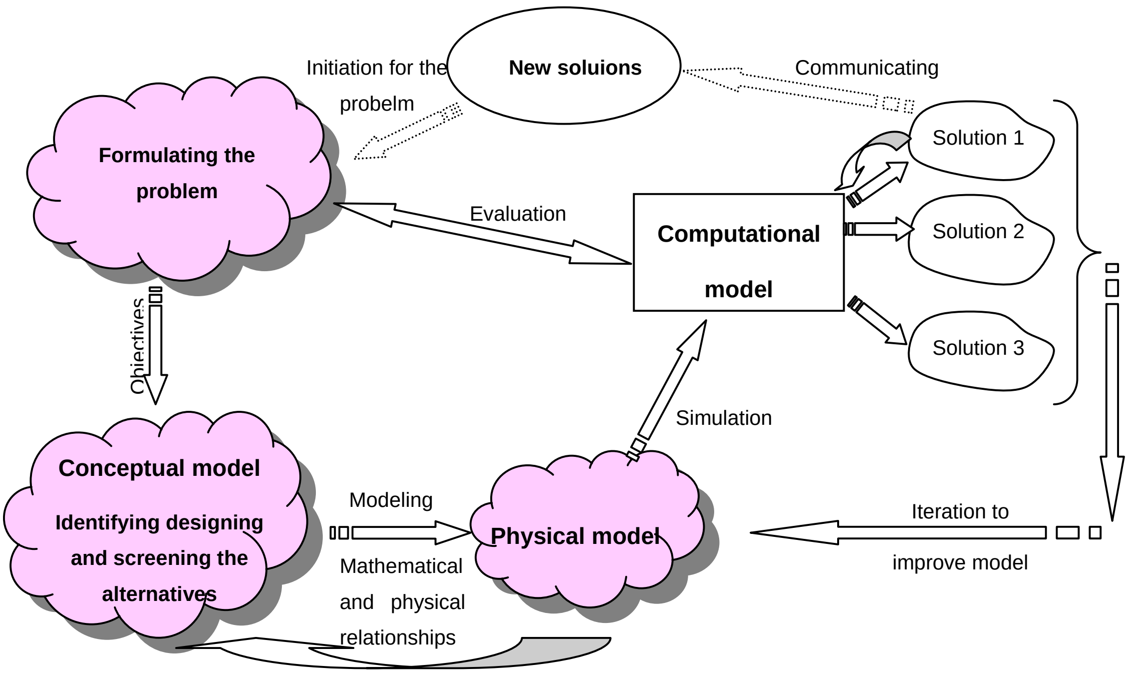

Figure 4.5. The system analysis procedure for problem solving applied in this research

A system might be characterized in terms of the number of components that define size of the model and level of detail (degree of interrelatedness of components) as suggested by Lundqvist (2005) (Figure 4.6.).

Very detailed models, on the component level, require meticulous study and contribute to new technological research. On the other hand, engineering experience with rules of thumb is used for modelling new systems. The level of detail decreases with increase in model size and number of interrelated components (Figure 4.6.).

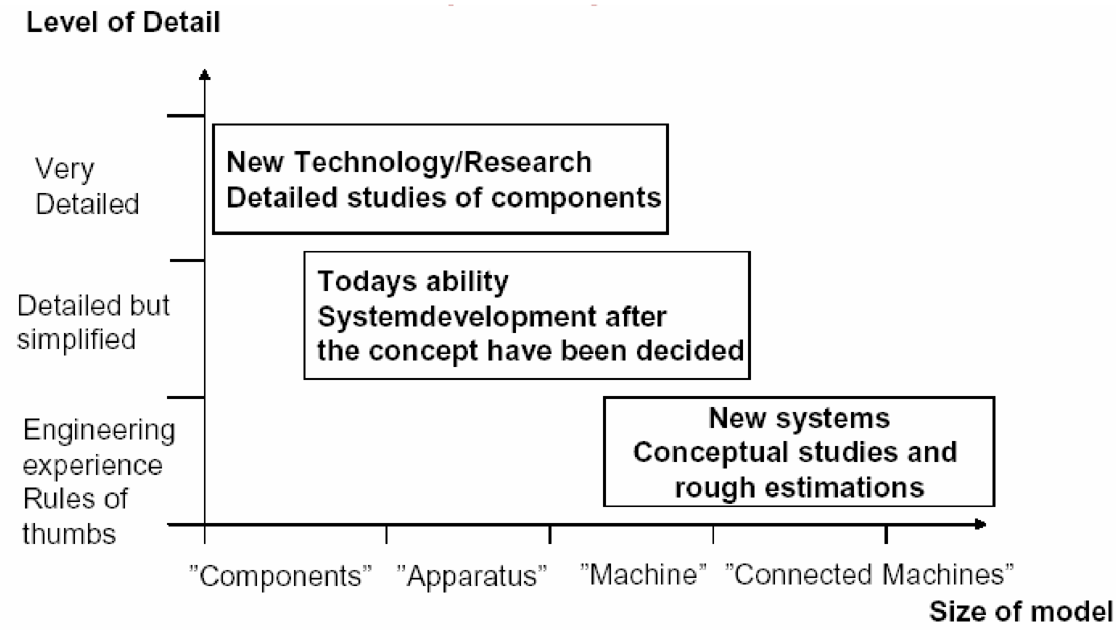

Figure 4.6. The complexity of models (Lundqvist 2005)

"Problems related to systems with relatively few, highly interrelated components can be addressed in analytical form, mathematically. Problems related to systems with relatively many, loosely related components can be addressed statistically. But problems related to systems with relatively many, closely interrelated components cannot be addressed effectively by either of these two problem solving methods. On the one hand, such systems cannot usually be solved mathematically because an analytical solution to the set of equations describing the system does not exist. On the other hand, the dynamics of these systems cannot be represented statistically, as average tendencies, because the interrelatedness of components, or system structure, cause markedly non-random behaviours. Systems analysis and simulated focus specifically on these "intermediate" systems characterized by "organized complexity" in which system structure both controls and is changed by system dynamics" (Grant et al 1997).

Modelling and simulation software tool abilities allow simulation of integrated systems. The next chapter discuses HVAC systems alternatives and how four models have been conceptualized and presented with computational models in TRNSYS.

5. HVAC SYSTEMS OPTIONS' MODELLING

This chapter discuses how the models have been conceptualized. Based on simulation software, the most common HVAC & DHW systems in hotels on the Adriatic coast will be modelled and compared with suggested possible alternatives. Modelling and simulation is done using the TRNSYS.

5.1. Conceptual Model

As it was elaborated in previous chapters, in order to provide improvements with respect to the energy performance of buildings and at the same time to provide thermal comfort and indoor climate, there is a need to look at the building and different subsystems as a integrated system, not as a sum of subsystems or components. Therefore the building, as an integrated system, should be optimized instead of combining individually optimized components.

The conceptual model includes a formulation of (i) the objectives of the model, (ii) the definition of the environment of the system, (iii) and identification of components of the system and (iv) their interconnections. (Arias 2005)

The main objective of the systems modelled in this research is to investigate how energy efficient alternative HVAC systems utilizing renewable energy sources such as solar energy and seawater can contribute to energy and environmental savings in the hotel sector. Furthermore, results of model simulations and analysis should be helpful in the future HVAC systems retrofit and design in hotels on the Adriatic coast. System boundaries, system components and their interconnection for one conventional and three alternative systems are defined in subchapter 5.3. (See Figure 5.7., Figure 5.13., Figure 5.17., Figure 5.20.)

According to Hansen and Clarke (Hensen, Clarke 2000) building simulation is desirable because it is not restricted to the building structure itself but includes the indoor conditions, while simultaneously taking into account the environment, mechanical, electrical or structural systems, with traditional and renewable energy supply systems. Building simulations can be used to characterise and assess proposed new equipment and system integration concepts. It also aids in the identification of such concepts. Simulation can thus be used for building analysis and design in order to achieve a good indoor environment in a sustainable manner.

Object related modelling is applied which begins with a physical description of the building system or component of interest. Also, to predict or simulate the peak and average energy use of such building, it is required to define the building geometry, geographical location, physical characteristics, type of equipment and operating schedules, type of HVAC system, building operating schedules, plant equipment, etc.

The flow chart that illustrates the ordering of the analysis that is typically performed by a building energy simulation program is showed in Figure 5.1.

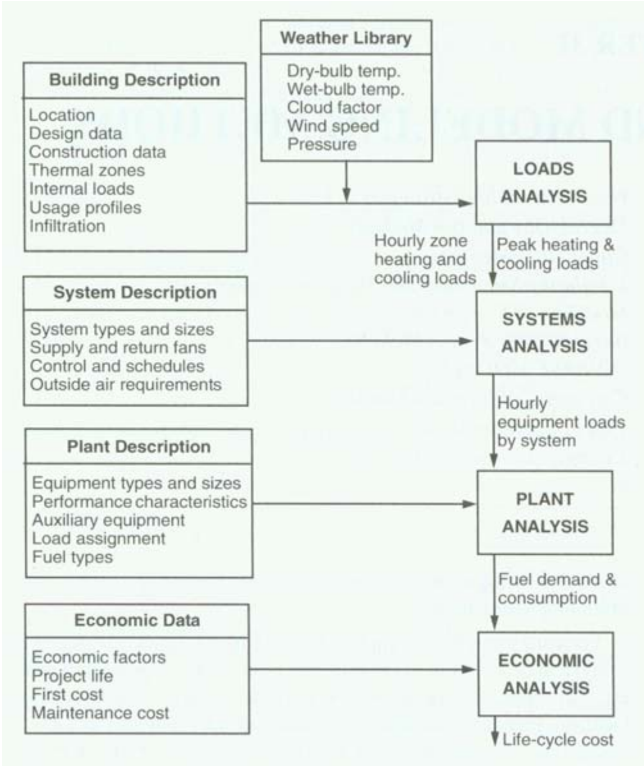

Figure 5.1. Flow chart for building energy simulation program (ASHRAE 2001)

Procedures for estimating energy requirements vary considerably according to complexity and have three common elements: space load, that is the amount of energy that must be added to or extracted from a space to maintain thermal comfort; secondary equipment load, that refers to the equipment that distributes the heating, cooling, or ventilating medium to conditioned spaces; and, primary equipment energy requirements, which refers to central plant equipment that converts fuel or electric energy to heating or cooling effect.

One of the ways of discrimination between various approaches to building systems modelling and simulation is by considering the level of abstraction – ranging from purely conceptual to fully explicit – in terms of user specification and/or mathematical/ numerical representation as summarised in Table 5.1. (Hansen, Clarke 2000)

Table 5.1. HVAC system modelling abstraction levels (Hansen, Clarke 2000)

Level	**Type**
A: Room processes only; ideal plant	CONCEPTUAL
B: System wise in terms of real systems (VAV, WCH, etc.)	⇓
C: Component wise in terms of duct, fan, pump, pipe, etc.	
D: Subcomponent level in terms of energy balance, flow balance, power balance, etc.	EXPLICIT

At level C both specific action by the user and the internal representation is in terms of individual plant components such as the fan, duct, heating coil, boiler, pump, pipe, etc, which are connected to form complete systems. Two main approaches can be distinguished in terms individual component models: input-output based (each separate part of the system such as the building zone, single component, sub-system, etc. is represented by an equivalent input-output relationship) and conservation equation based (each plant part is described by time-averaged discretised heat and mass conservation statements which are combined to form the plant system matrix, and which are solved simultaneously for each simulation time step). There are a number of advantages of the input-output method: it offers a mixture of modelling methods (analytical, numerical, internal look-up table, etc.); it may be used for the different configuration components thus enabling piecemeal component model development from simple to more complex descriptions; and because of the highly modular structure it is relatively easy to add or change certain component models. One of the bet known examples is TRNSYS. The main advantage of the conservation equation method is its implicit simultaneous solution method. The main disadvantage is that it does not allow a mixture of modelling methods (Hensen, Clarke 2000).

Since the primary task of this research is to compare three alternative HVAC systems that supply cooling or heating energy to the building, simulation is made according to space loads and primary equipment energy requirements.

The energy audit was used to give a picture about current status of HVAC system in hotels on the Adriatic coast and to identify opportunities for energy efficiency increase. The analysis of existing cooling systems in hotels has shown that 69% of these systems are vapour compression cooling units with air-cooled condensers. For hotels with 4 and 5 stars, control of thermal comfort during the cooling season is requirement for guest rooms and other facilities, therefore experience has shown that these systems are centralized. However, for hotels with 3 stars this is not the case, since cooling system are designed in a decentralized fashion with a number of split units[11] (mostly used in common spaces). Decentralized systems are cheaper if one looks at the investment cost, but during the life time of systems, due to lower efficiency, they consume more energy. A side effect is the visual pollution, due to the number of units outside.

Therefore the systems proposed as an alternative are centralised systems. Heat pump system (HPS) with seawater as a heat source or sink is not new in hotels, but the share is only 12% of total cooling systems. However, two other alternative systems, seawater cooling system – solar heating (SWC-SH) and solar absorption cooling system – solar heating (ACS) were not found in the hotels on the Adriatic coast.

5.2. Simulation tool - TRNSYS

In this research TRNSYS 16 is used for the development of building and HVAC systems models. TRNSYS is commonly used for HVAC analysis and sizing, solar design, day lighting, building thermal performance, PV, wind, analysis of control

[11] Split unit - This describes an air conditioning or heat pump system that is split into two sections - an outdoor section and an indoor section

schemes, etc. TRNSYS is a transient system simulation program with a modular structure. It is well suited for detailed analyses of system whose behaviour is time dependent. A system is defined in TRNSYS to be a set of components, interconnected in such a manner as to accomplish a specified task. One obvious characteristic of a system is its modularity. Because the system consists of components, it is possible to simulate the performance of the system by collectively simulating the performance of the interconnected components. The modular simulation technique reduces the complexity of system simulation because it essentially reduces a large problem into a number of smaller problems, each of which can be more easily solved independently (SEL 2000).

The performance of a system component will normally depend upon characteristic fixed parameters, the performance (or outputs) of other components, and time-dependent forcing functions. For example, for a solar water heating system, knowledge of the weather (i.e., solar radiation, ambient temperature, etc.) and the hot water demand as a function of time are necessary in order to determine the transient system performance.

With a program such as TRNSYS, which has the capability of interconnecting system components in any desired manner, solving differential equations, and facilitating information output, the entire problem of system simulation reduces to a problem of identifying all of the components and formulating a general mathematical description of each. However, if the system is too complex it can yield numerical instability.

The TRNSYS engine (solver) requires that the user create an input file (text) that describes which components are to be simulated and how these components are interconnected. This can be done either directly by editing the text that describes the components and the way they interfere in the menu-driven-environment programme (TRANSHELL), or by construction an information-flow diagram in the graphical pre-processor (IISIBAT). TRANSHELL and IISIBAT are included in TRNSYS simulation studio package. From the flow diagram in the graphical pre-processor, a deck-file is generated which can be read in TRNSHELL. When a deck-file exists, the simulation can be run.

5.3. HVAC & DHW systems models

Up until the early nineties, summer thermal comfort was not a priority in either public or private buildings. With respect to the hotel sector, there were only a few 5 star hotels that could offer adequate thermal comfort during the hottest summer days. Previous hotel categorization did not require air conditioning in hotels with 3 stars, which account for 50% of hotels on the Adriatic coast. Due to climate change and increased standards, air conditioning is one of the priorities for the tourism accommodation sector. Therefore, systems modelled in this study consist of both cooling and heating systems. It is assumed year round operation. Domestic hot water systems, as a precondition for hotel operation, will be modelled with all systems.

The term "energy efficient system" should also imply the performance optimization of each building's components and systems, individually and in its interactions with other energy consuming systems – air-conditioning, domestic hot water, etc. The TRNSYS programme calculates demand profiles and at the same time matches supply. Modelling of such big systems has the advantage of adjusting different parameters to optimise matching strategies prior to installation.

In the next subchapters the conventional HVAC system and three alternative systems models were described in detail, while in Appendix IV their deck files generated in TRNSYS simulation studio can be found.

In order to estimate energy consumption of a designed system as well as to make energy, economical and environmental analysis, systems are modelled and simulated. The simulation procedure is based on hourly profiles for climatic conditions and operational characteristics for a number of typical days of the year or for 8760 h of operation per year.

5.3.1. The hotel building model

For this research two hotels with 4 stars in region of Split were modelled. The hotels have year round operation and require adequate thermal comfort during the whole year:

- Model 1: hotel with 300 beds (150 rooms, A=9.000 m^2)
- Model 2: hotel with 600 beds (300 rooms, A=15.000 m^2)

The average room area is 20 m^2, while additionally conditioned spaces such as restaurants, reception, bars, sport facilities is:

- Model 1: 2.000 m^2
- Model 2: 3.000 m^2

The floor area of hotels without conditioning is:

- Model 1: 4.000 m^2
- Model 2: 6.000 m^2

5.3.1.1. Climate conditions

The geographical position on the Adriatic Sea provides conditions and mild climate that make all seven coastal counties in Croatia suitable for the use of solar and wind energy. In particular, the Adriatic Islands and the Dalmatian region have the highest insolation level of 2300-2800 sunshine hours per year (Figure 5.2.) (Hrastnik, Frankovic 2001). Split is placed at the 43°31′ latitude and 16°26′ longitude.

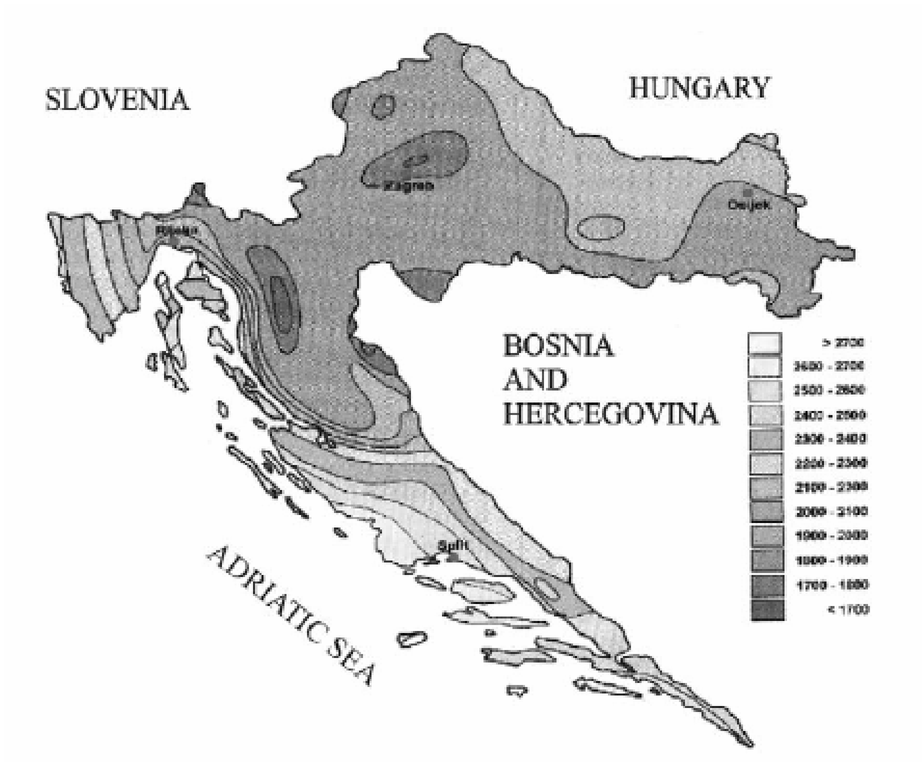

Figure 5.2. Geographical position of Split and solar irradiance in Croatia (h/year) (Hrastnik, Franković 2001)

A square metre of horizontal surface receives 1534 kWh/m^2 , while 30^o inclined surface receives 1741 kWh/m^2 in the south solar irradiance annually. The average monthly temperatures varies from $7{,}6^oC$ in January to $25{,}4^oC$ in July (MZOPU 2005b). The number of days with temperature >30 ^oC is 39,2 , while the number of days with temperature <0^oC is 0,4. The yearly number of hours with temperatures 30, 32 and 34^oC is 91, 30 and 16 respectively (Recknagel 2002). Average relative humidity is 60%.

Design indoor temperatures[12] and design outdoor temperatures[13] for heating and cooling seasons taken for calculations in this research are as follows:

---

[12] Design indoor temperature is the temperature required to be produced and maintained by cooling or heating system

[13] Design outdoor temperature is specified temperature used to calculate the heating or the cooling load

$\vartheta_{DH\ indoor}$ = 21 °C - design indoor temperature for heating season

$\vartheta_{DH\ out}$ = -1 °C - design outdoor temperature for heating season

$\vartheta_{DC\ indoor}$ = 26 °C - design indoor temperature for cooling season

$\vartheta_{DC\ out}$ = 32 °C - design outdoor temperature for cooling season

The heating season period last from October 15th until April 15th, while cooling season starts on June 1st and finishes on September 15th. However, the number of heating or cooling days in periods varies from year to year. The number of heating days with regards to outside temperature of 12°C is 121,6 while degree days is 1437 Kday/year (MZOPU 2005b).

5.3.1.2. The building model in TRNSYS

The intention of this research is to demonstrate how the three alternative HVAC systems, that supply heat and cold energy to hotel building, can contribute to energy and environmental savings compared to conventional HVAC system. Since emphasize was on the HVAC systems, the building model in TRNSYS is presented with simple, one-zone building (TYPE 12: Energy/(degree-hour) space heating or cooling load). The same model of the building is used for simulations in all four systems.

The energy/(degree-day) concept has been shown to be useful in estimating the monthly heating load of a structure. In this space heating load model, the energy/(degree-day), or more appropriately the energy/(degree-hour), concept is extended to estimate the hour by hour heating load of a structure. The model provide an estimate of the space heating load with minimal computational effort (SEL 2000).

There are four modes of operation in Type12. Models 1,2, and 3 are compatible with energy rate control. Mode 4 used in this thesis models a single lumped capacitance house compatible with temperature level control. Normally heating and/or cooling equipment and a controller are used in conjunction with this mode. Room temperature reflects both, the ambient conditions and the heating or cooling equipment inputs. The advantage of temperature level control is more detailed and realistic simulation of the interaction between the building and equipment. Building is modelled with a single lumped capacitance (*CAP*). That number is selected so that maximum swing of room temperature in a time step is on the order of the controller dead band ranges.

In this case, the building is modelled through the use of a single conductance *UA* for heat loss or gain, along with any additional gains due to solar, lights, people, etc. Single energy balance of the structure is performed for each simulation time step. Hour by hour energy loads that are calculated in this manner may be considerably incorrect. However, over a period of time, the model may provide reasonable good estimates of overall energy quantities. Since the same building model was used for all systems, reasonable good estimation and comparison of the energy systems may be done.

<u>Mathematical description</u>

The differential equation describing the rate of change of internal energy of a lumped capacity structure is:

$$CAP\frac{d\vartheta_R}{dt} = \gamma \cdot \varepsilon \cdot C_{\min} \cdot (\vartheta_i - \vartheta_R) + \dot{Q}_{gain} - U \cdot A \cdot (\vartheta_R - \vartheta_a) + \dot{Q}_{aux} - \dot{Q}_{sens} \qquad (5.1.)$$

where,

$\gamma =$ 1 if $\dot{m}_1$>0 (otherwise $\gamma = 0$)

Differential equation (5.1.) is solved for the final and average room temperature for each time step, ϑ_{RF} and $\overline{\vartheta}_R$.

$$\dot{Q}_{sens} = (1 - LHR) \cdot \dot{Q}_{cool} \qquad (5.2.)$$

When degree-day loads are used for air conditioning calculations ASHRAE suggests multiplying the sensible load by a constant factor to account for latent loads.

$$LHR = \frac{latent \quad load}{total \quad load} \tag{5.3.}$$

ASHRAE recommends LHR ratio of about 0.3 or 0.23. The total and latent cooling load are calculated as

$$\dot{Q}_{cool} = \frac{\dot{Q}_{sens}}{(1 - LHR)} \tag{5.4.}$$

$$\dot{Q}_{lat} = \dot{Q}_{cool} - \dot{Q}_{sens} \tag{5.5.}$$

In any case rate of energy transferred across the load heat exchanger and instantaneous heating load are calculated as

$$\dot{Q}_T = \gamma \cdot \varepsilon \cdot C_{\min} \left(\vartheta_i - \overline{\vartheta}_R \right) \tag{5.6.}$$

$$\dot{Q}_L = U \cdot A \cdot \left(\vartheta_R - \vartheta_a \right) - \dot{Q}_{gain} \tag{5.7.}$$

Also, depending of the mode of heating or cooling, instantaneous auxiliary heating and rate of sensible cooling load are

$$\dot{Q}_{aux} = \quad \dot{Q}_L - \dot{Q}_T + \frac{CAP \cdot \left(\vartheta_{RF} - \vartheta_{RL} \right)}{\Delta t} \qquad \text{if } >0$$

$$\text{otherwise} \quad \dot{Q}_{aux} = 0 \tag{5.8.}$$

$$\dot{Q}_{sens} = \quad \dot{Q}_T - \dot{Q}_L - \frac{CAP \cdot \left(\vartheta_{RF} - \vartheta_{RL} \right)}{\Delta t} \qquad \text{if } >0$$

$$\text{otherwise} \quad \dot{Q}_{sens} = 0 \tag{5.9.}$$

Parameters, inputs and outputs for building model are as follows:

<u>*Parameters*</u>

$U \cdot A$ - overall conductance for heat loss from house, [W/^{o}C]

CAP - lumped thermal capacitance of house, [J/^{o}C]

ϑ_{RI} - initial room temperature, [^{o}C]

c_{Pf} - specific heat of heat source fluid, [J/kg^{o}C]

$\varepsilon \cdot C_{\min}$ - product of the effectiveness and minimum capacitance rate of load heat exchanger, [W/°C]

$\vartheta_{\min}$ - room set temperature for heating, [°C]

$\vartheta_{\max}$ - room set temperature for cooling, [°C]

LHR - ratio of latent to total cooling load

Inputs

ϑ_i - temperature of the fluid from heat source, [^oC]

$\dot{m}_i$ - mass flow rate of fluid from heat source, [kg/s]

ϑ_a - ambient temperature, [^oC]

$\dot{Q}_{gain}$ - time variant heat gains, [W]

$\dot{Q}_{aux}$ - auxiliary heating input to space, [W]

$\dot{Q}_{cool}$ - rate of cooling energy removed from space, [W]

Outputs

ϑ_o - temperature of the fluid returning to heat source, [^oC]

$\dot{m}_o$ - mass flow rate of fluid returning to heat source, [kg/s]

$\overline{\vartheta}_R$ - average room temperature, [^oC]

$\dot{Q}_L$ - instantaneous heating load, [W]

$\dot{Q}_T$ - rate of energy transferred across the load heat exchanger, [W]

$\dot{Q}_{aux}$ - instantaneous auxiliary heating, [W]

$\dot{Q}_{sens}$ - rate of sensible cooling load, [W]

$\dot{Q}_{lat}$ - rate of cooling used to reduce room humidity, [W]

5.3.1.3. Energy requirements

In order to supply input data to the building model, calculations for heating and cooling capacity is made according to German standards commonly used in Croatia.

Heating losses

Heating losses are calculated according to German standard DIN 4701 (Recknagel 2002). The heating capacity is calculated as a sum of transmission $\dot{Q}_T$ and infiltration losses $\dot{Q}_{FL}$:

$$\dot{Q}_N = \dot{Q}_T(\vartheta_a) + \dot{Q}_{FL}(\vartheta_a) \quad , [W] \tag{5.10.}$$

$$\dot{Q}_T = U \cdot A(\vartheta_R - \vartheta_a), [W] \tag{5.11.}$$

$$\dot{Q}_{FL} = \dot{V} \cdot \rho \cdot c_p(\vartheta_R - \vartheta_a), [W] \tag{5.12.}$$

Where:

A – total area of building toward environment, [m^2]

U – coefficient of heat transfer, [W/m^2K]

ϑ_R - room temperature, [°C]

ϑ_a - ambient temperature, [°C]

$\dot{V}$ - air flow, [m^3/s]

c_p - specific thermal capacitance, [J/kgK]

ρ - density of the air, [kg/m^3]

Air flow due to infiltration is calculated as:

$$\dot{V} = \sum (a \cdot l) \cdot \sqrt[3]{\Delta p^2} \tag{5.13.}$$

Where

a - factor of infiltration, [$m^3/mhPa^{2/3}$]

l - length of fugue (cleft), [m]

Δp - pressure difference, [Pa]

Average a =0,6 $m^3/mhPa^{2/3}$, while it is given for pressure difference Δp =1 Pa

The calculated heating capacity is as follows:

- Model 1: 550 kW
- Model 2: 780 kW

Cooling load

The cooling capacity is calculated according to standard VDI 2078 (VDI 1996) which takes into account, building location and orientation, building materials, insulation, glazing characteristics, outside temperature, solar radiation through windows and walls, heat accumulation in the walls, internal gains and cooling load due to ventilation rate. The cooling load is calculated as a sum of the internal cooling load and the external cooling load:

$$\dot{Q}_{cool} = \dot{Q}_I + \dot{Q}_E \quad , [W] \qquad (5.14.)$$

The internal cooling load $\dot{Q}_I$ of a room is made up of the partial cooling loads due to heat emission from persons $\dot{Q}_P$, heat emission from equipment $\dot{Q}_{Eq}$ and heat $\dot{Q}_R$ flowing in from adjacent rooms via the internal surface. With $\dot{Q}_{Eq}$, a distinction is made between cooling load due to illumination heat $\dot{Q}_B$, machine and appliance heat $\dot{Q}_M$, heat absorption or emission in the event of material throughput through the room $\dot{Q}_G$ (e.g. cooling water for machines), and other heat supply and removal $\dot{Q}_C$ (e.g. chemical reactions). Thus

$$\dot{Q}_I = \dot{Q}_P + \dot{Q}_{Eq} + \dot{Q}_R \qquad (5.15.)$$

Where

$$\dot{Q}_{Eq} = \dot{Q}_B + \dot{Q}_M + \dot{Q}_G + \dot{Q}_C \qquad (5.16.)$$

Cooling load due to persons $\dot{Q}_P$ is calculated as :

$$\dot{Q}_P = n_p \cdot q_p \cdot S_i \qquad (5.17.)$$

Where

n_p - number of persons

q_p – heat emission from the human body, [W]

S_i – cooling load factor for internal loads

Cooling load due to lighting $\dot{Q}_B$ is calculated as:

$$\dot{Q}_B = P \cdot l_B \cdot \mu_B \cdot S_i \qquad (5.18.)$$

Where

P – total installed power of the lights, [W]

l_B – simultaneity factor of the lighting at the time concerned

μ_B – room load factor due to lighting

S_i – cooling load factor for internal loads

Cooling load due to machines and equipment $\dot{Q}_M$ is calculated as:

$$\dot{Q}_M = l_M \cdot S_i \sum_{j=1}^{n} \left(\frac{P_j}{\eta} \cdot \mu_{aj} \right) \quad (5.19.)$$

Where

P_j – rated power of the machine j, [W]

η – mean motor efficiency

μ_{aj} – load factor of the machine j at the time in question

l_M – simultaneity factor

S_i – cooling load factor for internal loads

Cooling load due to material throughput $\dot{Q}_G$ is calculated as:

$$\dot{Q}_G = \dot{m} \cdot c_p \cdot (\vartheta_E - \vartheta_A) \cdot S_i \quad (5.20.)$$

Where

$\dot{m}$ – mass of the material brought into the room or removed from in the unit of time, [kg/s]

c_p – mean specific heat capacity , [kJ/kgK]

ϑ_E – inlet temperature, [K]

ϑ_A – outlet temperature, [K]

S_i – cooling load factor for internal loads

Cooling load due to different temperatures in adjacent rooms $\dot{Q}_R$ is calculated as:

$$\dot{Q}_R = U \cdot A \cdot \Delta\vartheta \quad (5.21.)$$

Where

U – heat transmission coefficient, [W/m^{2}K]

A – area [m^2]

$\Delta\vartheta$ – temperature difference [K]

The effect of all other supply and removal $\dot{Q}_C$ on the room climate should be estimated, and taken into consideration. However, for this research $\dot{Q}_C$ was neglected, as well as $\dot{Q}_M$, since except room refrigerator and television there is no other machinery in hotel room. Cooling load due to material throughput $\dot{Q}_G$ was also neglected.

External cooling load is calculated as sum of cooling load through external walls and roofs $\dot{Q}_W$, cooling load due to transmission through windows $\dot{Q}_{TW}$, cooling load due to radiation through windows $\dot{Q}_S$ and cooling load due to infiltration $\dot{Q}_{FL}$.

$$\dot{Q}_E = \dot{Q}_W + \dot{Q}_{TW} + \dot{Q}_S + \dot{Q}_{FL} \qquad (5.22.)$$

The instantaneous heat flow $\dot{Q}_W$ through external walls and roofs into the room arises from the following:

$$\dot{Q}_W = U \cdot A \cdot \Delta\vartheta_{eq} \qquad (5.23.)$$

Where

U – heat transmission coefficient, [W/m²K]

A – area [m²]

$\Delta\vartheta_{eq}$ – equivalent temperature difference [K]

Cooling load due to transmission through windows $\dot{Q}_{TW}$ is calculated as:

$$\dot{Q}_{TW} = U_F \cdot A_M \cdot \left(\vartheta_a - \vartheta_R\right) \qquad (5.24.)$$

Where

U_F – heat transmission coefficient of the window, [W/m²K]

A_M – total window area [m²]

ϑ_a – ambient temperature, [K]

ϑ_R – room air temperature, [K]

Cooling load due to radiation through windows $\dot{Q}_S$ is calculated as:

$$\dot{Q}_S = \left[A_l \cdot I_{\max} + \left(A_g - A_l\right) \cdot I_{diff.\max}\right] \cdot b \cdot S_a \qquad (5.25.)$$

Where

A_l – sun-exposed glass area, [m²]

A_g – total glass area $A_g \approx g_v \cdot A_M$, [m²]

g_v – glass surface component of window area; A_M-A_g is the frame area

I_{max} – maximum value of the total radiation for the design month, [W/m²]

$I_{diff.max}$ – maximum value of diffuse radiation for the design month, [W/m²]

b – radiation transmission coefficient of the window and sun protection devices

S_a – cooling load factor for external radiation load

Cooling load due to infiltration $\dot{Q}_{FL}$ .is only taken into consideration in special cases, that was not the case in this research.

The room cooling load is the sum of the internal and external cooling load components, while the building cooling load at time *t* is obtained from the sum of all room cooling loads at time *t:*

$$\dot{Q}_{cool} = \sum_{j=1}^{n} \dot{Q}_{cool}(t) \quad , [W] \qquad (5.26.)$$

Calculated cooling loads for two hotels are as follows:

- Model 1: 280 kW
- Model 2: 485 kW

<u>Domestic hot water - DHW</u>

Bearing in mind an average daily hot water consumption (DHW) of 80-100 litres per guest (Recknagel 2002), estimated DHW consumption, with 100% occupancy rate would be:

- Model 1: 26.900 l/day
- Model 2: 53.800 l/day

The histogram of hourly hot water demand is presented in Figure 5.3. Building characteristics for both hotel models are summarized in Table 5.2.

Table 5.2. Hotels' buildings characteristics

	Hotels' model	
	I	II
Number of rooms	150	300
Number of beds	300	600
Total rooms area, m^2	3000	6000
Floor area of the restaurant, m^2	600	1200
Floor area of the additional facilities: reception, halls, public areas, m^2	950	1200
Floor area of the swimming pool and sport facilities, m^2	450	600
Non conditioned floor area, m^2	4000	6000
Hotel regional location	Split	Split
Location and orientation	Close to the coast line, SW	Close to the coast line, SW
Walls	Concrete, k=1,8 w/m^2K	Concrete, k=1,8 w/m^2K
Roof	Flat roof, concrete, 10 cm insulation	Flat roof, concrete, 10 cm insulation
Walls' and roof thermal insulation	Walls without insulation	Walls without insulation
Glazing	Double glazing, wooden frame, inside venetian blades k=3 W/m^2K	Double glazing, wooden frame, inside venetian blades k=3 W/m^2K
Daily DHW consumption, l/day	26900	53800
Heating capacity, kW	550	780
Cooling capacity, kW	280	485

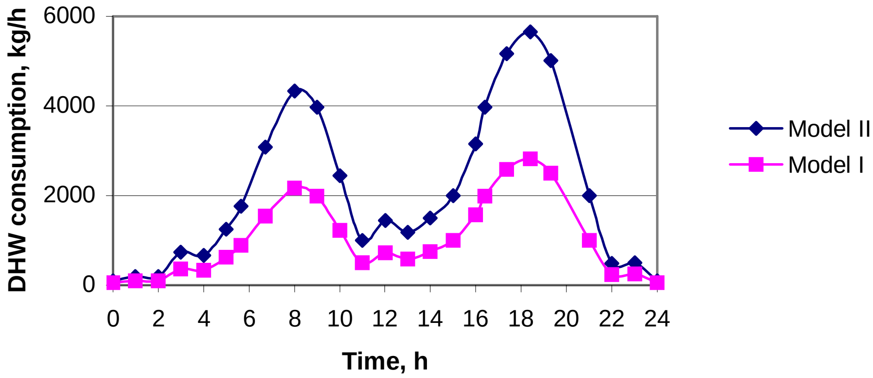

Figure 5.3. DHW histogram

The time step for simulations is chosen sufficiently small such that the numerical integration algorithm remains stable during the evaluation of the time-dependent variables of the system model and it goes from 10s to 200s.

5.3.2. Conventional system – (CS)

Cooling

The cooling system model consists of a number of parallel vapour compression cooling units with air cooled condenser. Cooling units produce cold water with temperatures ranging from 7 - 12°C, which is distributed to cooling devices (fan coils) within the hotel. The COP of this system during simulations was relatively low (COP=3,15) due to a high condensing temperature, influenced by high outdoor temperatures ($\vartheta_{DC\ out} = 32^{o}C$).

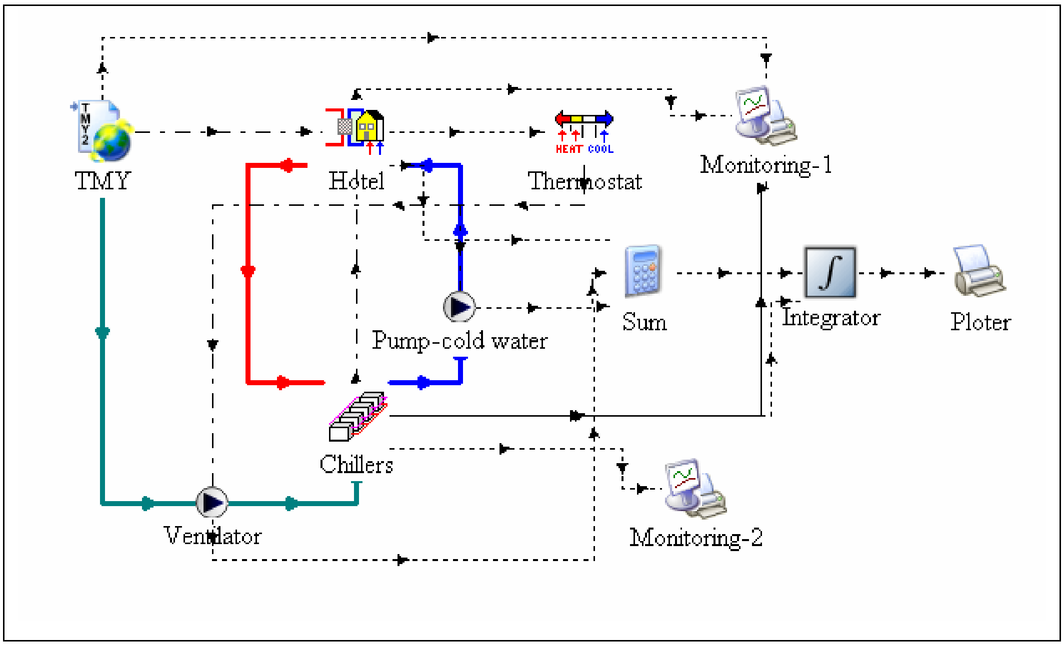

Figure 5.4. Interrelationship of conventional cooling system (CS) components modelled in TRNSYS

TRNSYS components used to build the CS cooling model are: TYPE 3. Pump/ventilator, TYPE 8. Three-stage room thermostat, TYPE 12. Energy/degree-hour house: temperature level control, TYPE 24. Quantity integrator, TYPE 53. Parallel chillers, TYPE 65. Online graphical plotter with output file, TYPE 109. Data reader and radiation processor. Description of components is given in Appendix III.

Heating

The heating system consists of a boiler powered by heating oil. Hot water set temperature in boiler is 55°C. Hot water is distributed to fan coils and radiators in the building. The temperature difference between the hot water supply and return line is 7°C. The system is designed to cover heating and DHW demand simultaneously.

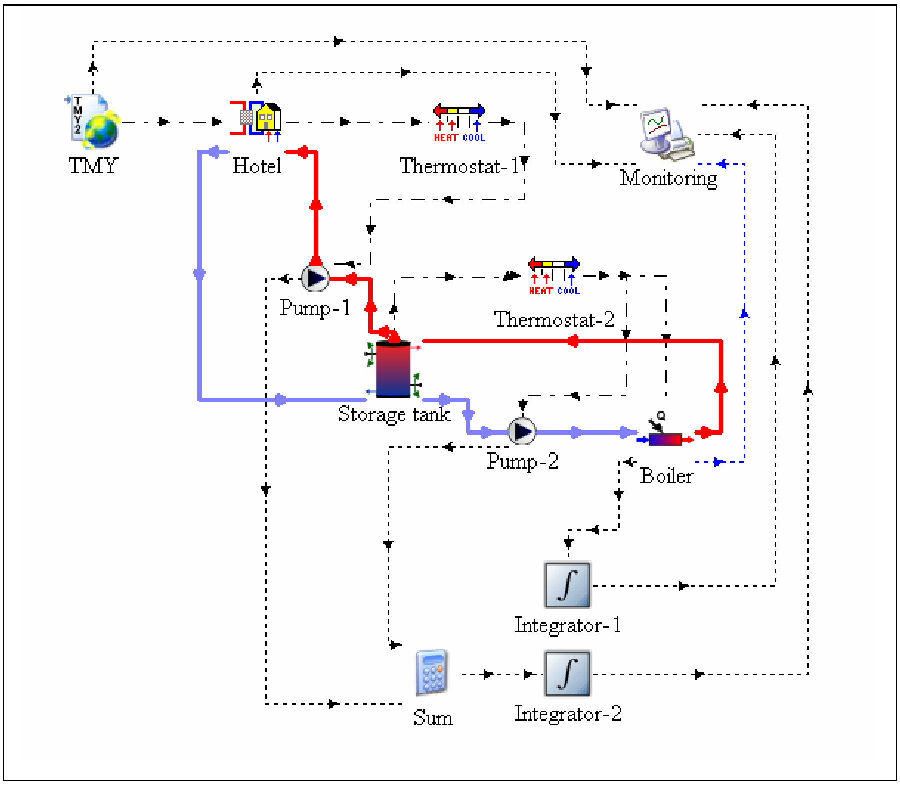

Figure 5.5. Interrelationship of conventional heating system (CS) components modelled in TRNSYS

TRNSYS components used to build the CS heating model are: TYPE 3. Pump/ventilator, TYPE 4. Stratified hot water storage tank, TYPE 6. On-Off auxiliary heater, TYPE 8. Three-stage room thermostat, TYPE 12. Energy/degree-hour house: temperature level control, TYPE 24. quantity integrator, TYPE 65. Online graphical plotter with output file, TYPE 109. Data reader and radiation processor. Description of components is given in Appendix III.

DHW system

The same boiler described above is used for domestic hot water. The minimum set temperature in the hot water storage tank is 40-45^{o}C, which prevents unnecessary transmission heat losses due to water preheating, extensive scale formation on heat exchanger surfaces and storage tank. On the other hand, it is necessary to ensure minimum hygienic conditions for hot water and to prevent the growth of various bacteria. Therefore, the storage tanks are periodically heated to a temperature of 60°C. DHW at 40°C is distributed to consumers (guest rooms, kitchens, toilettes…).

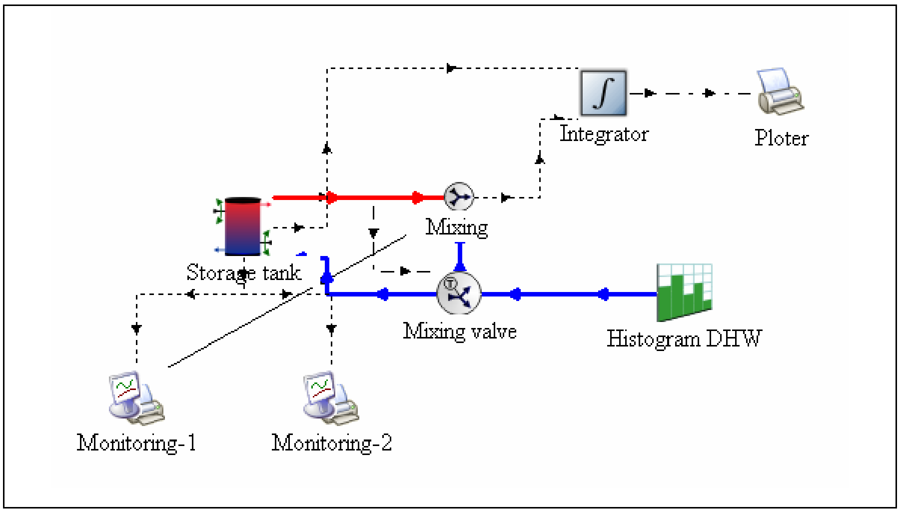

Figure 5.6. Interrelationship of conventional DHW system (CS) components modelled in TRNSYS

TRNSYS components used to build the CS DHW model are: TYPE 4. Stratified hot water storage tank, TYPE 11. Tee piece, tempering valve, TYPE 14. Time dependent forcing function, TYPE 24. Quantity integrator, TYPE 65. Online graphical plotter with output file. Description of components is given in Appendix III.

A schematic view of conventional cooling and heating system can be seen in Figure 5.7., while a list of components and their capacities are given in Table 5.3.

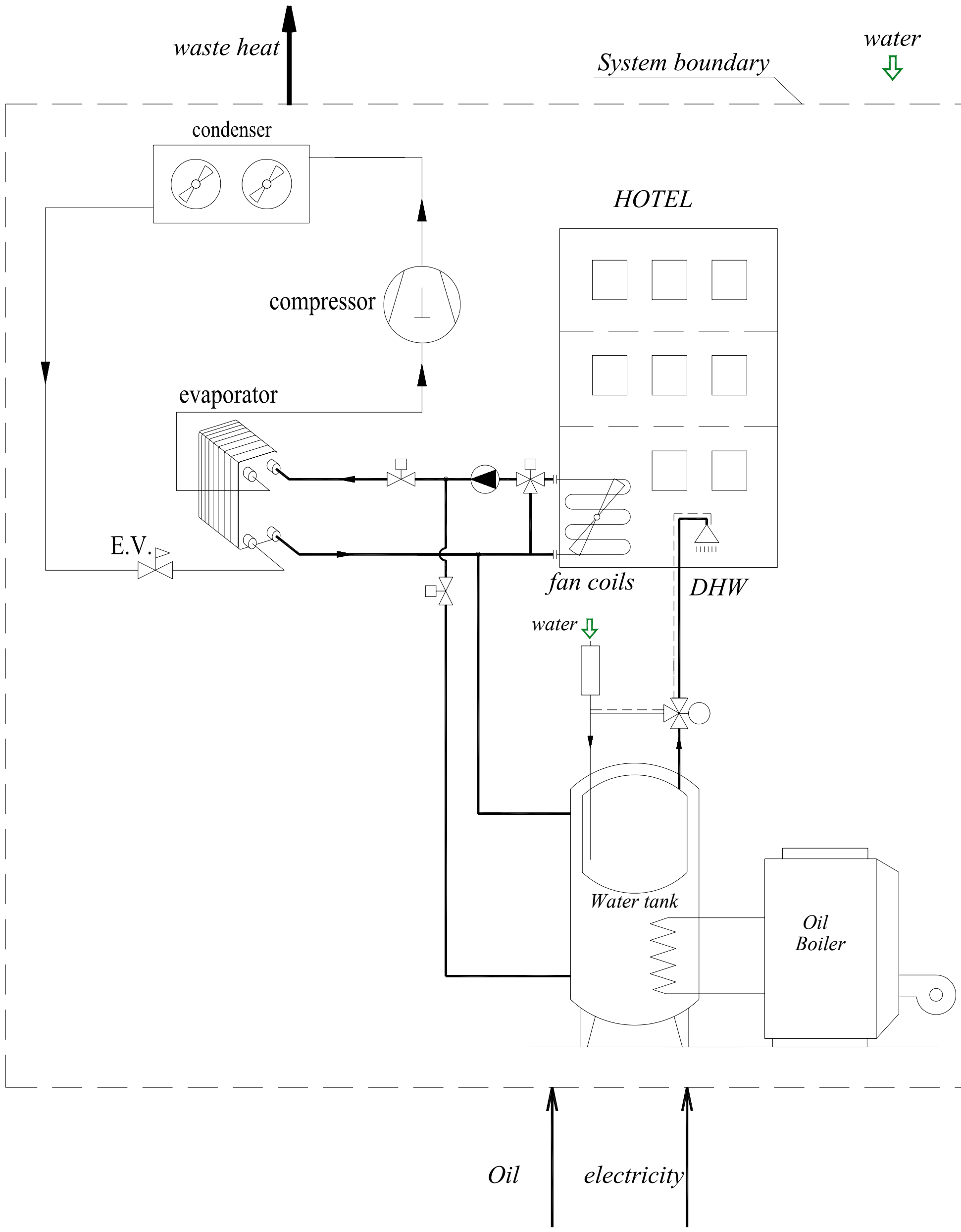

Figure 5.7. Schematic view of conventional (CS) system

Table 5.3. System's components – capacities and prices (CS)

Conventional system with vapour compression cooling unit and oil boiler (CS)							
System's components		Model hotel I – 150 rooms Q_{cool}=300kW, $Q_{heating}$=600kW, V_{DHW}= 26,9 m³/day			Model hotel II – 300 rooms Q_{cool}=500kW, $Q_{heating}$=800kW, V_{DHW}= 53,8 m³/day		
		Working parameters	pc	Price, EUR	Working parameters	pc	Price, EUR
1.	Vapour compression unit with air cooled condenser	300 kW, cold water 12/7°C	1	32.700	500 kW, cold water 12/7°C	1	50.700
2.	Cold water pump	16 kg/s, Δp=30 m	1	1.400	24 kg/s, Δp=30 m	1	1.900
3.	Fan coils	1.6 kW	150 50	50.000	1.6 kW 4.3 kW	300 60	90.000
4.	Hot water storage tank	24 m³	2x12 m³	15.400	36 m³	3x12 m³	23.100
5.	Boiler	Total capacity 700 kW: 100 for DHW 600- for heating.	1	14.900	Total capacity 950 kW: 150 kW for DHW and 800kW for heating	1	24.300
6.	Hot water pump	20 kg/s, Δp=30 m	1	1.900	30 kg/s, Δp=30 m	1	2700
7.	Pump DHW	1 kg/s, Δp=20 m	1	600	2.5 kg/s, Δp=30m	1	700
8.	Automatic regulation			1.400			1.400
9.	Pipes, valves, assembling parts		cca	4.000		cca	6.000

5.3.3. Seawater cooling system – solar heating (SWC – SH)

Use of the seawater for cooling is not new, especially as a heat sink in heat and power stations or nuclear stations where huge amounts of water are needed for cooling purposes. The seawater, where available, is used as a heat sink on the condenser side of the refrigeration unit.

There are some examples in the world where sea, lake, river or ground water is used directly for cooling purposes, making the cooling system less complex than conventional water chilling systems. These systems operate with deep cold water and are called Deep Water Source Cooling (DWSC) systems (Hazen 1995).

Deep water source cooling (DWSC) refers to the renewable use of a large body of naturally cold water as a heat sink for process and comfort space cooling. The cold water can be found in deep areas within lakes, oceans, aquifers and rivers which is then pumped through the primary side of a heat exchanger. On the secondary side, clean chilled water is produced with one tenth of the average energy required by conventional, chiller based systems. Coinciding with significant energy and operating cost savings, DWSC offers reductions in air-borne pollutants and the release of environmentally harmful refrigerants (Hazen 1995).

There are two positive reasons for using DWSC in district energy systems:

1) A DWSC system provides an environmentally passive method for reducing contributions to global warming and climate change. DWSC, by replacing the equipment in a conventional energy chilled water plant, could use approximately 10-20% of the energy required to operate the centrifugal chillers, cooling towers and pumps. To the extent that fossil fuel-fired electricity generating plants are being used to provide power for chiller operation, any reduction in the power demand for cooling will reduce CO_2 emissions and the subsequent global warming effects.
2) Using naturally chilled water there is no need for refrigerants that cause ozone depletion or global warming. Also, need for cooling towers and the use of chemically treated cooling water is eliminated. Eliminating the cooling tower can reduce fresh water consumption, noise and blow down water discharge. (Zanki, Galaso 2002)

A typical electrical requirement at peak, for large building air conditioning, is approximately 0.24 kWh_{el}/kWh of cooling capacity (Hazen 1995). This value can vary greatly depending on the load, ambient conditions and efficiency of the chiller. A typical peak electrical energy requirement for a lake or ocean source cooling system will be in the range of 0.028-0.057 kWh_{el}/kWh of cooling capacity. The net effect of a DWSC system is a net reduction in energy and instantaneous power consumption attributed to conventional chilled water generation and distribution of 80 to 90% (Hazen 1995).

Seawater used in existing systems worldwide is deep, cold sea or lake water with temperatures in the range of 6-12^{o}C (Zanki 2003). These temperatures would correspond to those produced in chillers for conventional air conditioning units. The Adriatic Sea, compared to Oceans, is shallow with the deepest spots of 200 m approximately 20-50 km's from the described sites on the coast (Figure 5.8.).

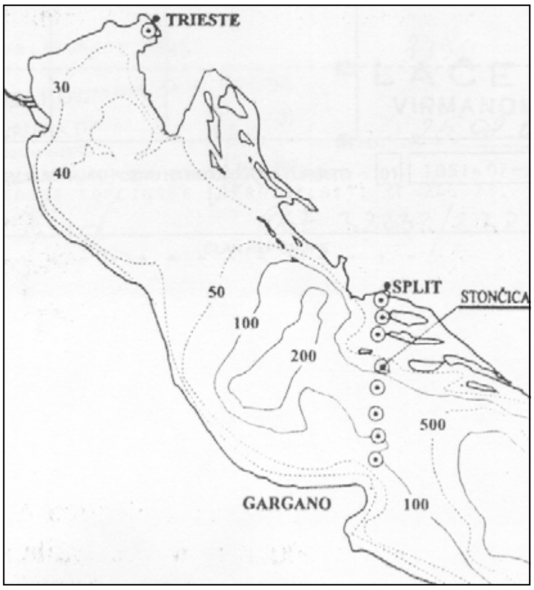

Figure 5.8. The map of the Adriatic and depth profile (Zore 1999)

The average temperature at the depth of 200 m during the summer months is 12,89^{o}C (Buljan 1976), which is not low enough for the cooling application using fan coils. Furthermore, any investment in a pipeline of that distance would be too expensive. The range of the seawater temperatures in the Adriatic are shown in Table 5.4.

Table 5.4. Average annual and seasonal values of sea water temperatures (°C) for the whole Adriatic (Buljan 1976)

Depth (m)	Year (Whole)	Winter (Jan., Feb., Mar.)	Spring (Apr., May., June)	Summer (July, Aug., Sept.)	Autumn (Oct., Nov., Dec.)	Amplitude (max-min)
0	17,88	12,14	17,85	23,12	17,91	10,98
5	16,80	11,65	16,39	22,65	16,25	11,00
10	16,77	11,95	16,05	21,78	16,53	9,83
20	15,61	12,44	14,96	18,53	16,95	6,09
30	14,84	12,37	14,34	16,31	16,62	4,25
40	14,43	12,25	13,72	15,23	16,95	4,70
50	14,28	13,03	13,74	14,63	16,11	3,08
75	14,04	13,27	13,62	14,16	15,48	2,21
100	13,79	13,27	13,55	13,86	14,63	1,36
150	13,19	13,11	12,98	13,08	13,64	0,56
200	13,01	13,01	12,99	12,89	13,15	0,26
300	13,72	13,58	13,84	13,72	13,78	0,26
500	13,45	13,42	13,53	13,39	13,50	0,14
800	13,23	13,22	13,27	13,19	13,26	---
1000	12,82	12,82	12,76	12,93	12,77	---

When analyzing the possibilities to apply free cooling in the Mediterranean region of the Adriatic Sea, where deep seawater is not available, higher quantities of cooling water should be considered. High temperature cooling systems might be applied if buildings are not already equipped with conventional fan coil units. If radiant cooling systems[14] are considered with building temperatures in the order of 18/21°C, it would be possible to obtain the same cooling capacity and necessary thermal comfort. Seawater that could produce cold water at 18/21°C should be at the maximum 15°C, which could be pumped from depths of 50 m and a few hundred meters offshore.

When analyzing heat transfer loops in the cooling systems it is important to minimize their number while providing the same cooling capacity. It is obvious that each heat transfer loop has its own efficiency, and in order to increase efficiency of the whole

[14] Radiant cooling -the process of cooling by which a heat absorbing media absorbs heat from one source and radiates the heat away. A controlled-radiant surface is called a radiant panel if 50% or more of the heat transfer is by radiation to other surfaces seen by the panel.

system, design should strive toward decreased number of heat transfer loops. On the Figure 5.9. schematic view of heat transfer loops in vapour compression system with air cooled condenser is given.

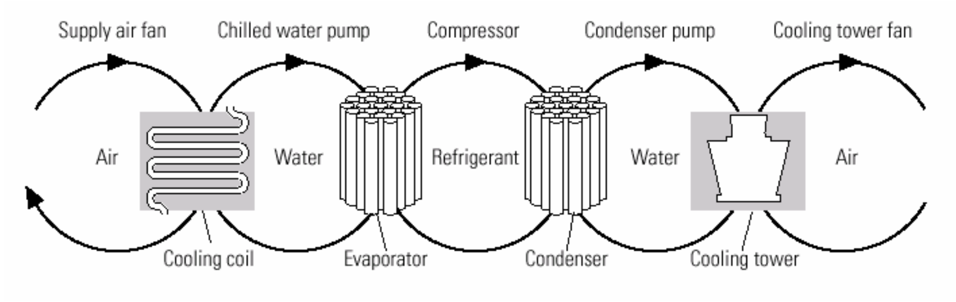

Figure 5.9. Conceptual view of a chilled-water air-conditioning system (Esource 2001)

Since cold energy in seawater cooling system is transferred to the space via the radiant mechanism, there is no longer a need for air loops that maintain thermal comfort in the cooling spaces. The total electricity needed for the system, compared with vapour compression system, is diminished in accordance with savings from air fan electricity and electricity to drive compressor. A schematic view of the heat transfer loops for the SWC system can be seen in Figure 5.10. A literature survey shows that seawater for high temperature cooling is neither mentioned or applied yet. The study of high temperature cooling systems for tourist complexes was done by the same author of this research as a master thesis. Analysis has shown that seawater cooling system can save up to 90 % of energy compared to vapour compression systems, with air cooled condensers (Zanki 2002).

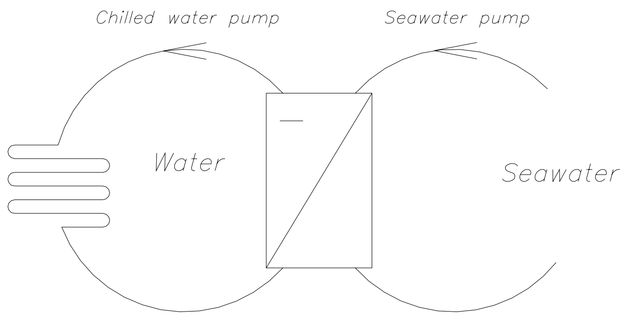

Figure 5.10. Conceptual view of the seawater cooling system (Zanki 2002)

Advantages of radiant cooling/heating systems

Due to the high heat capacity and density of water, thermal energy can be transported via water in pipes with little pumping power; saving approximately 70-80% of the fan power normally used for conditioning of a building (in all air systems). This alone reduces the peak-power of the air conditioning system by about 30-45%. Besides power savings, radiant cooling systems have numerous of advantages, as follows (ASHRAE 2000):

- Separation of the ventilation task from the thermal conditioning
- space savings due to less area needed for air channels
- no drafts
- no noise
- the same installation for heating and cooling
- free of maintenance and durability

Cooling

The seawater cooling system is very simple and consists of three primary components: central seafront screening, pumping and treatment plant, the central transfer line and the end-user distribution network.

The SWC cooling system consists of two main loops. In the first loop, centrifugal pumps draw cold seawater from the bottom of the sea, and then circulate it through heat exchangers that are located in the hotel's machine room. The warmed seawater is then returned back to the sea. In the heat exchanger, air-conditioning water is chilled while heat is transferred to the seawater. The second pump then circulates the chilled water throughout the hotel. The seawater, at a temperature of 15^{o}C, is pumped from depths greater than 50m and a few hundred meters offshore, and results in cold water at 18/21^{o}C. Cold water is distributed to radiant panels in the hotel. The room set temperature is 25-26^{o}C.

Heat exchangers should be of the plate and frame type, which generally provide superior thermal performance. They are more economical and have smaller dimensions. Plates fabricated from titanium are used in seawater applications while stainless steel provides good performance in fresh water applications. Aluminium plates are now being developed as a cost effective alternative to titanium. Plate heat exchanger allow 0.5-1.7^{o}C temperature difference within the heat exchanger, (Hazen 1995).

TRNSYS components used to build the SWC-SH cooling model are: TYPE 3: Pump/ventilator, TYPE 5. Counter flow heat exchanger: counter flow, TYPE 8. Three-stage room thermostat, TYPE 12. Energy/degree-hour house: temperature level control, TYPE 24. Quantity integrator, TYPE 65. Online graphical plotter with output file, TYPE 109. Data reader and radiation processor. Description of components is given in Appendix III. Interrelationship of the seawater cooling system (SWC-SH) components modelled in TRNSYS is given on Figure 5.11.

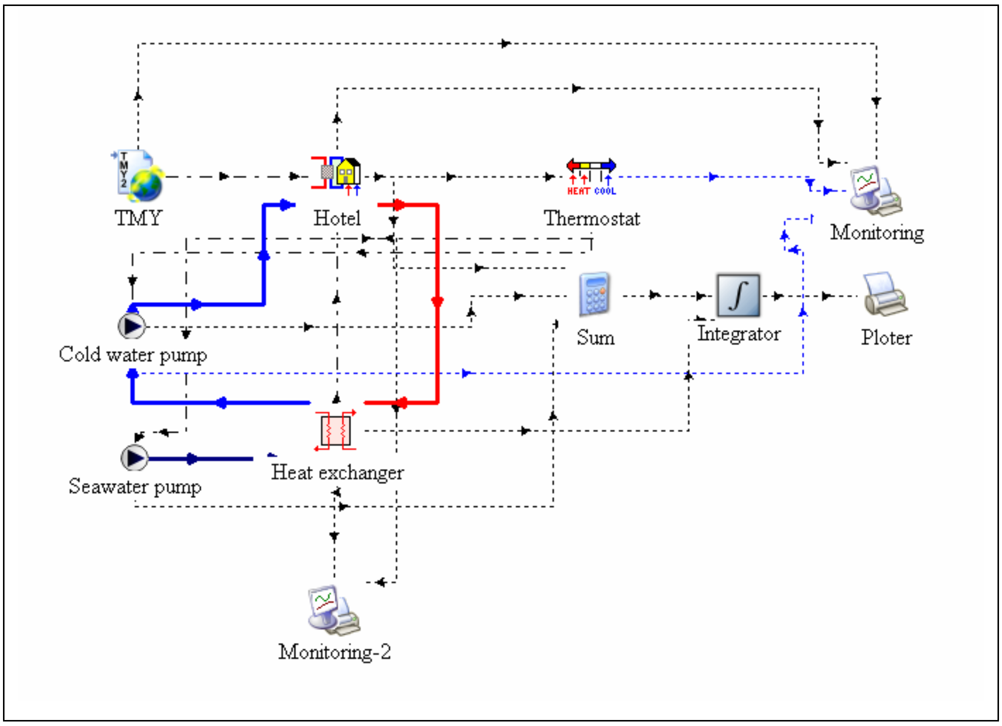

Figure 5.11. Interrelationship of the seawater cooling system (SWC-SH) components modelled in TRNSYS

Heating & DHW

The heating system consists of solar collectors, hot water storage tank and a boiler power by LPG as a back up system. Hot water is provided during the whole year for domestic hot water and for space heating. The solar collector system is designed to provide DHW during the summer months. The minimum temperature in the hot water storage tank is 42°C due to certain bacteria's (legionela). However, the temperature in the storage tank can reach 90°C in the summer months. During the winter months, when occupancy rate and DHW consumption is lower, storage tanks are periodically heated to temperatures of 60°C to prevent bacteria growth. Solar collectors are placed on the roof with a 45° slope, oriented towards south. Hot water with temperatures of 40-45°C is distributed to radiator panels. The temperature difference between hot water supply and return line is 10°C. Wall temperature is approximately 22-23°C to provide thermal comfort for people even when room temperature is 18°C.

TRNSYS components used to build the SWC-SH heating and DHW model are: TYPE 1. Solar collector; quadratic efficiency, 2nd order incidence angle modifiers, TYPE 2. On-off differential controller, TYPE 3. Pump/ventilator, TYPE 4. Stratified hot water storage tank, TYPE 8. Three-stage room thermostat, TYPE 11. Tee piece, tempering valve, TYPE 12. Energy/degree-hour house: temperature level control, TYPE 14. Time dependent forcing function, TYPE 24. Quantity integrator, TYPE 65. Online graphical plotter with output file, TYPE 109. Data reader and radiation processor. Description of components is given in Appendix III. Interrelationship of the solar heating system (SWC-SH) components modelled in TRNSYS is given on Figure 5.12.

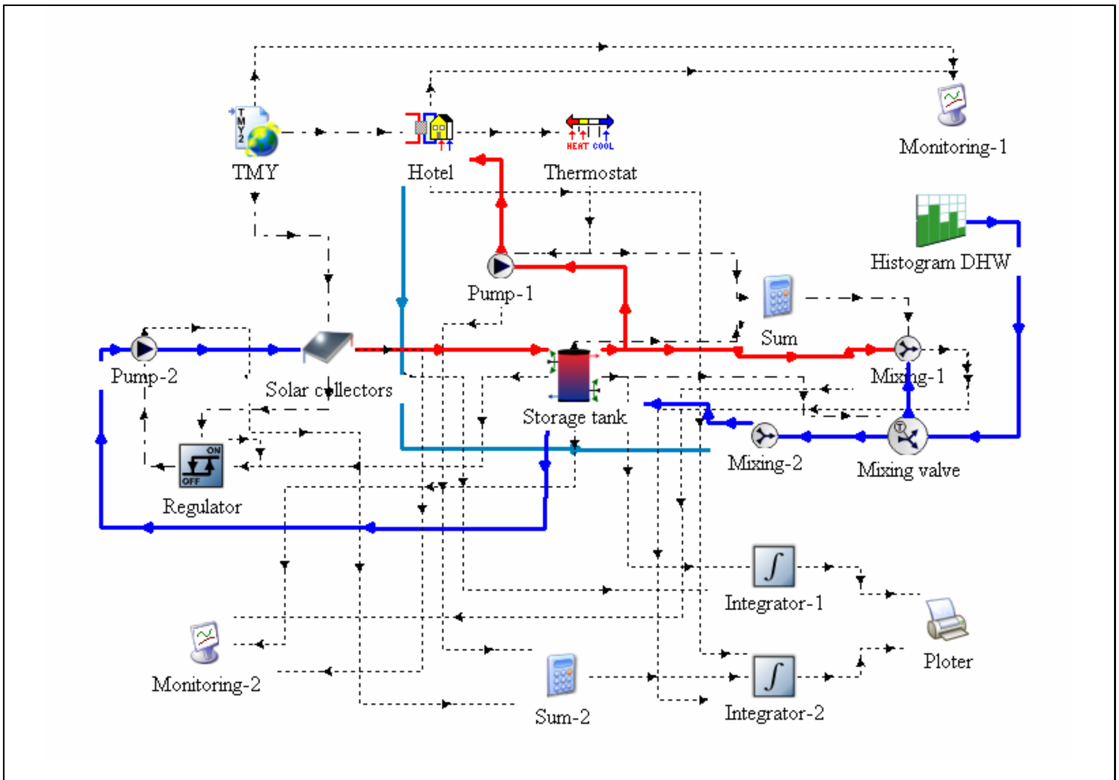

Figure 5.12. Interrelationship of the solar heating system (SWC-SH) components modelled in TRNSYS

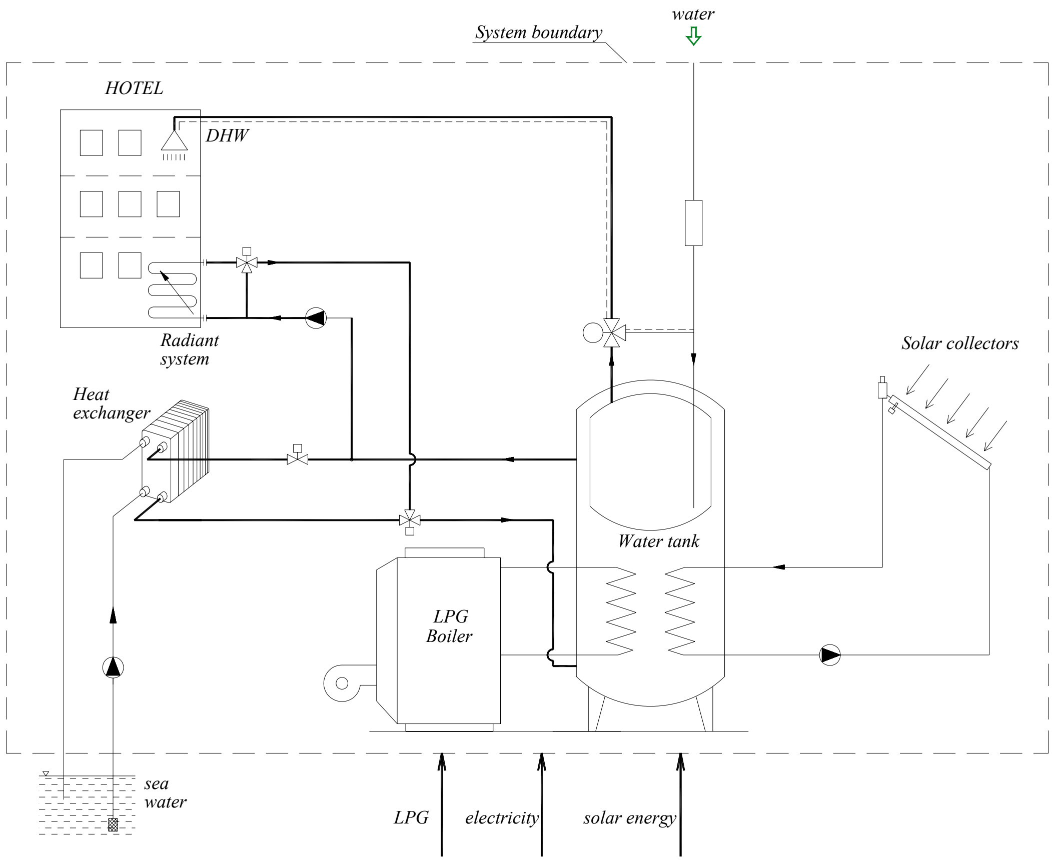

Figure 5.13. Schematic view of the seawater cooling and solar heating systems

Schematic view of the seawater cooling and solar heating systems can be seen on Figure 5.13. while list of components and their capacities are given in Table 5.5.

Table 5.5. System's components – capacities and prices (SWC-SH)

Seawater cooling system and solar heating (SWC-SH)							
System's components		Model hotel I – 150 rooms Q_{cool} =300 kW, $Q_{heating}$=600 kW, V_{DHW}=26,9 m^3/day			Model hotel II – 300 rooms Q_{cool}=500 kW, $Q_{heating}$=800 kW, V_{DHW}= 53,8 m^3/day		
		Working parameters	pc	Price, EUR	Working parameters	pc	Price, EUR
1.	Titanium plate heat exchanger	300 kW, seawater 15/18°C, cold water 21/18°C	1	8.000	500 kW, seawater 15/18°C, cold water 21/18°C	1	19.500
2.	Seawater pump	25 kg/s, Δp=30 m	1	3.000	40 kg/s, Δp=30 m	1	3.300
3.	Cold/hot water pump	24 kg/s, Δp=30 m; 15 kg/s, Δp=30 m	1	1.900	40 kg/s, Δp=30 m; 20kg/s, Δp=30 m	1	2.700
4.	Radiant cooling/heating installation and pipes	9600 m^2, PP pipes 6x1 mm		26.000	16200 m^2, PP pipes 6x1 mm		43.800
5.	Plate solar collectors	350 m^2	166x2.1 m^2	90.000	600 m^2	280x 2.1 m^2	151.400
6.	Hot water storage tank	24 m^3	2x12 m^3	15.400	36 m^3	3x12 m^3	23.100
7.	Boiler - LPG	Total 700 kW: 100kW DHW + 600kW for heating	1	14.900	Total 950 kW: 150 kW for DHW+ 800kW for heating	1	24.400
8.	Pump for solar collector loop	2 kg/s, Δp=20 m	1	700	6,5 kg/s, Δp=20 m	1	900
9.	Hot water pump	1 kg/s, Δp=20 m		600	2.5 kg/s, Δp=20 m	1	700
10.	Automatic regulation			1.400			1.400
11.	Pipes, valves, assembling parts			cca 5000			cca 7000

5.3.4. Heat pump system (HPS)

Cooling and Heating

The cooling system model consists of four and two parallel vapour compression units with seawater cooled condensers for the case of hotel with 300 and 150 rooms respectively. Cooling units produces cold water in the temperature range of 7/12°C and is distributed to cooling devices (fan coils) within the hotel. Due to the relatively low temperature of seawater ($\vartheta_{SWC\ HPc}$ = 20°C) used as a heat sink, the COP of this system during simulations was relatively high (COP=4,64), therefore less electricity needed to power the compressor. Since seawater temperatures at a depth of 10m is constant during the summer months, it is expected that system operation will be stable which results in longer equipment lifetime and reduced servicing. Parts of the system in contact with seawater should be corrosion resistant. Passing through the condenser, seawater is heated with a $\Delta\theta$ = 3–4°C. This is in line with regulations regarding dangerous materials and boundary values for waste water (DUV 1999), and therefore sea-life will not be disturbed.

The refrigerant used in the vapour compression system is R134a which belongs to the group of environmentally acceptable refrigerants, HFC (hydrofluorocarbons). They do not contain chlorine which is harmful for ozone layer.

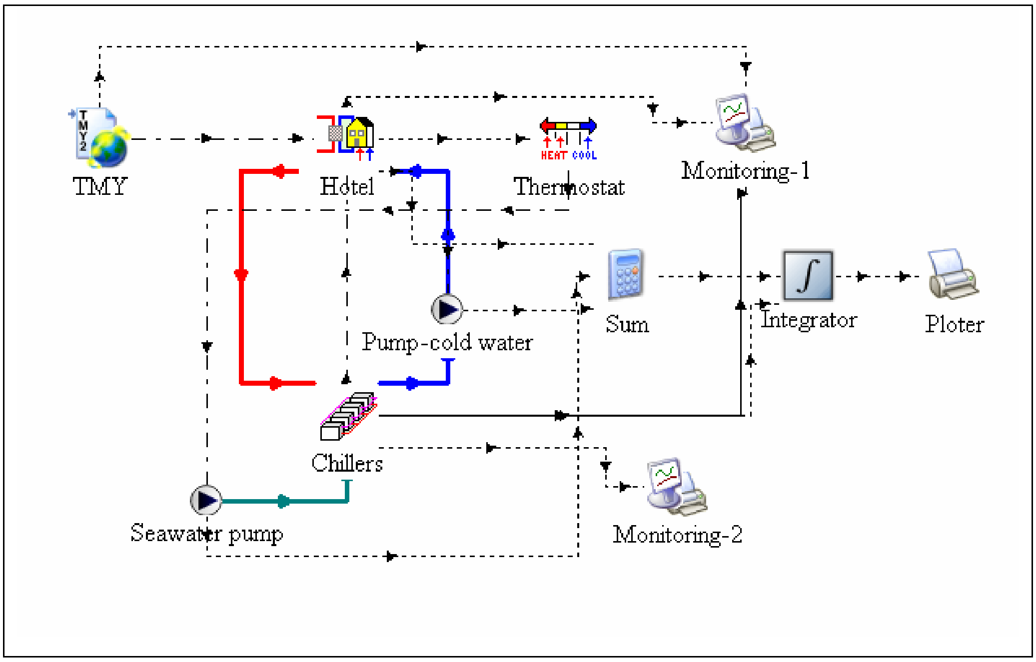

Figure 5.14. Interrelationship of the vapour compression cooling system (HPS) components modelled in TRNSYS

TRNSYS components used to build the HPS cooling model are: TYPE 3. Pump/ventilator, TYPE 8. Three-stage room thermostat, TYPE 12. Energy/degree-hour house: temperature level control, TYPE 24. Quantity integrator, TYPE 53. Parallel chillers, TYPE 65. Online graphical plotter with output file, TYPE 109. Data reader and radiation processor. Interrelationship of the vapour compression cooling system (HPS) components modelled in TRNSYS is given on Figure 5.14.

Vapour compression units should be designed to fulfil, both cooling and heating needs. Since the heating requirements of a vapour compression unit during the heating season is higher, the unit is selected to cover these needs. As a consequence, available cooling capacity during the cooling season is higher than required. Therefore, a number of parallel units were selected, so that optimum operation for both cooling and heating season could be achieved.

During the heating season mode for the heat pump, hot water with temperatures of 50-55°C is produced in the condenser and further on distributed to the fan coils in the rooms and radiators for areas that are only heated. Temperature difference between supply and return hot water is 7°C.

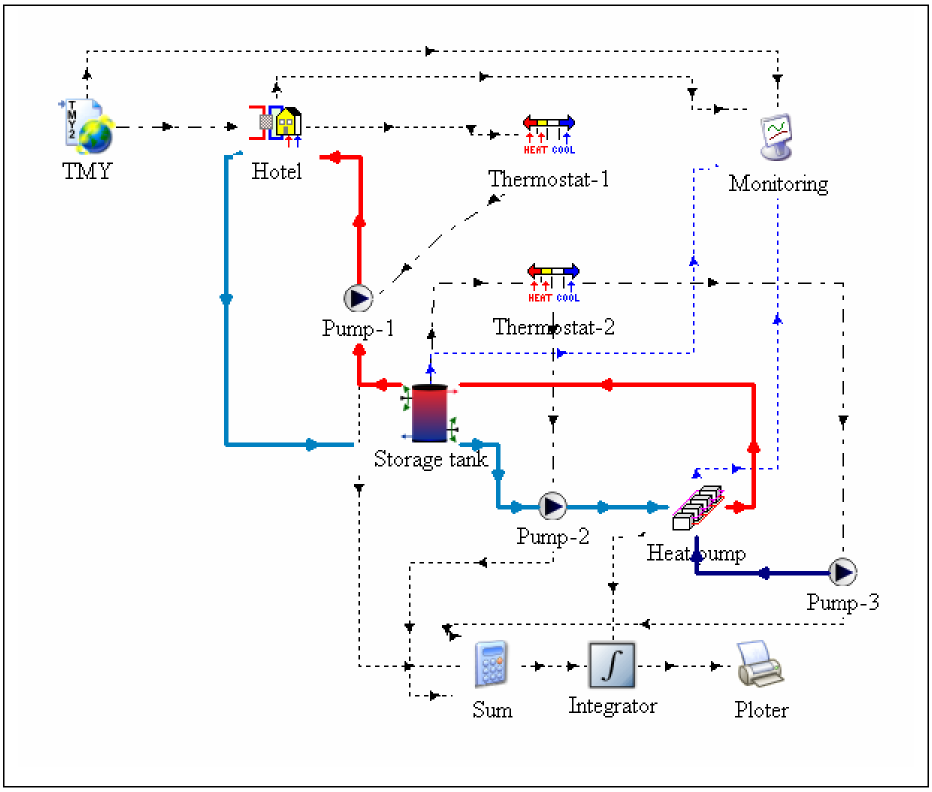

Figure 5.15. Interrelationship of the heat pump heating system (HPS) components modelled in TRNSYS

TRNSYS components used to build the HPS heating model are: TYPE 3. Pump/ventilator, TYPE 4. Stratified hot water storage tank, TYPE 8. Three-stage room thermostat, TYPE 12. Energy/degree-hour house: temperature level control, TYPE 24. Quantity integrator, TYPE 53. Parallel chillers, TYPE 65. Online graphical plotter with output file, TYPE 109. Data reader and radiation processor. Interrelationship of the heat pump heating system (HPS) components modelled in TRNSYS is given on Figure 5.15. Description of components is given in Appendix III.

DHW system

DHW system consists of solar collectors, hot water storage tank, circulation pump and a boiler powered by LPG as a back up system. Hot water is provided during the whole year for domestic hot water. The solar collector system is designed to provide DHW during the summer months. The temperature regime in the storage tank is the same as in the case of SWC-SH system Solar collectors are placed on the roof with 45^o slope, oriented towards south. Mixing valves ensure that hot water of 40^{o}C is distributed to the consumers (guest rooms, kitchens, toilettes…) in the hotel.

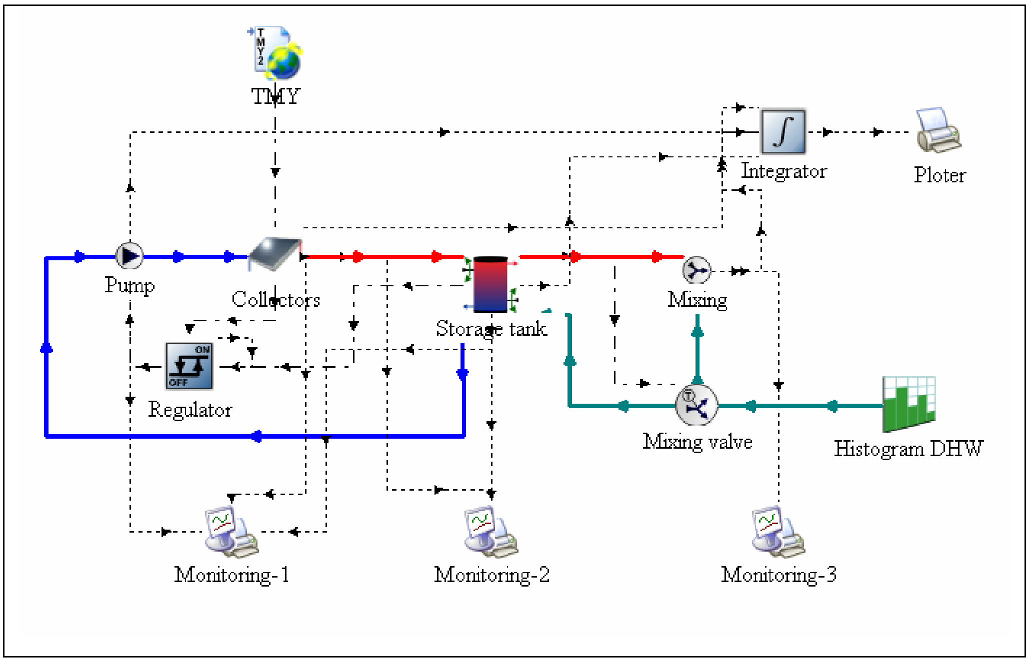

Figure 5.16. Interrelationship of the solar DHW system (HPS) components modelled in TRNSYS

TRNSYS components used to build the HPS DHW model are: TYPE 1. Solar collector, TYPE 2. On-off differential controller, TYPE 3. Pump/ventilator, TYPE 4. Stratified hot water storage tank, TYPE 11. Tee piece, tempering valve, TYPE 14. Time dependent forcing function, TYPE 24. Quantity integrator, TYPE 65. Online graphical plotter with output file, TYPE 109. Data reader and radiation processor. Interrelationship of the solar DHW system (HPS) components modelled in TRNSYS is given on Figure 5.16.

Schematic view of vapour compression cooling and heating system (HPS) can be seen on Figure 5.17. while a list of components and their capacities are given in Table 5.6.

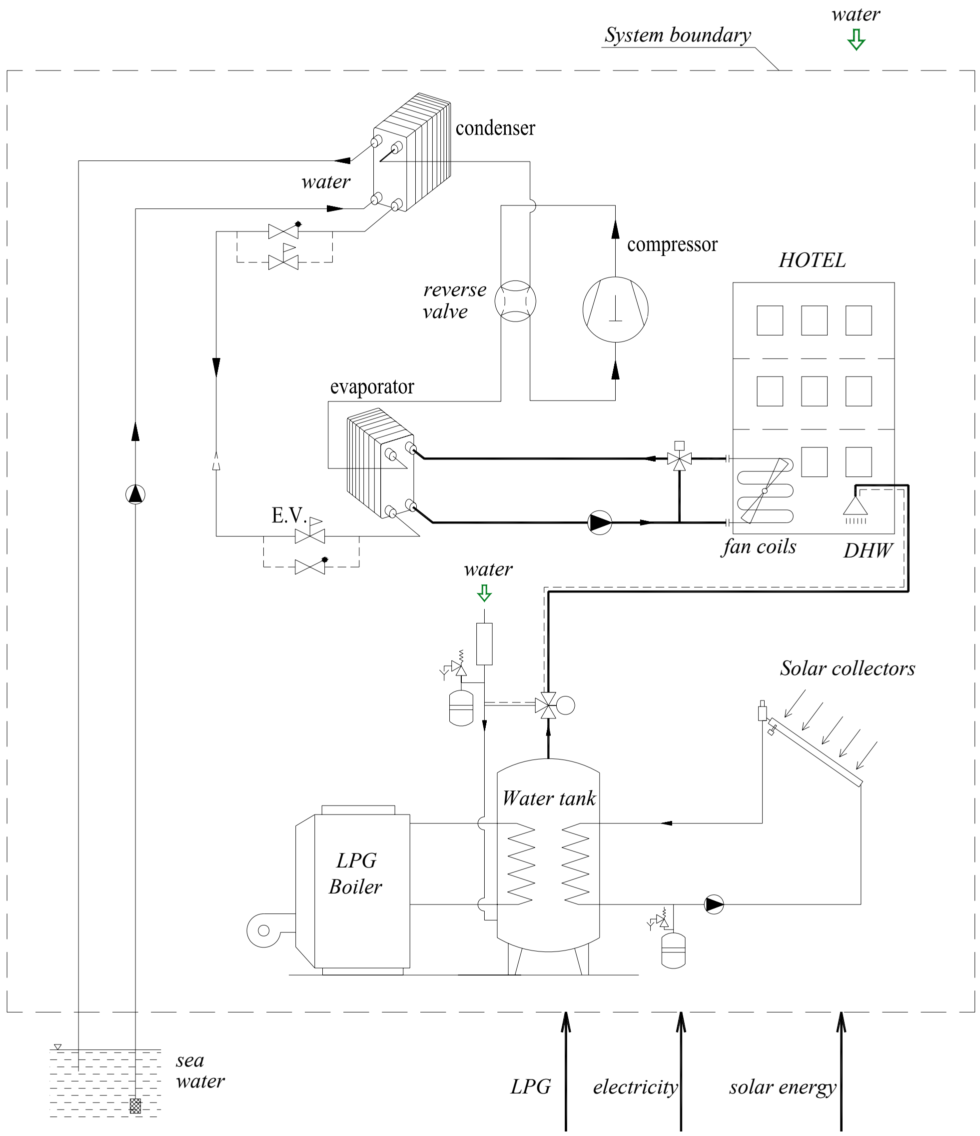

Figure 5.17. Schematic view of the vapour compression cooling and heating system (HPS)

Table 5.6. System components – capacities and prices (HPS)

Vapour compression cooling and heating system, DHW – solar collectors								
System's components		Model hotel I – 150 rooms Q_{cool}=300 kW, $Q_{heating}$=600 kW, V_{DHW}= 26,9 m^3/day			Model hotel II – 300 rooms Q_{cool} =500 kW, $Q_{heating}$=800 kW, V_{DHW}=53,8 m^3/day		
		Working parameters	pc	EUR	Working parameters	pc	EUR
1.	Vapour compression unit (chiller+heat pump mode)	Chiller: 300 kW cooling capacity, evaporator: cooling water 7/12°C; condenser: seawater 20/23°C, Heat pump: 600 kW heating capacity, condenser: hot water 45/50°C; evaporator: seawater 12/9°C	2x Carrier type:30RH2 40-B	101.000	Chiller: 500 kW cooling capacity, evaporator: cooling water 7/12°C; condenser: seawater 20/23°C, Heat pump: 800 kW heating capacity, condenser: hot water 45/50°C; evaporator: seawater 12/9°C	4x Carrier tip:30RH2 40-B	202.000
2.	Seawater pump	32 kg/s, Δp=30 m	1	3.300	50 kg/s, Δp=30 m	1	3.800
3.	Cold/hot water pump	24 kg/s, Δp=30 m; 15 kg/s, Δp=30 m	1	1.900	40 kg/s, Δp=30 m; 20 kg/s, Δp=30 m	1	2.700
4.	Fan coils	1.6 kW 4.3 kW	150 50	50.000	1.6 kW 4.3 kW	300 60	90.000
5.	Flat plate solar collectors	350 m^2	166x 2.1m^2	90.000	600 m^2	280x2.1 m2	151.400
6.	Hot water storage tank	24 m^3	2x12 m^3	15.400	36 m^3	3x12 m^3	23.100
7.	Boiler - LPG	Total 100 kW: (for DHW)	1	3.800	Total 150 kW: (for DHW)	1	4.800
8.	Pump for solar collector loop	3.8 kg/s, Δp=20 m	1	700	6.5 kg/s, Δp=20 m	1	900
9.	Hot water pump	1 kg/s, Δp=20 m	1	600	2.5 kg/s, Δp=20 m	1	700
10.	Automatic regulation			1.400			1.400
11.	Pipes, valves, assembling parts		cca	4.000		cca	6.000

5.3.5. Solar absorption cooling system – solar heating (ACS – SH)

Cooling

The cooling system model consists of an absorption cooling unit. The generator is powered by hot water produced in solar collector system. When solar energy is not sufficient to produce hot water of 90°C, water is preheated in the boiler powered by LPG. Temperature difference of the hot water at the generator is 10°C. The evaporator produces cold water in the temperature range of 7/12°C and distributed to cooling devices (fan coils) within the hotel. The condenser and absorber are cooled with seawater (20°C). Under the described temperature conditions it is possible to achieve COP =0,7-0,75 (Granryd 1999). Working fluids in the absorption cooling unit are LiBr and H_2O which do not have an influence on the environment. Parts of the system in contact with seawater should be corrosion resistant.

Passing through the condenser, seawater is heated with $\Delta\theta = 3 - 4$°C. It is in line with the regulation about dangerous materials and boundary values for waste water (DUV 1999) , and therefore sea-life will not be disturbed.

TRNSYS components used to build the ACS cooling and DHW model are: TYPE 1. Solar Collector, TYPE 2. On-off differential controller, TYPE 3. Pump/ventilator, TYPE 4. Stratified hot water storage tank, TYPE 6. On-off auxiliary heater, TYPE 8. Three-stage room thermostat, TYPE 11. Tee piece, tempering valve, TYPE 12. Energy/degree-hour house: temperature level control, TYPE 14. Time dependent forcing function, TYPE 24. Quantity integrator, TYPE 65. Online graphical plotter with output file, TYPE 107. Hot water-fired single-effect absorption chiller, TYPE 109. Data reader and radiation processor. Interrelationship of the solar absorption cooling system (ACS) components modelled in TRNSYS is given on Figure 5.18. Description of components is given in Appendix III.

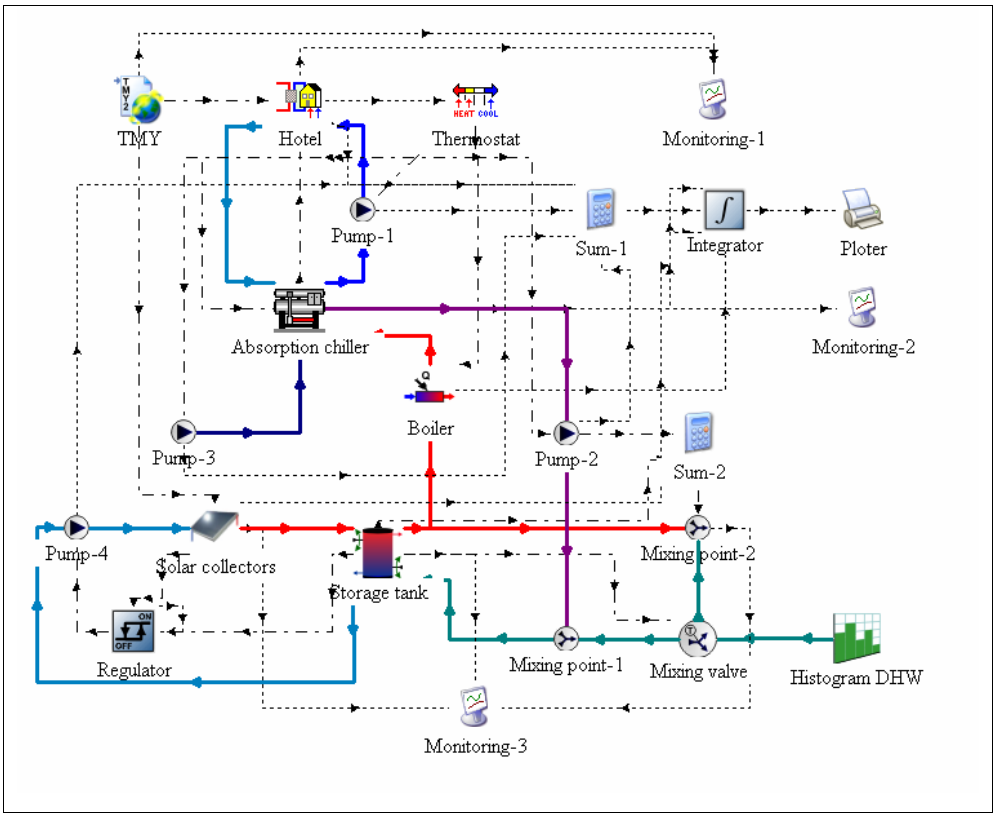

Figure 5.18. Interrelationship of the absorption cooling system (ACS) components modelled in TRNSYS

Heating & DHW system

The heating system consists of solar collectors, a hot water storage tank and the boiler powered by LPG as a back up system. Hot water is provided during the whole year for domestic hot water and for space heating. The solar collector system is designed to provide DHW during the summer months. The temperature regime in the storage tank is the same as in the case of SWC-SH system. Solar collectors are placed on the roof with a 45° slope, oriented towards south. Hot water set temperature is in the range 40-45°C and is distributed to fan coils in the hotel.

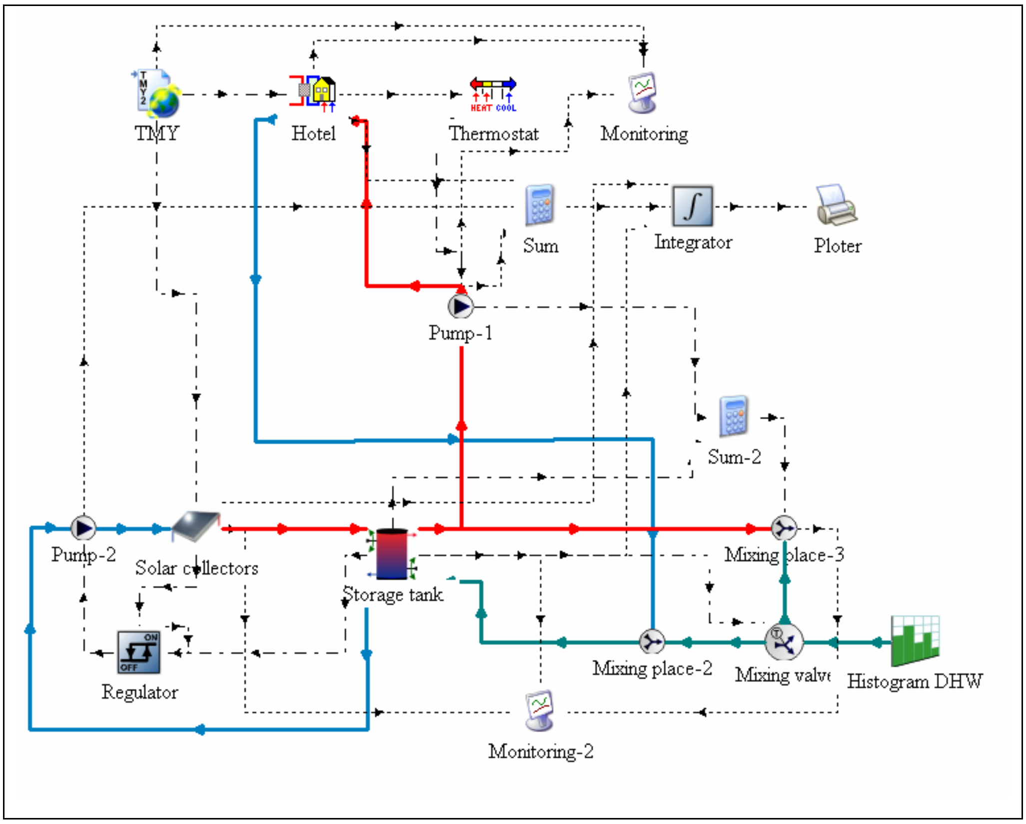

Figure 5.19. Interrelationship of the solar heating system and DHW (ACS) components modelled in TRNSYS

TRNSYS components used to build the ACS heating and DHW model are: TYPE 1. Solar Collector, TYPE 2. On-off differential controller, TYPE 3. Pump/ventilator, TYPE 4. Stratified hot water storage tank, TYPE 8. Three-stage room thermostat, TYPE 11. Tee piece, tempering valve, TYPE 12. Energy/degree-hour house: temperature level control, TYPE 14. Time dependent forcing function, TYPE 24. Quantity integrator, TYPE 65. Online graphical plotter with output file, TYPE 107. Hot water-fired single-effect absorption chiller, TYPE 109. Data reader and radiation processor. Interrelationship of the solar heating system (ACS) components modelled in TRNSYS is given on Figure 5.19. Description of components is given in Appendix III.

Schematic view of the absorption cooling and solar heating system (ACS) can be seen on Figure 5.20. while a list of components and their capacities are given in Table 5.7.

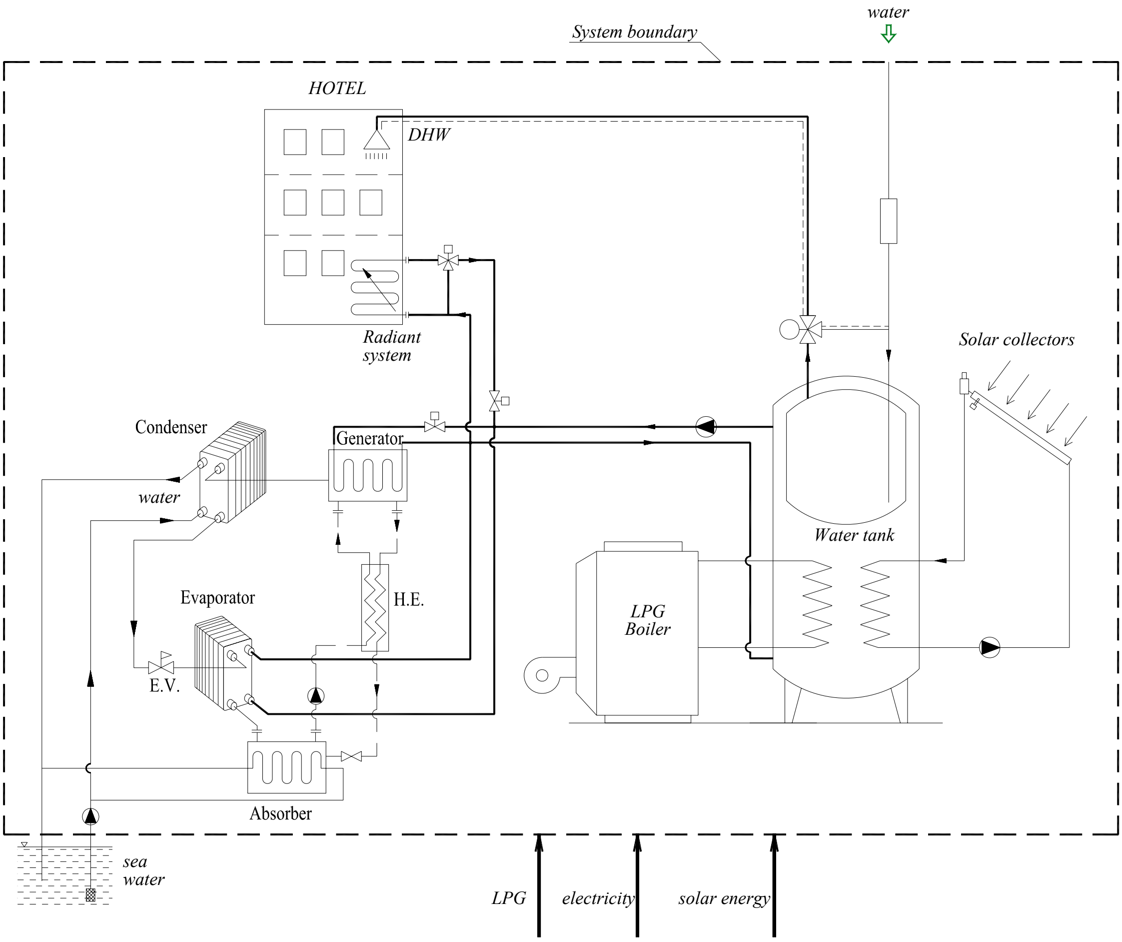

Figure 5.20. Schematic view of absorption cooling and solar heating (ACS) system

Table 5.7. System's components – capacities and prices (ACS)

Absorption cooling and solar heating system - ACS							
System's components		Model hotel I – 150 rooms Q_{cool}=300 kW, $Q_{heating}$=600 kW, V_{DHW}= 26,9 m^3/day			Model hotel II – 300 rooms Q_{cool} =500 kW, $Q_{heating}$=800 kW, V_{DHW}=53,8 m^3/day		
		Working parameters	pc	Price, EUR	Working parameters	pc	Price, EUR
1.	Absorption unit	Chiller: 300 kW cooling capacity, evaporator: cold water 7/12°C; condenser: seawater 20/23°C	1	65.500	Chiller: 500 kW cooling capacity, evaporator: cold water 7/12°C; condenser: seawater 20/23°C	1	91.000
2.	Seawater pump	42 kg/s, Δp=30 m	1	3.300	68 kg/s, Δp=30 m	1	6.900
3.	Cold/hot water pump	24 kg/s, Δp=30 m; 15 kg/s, Δp=30 m	1	1.900	40 kg/s, Δp=30 m; 20 kg/s, Δp=30 m	1	2.700
4.	Fan coils	1.6 kW 4.3 kW	150 50	50.000	1.6 kW 4.3 kW	300 60	90.000
5.	Plate solar collectors	1500 m^2= 715x2.1 m^2		386.500	2000 m^2= 952x2.1 m^2		514.600
6.	Hot water storage tank	200 m^3		36.800	200 m^3		51.500
7.	Boiler - LPG	Total 700 kW: 600 kW for heating 100 kW for DHW	1	14.900	Total 950 kW: 800 kW for heating 150 kW for DHW	1	24.300
8.	Pump for solar collector loop	5.5 kg/s, Δp=20 m	1	800	9 kg/s, Δp=20 m	1	1000
9.	Hot water pump	1 kg/s, Δp=20 m		600	2.5 kg/s, Δp=20 m	1	700
10.	Automatic regulation			1.400			1.400
11.	Pipes, valves, assembling parts			cca 4.000			cca 6.000

6. ENERGY AND ECONOMICAL ANALYSIS OF HVAC SYSTEMS OPTIONS

This chapter gives energy and economic analysis of HVAC systems described and modelled in the previous chapter. The three proposed alternatives are compared with conventional system from an energy point of view, during one year of operation. Economic analysis provides information about payback period if one is to invest in energy efficiency HVAC retrofit solutions.

6.1. Energy analysis

HVAC system solutions described in Chapter 5 were modelled and simulated using the computer programme TRNSYS. Simulations were made for seasonal and non-seasonal operation of hotels. Seasonal operation is considered to last from April 15th until October 15th. The simulation programme uses Typical Meteorological Year (TMY) as its input data, which is presented with hourly temperatures and solar radiation. TMY is produced by Meteonorm[15] software. According to TMY, instantaneous cooling and heating demand for the modelled building is determined. Furthermore, cooling and heating demand is covered by the HVAC system, and its operation is simulated using the TMY. In this way it is possible to estimate actual building needs for energy, taking into account building physic and passive energy sources, as well as energy (heat and cold) that HVAC systems can provide. The programme allows for optimization of all components in the system to obtain the best energy performance of the systems.

[15] Meteonorm is a comprehensive climatological database for solar energy applications

Simulations were made for a hotel with 150 rooms, which is the average number of rooms in hotels on the Adriatic coast, and for a hotel with 300 rooms. Monthly energy requirements for heating and cooling for a hotel with 150 rooms is given in Figure 6.1.

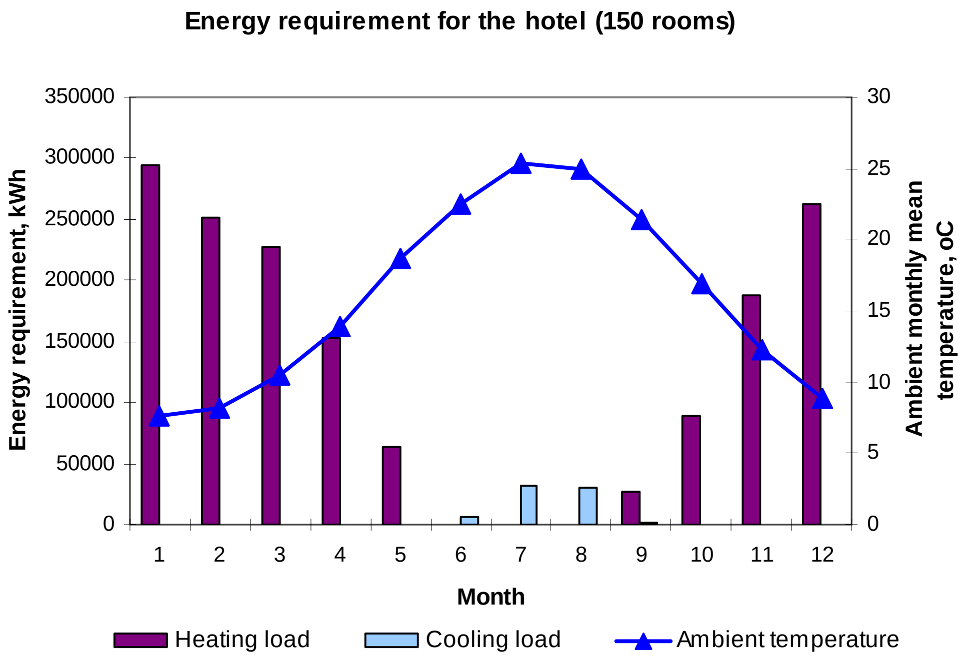

Figure 6.1. Monthly energy requirements and mean monthly ambient temperature for a hotel with 150 rooms

6.1.1. Non-seasonal hotels

Hotels with year-round operation should provide thermal comfort during the whole year. Therefore, systems for heating, cooling and domestic hot water should be installed. Simulation results for conventional systems and three proposed energy efficient systems are given in Table 6.1.-Table 6.4. Energy (electricity, oil and LPG) consumption for heating, cooling and domestic hot water system is given separately. The efficiency ratios for oil and gas boilers are 0,9 and 0,99 respectively (Recknagel 2002)

Table 6.1. Yearly primary energy consumption for conventional system (CS) operation

Conventional system: vapour compression unit with air cooled condenser + boiler (CS)						
			Hotel 150 rooms		Hotel 300 rooms	
System	Q	Energy resource	Energy, kJ	ratio of energy used compared to conventional system, %	Energy, kJ	ratio of energy used compared to conventional system, %
Heating (1.01-15.04. and 15.10.-31.12)	$Q_{heating}$	oil	5.5535E+09		7.8169E+09	
	$Q_{el\text{-}pump}$	electricity	5.7761E+07		7.9463E+07	
	Σ		**5.6112E+09**		**7.8964E+09**	
Cooling (15.04.-15.10.)	$Q_{cooling\text{-}compressor}$	electricity	7.9380E+07		1.5427E+08	
	$Q_{el\text{-}pump}$	electricity	3.8828E+06		8.9011E+06	
	Σ		**8.3262E+07**		**1.6317E+08**	
DHW (whole year)	$Q_{heating}$	oil	1.3823E+09		2.7571E+09	
	$Q_{el\text{-}pump}$	electricity	3.6120E+06		7.2240E+06	
	Σ		**1.3860E+09**		**2.7644E+09**	
Total HVAC&DHW (whole year)			**7.0804E+09**	**100%**	**1.0824E+10**	**100%**

Table 6.2. Yearly primary energy consumption for seawater cooling and solar heating system (SWC-SH) operation

Seawater cooling system +solar heating (SWC-SH)						
			Hotel 150 rooms		Hotel 300 rooms	
System	Q	Energy resource	Energy, kJ	ratio of energy used compared to conventional system, %	Energy, kJ	ratio of energy used compared to conventional system, %
Heating (1.01-15.04. and 15.10.-31.12)+DHW (whole year)	$Q_{heating\text{-}additional}$	LPG	4.4969E+09		6.2326E+09	
	$Q_{el\text{-}pump}$	electricity	1.9247E+07		3.1180E+07	
	Σ		**4.5162E+09**	**64,5%**	**6.2638E+09**	**58,8%**
Cooling (15.04.-15.10.)	$Q_{cooling\text{-}pump}$	electricity	1,0700E+07		2.1713E+07	
	Σ		**1,0700E+07**	**12,9%**	**2.1713E+07**	**13,3%**
DHW (whole year)	$Q_{DHW\text{-}additional}$	LPG	1.2639E+08		4.8822E+08	
	$Q_{el\text{-}pump}$	electricity	4.0209E+06		1.1499E+07	
	Σ		**1.3042E+08**	**9,4%**	**4.9972E+08**	**18,1%**
Total HVAC&DHW			**4.5269E+09**	**63,9%**	**6.2855E+09**	**58,1%**

Table 6.3. Yearly primary energy consumption for vapour compression cooling and solar heating system (HPS) operation

Vapour compression cooling and heating system (HPS), DHW – solar collectors						
			Hotel 150 rooms		Hotel 300 rooms	
System	Q	Energy resource	Energy, kJ	ratio of energy used compared to conventional system, %	Energy, kJ	ratio of energy used compared to conventional system, %
Heating (1.01-15.04. and 15.10.-31.12)	$Q_{heating-compressor}$	electricity	9.2354E+08		1.2375E+09	
	$Q_{el-pump}$	electricity	1.3553E+08		1.9104E+08	
	Σ		**1.0591E+09**	**18,9%**	**1.4285E+09**	**18,1%**
Cooling (15.04.-15.10.)	$Q_{cooling-compressor}$	electricity	5.5345E+07		1.0634E+08	
	$Q_{el-pump}$	electricity	5.3826E+06		1.0342E+07	
	Σ		**6.0728E+07**	**72,9%**	**1.1668E+08**	**71,5%**
DHW (whole year)	$Q_{DHW-additional}$	LPG	1.2639E+08		4.8822E+08	
	$Q_{el-pump}$	electricity	4.0209E+06		1.1499E+07	
	Σ		**1.3042E+08**	**9,4%**	**4.9972E+08**	**18,1%**
Total HVAC&DHW			**1.2502E+09**	**17,4%**	**2.0449E+09**	**19,9%**

Table 6.4. Yearly primary energy consumption for absorption cooling and solar heating system (ACS) operation

Absorption cooling and solar heating system (ACS)						
			Hotel 150 rooms		Hotel 300 rooms	
System	Q	Energy resource	Energy, kJ	ratio of energy used compared to conventional system, %	Energy, kJ	ratio of energy used compared to conventional system, %
Heating + DHW (1.01-15.04. i 15.10.-31.12)	$Q_{heating-additional}$	LPG	2.8954E+09		3.3645E+09	
	$Q_{el-pump}$	electricity	4.6523E+07		4.4679E+07	
	Σ		**2.9419E+09**	**46,7**	**3.4092E+09**	**36,7%**
Cooling + DHW (15.04.-15.10.)	$Q_{gheating-addtional}$	LPG	2.6165E+08		4.7563E+08	
	$Q_{el-pump}$	electricity	2.1335E+07		2.5870E+07	
	Σ		**2.8299E+08**	**36,5%**	**5.0151E+08**	**32,5%**
Total HVAC&DHW			**3.2249E+09**	**45,55%**	**3.9107E+09**	**36,13%**

Two of the columns in each of the Table 6.2.-Table 6.4. present ratios of energy used to fulfil required cooling or heating demand compared to conventional systems for hotels with 150 and 300 rooms respectively. One can observe that the results for two different sizes of hotels are similar. If one considers only cooling systems, it can be seen that seawater cooling system - SWC (for the hotel with 150 rooms) consumes only 12,9% of the energy consumed in conventional cooling systems for the same cooling demand. The vapour compression cooling system with seawater cooled condenser (HPS) consumes 72,9%, while the absorption cooling system (ACS) consumes 161,6% of the energy used in conventional cooling systems. If only heating systems are considered, the solar heating system (SWC - SH) with back up boiler (LPG) consumes 78,2%,, the heat pump heating system consumes 18,9%, while the solar heating system designed with the absorption solar cooling system consumes 51,3% of the energy used in the conventional systems. In Table 6.1.-Table 6.4. energy consumption for SWC-SH and ACS cooling and heating systems are given together with energy consumption for DHW, since they represents one system. However, from the energy balance ratios, energy savings in ACS cooling or heating system stated above were obtained.

The solar absorption cooling system consumes 2,6 times more energy for the same cooling demand compared to conventional cooling systems. However, if one look at the entire HVAC&DHW system (whole year operation), it can be seen that ACS is favourable compared to conventional systems (CS) since it consumes 36-45 % of the total energy in CS systems. The reason for this is utilization of solar energy for DHW and heating systems.

Figure 6.2. provides a comparison between energy consumption in different systems. If one looks at the whole year operation it can be seen that the HPS system is the best one and it consumes 17,4% of energy consumed in CS systems, 28% of energy

consumed in the SWC-SH system and 38,8% of the energy consumed in the ACS system.

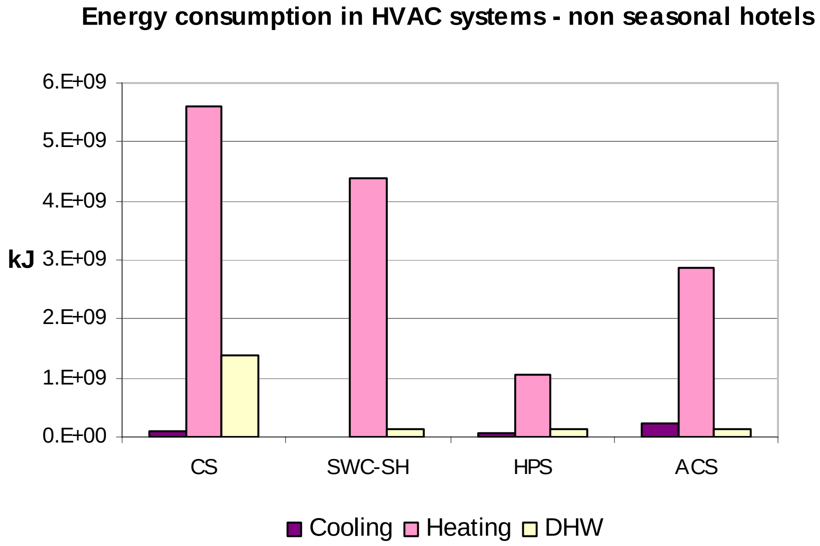

Figure 6.2. Energy consumption in HVAC&DHW systems for non-seasonal hotels

It can also be seen in the Figure 6.2. that the highest energy consumption in all four systems is the one required for heating. Although CS cooling system influences pick loads in the summer seasons, they consume only 1,2% of energy consumed in hotels to provide thermal comfort and DHW over the year (Figure 6.3.). Ratios of energy consumption for cooling in the three proposed sustainable options go from 0,2% for the SWC system to 6,8% for the ACS system (Figure 6.4.-Figure 6.6.). All three proposed alternative systems utilize solar energy for DHW and therefore consumes only 9,4% of the energy needed in conventional system (CS) for year-round operation.

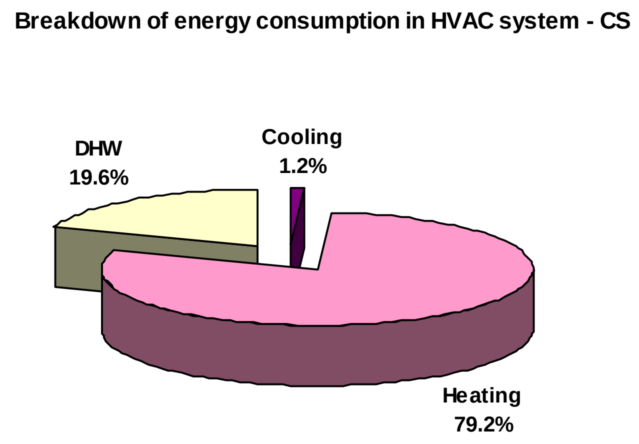

Figure 6.3. Breakdown of energy consumption in conventional system (CS)

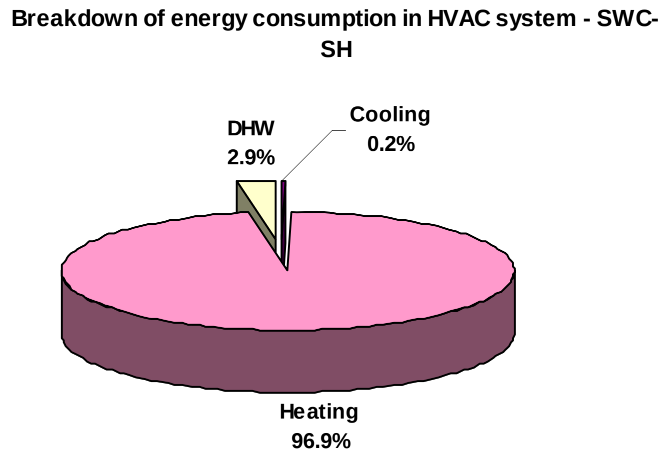

Figure 6.4. Breakdown of energy consumption in seawater cooling and solar heating system (SWC-SH)

The ratio of energy consumption for DHW systems in total energy consumption for each system varies from 19,6% in conventional system, to 10,4% in HPS, 4% in ACS and 2,9% in the SWC-SH system.

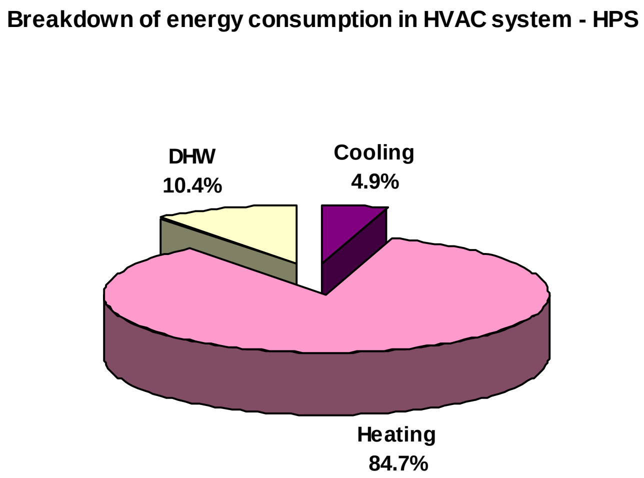

Figure 6.5. Breakdown of energy consumption in vapour compression cooling and heating system (HPS)

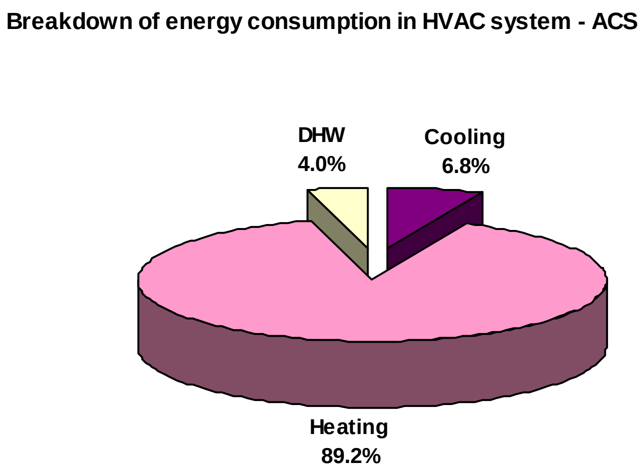

Figure 6.6. Breakdown of energy consumption in absorption cooling and solar heating system (ACS)

From the Table 6.5. one can see the primary energy consumption per square meter of hotel total area used in HVAC&DHW systems as a results of a simulation process. In order to give comments to results shown it is necessary to bear in mind that guests occupancy rate taken into account was 100%. The hotel is considered to be heated during the heating season (15^{th} October – 15^{th} April), while hot water was produced every day in amount stated in Table 5.2. The energy audit showed that energy consumption for heating and DHW system (measured in heating oil consumption) in non seasonal hotels varies considerably and goes from 55 - 152 kWh/m^2. As stated earlier, the average occupancy rate during the year was 28%. In winter months occupancy rate goes below 10%. Differences between real occupancy rate and the one taken in simulations might explain why energy consumption in real hotels is lower than in the case of simulations. However, installed capacities in hotels are high enough to cover demand for heating or cooling during the occupancy rate of 100%. The reason why simulations are made with 100 % occupancy rate is because the aim of research is to compare conventional and alternative HVAC&DHW systems during the high demands. It might be expected that in years to come occupancy rate of hotels on the Adriatic coast will increase.

Table 6.5. Simulated primary energy consumption per square meter (hotel with 150 rooms)

System	**CS**	**SWC-SH**	**HPS**	**ACS**
Cooling, [kWh/m^2]	2.57	0.33	1.87	6.72
Heating, [kWh/m^2]	173.19	135.36	32.69	88.79
DHW, [kWh/m^2]	42.78	4.03	4.03	4.03
Total HVAC&DHW	**218.53**	**139.72**	**38.59**	**99.54**

6.1.1.1. Influence of room set temperature on energy consumption in cooling season

The room set temperature or design indoor temperature during the cooling season for this research was 26°C. The author considered it as a satisfactory indoor temperature that will provide thermal comfort in the hotel. From Table 6.5. it can be seen that share of energy consumed for cooling is only 1,2% for conventional system. In order to see how room set temperature influences energy consumption for cooling, simulations were made for 1 and 2°C lower set temperatures. The analysis has showed that energy consumption for cooling is 58,3% higher if the room set temperature is 25°C. The additional room set temperature decrease for 1°C (24°C) will increase energy consumption for 48,8% compared to energy consumption for the room set temperature 25°C. The share of energy consumption for cooling will be 1,85 and 2,7% for the room set temperature 25 and 24°C respectively. It can be concluded that it is reasonable to chose higher room set temperature in order to achieve energy savings.

6.1.1.2. Energy analysis after improvements in building envelope

Although the objective of this research is to find the best alternative for the existing HVAC systems in the hotels on the Adriatic coast, the analysis was also made for the case of improvements in building envelope. Information about existing hotel building on the Adriatic coast, which is used in the original building model in TRNSYS programme is presented in Table 5.2. That building is built of concrete and does not have thermal insulation (U=1,8 W/m^{2}K). Windows are the age of the building construction, approximately 30 years (it is assumed U=3 W/m^{2}K). Improvements in building model were done according to Croatian regulation about minimum thermal performance of the building (MZOPU 2005b) which is in fact an adoption of the EU directive Energy Performance of Buildings. In order to improve the coefficient of heat transfer to U=0,4 W/m^{2}K, the walls are covered with insulation. New windows with U=1,4 w/m^2 were taken into account, which gave the overall U-value 0,79 W/m^{2}K (approximately 4 times better thermal properties of the building).

Simulations were done for conventional system for both cooling and heating season. Results have shown that energy consumption for space heating and space cooling are 25,87% and 19,11% of the energy consumption before improvements. The energy consumption for DHW system remained the same. If one look at the whole HVAC and DHW system, energy consumption is 40,26% of the energy consumption before improvements. The breakdown of energy consumption for different end-users is showed in the Figure 6.7. One can see, that compared to a breakdown of energy consumption prior to improvements (Figure 6.3.), energy consumption for thermal comfort is lower and it goes from 80% to 51,5% while the rest (48,5%) is energy consumption for DHW system. The economical analysis of such improvements in the building envelope is presented in subchapter 6.2.

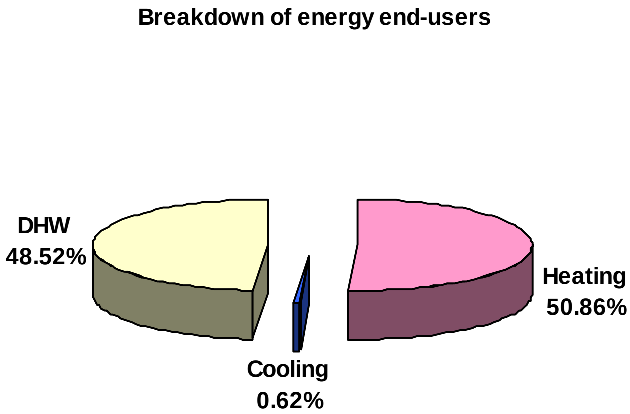

Figure 6.7. Breakdown of energy consumption in conventional system after building envelope improvements

6.1.2. Seasonal hotels

Seasonal hotels with operating time from the April 15th to October 15th are considered to have only cooling and domestic hot water systems. Figure 6.8. shows that the three proposed sustainable systems are much more energy efficient than CS system. Energy savings are the highest for the SWC-SH system in the amount of 90,2%. The second best is the HPS system with 83,8% savings, while the last one is ACS that can achieve 63,5% energy savings. The SWC-SH system is the best one for seasonal operation since, compared to CS system, it utilizes only 12,9% and 9,4% of the energy for cooling and DHW respectively. How much these energy savings can contribute to environmental savings is elaborated in chapter 7.

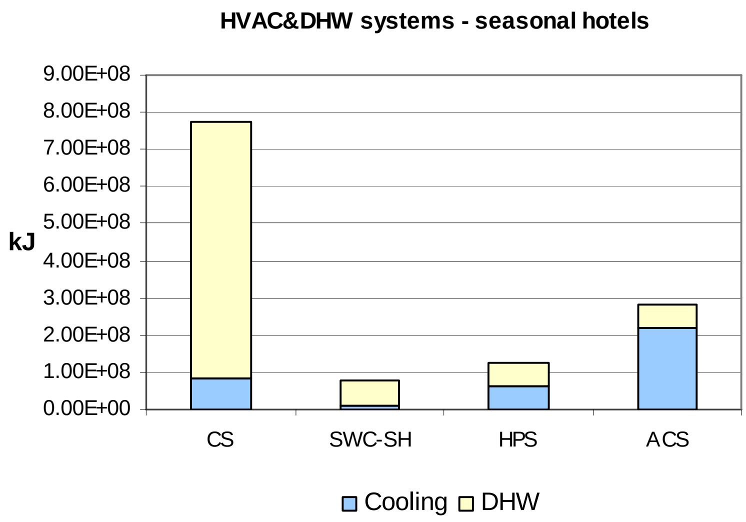

Figure 6.8. Energy consumption in cooling and DHW systems for seasonal hotels

Table 6.6 gives the energy consumption breakdown for four cooling and DHW systems with seasonal operation.

Table 6.6.Energy usage breakdown for different cooling and DHW systems in seasonal hotels

	CS	SWC-SH	HPS	ACS
Cooling	10,7%	14,10%	48,20%	77%
DHW	89,3%	85,90%	51,80%	23%

If the energy consumption for HVAC&DHW systems in the summer (15th April – 15th October) and winter (15th October – 15th April) seasons is to be compared, one can see from Figure 6.9. that during the winter season approximately 90% of the energy is consumed. This ratio goes from 89% in CS system, 90% in HPS, 91% in ACS system to 98% in the SWC system.

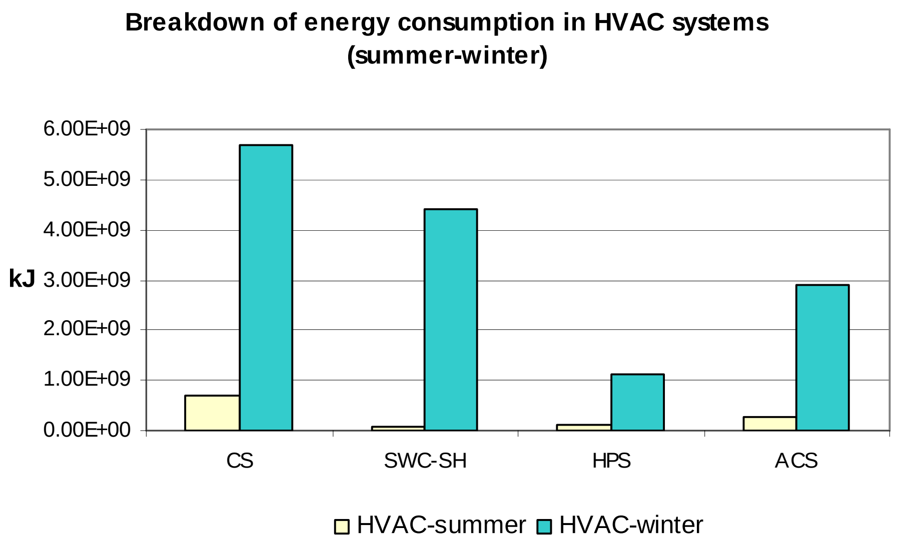

Figure 6.9. Breakdown of energy consumption in HVAC systems (summer and winter operation)

6.2. Economical analysis

Sustainable solutions for energy savings in buildings are not new, but it is always a question how they can be implemented with respect to the investment costs. In most cases these systems have high investments which are not acceptable to investors. Furthermore, some investors are not aware of the fact that even with higher initial investment, it is possible to achieve high economical savings during the life time of the equipment. However, those of them who are aware of economical saving do not care because the operating costs are only 4-6% of total turn over and are anyway charged to tourists. These are the main obstacles for implementation of sustainable energy technologies. Due to lower operating costs during the operation of sustainable technologies, pay back period in some cases can be just a few years. Therefore, owning and operating cost information for the HVAC system should be part of the investment plan of a facility.

Economical analysis was made for three described alternative systems which results were compared with the cost of conventional system.

6.2.1. Costs structure

Owning costs

The following elements must be establish to calculate annual owning costs:

- Initial cost of system
- Analysis or study period
- Interest of discount rate
- Insurance
- Property taxes
- Refurbishment or disposal fees
- Replacement cost
- Salvage value

Once established, these elements are coupled with operating costs to develop an economic analysis, which may be a simple payback evaluation or an in depth analysis. The list of components and initial costs of all HVAC &DHW systems are given in Table 5.3.,Table 5.5.-Table 5.7.

Operating costs

Operating costs are those incurred by the actual operation of the system. They include costs of fuel and electricity. Future energy costs used in discount payback analysis must be evaluated.

The electricity price for this analysis is taken from the Croatian electricity utility company (HEP) official price list for 2002. (see Table 6.7.) It is important to emphasize that total electricity price depends of tariff model, time of the day when electricity is utilized, oil prices, maximum demand and applicable taxes (ASHRAE 2003). Heating oil price and price of natural gas for the period 2002 – 2006 is given in Table 6.7. One can observe a continuous increase of fuel prices in the recent years. The price of electricity is still controlled by the Government, since it is considered that any increase in price would affect social situation in the country. The price of LPG has been constant during the recent year (4,1 KN/kg=0,554 EUR/kg), (Proplin 2006). Net calorific values for light heating oil and LPG taken for calculation are 37,158 MJ/l and 46,89 MJ/kg.

Table 6.7. Electricity and fuel prices in Croatia for period 2000-2006

	2000	**2001**	**2002**	**2003**	**2004**[16]	**2005**	**2006**[17]
Electricity, EUR*/kWh	0,107	0,095	0,094	0,094	0,092	0,091	0,091
Light heating oil, EUR/l	0,357	0,424	0,366	0,374	0,444	0,486	0,646
Natural gas, EUR/m^3	0,196	0,232	0,268	0,269	0,281	0,289	0,289

**Exchange rate for Croatian currency "kuna" is 1 EUR=7,4 KN*

Maintenance costs

The quality of maintenance and maintenance supervision can be a major factor in the energy cost of a building (ASHRAE 2003). However it is very hard to estimate maintenance costs. The type of HVAC equipment may have a large effect on the maintenance costs. Total maintenance cost is influenced by age of the building, type of heating and cooling system and energy distribution system within the building. Special care should be given to type of refrigerant used in refrigeration system. Therefore for the purpose of this analysis maintenance costs were taken as a 1% of

[16] Reference for years 2000-2004, MGRP 2004, MGRP 2006

[17] Reference for years 2005-2005, Gorički 2006

investment costs.Calculated investment, operating and maintenance costs for HVAC systems described in Chapter 5. are showed in Table 6.8.

Table 6.8. Total costs of HVAC systems in 2002

Total costs					
		CS	**SWC-SH**	**HPS**	**ACS**
Investment costs, EUR	150 rooms	122,300.00 €	166,900.00 €	272,100.00 €	565,700.00 €
	300 rooms	200,800.00 €	278,200.00 €	486,800.00 €	790,100.00 €
Operating costs, EUR/year	150 rooms	72,123.10 €	53,915.67 €	30,757.14 €	39,071.15 €
	300 rooms	110,720.17 €	75,022.03 €	46,305.02 €	47,212.60 €
Maintenance costs, EUR/year	150 rooms	1,223.00 €	1,669.00 €	2,721.00 €	5,657.00 €
	300 rooms	2,008.00 €	2,782.00 €	4,868.00 €	7,901.00 €

6.2.2. The payback analysis

In the simple payback technique, a projection of the revenue stream, cost savings, and other factors is estimated and compared to the initial capital outlay. This simple technique ignores the cost of borrowing money (interest) and lost opportunity costs. It also ignores inflation and the time value of money.

Improved payback analysis was applied for economical analysis in this thesis. This is a more sophisticated payback approach than a simple pay back method since cost of the money (interest rate and discount rate) is considered (ASHRAE 2003). Payback years, n is calculated with equation 6.1.

$$n = \frac{\ln\left[CRF/\left(CRF - i'\right)\right]}{\ln\left(1 + i'\right)}, \text{ [years]} \quad (6.1.)$$

Where capital recovery factor – CRF is calculated for alternative investments as:

$$CRF = \frac{operaional \quad savings + ma\,\mathrm{int}\,enance \quad savings}{difference \quad in \quad investments} \tag{6.2.}$$

The effective interest rate *i′*, sometimes called the real rate accounts for inflation rate *j* and interest rate *i* can be expressed as follows:

$$i' = \frac{i - j}{1 + j} \tag{6.3.}$$

6.2.2.1. The payback analysis of HVAC systems

The results of improved pay back analysis for three alternative system during the round year operation are given in Table 6.9. It can be seen that the best options for the hotel with 150 rooms is SWC-SH (seawater cooling and solar heating) with only 2,6 years payback time. The second best option is the HPS (cooling and heating with vapour compression unit utilizing seawater as a heat sink/source) system with 3.8 years payback time. For the hotel with 300 rooms, the SWC-SH system gives 2,3 while the HPS system gives 4,8 years of payback time. The worst option for both sizes of the hotel is the ACS system (absorption cooling and solar heating) with payback period of 16,9 and 10,8 years for hotels with 150 and 300 rooms respectively. Although from the yearly energy consumption point of view the ACS system is better than the SWC-SH system, due to high initial investment costs payback period for the SWC-SH system is much lower.

Table 6.9. Results of improved payback analysis for HVAC systems with energy prices in 2002

Payback analysis for HVAC systems (2002)*						
Inflation rate *j*, %	3	CS	SWC-SH	HPS	ACS	
Interest rate *i*, %	4					
Effective interest rate, *i'*	0.0097					
Savings, EUR/year	150 rooms	0.00 €	17,761.43 €	39,867.96 €	28,617.95 €	
	300 rooms	0.00 €	34,924.14 €	61,555.16 €	57,614.57 €	
CRF	150 rooms	0.00 €	0.3982	0.2661	0.0645	
	300 rooms	0.00 €	0.4512	0.2152	0.0978	
Payback time, years	150 rooms	**0.0**	**2.6**	**3.8**	**16.9**	
	300 rooms	**0.0**	**2.3**	**4.8**	**10.8**	

*Price of electricity 0,094 EUR/kWh, price of heating oil 0,366 EUR/litre, price of LPG 0,554 EUR/kg

The year 2002 was chosen for the economical analysis since it was the year for which energy audit was done. However, during the 4 years period there were rises in the price of fuel, especially heating oil. The price of light heating oil was changed from 0,366 EUR/l to 0,646 EUR/l which represents 76% price increase. Therefore, operating costs of conventional system increases by 72%.

Table 6.10. Results of the payback analysis for HVAC systems with energy prices in 2006

Payback analysis for HVAC systems (2006)*					
Inflation rate *j*, %	3	CS	SWC-SH	HPS	ACS
Interest rate *i*, %	4				
Effective interest rate, *i'*	0.0097				
Savings, EUR/year	150 rooms	0.00 €	69,826.84 €	92,865.14 €	80,715.66 €
	300 rooms	0.00 €	114,282.03 €	142,194.01 €	136,987.50 €
CRF	150 rooms	0.00 €	1.5656	0.6199	0.1820
	300 rooms	0.00 €	1.4765	0.4972	0.2325
Payback time, years	150 rooms	**0.0**	**0.6**	**1.6**	**5.7**
	300 rooms	**0.0**	**0.7**	**2.0**	**4.4**

*Price of electricity 0,091 EUR/kWh, price of heating oil 0,646 EUR/litre, price of LPG 0,554 EUR/kg

In order to show how energy prices influence cost-effectiveness of different alternative systems Table 6.10. gives results of payback analysis with latest energy prices in 2006. It can be seen that payback period for all three alternatives has significantly changed. The payback period goes from 0,7 to 5,9 years which makes all three alternatives attractive to investors and hotel owners.

6.2.2.2. The payback analysis of DHW systems

It is interesting to analysis only DHW systems and to calculate payback period for solar thermal installation, because these systems are the biggest energy consumers during the summer season. Furthermore DHW systems are the most prosperous for utilization of renewable energy sources (solar energy). Since energy savings are approximately 90% compared to conventional system with oil boiler, renewable energy source should be more widely used in hotels on the Adriatic coast. In the Table 6.11. costs analysis for two DHW systems is given. It can be seen that investment costs are 5,3 times higher (hotel with 150 rooms) for solar thermal installation than for conventional system. However, operating costs for 2002 were 8,6 times lower for solar option. The payback period was 8,3 and 8 years for hotel with 150 and 300 rooms respectively (see Table 6.12.).

Table 6.11. Total costs of DHW systems in 2002

2002		DHW - oil boiler	DHW - solar collectors + LPG boiler
Investment costs, EUR	150 rooms	20,800.00 €	110,200.00 €
	300 rooms	28,500.00 €	180,800.00 €
Operating costs, EUR/year	150 rooms	13,717.94 €	1,598.18 €
	300 rooms	27,361.52 €	6,068.21 €
Maintenance costs, EUR/year	150 rooms	208.00 €	1,102.00 €
	300 rooms	285.00 €	1,808.00 €

Table 6.12. Results of improved payback analysis for DHW systems with energy prices in 2002

Payback analysis (2002)			
Inflation rate ***j***, %	3	**DHW - oil boiler**	**DHW - solar collectors + LPG boiler**
Interest rate ***i***, %	4		
Effective interest rate, ***i'***	0.0097		
Savings, EUR/year	150 rooms	0.00 kn	11,225.75 €
	300 rooms	0.00 kn	19,770.31 €
CRF	150 rooms	0.00	0.13
	300 rooms	0.00	0.13
Payback time, years	150 rooms	**0.0**	**8.3**
	300 rooms	**0.0**	**8.0**

If recent heating oil prices are taken into account operating costs for conventional DHW system are increased by 76% (Table 6.13). Therefore it is obvious that the payback period for solar option should decrease. It can be seen from the Table 6.14. that the payback time for DHW with solar thermal installation is much lower, 4,2 and 3,8 years for hotel with 150 and 300 rooms respectively.

Table 6.13. Total costs of DHW systems in 2006

2006		**DHW - oil boiler**	**DHW - solar collectors + LPG boiler**
Investment costs, EUR	150 rooms	20,800.00 €	110,200.00 €
	300 rooms	28,500.00 €	180,800.00 €
Operating costs, EUR/year	150 rooms	24,111.24 €	1,594.76 €
	300 rooms	48,091.39 €	6,058.42 €
Maintenance costs, EUR/year	150 rooms	208.00 €	1,102.00 €
	300 rooms	285.00 €	1,808.00 €

Table 6.14. Results of improved payback analysis for DHW systems with energy prices in 2006

Payback analysis (2006)*			
Inflation rate ***j***, %	3	**DHW - oil boiler**	**DHW - solar collectors + LPG boiler**
Interest rate ***i***, %	4		
Effective interest rate, ***i'***	0.0097		
Savings, EUR/year	150 rooms	0.00 kn	21,622.48 €
	300 rooms	0.00 kn	40,509.97 €
CRF	150 rooms	0.00	0.24
	300 rooms	0.00	0.27
Payback time, years	150 rooms	**0.0**	**4.2**
	300 rooms	**0.0**	**3.8**

6.2.2.3. The payback analysis of SWC cooling system

The cooling systems proposed within three alternative HVAC systems are in the case of HPS and ACS systems combined with heating systems. However, the SWC system is designed as separate system that utilize seawater as a renewable source of cold energy. Since energy analysis showed that in cooling season SWC system can save up to 87% of energy compared to conventional system, analysis of the total costs is made. From the Table 6.15. one can see that operating costs are approximately 9 times lower, while investment costs are half of the one for conventional system. This leads to the conclusion that the SWC system is an advantageous system from energy and economic points of view.

Table 6.15. Total costs of cooling systems in 2006

2006		**CS – vapour compression unit**	**SWC – seawater cooling system**
Investment costs, EUR	150 rooms	84,200.00 €	38,900.00 €
	300 rooms	141,800.00 €	69,300.00 €
Operating costs, EUR/year	150 rooms	2,097.19 €	269.51 €
	300 rooms	4,109.90 €	546.90 €
Maintenance costs, EUR/year	150 rooms	842.00 €	389.00 €
	300 rooms	1,418.00 €	693.00 €

6.2.2.4. The payback analysis of improved envelope

The energy analysis of suggested improvements in the building envelope was presented in subchapter 6.1.1.1. The economical analysis is done for the conventional system operation of an existing building with comparison to the building with improved building envelope (hotel with 150 rooms). The investment cost of thermal insulation and new glazing is significant (Table 6.16.). Although operating costs of improved building are approximately 40% of the costs of existing building, due to the high investment costs, the payback period is 36,8 and 20 years for the energy prices from 2002 and for the existing prices of heating oil and electricity respectively.

Table 6.16. Total costs of CS system with existing and improved building

300 rooms		CS – existing building	CS – improved building
Investment costs, EUR	2002	0.00 €	1,361,360.00 €
	2006	0.00 €	1,361,360.00 €
Operating costs, EUR/year	2002	110,720.17 €	29,199.12 €
	2006	190,033.01 €	50,022.91 €
Maintenance costs, EUR/year	2002	1,200.00 €	0.00 €
	2006	1,200.00 €	0.00 €

Table 6.17. Results of improved payback analysis for improved building envelope

Payback analysis (2002/2006)*			
Inflation rate ***j***, %	3	**CS – existing building**	**CS – improved building**
Interest rate ***i***, %	4		
Effective interest rate, ***i'***	0.0097		
Savings, EUR/year	2002	0.00 €	44,123.98 €
	2006	0.00 €	75,340.10 €
CRF	2002	0.00	0.03
	2006	0.00	0.06
Payback time, years	2002	**0.0**	**36.8**
	2006	**0.0**	**20.0**

7. ENVIRONMENTAL IMPACT ANALYSIS

This chapter analyses the environmental impacts of energy consumption in tourism accommodation sector (hotels and private accommodations) and HVAC systems described and modelled in the chapter 5. TEWI[18] concept is implemented for two systems with vapour compression units. At the end, four scenarios with energy efficient solutions are given and compared with business as usual practice.

Air pollution problems are connected with impacts that manifest themselves on a global, regional and local level. Global pollutions are geographically related to the whole planet Earth, regional pollutions are related to areas from a few hundreds square kilometres to a whole geographical continent, and local pollutions are related to city or industrial areas. A simplified illustration of relation between particular pollutants and their most important impacts is given in the Table 7.1. (Jurić 2005).

Table 7.1. Relation between particular pollutants and their most important impacts

Impact	**Pollutants**										
	PM	HMs	POPs	**SO_2**	NH_3	**NO_x**	NMVOC	**CO**	**CO_2**	CH_4	N_20
LOCAL (health)											
REGIONAL											
- acidification											
- eutrophication											
- ground-level ozone											
GLOBAL											
- green house effect (indirect)											
- green house effect (direct)											

PM – Particulates, HMs – Heavy Metals, POPs – Persistent Organic Pollutants, SO_2 – Sulphur Dioxide, NH_3 – Ammonia, NO_x – Oxides of Nitrogen, NMVOC - Non-Methane Volatile Organic Compounds, CO – Carbon Monoxide, CO_2 – Carbon Dioxide, CH_4 – Methane, N_2O – Nitrogen Dioxide,

[18] TEWI – Total Equivalent Warming Impact

The most significant pollutants with potentially harmful impacts emitted from hotel facilities are SO_2 and NO_x (local and regional impacts), particles and CO (local impact), and CO_2 as a green house gas (global impact). Gases SO_2 and NO_x, except their potential health impact, are known as "acid" gases because of their transformation, when transported on a long distance, results in the formation of acid compounds that are settling down in a wet (acid rains) and dry forms. NO_x, together with NMVOC[19], form photo-oxidative gas ozone (O_3) in the lowermost layers of the atmosphere (troposphere), and has a harmful impact on human health and vegetation (Ekonerg 2005). CO emissions are the result of unburned fuel during combustion, mostly in vehicles and small combustion chambers, and have a harmful impacts on human health, mainly on a local level. Particles carry various chemical elements and chemical compounds (e.g. heavy metals), which settle down in the vicinity of the source and have significant impacts on local air pollution, while CO_2 is the most significant contributor to global warming.

7.1. International obligations

The Republic of Croatia has an obligation to balance greenhouse gas emissions in accordance with the United Nations Framework Convention on Climate Change (UNFCCC), while the other pollutants have to be determined in compliance with the Long Range Transboundary Air Pollution Convention (LRTAPC). The obligation for emission monitoring and calculation arise from the Croatian Environmental Protection Law (NN[20] 48/95 and NN 178/04).

The Republic of Croatia has signed and ratified the Convention on Climate Change and according to it, is obligated to keep the amount of CO_2 emissions on the 1990

[19] Non-Methane Volatile Organic Compounds

[20] NN is an acronym for „narodne novine" or Croatian Official Journal

level. The Kyoto Protocol obliges Croatia to reduce total emissions of greenhouse gases (CO_2, CH_4, N_2O, HFCs[21], PFCs[22] and SF_6[23]) by at least 5%, calculating from the average 2008 to 2012 emissions with respect to the base year (one of years in the period from 1985 to 1990 – most probably 1990)(Ekonerg 2005). Croatia will became a full member of the Protocol, with all rights and obligations, after ratification of the Kyoto Protocol in the Croatian National Parliament.

Table 7.2: Emissions (without natural) in Croatia (1990) and international obligations (Jurić 2005)

	UNFCCC[24]		LRTAPC[25]				
	UNFCCC	Kyoto Protocol	The Protocol on Further Reduction of Sulphur Emissions	The Protocol to Abate Acidification, Eutrophication and Ground-Level Ozone (MPME)			
	eq-CO_2 [Mt]	eq-CO_2 [Mt]	SO_2 [Kt]	SO_2 [Kt]	NO_x [Kt]	NMVOC** [Kt]	NH_3 [Kt]
1990*			180	180	87	105	37
2010			117	70	87	90	30
Reduction	0%	- 5%	- 35%	- 61%	0%	- 14%	- 19%

** possible base year for certain Protocols*
*** Non-Methane Volatile Organic Compounds*

Within the Long Range Transboundary Air Pollution Convention a number of obligatory protocols are given. Simplified obligations given in the Protocol on Further Reduction of Sulphur Emissions and Protocol to Abate Acidification, Eutrophication and Ground-Level Ozone (MPME) are presented in Table 7.2. According to the Protocol on Further Reduction of Sulphur Emissions Croatia has an obligation to retain sulphur emissions below 117 Kt until 2010. MPME protocol simultaneously

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[21] HFCs - Hydrofluorocarbons

[22] PFCs - Perfluorocarbons

[23] SF_6 – Sulphur Hexafluoride

[24] UNFCCC – The United Nations Framework Convention on Climate Change

[25] LRTAPC – Long Range Transboundary Air Pollution convention

limits emissions of SO_2, NO_x, NMVOC[26] and NH_3 (multi-pollutant), and effects of acidification, eutrophication and ground-level ozone (multi-effect), with given values for stationary and mobile sources.

7.2. Emissions of pollutants from the tourism accommodation sector

7.2.1. Greenhouse gases emissions

Globally, the most significant emissions are those of greenhouse gases. Excessive anthropogenic greenhouse gases emissions results in an increase of their concentration in the atmosphere which results in global warming and climate change over the long-term.

If the fuel is fully combusted, carbon contained in the fuel oxidize to CO_2, and if there is unburned fuel a smaller portion of CH_4, CO and NMVOC emissions occur. Until now there is no developed technology for reducing CO_2 emissions. Emission of CO_2 is dependant on the type and amount of fuel. The largest emissions occur during the coal combustion, followed by oil and gas combustion. The guide ratio of related emissions of the most common fossil fuels is 1 : 0.75 : 0.55 (coal : oil : gas) (Jurić 2005).

For determining greenhouse gases emission levels, so called IPCC[27] methodology is used, developed within the UNFCCC convention. Emission calculating factors for years 2002-2004 are given in Table 7.3 and Table 7.4. From the Table 7.4. one can see how specific greenhouse gasses emissions due to electricity consumption were

[26] Non-Methane Volatile Organic Compounds

[27] Intergovernmental Panel on Climate Change

changed during years. Croatia has a very small specific emission per unit of consumed electricity (CO_2 – 302 g/kWh in 2002), because a big share of electricity is produced without direct emission production (in hydropower plants or in nuclear power plant “Krsko”) or is imported. In 2002 only 40% of total consumed energy was produced in Croatian thermal power plants, with a relatively favourable type of fuel consumed (mostly natural gas). It can be seen that specific CO_2 emission for 2004 is the lowest for period 2002-2004 with Regional Conversion factor (RC) only 233 gCO_2/kWh. The specific emission over electricity production in thermal power plants was also lower in 2004 compared with previous years.

Table 7.3: Emission factors of greenhouse gases (Jurić 2005)

	CO_2	CH_4	NO_2
	[kg/GJ]	[g/GJ]	[g/GJ]
Extra light fuel oil	73.3	10	0.6
Liquid petrol gas	62.4	10	0.6

Table 7.4: Specific greenhouse gases emissions [g/kWh] for 2002-2004 (Jurić 2005, Maljković 2006)

	year	CO_2	CH_4	NO_2
		[g/kWh]	[g/kWh]	[g/kWh]
Specific emission over total electricity consumption	2002[28]	302.37	0.00658	0.00264
	2003[29]	315,53	0,00780	0,00304
	2004[30]	233,30	0,00507	0,00234
Specific emission over electricity production in thermal power plants	2002	760.21	0.01655	0.00664
	2003	730,91	0,01807	0,00705
	2004	696,93	0,01514	0,00698

Emissions of the most significant anthropogenic greenhouse gas, CO_2, due to fossil fuel combustion in hotels for 2002 is given in Table 7.5. The conversion is made according to heating oil and gas consumption estimation presented in Chapter 3 (Table 3.7. and Table 3.9.) The biggest portion of greenhouse gases emissions (88%)

[28] Reference: Hitra report 2005

[29] Reference: Maljković 2006

[30] Reference: Maljković 2006

are the result of burning of extra light fuel oil, while the rest is due to the burning of liquid petrol gas (12%). To compare emissions of greenhouse gases, CH_4 and N_2O are given, although their share in total green house gases production as a consequence of fuel contribution is minor (less then 1%). The total CH_4 and N_2O emissions are converted to equivalent CO_2 emissions (CO_2-eq) with equation 7.1. Global warming potential (for 100 year time horizon) for Methane (CH_4) is 21, while for Nitrous oxide (N_2O) is 310 (US EPA 2003).

$$TgCO_2\text{-eq} = (\text{Gg of gas}) \times (\text{GWP}) \times (\text{Tg}/1000\ \text{Gg}) \qquad (7.1)$$

Where

Tg CO_2-eq=Teragrams of Carbon Dioxide Equivalents

Gg = Gigagrams (equivalent to a thousand metric tons)

GWP = Global Warming Potential

Tg = Teragrams

Table 7.5: Greenhouse gases emissions due to fossil fuel combustion in hotels for 2002

2002	CO_2	CH_4	NO_2	CO_2-eq
	[kt]	[t]	[t]	[kt]
Dubrovnik	10,3	1,4	0,1	10,36
Istria	23,2	3,2	0,2	23,33
Rijeka	19,4	2,7	0,2	19,52
Split	8,3	1,2	0,1	8,36
Zadar	3,8	0,5	0,0	3,81
Total	65,0	9,0	0,6	65,38

Greenhouse gases emission resulting from electricity consumption in hotels are given in Table 7.6. Estimated electricity consumption in hotels on the Adriatic coast for 2002 taken for this analysis is given in Table 3.5.

Table 7.6: Greenhouse gases emissions due to electricity consumption in hotels

2002	CO_2	CH_4	NO_2	CO_2-eq
	[kt]	[t]	[t]	[kt]
Dubrovnik	8,97	0,2	0,08	9,00
Istria	19,83	0,43	0,17	19,89
Rijeka	10,32	0,22	0,09	10,36
Split	9,68	0,21	0,08	9,71
Zadar	5,69	0,12	0,05	5,71
Total	54,50	1,19	0,48	54,67

For the purposes of this analysis, emissions from other types of tourism accommodation such as camps and private accommodation is analysed. It is estimated that it was approximately 25,15 millions of guest nights (MINT 2004b) accommodated in various types of accommodation other than hotels in 2002. These guests night are mostly achieved during three summer months (June – August) . It is assumed that each guest consumes approximately 7 kWh per day of electricity due to meals preparation (3,8 kWh) and hot water consumption (3,2 kWh) (Bohdanowicz 2003). Domestic hot water systems in private accommodation are electrical boilers, therefore emissions due to fossil fuel are not taken into account. Estimated total electricity consumption for 2002 was 176 GWh that is only 3% lower consumption than the total estimated electricity consumption in hotel sector. Estimated greenhouse gases emissions due to electricity consumption in camps and private accommodations are given in Table 7.7.

Table 7.7: Greenhouse gases emissions due to electricity consumption in camps and private accommodations

2002	CO_2	CH_4	NO_2	CO_2-eq
	[kt]	[t]	[t]	[kt]
Dubrovnik	8.9	0.19	0.08	8,93
Istria	19.3	0.42	0.17	19,36
Rijeka	10.1	0.22	0.09	10,13
Split	9.4	0.21	0.08	9,43
Zadar	5.5	0.12	0.05	5,52
Total	53.2	1.16	0.47	53,37

Total greenhouse gases emissions due to fuel combustion and electricity consumption in hotels, camps and private accommodation in Croatia was about 174 kt CO_2-eq in 2002. Contribution of emissions in hotel accommodations with respect to total emissions is about 69% (Figure 7.1.).

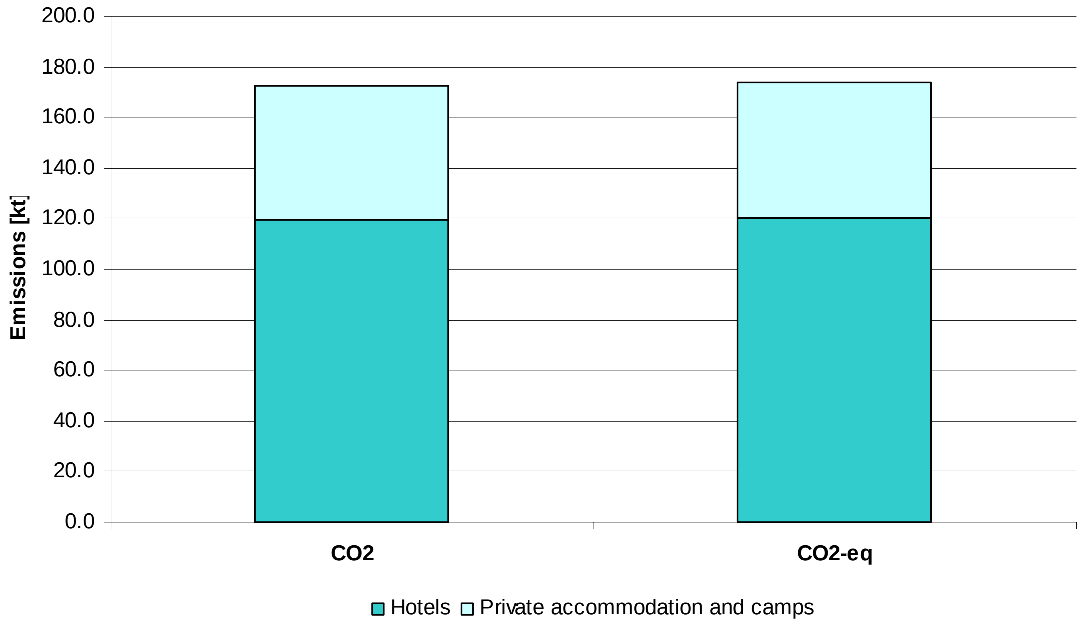

Figure 7.1: Contribution of hotels, private accommodation and camps to total CO_2 and greenhouse gases emissions

The service sector (catering industry, facilities/institutions and small entrepreneurship) contributes to total anthropogenic emissions in Croatia with 2-3%. If greenhouse gases emissions from hotels, camps and private accommodations is compared with the total emissions of the service sector, their share sums up to about 9%., and if indirect emissions are taken into account, that portion reaches as high as 23% (Figure 7.2.).

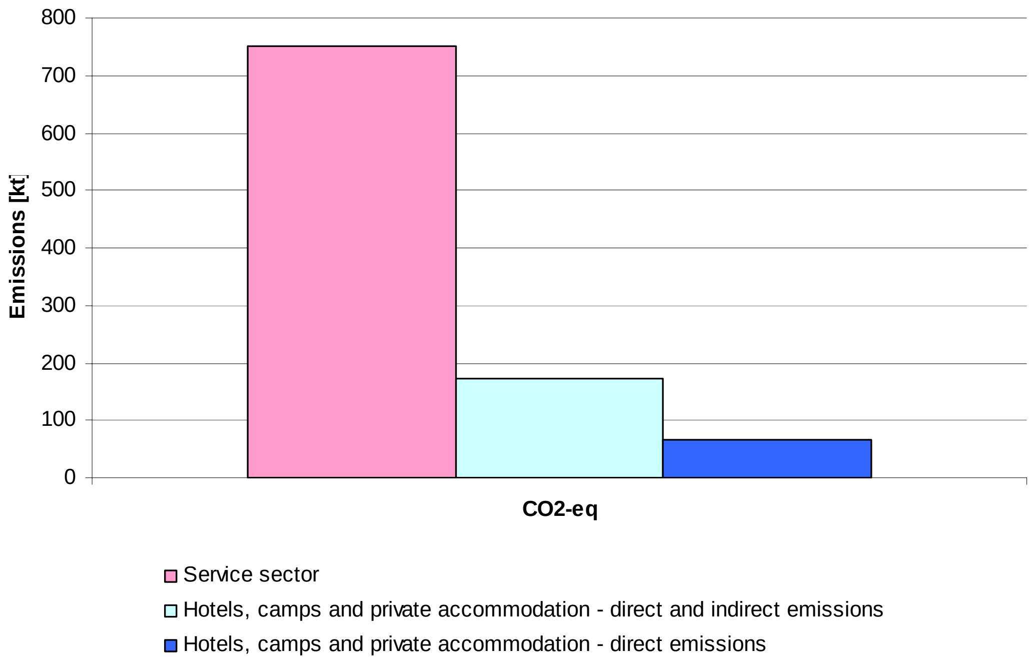

Figure 7.2: Comparison of emissions from hotels, camps and private accommodation with emissions from service sector

7.2.2. Emissions of SO_2, NO_x, CO and particles

When observing Europe as a region today, the biggest problem environmentally is high concentration of ground-level ozone because of its harmful effects on human health and the ecosystem. The second biggest problem is acidification, because of its detrimental effect on forests.

In the following paragraph, emissions of SO_2, NO_x, CO and particles will be of concern. SO_2 is known as an "acid" gas because of its transformation, when transported over long distances, results in the formation of acid compounds that are settling down in wet (acid rains) and dry forms. NO_x is a mixture of NO and NO_2 and is weighted as NO_2. Except of the fact that NO_x effects acidification and eutrophication. NOx is a gas that, when emitted into the atmosphere, reacts with volatile organic compounds and other reactive gases, and with the presence of solar irradiation, to form ground-level ozone. As opposed to SO_2 and NO_x, particles and CO have mainly local influences, i.e. have harmful human health impacts in the vicinity of the source (Jurić 2005).

For the purpose of emissions calculations, so called EMEP[31]/CORINAIR[32] methodology is developed within LRTAPC conventions. SO_2 emissions are calculated stoichiometricaly based on the fuel's sulphur content, while NO_x, CO and particle emission calculations are related to emission factors, i.e. type and quality of the fuel, and to the type of the facility in which the fuel is combusted (Jurić 2005). For the sulphur content in extra light fuel oil in 2002, data obtained from a Croatian petrol producer in which the Republic of Croatia is a major shareholder, was 0.4%. Emission factors used in calculations for fossil fuels and specific emissions per kWh are given in Table 7.8. and

Table 7.9.

Table 7.8: Emission factors for SO_2, NO_x, CO and particles (Jurić 2005)

	SO_2	NO_x	CO	Particles
	[g/GJ]	[g/GJ]	[g/GJ]	[g/GJ]
Extra light fuel oil	187.3	50	41	5
Liquid petrol gas	0	50	41	0

Table 7.9: Specific emissions of SO_2, NO_x, CO and particles [g/kWh] (Jurić 2005)

	SO_2	NO_x	CO	Particles
	[g/GJ]	[g/GJ]	[g/GJ]	[g/GJ]
Specific emission by total electricity consumption	1.072	0.64	0.0363	0.07
Specific emission by electricity produced in thermal power plants	2.694	1.597	0.0913	0.177

31 EMEP – the Co-operative programme for monitoring and evaluation of the long range transmission of air pollutants in Europe linked to the LRTAP(EEA 2002)

32 CORINAIR – CORe INventory of AIR emissions. CORINAIR is a project prefromed since 1995 by the European Topic Centre on Air Emissions under contract to the European Environment Agency, (EEA 2002)

SO_2, NO_x, CO and particle emissions due to fossil fuel combustion in hotels along the Adriatic coast are given in the Table 7.10. Total SO_2 and particles emissions (100%) and most of NO_x and CO emissions (86%) are the result of burning extra light fuel oil.

Table 7.10: Emissions of pollutants due to fossil fuel combustion in hotels

2002	SO_2	NO_x	CO	Particles
	[t]	[t]	[t]	[t]
Dubrovnik	22.1	7.2	5.9	0.6
Istra	50.7	16.2	13.3	1.4
Primorje	46.6	13.4	11.0	1.2
Split	18.3	5.8	4.7	0.5
Sibenik-Zadar	7.9	2.7	2.2	0.2
Total	145.6	45.3	37.1	3.9

Indirect emissions due to electricity consumption is given in Table 7.11. and Table 7.12. For emission calculations, average specific emissions based on consumed electric energy are used (Table 7.9), according to production and import structure from 2002..

Table 7.11: Emissions of pollutants due to electricity consumption in hotels

2002	SO_2	NO_x	CO	Particles
	[t]	[t]	[t]	[t]
Dubrovnik	32.5	19.3	1.1	2.1
Istria	70.3	41.6	2.4	4.6
Rijeka	36.6	21.7	1.2	2.4
Split	34.3	20.3	1.2	2.3
Zadar	20.2	11.9	0.7	1.3
Total	193.9	114.8	6.6	12.7

Table 7.12: Emissions of pollutants due to electricity consumption in camps and private accommodation

2002	SO_2	NO_x	CO	Particles
	[t]	[t]	[t]	[t]
Dubrovnik	31.7	18.8	1.1	2.1
Istria	68.4	40.5	2.3	4.5
Rijeka	35.6	21.1	1.2	2.3
Split	33.4	19.8	1.1	2.2
Zadar	19.6	11.6	0.7	1.3
Total	188.7	111.8	6.4	12.4

Overall emission of SO_2, NO_x, CO and particles due to fossil fuel combustion and electricity consumption in hotels, camps and private accommodations is given in Table 7.13. While contribution of the hotel sectors emissions to total emissions is between 57% and 87%, depending on the pollutant in question (Figure 7.3.).

Table 7.13: Overall SO_2, NO_x , CO and particles emissions in hotels, camps and private accommodation

2002	SO_2	NO_x	CO	Particles
	[t]	[t]	[t]	[t]
Total	528.2	271.9	50.1	29

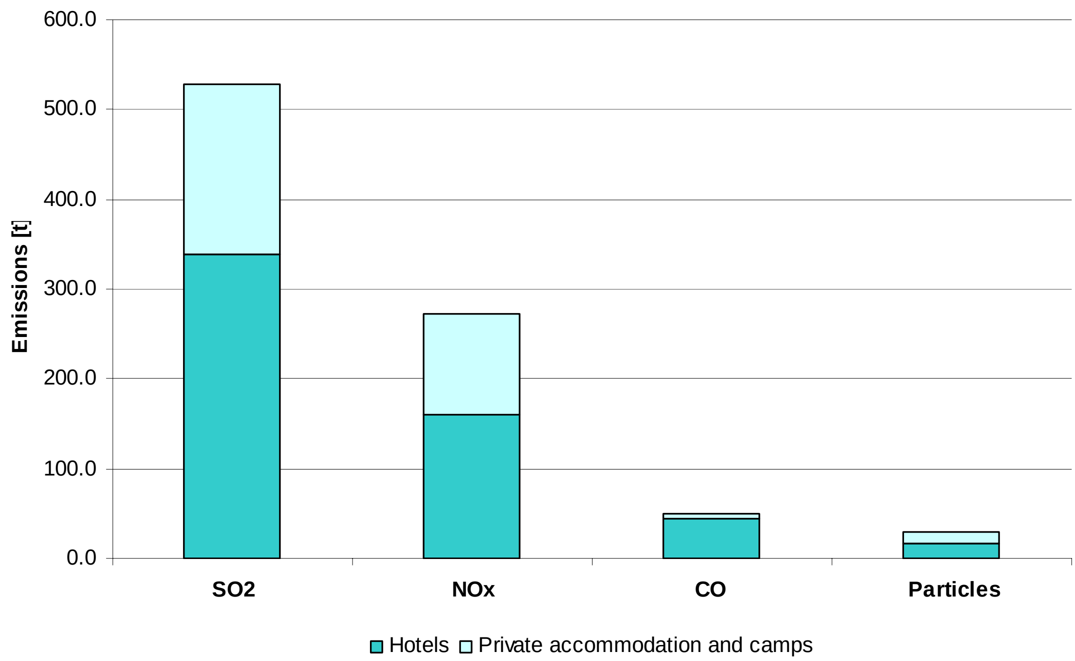

Figure 7.3: Overall emissions of SO_2, NO_x, CO and particles produced in hotels, camps and private accommodations

Hotels, camps and private accommodations in the costal area contribute significantly to the overall service sector emissions. If indirect emissions are taken into consideration as well, this portion amounts to 11-45% (11% for CO, 22% for particles, 26% for SO_2 and 45% for NO_x). To illustrate, the overall emissions of SO_2 and NO_x for the service sector and same indicators for analyzed hotels, camps and private accommodations, are given in the Figure 7.4.

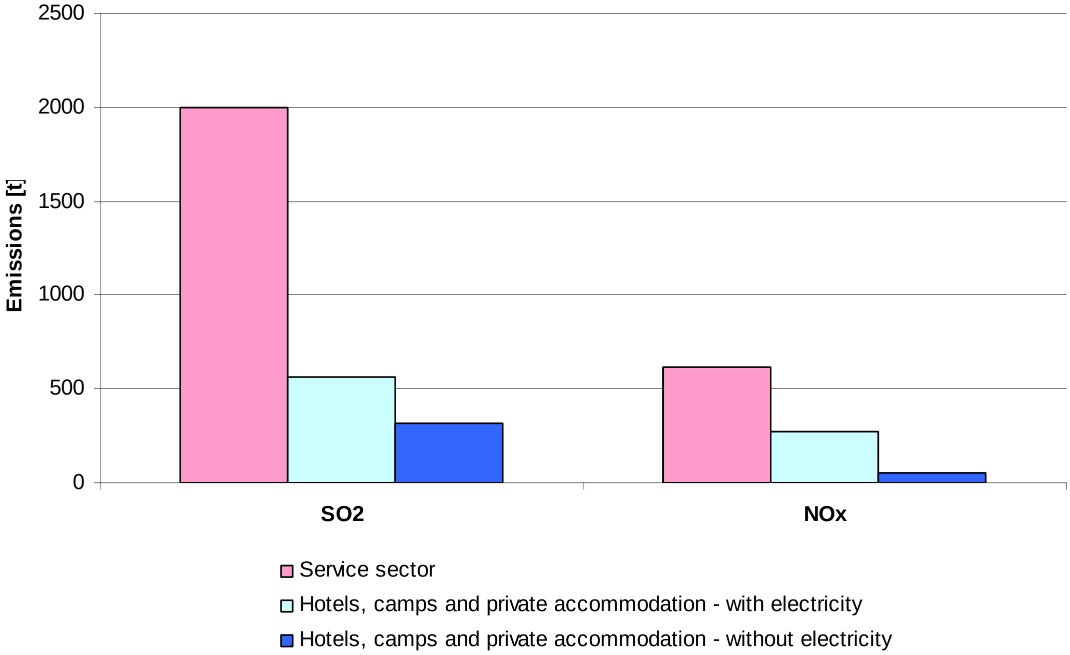

Figure 7.4: Comparison of emissions from hotels, camps and private accommodations sector with emissions from service sector

7.3. The analysis of the HVAC system

To obtain the full picture of the alternative HVAC and domestic hot water (DHW) systems suggested and analysed in previous chapters it is necessary to estimate their environmental impact, especially their potential for air pollution. Two hotels from the Split region have been analysed with 150 and 300 rooms respectively. Conventional system with vapour compression cooling unit, heating oil boiler for space heating and DHW is compared with three alternative retrofit systems:

- SWC-SH: sea water cooling system and solar heating
- HPS: compressor unit cooling and heating
- ACS: absorption cooling and solar heating

For the air pollution analysis it is necessary to know electricity and fossil fuels consumption data, needed for a system operation (Table 7.14.).

Table 7.14: Electricity and fossil fuels consumption for analysed HVAC options

	Hotel in Split area	
	150 rooms	300 room
CS		
Extra light fuel oil. TJ	6,94	10,57
Electricity. MWh	40,18	69,40
SWC		
Liquid petrol gas. TJ	4,5	6,23
Electricity. MWh	8,32	14,69
HPS		
Liquid petrol gas. TJ	0,13	0,49
Electricity. MWh	311,65	433,39
ACS		
Liquid petrol gas. TJ	3,16	3,84
Electricity. MWh	18,85	19,6

Emissions of SO_2, NO_x and CO_2 for analysed options are given in the Table 7.15.

Table 7.15: CO_2, NO_x and SO_2 emissions for conventional system and analysed options

	Hotel with 150 rooms			Hotel with 300 rooms		
	CO_2	NO_x	SO_2	CO_2	NO_x	SO_2
	[t]	[kg]	[kg]	[t]	[kg]	[kg]
CS	520.85	347.09	1300.02	795.77	528.66	1980.03
SWC-SH	283.32	225.02	0.03	393.19	311.53	0.06
HSP	102.35	7.22	1.20	161.62	25.50	1.67
ACS	202.88	158.04	0.07	245.54	192.05	0.08

If the conventional system (CS) is replaced with the SWC-SH system, CO_2 emission would reduce by 45% (hotel with 150 rooms) or 50% (hotel with 300 rooms). NO_x emissions would reduce by 35% and 41%. Possible conventional system (CS) replacement with the HPS system would result in CO_2 emission reduction by 80% and NO_x reduction by 98%. The third alternative system (ACS system) would reduce CO_2 emissions by 62% and 70%, NO_x emissions by 55% and 64%. SO_2 emissions for all three alternative systems are negligible due to utilization of LPG instead extra light fuel oil. Present emissions of these three pollutant gases, for hotels with 150 and 300 rooms, is given in Figure 7.5. and Figure 7.6.

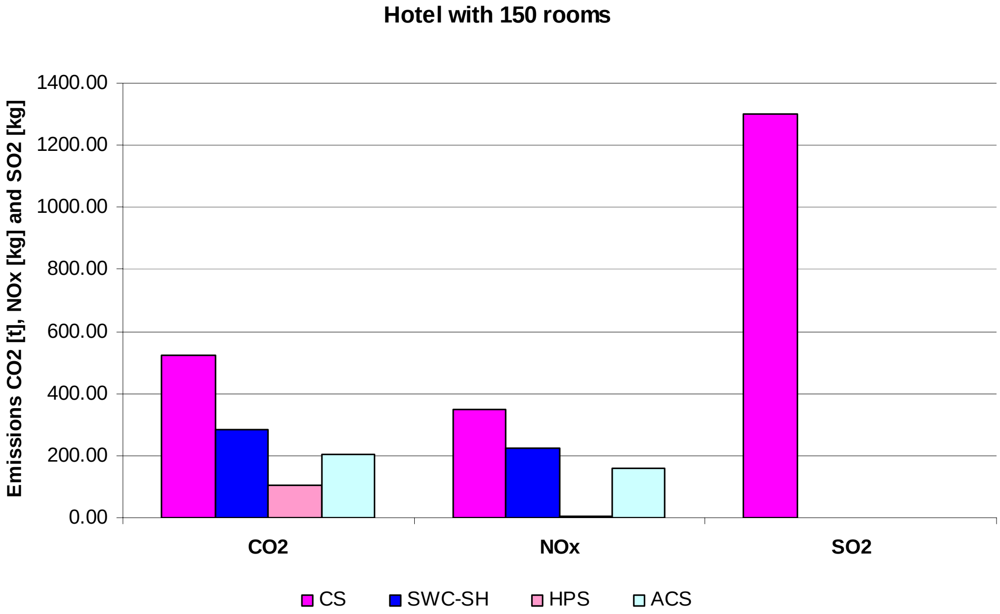

Figure 7.5: CO_2, NO_x and SO_2 emissions due to HVAC systems operation during one year for a hotel with 150 rooms

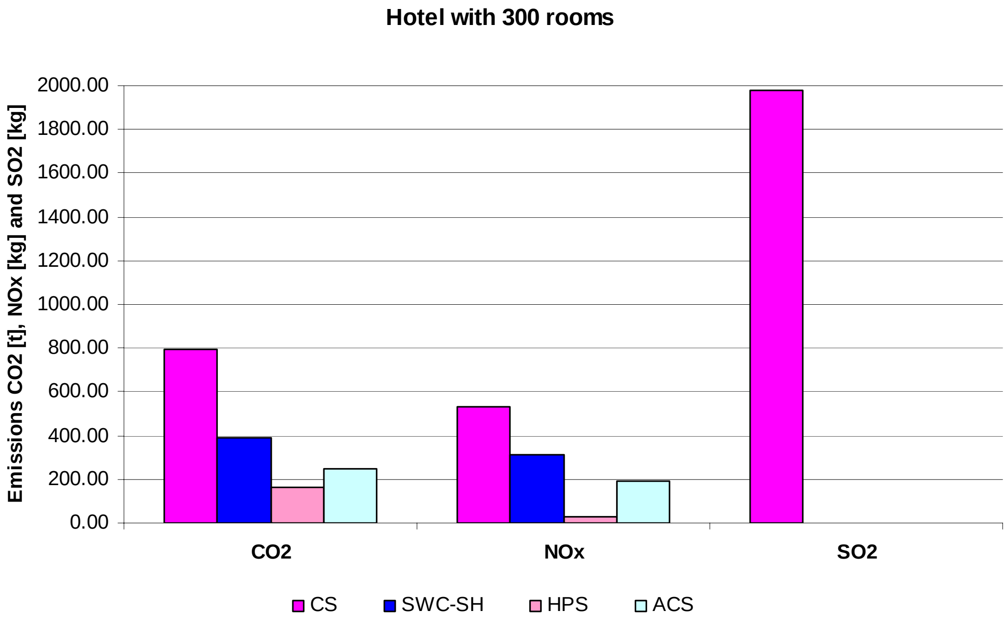

Figure 7.6: CO_2, NO_x and SO_2 emissions due to HVAC systems operation during one year for a hotel with 300 rooms

It is estimated that a typical hotel globally releases about 160 kg CO_2/m^2 of floor area annually, which is equivalent to about 10 tons of CO_2 per bedroom per year (Bohdanowicz 2003). The results of this research show that typical non seasonal 4* hotel with 150 room on the Adriatic coast releases about 3,5 t of CO_2 per room and 58 kg CO_2/m^2 due to operation of HVAC systems. If one takes into account the electricity consumption for catering, lighting, and other appliances in hotels and gas consumption for cooking, these emissions can be assumed to be 40% higher (see Table 3.14.).

It is obvious from Figure 7.5. and Figure 7.6. that significant environmental savings can be achieved. Therefore it is interesting to calculate the cost of possible emission savings per kilograms of reduced CO_2 emissions (so-called mitigation cost). In the Table 7.16. one can see calculated environmental emissions during the life time of conventional system (CS) and the three alternative systems (SWC-SH, HPS and ACS) and possible CO_2 savings . The cost of saved kg of CO_2 varies from 0,032 for HPS system, 0,035 for SWC-SH system and 0,089 EUR/kgCO_2 for ACS system.

Table 7.16. Costs of environmental savings, EUR/kgCO_2

System	Investment costs, EUR	Environmental emissions, kgCO_2/year	Environmental emissions, kgCO_2/20 years	CO_2 savings during the lifetime of equipment, kgCO_2	Cost of saved kgCO_2, EUR/kgCO_2
CS	122260	520851,23	10417024,53	-	-
SWC-SH	165500	283315,72	5666314,37	4750710,16	0,035
HSP	271680	102345,61	2046912,21	8370112,32	0,032
ACS	565300	202883,67	4057673,49	6359351,04	0,089

7.3.1. Total Equivalent Warming Impact - TEWI

The environmental emissions discussed in this chapter so far were all related to indirect emissions of greenhouse gasses due to electricity consumption and direct emissions due to combustion of fossil fuels. However, vapour compression refrigeration systems use refrigerants, so-called HFCs[33] that are strong climate gas as well. During the operation of these kind of systems direct emissions occur due to leakage, service etc. Total Equivalent Warming Impact (TEWI) is a concept that takes into account, not only direct, but also indirect emissions of greenhouse gases attributed to refrigerating plant. Direct emissions (leaks) of refrigerants contained in refrigerating installations typically[34] account for about 20% of the overall impact of the refrigeration sector on global warming (IIR 2002). TEWI concept was described into details in Chapter 1. (Subchapter 1.1.1.)

In this thesis, two cooling systems were compared using the TEWI concept, the conventional cooling system - CS (air cooled condenser of vapour compression unit) and the heat pump system –HPS (seawater cooled condenser of vapour compression unit). It is assumed that equipment lifetime is 20 years. Refrigerant charge is obtained from equipment producers (Carrier 2005). Conventional system operates with R22 (HCFC[35]) as a refrigerant, while working fluid in HPS system is R134a (HFC[36]). According to new regulations for ozone depleting substances refrigeration systems that contain more than 30 kg of refrigerant should be serviced regularly every 6 months (MZOPU 2005a). Therefore it is assumed that yearly leakage is 10% in both cases. Due to regular servicing end of life recovery rate should be relatively high as well, therefore it is assumed that it is 50% and 75% for CS system and HPS system respectively. Yearly direct and end of life emissions are calculated according to equation 7.2. and 7.3. (Lunqvist 2006b).

$$TEWI_{Dy} = \left(\frac{M_{losses}}{100} \cdot M_{ref} \right) \cdot GWP_{ref} \tag{7.2.}$$

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[33] HFCs - Hydrofluorocarbons

[34] There are large differences between different types of systems. Mobile air-conditioning and supermarkets are well known system types where the impact of direct leakage is large

[35] HCFC – Hydrochlorofluorocarbons

[36] HFC – Hydrofluorocarbons

$$TEWI_{ENDy} = \left(M_{ref} \cdot (1-\kappa)\right) \cdot \frac{GWP_{ref}}{N} \quad (7.3.)$$

Where M_{losses} is the refrigerant leakage, N is the lifetime of the refrigeration system, M_{ref} is the refrigerant charge, κ is the recycling factor, GWP_{ref} is the Global Warming. All assumptions for calculation are presented in the Table 7.17.

Table 7.17. Total Equivalent Warming Impact analysis for CS and HPS system

	CS system		HPS system	
Lifetime	**20**	[year]	**20**	[year]
Charge	**78**	[kg]	**55**	[kg]
refrigerant	**R22**	[ASHRAE N°]	**R134a**	[ASHRAE N°]
G W P:	**1.700**	[CO_2 = 1]	**1.300**	[CO_2 = 1]
Yearly leakage	**10**	[%]	**10**	[%]
End of life recovery	**50**	[%]	**75**	[%]
Direct emissions / year	**13260**	[kg CO_2] / year	**7150**	[kg CO_2] / year
End of life emission / year	**3315**	[kg CO_2] / year	**894**	[kg CO_2] / year
Nominal capacity	**300**	[kW]	**300**	[kW]
COP	**3.1**	[kW/kW]	**4.64**	[kW/kW]
Yearly operation time	**3**	[%]	**3**	[%]
Yearly electricity	**23128**	[kWh] / year	**16868**	[kWh] / year
Regional conversion factor	**0.302**	[kg CO_2/kWh]	**0.302**	[kg CO_2/kWh]
Indirect emissions CO_2 eq	**7,425**	[kg CO2 eq]	**5,131**	[kg CO2 eq]
Direct emission	**13260**	[kg CO2 eq]	**7150**	[kg CO2 eq]
End of life emission	**3315**	[kg CO2 eq]	**894**	[kg CO2 eq]
Total emission CO_2 eq:	**24000**	[kg CO2 eq]	**13175**	[kg CO2 eq]
ratio indirect / direct	**0.45**	[1]	**0.64**	[1]

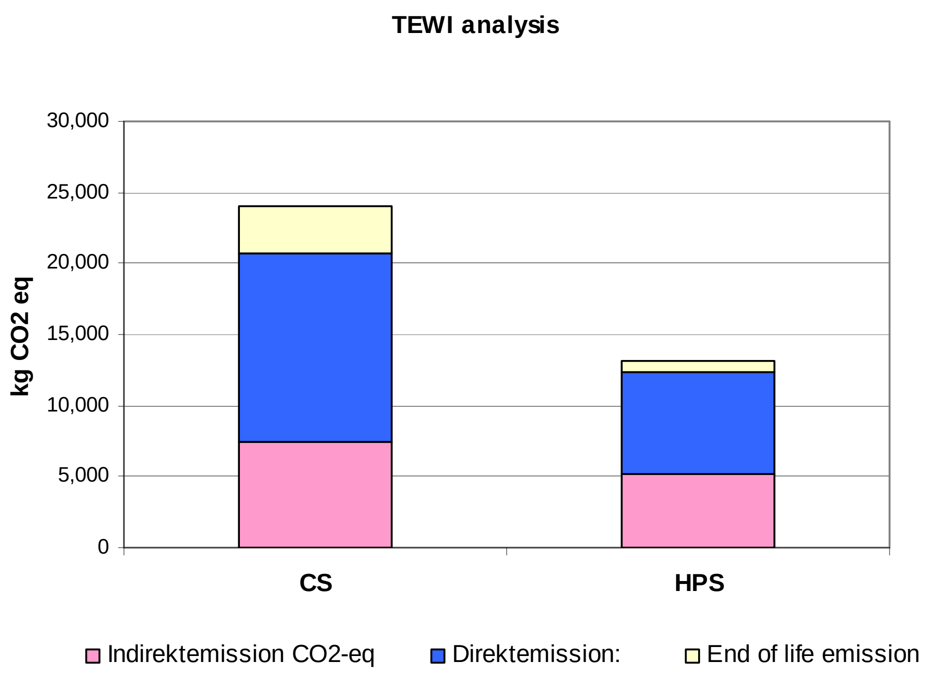


Figure 7.7. TEWI analysis for CS and HPS system during one year operation (cooling mode)

The analysis shows that due to the short yearly operating time the direct emissions (with the assumptions stated above) are higher than the indirect emissions. For the CS systems it amounts to 24 kt CO_2-eq per year. Direct emissions are 55% and 54% for CS and HPS system respectively. The short operating time, approximately 263 h, is due to the fact that the design indoor temperature was 26°C while the outdoor design temperature is 32°C. According to simulations that were done for the period June 1st – September 15th there is no need for constant cooling of the building since night outdoor temperatures are lower which allows passive cooling of the building. Furthermore, it is clear from the experience that guests do not spend a lot of time indoors during the summer period.

7.4. Scenarios for future environmental emissions

As it was stated in Chapter 1. (subchapter 1.1.5.) there is a constant growth in tourist overnights in Croatia. The year 2003 recorded 7% more tourists and 4% more overnight stays in comparison with the previous years (HGK 2004). While in the year 2004 tourist arrival growth was 6% with a total 9,4 million tourists, which confirmed the estimated trends. (HGK 2005). A further annual growth in tourist arrivals has been estimated to 8,4% by WTO (HGK 2004). Any further growth in tourism arrivals will produce additional emissions into environment.

To get a clear picture about future emissions generated in the hotel sector, a scenario of emissions according to predicted increase in number of guest night was made. In the Table 7.18. and Figure 7.8. the number of guest nights for years 1990 – 2010 are given. Data for 1989-2005 are obtained from official tourist statistics (MINT 2006), while for the period 2006-2010 estimation was made with a 6% increase of guest nights per year.

Table 7.18. Number of guest nights throughout the period 1989-2010

year	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**
Guest nights	61849000	52523305	10158000	10725000	12908000	19977000
year	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**
Guest nights	12884000	21457000	30313000	31287000	26564000	39183000
year	**2001**	**2002**	**2003**	**2004**	**2005**	
Guest nights	43404354	44692456	46635103	47797287	51420948	
year	**2006**	**2007**	**2008**	**2009**	**2010**	
Guest nights (estimation)	54506205	57776577	61243172	64917762	68812828	

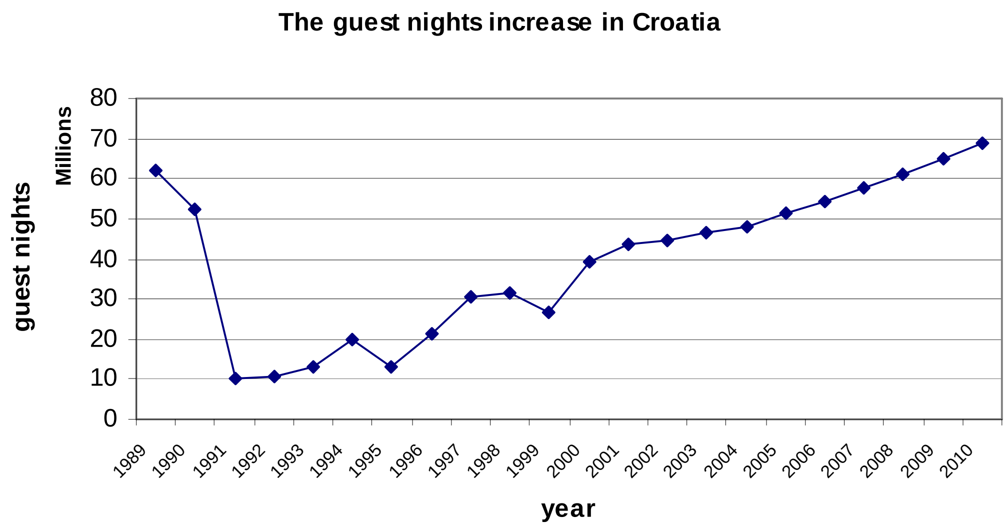


Figure 7.8. The guest nights increase in Croatia for period 1990-2010. (MINT2006)

The statistic shows that approximately 30% of guest nights is achieved in hotels. Therefore, the energy consumption and emissions for guest nights stated in Table 7.18. are calculated on the basis of 30% of guest nights in hotels and 70% in other types of accommodation.

7.4.1. Business as usual scenario

For the business as usual scenario - BAU (operation with existing conventional HVAC systems) it is estimated that the increase in electricity consumption is related to the increase in guest night with factor 0,9 in hotels and factor 1 in other types of accommodation. Coefficient 0,9 instead 1 is taken due to the fact that one portion of electricity is consumed for public spaces and services that do not depend on number of guests. It is assumed that heating oil consumption is related to the increase in guest nights with factor 0,8 in hotels, due to the fact that public services and even rooms are heated regardless number of guests. DHW consumption is related to number of guests, however, regardless number of guests storage tanks are maintained at the design temperature and hot water is recalculated through the building.

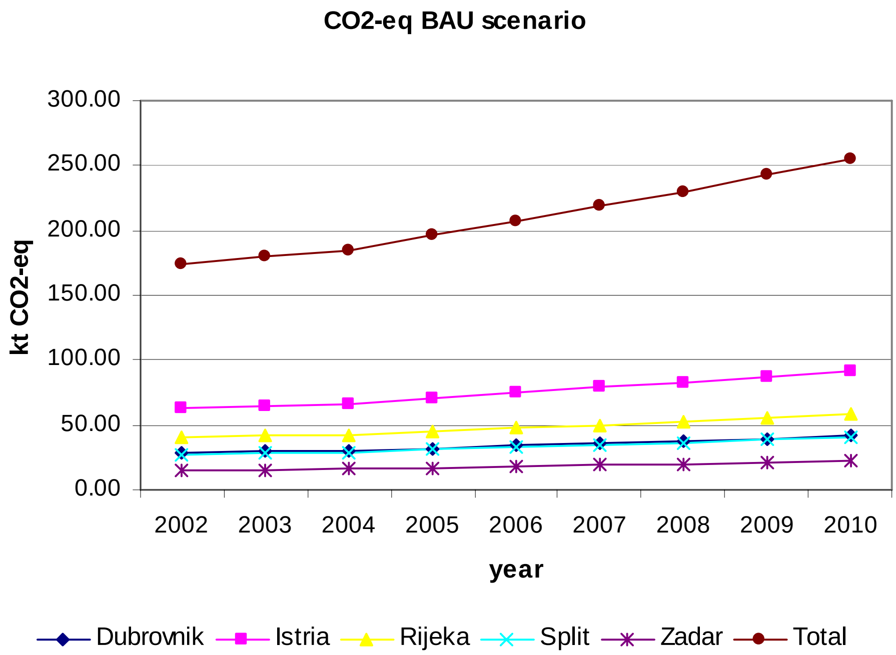


Figure 7.9. Estimated CO_2-eq emissions from tourist accommodation sector till 2010 with BAU (business as usual) scenario

Globally, the hotel industry is responsible for emissions of at least 130 10^3 kt of CO_2 annually. (Bohdanowicz). Croatian hotel industry contributes to those emissions with one portion as well. From the Figure 7.9. it can be seen that annual emissions of CO_2-eq from tourism accommodation sector will increase from 174 kt CO_2-eq in 2002 to 255 kt CO_2-eq in 2010 with business as usual scenario. This is an increase of greenhouse gas emissions of 47% in 8 years. The hotel sector is responsible for 68% of these emissions, while the rest, 32% is due to electricity consumption in other types of accommodation facilities.

There is a growing concern in Croatia due to increasing CO_2 emissions caused by growing consumption of fossil fuels. If observed separately only the most significant greenhouse gas – CO_2 was above the limit set by the Kyoto protocol already in 2003

(Figure 7.10.) In 2004, total emission of CO_2 was 4% lower than the previous year but, however, it exceeds the limit specified by Kyoto Protocol by 1%.

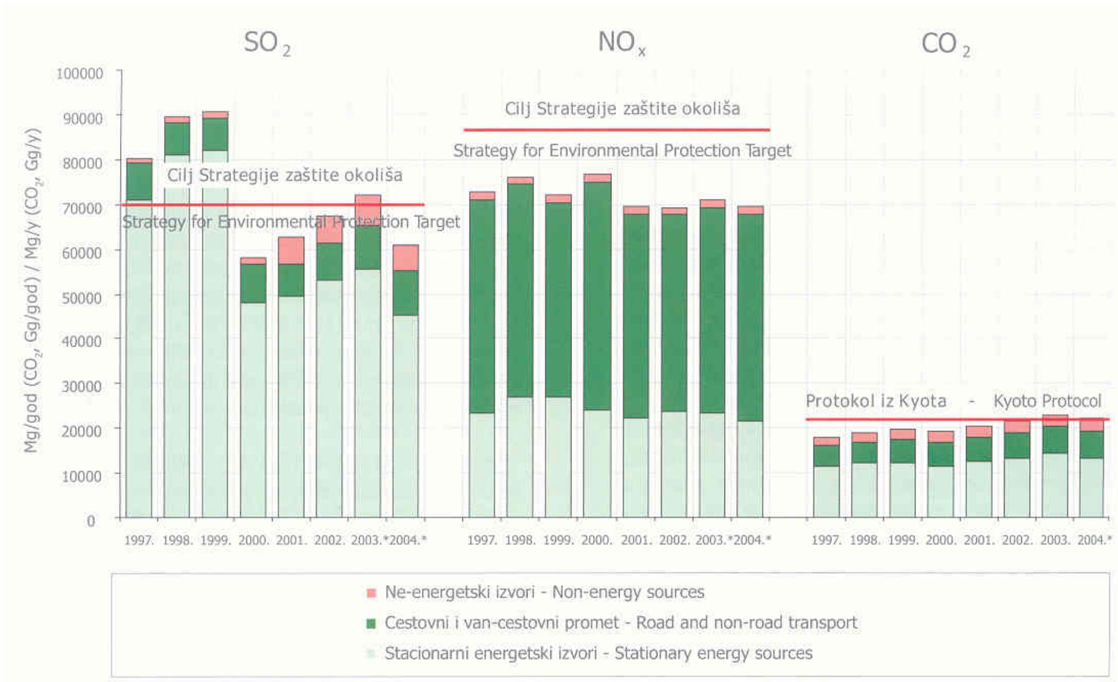


Figure 7.10.Emissions trends – SO_2, NO_x and CO_2 (MGRP 2006)

Since tourist industry is growing this will consequently lead to emission increase as shown in Figure 7.9. In order to comply with the Kyoto protocol energy efficient measures and technologies (already available) should be implemented widely in the hotel industry. However, there is no established energy and ecological criteria for tourist accommodation facilities in Croatia, that could enhance implementation of energy efficient measures and technologies.

Tourism-induced CO_2 emissions are unlikely to be reduced through voluntary environmental efforts by a growth-oriented economy. Instruments like eco-labelling and environmental awards and prizes can help, but CO_2 - energy tax to implement the "polluter pays principle" are unavoidable. Greater sustainability of the tourism product i.e. more regional products, less noise and emissions, less waste and unpurified sewage- means the creation of jobs and quality of life for the local population, and an improved quality of holidays for the guests (Ecotrans 2001).

European Union with commission decision 2003/287/EC of 14 April 2003 established the ecological criteria for the award of the Community eco-label to tourist accommodation service (EU 2003). There are a number of ecological criteria set out in the Annex to Decision that "tourist accommodation service" must comply with. The criteria aim to limit the main environmental impact from the three phases of the service's life cycle (purchasing, provision of the service, waste) with aim to:

- limit energy consumption
- limit water consumption
- limit waste production
- favour the use of renewable resources and of substances which are less hazardous to the environment
- promote environment communication and education

Energy criteria comprises the following issues: electricity from renewable sources, coal and heavy oils, electricity for heating, boiler efficiency, air conditioning, window insulation, switching off heating or air conditioning, switching off lights, energy efficient light bulbs, sauna timer control. (EU 2003)

According to survey undertaken in hotels on the Adriatic coast, it has been shown that none of the hotels on the Adriatic coast fulfil these strict criteria. This is one more reason to establish a methodology that will help hotels to retrofit their energy system according to ecological criteria as well. Furthermore, two scenarios with implementation of solar collectors for DHW and alternative HVAC systems will indicate possible savings and how greenhouse emissions increase could be mitigated.

7.4.2. Scenario with solar collectors for DHW system

The three analysed alternative HVAC&DHW systems for hot water production consist of solar collectors installation and LPG boiler as a back up system. It has been shown that this system is the best alternative with regards to energy consumption due to the high insolation on the Adriatic coast. Results of simulations in TRNSYS software showed that solar collector installation can save up to 90% of fossil fuel annually.

Two scenarios have been developed. The first one (S1) considers retrofit of existing conventional DHW system (heating oil boiler) with solar collector installation with a "retrofit rate" of 10% annually. This would mean that by 2016 all hotels on the Adriatic coast will have solar collectors installations. The second scenario (S2) assumes 5% of new solar DHW systems annually, that will lead to 50% renewable energy installations in hotels on the Adriatic coast by 2016. The business as usual scenario (BAU) assumes that there is no changes in existing systems and that all hotels operates with conventional DHW system. For the period 2002-2005 real guest night number in hotels were taken from official statistics, while for period 2006-2016 a 6% annual increase is assumed.

From Figure 7.11. one can see that scenario S1 will lead to significant CO_2 emissions savings during the period 2007-2016, while scenario S2 will leave CO_2 emissions on approximately the same level as in 2006. During the period 2007-2016, according to the BAU scenario DHW system will be responsible for 212 kt of CO_2. Scenario S1 will achieve 55% savings with 95,1 kt of emitted CO_2, while scenario S2 will achieve 28% emission savings with the total 153,5 kt of emitted CO_2.

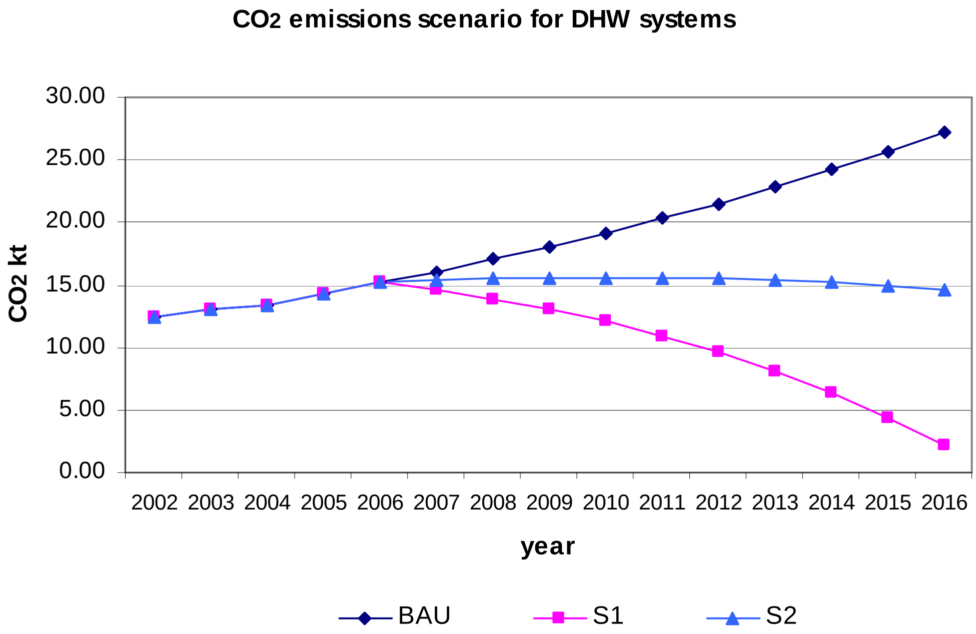


Figure 7.11. CO_2 emissions scenarios for DHW systems for the period 2002-2016

Emission savings from DHW systems are especially significant for seasonal hotels, since approximately 90% of the total energy consumed in thermal system is for domestic hot water production. The rest, 10% is energy used for space cooling. (Table 6.6)

7.4.3. Scenarios for HVAC systems

Although DHW systems contributes with 20% of the total consumption in thermal systems (conventional HVAC&DHW system) scenarios S1 and S2 has shown that retrofit of DHW systems can achieve significant environmental savings. Furthermore, energy analysis has showed that the three analysed HVAC options can achieve up to 81% savings for space heating (HPS system) and up to 87% savings for cooling (SWC system). In order to investigate future emissions from existing HVAC systems and possible environmental savings two scenarios were made. These scenarios consider heating and cooling systems retrofit in non seasonal hotels. The environmental analysis of different HVAC options has shown that approximately 3,47 tCO_2/room and year is emitted due to operation of conventional HVAC&DHW system (such as described in this study with round year operation). There were total 14208 rooms registered in 139 non seasonal hotels on the Adriatic coast in 2002 (MINT 2003b). It is assumed that total number of rooms will annually grow for 1% (MINT 2006) . The third scenario, S3 assumes 2% of new HPS systems installations and 1% of new SWC installations annually based on the number of rooms. That would mean that 3% of the rooms will be provided with heat and cold energy produced in energy efficient systems. According to this scenario approximately 30% of hotels will have energy efficient solution for heating and cooling by 2016. The fourth scenario, S4 assumes 5% of new HPS systems installations and 2% of new SWC installations annually, that would lead to 75% of energy efficient system by 2016.

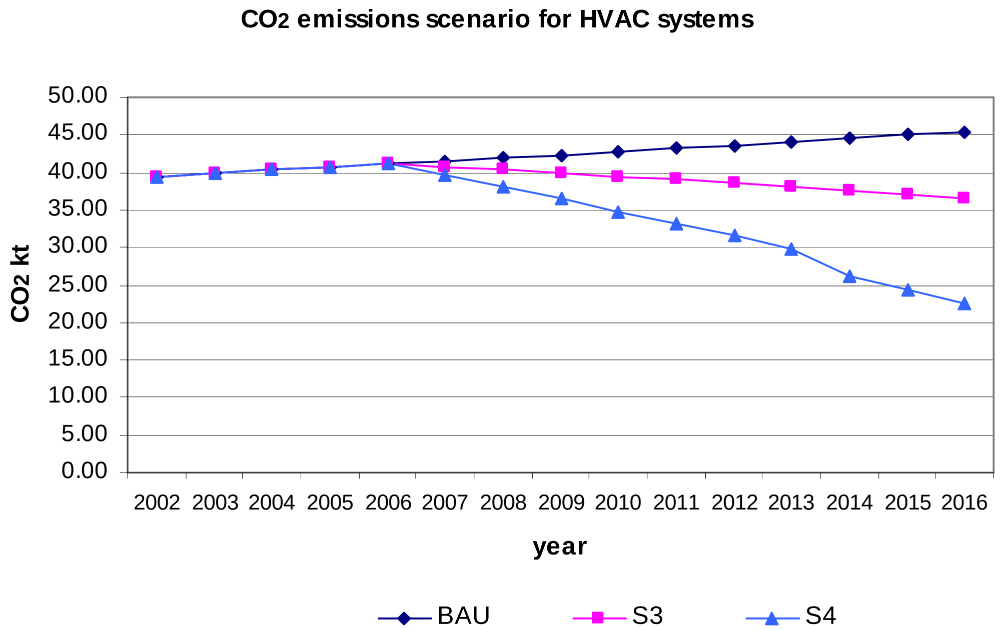


Figure 7.12. CO_2 emissions scenarios for HVAC systems for the period 2002-2016 – non seasonal hotels

Figure 7.12. shows the emissions from HVAC systems in non seasonal hotels for the period 2002-2016. Changes are assumed to start in 2007. The business as usual scenario would produce 434,3 kt CO_2 in the next 10 years. If scenario S3 or S4 is applied it would be possible to achieve 11% (46,7 kt CO_2) and 27% (117,7 kt CO_2) emission savings respectively for the same period. In 2016, annual emissions would decrease from 45,4 kt CO_2 in BAU scenario to 36,65 kt CO_2 and 22,58 for S3 and S4 scenario respectively.

8. HOTECO METHODOLOGY

This chapter summarises research presented in this thesis and presents an algorithm, a methodology developed for improving energy performance in hotels and energy efficient retrofit of HVAC systems in hotels on the Adriatic coast.

There are a number of strategies and energy acts based on sustainability principles that each country or bigger energy associations develop. These strategies are established with the purpose to decrease production and energy utilization, and in that way decrease GHG emissions and pollution. Strategies promote sustainable energy development, e.g. renewable energy technologies, energy savings measures, increased energy efficiency, and energy conservation measures. For example research and development strategies for International Energy Agency (IEA) under Energy Conservation in Buildings and Community Systems Program (ECBCS) are based on: 1) Technological opportunities to save energy in the building sector and, 2) Means to remove technical obstacles to market penetration of new energy conservation technologies.

The strategies are developed in order to:

- develop an energy efficient, comfortable and sustainable building;
- introduce low energy building concepts based on advanced installations and energy recovery systems as well as on optimized integration of energy conservation and utilization of renewable energies;
- introduce integrated building technical-system concept that can be upgraded using the advancements in building energy conservation technologies;
- minimize non-renewable energy used for heating, cooling and lighting;
- identify ways to improve HVAC-systems and components to use less electricity;

- improve the utilization of building energy management systems by analyzing the need of users and developing guides to design man-machine interfaces of technical systems;
- assess the feasibility of advanced control strategies of HVAC systems;
- establish indoor air quality and optimal ventilation needs and to identify alternative energy efficient strategies in controlling the indoor environment;
- develop and asses system concepts, for local integrated power, cooling and heating generation and distribution systems (ECBCS 2002).

The strategies and activities, which might be connected to the tourism accommodation sector are (i) sustainable building design, (ii) alternative HVAC systems, (iii) renewable energy sources, (iv) energy consumption in buildings and (v) environmental impact of extensive utilization of energy resources. However, in order to understand energy performance in different types of buildings each type of building should be studied separately. In that way specific problems can be identified. Moreover, it is also necessary to take into account the geographical location of the building, local weather conditions, year of construction, current regulations, international obligations, social and other trends that might influence energy consumption in buildings.

One objective of this research was to establish a useful methodology for HVAC energy efficient retrofit solutions. The findings are summarized in the algorithm that consists of 4 parts:

Part I: Hotel data collection and energy consumption analysis (Figure 8.1.)

Part II: HVAC systems modelling (Figure 8.2.)

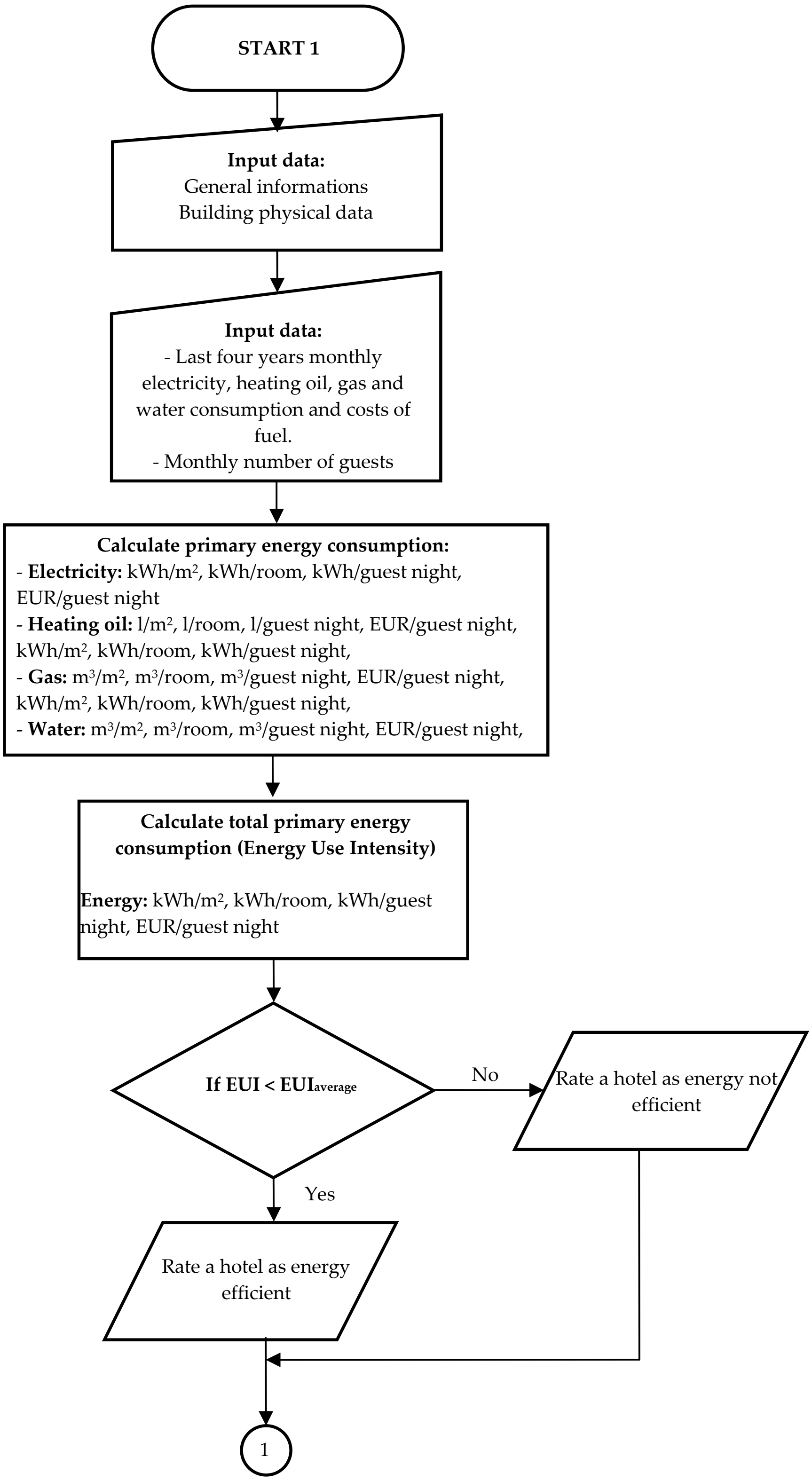
Part III: Economical analysis (Figure 8.3.)

Part IV: Environmental analysis (Figure 8.4.)

Part I collects the majority of hotel building parameters and energy and water consumption. The result is an evaluation of current state of energy consumption and energy efficiency of the HVAC systems. The input data from hotel management include location, hotel category, operational schedule, year of construction, total floor area, number of rooms, number of beds, additional facilities (restaurant, swimming pool), heated floor area, cooled floor area and room floor area. Furthermore, it is necessary to give data about the type of cooling and heating system, as well as that of the domestic hot water system. Input data required are presented with the questionnaire in Appendix I. During this research it was realised that the guest nights are one of the significant explanatory factors for energy consumption. Therefore it should be included as input data while energy consumption as output should be also presented in the form of kWh/guest night. Monthly consumption and costs for electricity and fossil fuels as well as guest nights are needed. In order to rate and compare current energy consumption in the hotel, it is necessary to use the benchmarks for hotels established and presented in Chapter 3. In order to convert litres of heating oil and m^3 of gas or kg of LPG into primary energy, the type of fuel and its calorific value should be known. At the end, a graphical presentation of results is produced (Figure 8.1.).

Based on results and analysis from Part I, alternative HVAC systems utilizing energy efficient and renewable energy technologies are suggested in the Part II. The building geometry and thermal properties are needed as inputs. Design indoor and design outdoor temperatures should be known. Building is modelled as a simple one zone model, since a multi-zone model would require too much time for this type of analysis. Heating and cooling capacities are calculated according to procedure given in Subchapter 5.3. If theses capacities are known for the existing hotel, they are used for HVAC systems modelling. Further on, HVAC systems are modelled and simulated in TRNSYS simulation studio. Outputs are electricity and fuel consumption for modelled systems (Figure 8.2.).

PART I: Hotel data collection and energy consumption analysis



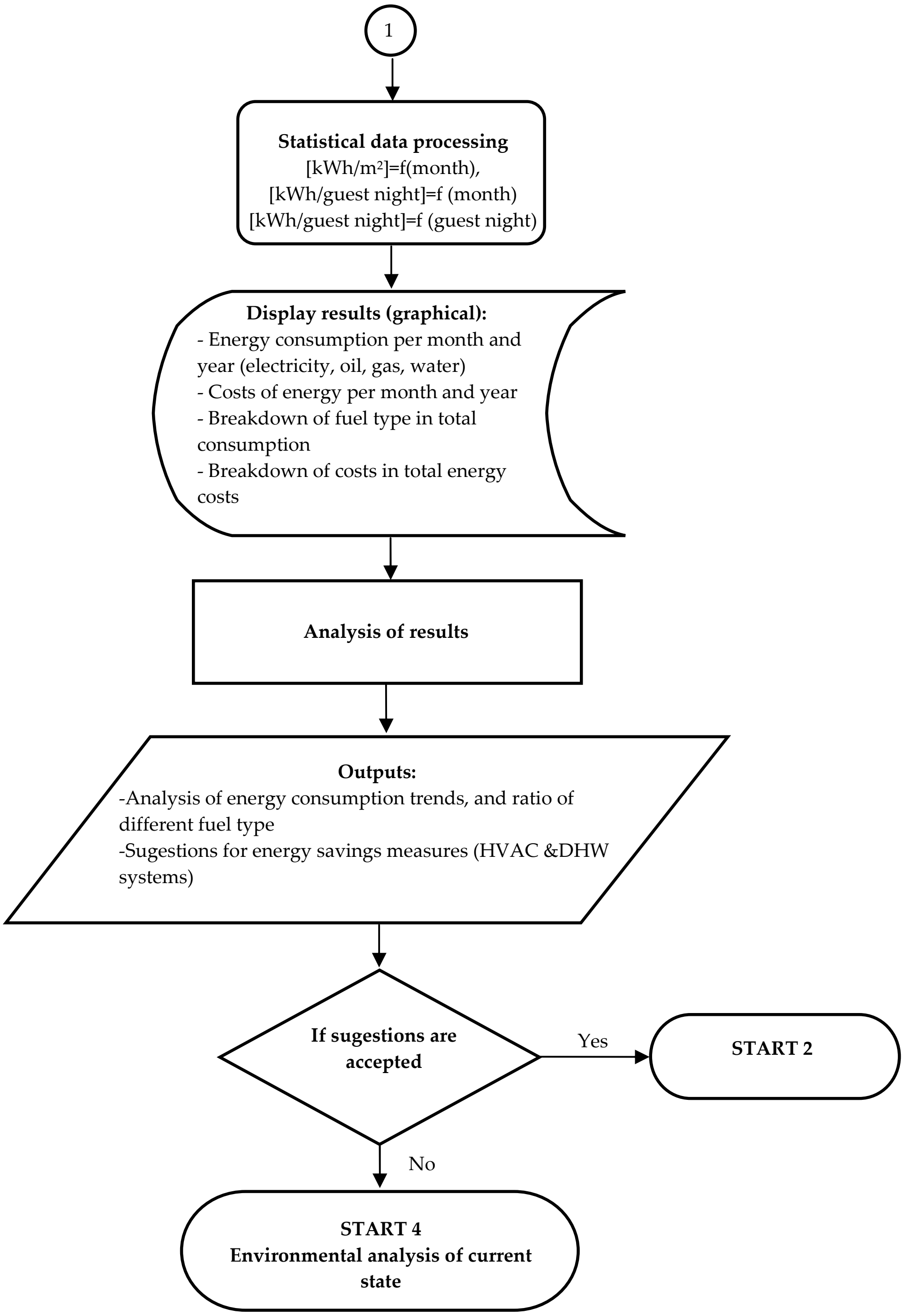


Figure 8.1. Part I - Hotel data collection and energy consumption analysis

PART II: HVAC systems modelling

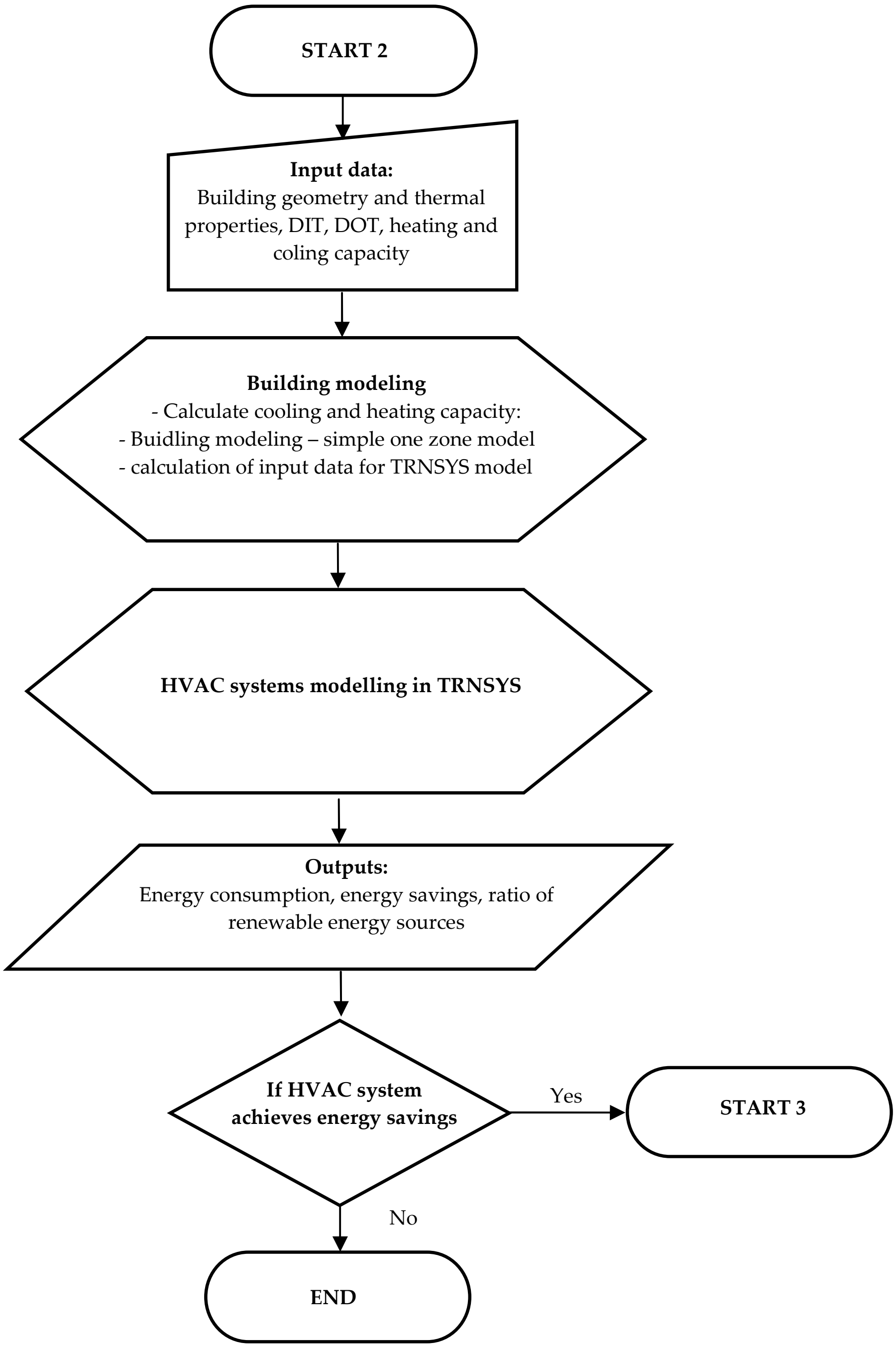


Figure 8.2. Part II – HVAC systems modelling

PART III: Economical analysis

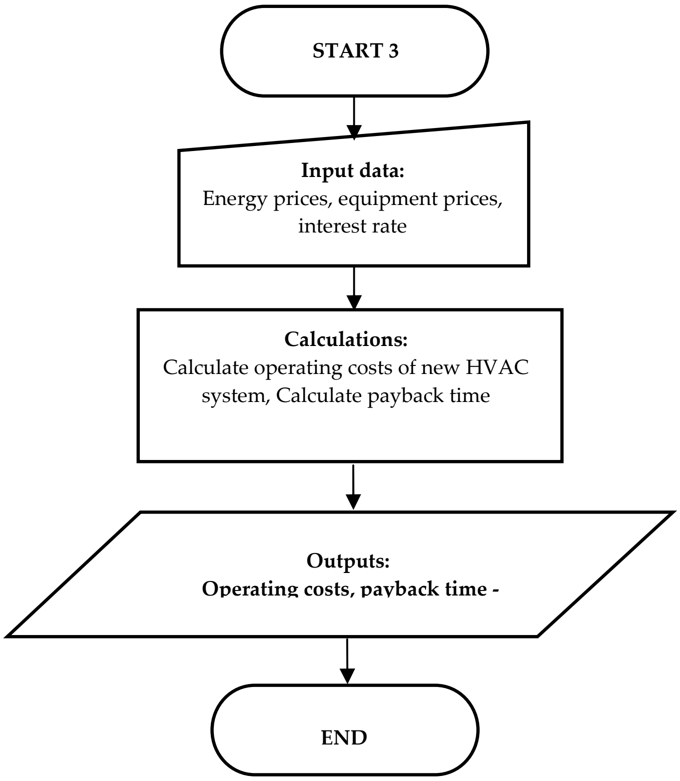


Figure 8.3. Part III – Economical analysis

Part III is a calculation of the economical viability of the suggested HVAC options as explained in subchapter 6.2. Prices of fuel, investment costs and interest rates are input data (Figure 8.3.).

Part IV gives an environmental analysis due to energy usage in the hotel and possible environmental savings if current HVAC systems would be replaced with energy efficient solutions. The input data for this part of the algorithm are regional conversion emission factors for different types of fuel. For the TEWI calculations, the type of refrigerant and the charge and typical annual leakage is needed (Figure 8.4.). A detailed procedure for the environmental analysis is given in Chapter 7.

PART IV: Environmental analysis

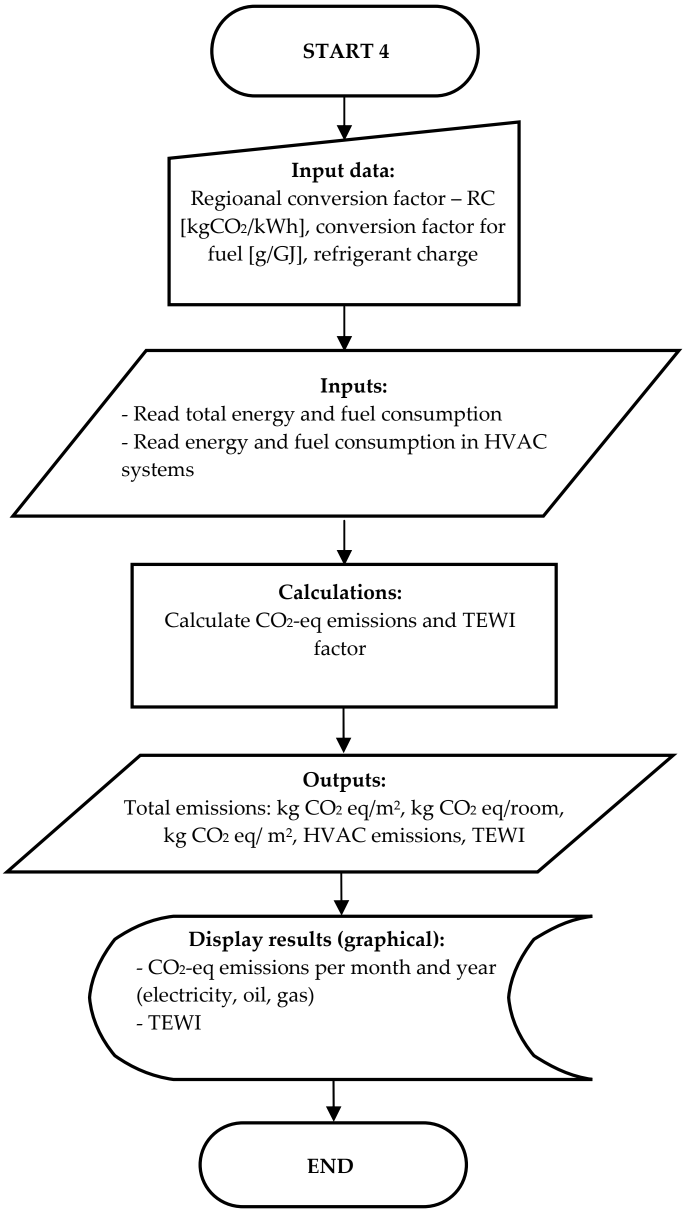


Figure 8.4. Part IV – Environmental analysis

9. CONCLUSIONS AND FUTURE WORK

This chapter summarizes the main conclusions of the research about energy performance in hotels and energy efficient solutions for HVAC systems retrofit on the Adriatic coast. Finally, some suggestions for future research are presented.

9.1. Conclusions

9.1.1. Energy use in hotels and environmental emissions

The World Summit on Sustainable Development in Johannesburg 2002, acknowledged tourism as one of the major energy-consuming sectors and requested states to integrate energy efficiency into tourism related polices. European hotels, for example, consume approximately 39TWh/year (CHOSE 2001). According to the European Environmental Agency (EEA), tourism is responsible for 5-7% of the total emissions in Europe. Depending on the source of energy (hydro-, wind-, nuclear-, oil- or coal- based) hotels can be responsible for the annual generation of up to 160 kg of carbon dioxide per square meter of area, which is equivalent to 10 tons of CO_2 per bedroom. Energy consumption for thermal systems in hotels depending on hotel category and location, is in the range of 61 - 70%. Therefore if energy efficient measures would be applied to HVAC and DHW systems, significant energy and environmental savings could be achieved, what this research has been shown.

The analysis has shown that energy consumption in hotels on the Adriatic coast is in the range of 124 to 327 kWh/m^2 and 97 to 234 kWh/m^2 for seasonal and non seasonal hotels respectively. Higher values correspond to higher hotel categories. With comparison to other Mediterranean hotels, hotels on the Adriatic coast consume less energy (25-30%). This fact can be explained with a low average yearly occupancy rate of 28% and lower energy consumption for cooling compared to, for example, Italy or Greece. Further, 65% of seasonal hotels operate heating systems only during the period April to October or do not possess heating system at all. Fifty percent of hotels with a 3 star category are not obliged to install cooling systems. However, in years to come it is expected that the number of tourists and hotels occupancy rates will grow, while tourist season will be extended to autumn and winter months. Furthermore, many hotels will upgrade their services and install cooling systems. The significance of the established benchmarks will be demonstrated in the hotels' ability to compare their performance with similar groups of hotels and to assess environmental performance, which will helps to identify and prioritise areas to manage.

A regression analysis, which is often used for studying building energy performance, was applied. Single parameter and multiple regression models have been made in order to establish correlations between energy consumption and a number of fixed hotel parameters such as the number of rooms and total floor area of the buildings. Although analysis showed that these parameters are significant for explaining energy consumption (R^2=0,43-0,73 for seasonal and 0,38-0,86 for non seasonal hotels –with total floor area as variable), hotel do differ a lot with regards to energy consumption even within the same hotel category. For example, electricity consumption in non seasonal hotels with 3 star rating goes from 29,15 to 148,88 kWh/m^2. It is thus impossible to accurately estimate the energy consumption without analysis of the hotel itself. Furthermore, it has been shown that the number of guests and the occupancy rates are significant parameters for energy consumption estimation. Therefore, these parameters should be regularly used for future analysis.

It has been estimated that the total floor area of the hotel stock is approximately 3 million m^2, among which 72% is placed on the main land, while the rest of the 28% is placed on the islands. The hotel sector consumes approximately 181 GWh of electricity (1,14% of total electricity consumed in Croatia) and 229,5 GWh of energy from heating oil and 35,36 GWh of energy from LPG. Due to energy consumption, the tourist accommodation sector (hotels, private accommodation and camps) released into the atmosphere approximately 174 kt CO_2-eq in 2002. These emissions presented approximately 0,8% of total CO_2-eq emissions in Croatia in 2002. According to the BAU scenario, the tourist accommodation sector will contribute a 0,4 % emission increase above limitations defined by Kyoto protocol by 2010. It has been shown that energy efficient HVAC and DHW system retrofit, depending on tempo, can contribute to either emission limitation to current state or to gradually decrease emissions in years to come. It is estimated that the average hotel generates approximately 69 $kgCO_2/m^2$, which is equivalent to 3,9 tCO_2/room annually (based on data from 2002). Average non seasonal hotel with a 3 star rating and 150 rooms are responsible for 585 tCO_2.

9.1.2. Modelling and Simulations

Although the Adriatic Islands and Dalmatian region have a high insolation level of 2300-2800 sunshine hours per year, the energy audit has shown that utilization of renewable energy sources (solar) in the hotel sector is on a very low level. It was recorded that only 5% of hotels have solar collectors installed. Therefore, a majority of hotels consume heating oil as a fuel for domestic hot water production and space heating, while LPG is used for cooking.

There are a number of energy efficient measures and technologies available, but they should be applied in the proper manner taking into account a number of local factors. It has been shown that a systems thinking approach in the HVAC systems and building design and system modelling are necessary in the design phase. TRNSYS is the suggested software that can help in HVAC system modelling and analysis. Three alternative systems proposed in this research have a great potential for the energy savings with regard to current and future needs for heat and cold energy. Although the solar absorption cooling system (ACS) and the seawater cooling system (SWC) are not found on the Adriatic coast jet, they should be considered as a viable alternative for the conventional vapour compression system (CS). Installations of these two systems are possible if local conditions allows the placement of a large solar collector fields or if cold seawater is available.

The simulation results have shown that energy use in existing and new hotels can be reduced significantly - in an economical fashion -, while still providing the building services that tourists need, without sacrificing comfort, health or safety. The best alternative system from an energy, environmental and economical point of view is the HPS system that can reduce energy consumption up to 17,4% in non seasonal hotels. With regards to cooling systems, the best alternative is the SWC system that can achieve up to 87% of energy and environmental savings. This system is recommended in seasonal hotels where space heating is not needed. Operation of such systems with a combination of solar collectors for domestic hot water can achieve 90,2% of energy savings compared to conventional system. Since radiant cooling system has a slow response to outside temperatures this system is recommended in hotels with a 3 stars rating where a highly controlled indoor environment is not required. However, this system will still provide a satisfactory indoor climate. Although ACS has a higher investment cost, it has been shown that with the growing trend of increasing fossil fuel prices that even that system can pay of in 5,7 years. The cost per saved kg of CO_2 varies from 0,032 for an HPS system, 0,035 for a SWC-SH system and 0,089 EUR/kgCO_2 for an ACS system. The costs of possible CO_2 savings will be an argument when emission trading is established.

9.1.3. Practical application of the study

Energy efficiency has an important role on both state, energy utility as well as on energy consumer level. Improving energy efficiency, and thereby decreasing environmental emissions, will play an important role in years to come. Croatia, as a candidate country for EU, will have to implement energy efficiency measures, not only as a consequences of EU directives (such as directive 2002/91/EC on the Energy Performance of Buildings), but also to reduce the environmental impact in its own backyard. In that way, Croatia will contribute to the reduction of greenhouse gasses emission and climate change and show its own commitments to sustainability that are in line with the Kyoto and Montreal protocols. Energy efficiency is, in fact, one of strategic issues of any country. Besides environmental impacts it can have impact on socio-economic issues as well.

This study tries to give a clear picture about energy use and environmental emissions from the hotel sector and has identified areas for possible energy and environmental savings. We hope that the data presented will be of great help for energy planning on both regional and state levels, since the tourism industry has an important share in Croatian economy and development. Hoteliers will also be able to compare their energy performance with the average hotel on the Adriatic coast and further initiate energy efficiency measures.

Since the building sector where hotels belongs is responsible for 40% of CO_2 emissions, implementation of the HOTECO methodology, or similar, for the HVAC systems retrofit in general can have a positive impact and can contribute to energy and emissions savings in the future. Approximately 50% of hotels on the Adriatic coast were built in the period 1961-1980. Today a majority of these hotels require substantial refurbishment. On the other side, during the war period a number of hotels were devastated or inhabited with refugees. The process of hotels refurbishment is still ongoing and it should be considered as a possibility for the implementation of energy efficient technologies that already exist on the market.

It is expected that the HOTECO methodology will have practical application in the hotel sector in Croatia and in other Mediterranean countries. It will be useful for both hotel management and for the building and HVAC system designers. Furthermore, the HOTECO methodology is a basis for further research in the area of the HVAC system modelling in hotels and other types of buildings. The evaluation of energy use in hotels will additionally encourage hotel management to start implementing monitoring procedure and to improve energy management of the hotel building.

According to the Ministry of Tourism, the main goals for the development of tourism are to profile Croatia as one of the best tourist destinations in the Mediterranean and Europe, and to increase earnings from tourism. In order to implement the tourism development policy in a way to achieve the set up goals, it is necessary to create new types of offerings and products in tourism. It is also imperative to raise the quality of accommodation, catering and other services in the tourist industry while protecting the environment, cultural and historical heritage. It should be clear that sustainable development of the hotel and tourist industry can not be done without special care for the environment and by association, the development of sustainable energy systems, in terms of the implementation of energy efficient technologies and renewable energy sources. Therefore, Ministry of Tourism should encourage any environmentally oriented initiative in the hotel sector and promote energy efficiency technologies. First step might be an adoption of the ecological criteria for the award of the Community eco-label to tourist accommodation service, or development of its own eco-label for tourism accommodation facilities.

9.2. Future work

The methodology presented in this thesis provides a basis for future research about energy performance in hotels. The next step would be to include detailed information about guest nights into the analysis, since it as been shown on the basis of 20 hotels that the number of guest nights has a significant impact on energy consumption in hotels. A web based application for better data collection is planned. Hotels should be encouraged to provide energy consumption data and occupancy rates for the last four years. Using this information it would be possible to establish a relationship between occupancy rates and energy consumption for each hotel. Input data should be extended to the lighting system and electrical equipment in restaurants and other facilities and detailed data on water consumption. It would be desirable to set up a measurement procedure, for example, how to determine hot and cold water consumption.

Furthermore, on the basis of the HOTECO methodology and the modelled HVAC systems, an easy to use software programme should be developed. This software should be able to set ratings for each hotel on the basis of established benchmarks and further, to analyse the best HVAC retrofit option for each hotel. The software should produce energy, environmental and economical data as well. This software would help hoteliers in decision making about HVAC system retrofit and monitoring of energy consumption. Continuous monitoring and reporting will raise their awareness about environmental emissions from hotels. With respect to the Croatian obligations to the Kyoto and Montreal protocols and EU directives, all realistic energy efficient actions will be necessary for commitment fulfilments in the years to come. A similar approach with a systems thinking and modelling could be applied to other types of buildings, such as commercial, residential or educational buildings.

NOMENCLATURE

Roman

a	Factor of infiltration	$m^3/mhPa^{2/3}$
A	Area	m^2
A_g	Glass area	m^2
A_l	Sun-exposed glass area	m^2
A_M	Total window area	m^2
b	Radiation transmission coefficient of the window and sun protection devices	-
c_p	Specific heat capacity	J/kgK
CAP	Lumped thermal capacitance of house	J/K
COP	Coefficient of performance	-
CRF	Capital recovery factor	-
E_{FA}	Electricity consumption estimated by floor area	kWh/year
E_{NR}	Electricity consumption estimated by number of guests rooms	kWh/year
$E_{FA\text{-}NR\text{-}RFA}$	Electricity consumption estimated by floor area, number of guests rooms and room floor area	kWh/year
$E_{FA\text{-}NR\text{-}GN}$	Electricity consumption estimated by floor area, number of guests rooms and guest nights	kWh/year
$E_{FA\text{-}NR\text{-}GN\text{-}OR}$	Electricity consumption estimated by floor area, number of guests rooms, guest nights and occupancy rate	kWh/year
$E_{FA\text{-}NR\text{-}GN\text{-}OR\text{-}FAR}$	Electricity consumption estimated by floor area, number of guests rooms, guest nights, occupancy	kWh/year

	rate and room floor area	
$\varepsilon \cdot C_{\min}$	Product of the effectiveness and minimum capacitance rate of load heat exchanger	W/K
FA	Total floor area of the hotel	m^2
GN	Guest nights	-
g_v	Glass surface component of window area	-
GWP	Global Warming Potential	-
i	Interest rate	-
i′	Effective interest rate	-
$I_{diff.max}$	Maximum value of diffuse radiation for the design month	W/m^2
I_{max}	Maximum value of the total radiation for the design month	W/m^2
j	Inflation rate	-
l	Length of fugue (cleft)	m
l_B	simultaneity factor of the lighting at the time concerned	-
l_M	Simultaneity factor of machines	-
LHR	Ratio of latent to total cooling load	-
$\dot{m}$	Mass of the material brought into the room or removed from in the unit of time	kg/s
$\dot{m}_i$	Mass flow rate of fluid from heat source	kg/s
$\dot{m}_o$	Mass flow rate of fluid returning to heat source	kg/s
M_{losses}	Refrigerant leakage	kg
M_{ref}	Refrigerant charge	kg
n	Number of years	-
n_p	Number of persons	-
N	Lifetime of refrigeration system	year

NR	Number of guests rooms	-
O_{FA}	Heating oil consumption estimated by floor area	litres/year
O_{NR}	Heating oil consumption estimated by number of guests rooms	litres/year
$O_{FA\text{-}NR\text{-}RFA}$	Heating oil consumption estimated by floor area, number of guests rooms and room floor area	litres/year
$O_{FA\text{-}NR\text{-}GN}$	Heating oil consumption estimated by floor area, number of guests rooms and guest nights	litres/year
$O_{FA\text{-}NR\text{-}GN\text{-}OR}$	Heating oil consumption estimated by floor area, number of guests rooms, guest nights and occupancy rate	litres/year
$O_{FA\text{-}NR\text{-}GN\text{-}OR\text{-}FAR}$	Heating oil consumption estimated by floor area, number of guests rooms, guest nights, occupancy rate and room floor area	litres/year
OR	Occupancy rate	%
p	p-level (statistically significant at level of 95% or 99% if p<0,05 or p< 0,01)	-
P	Total installed power of the lights	W
Δp	Pressure difference	Pa
P_j	Rated power of the machine j	W
q_p	Heat emission from the human body	W
$\dot{Q}_{aux}$	Auxiliary heating input to space	W
$\dot{Q}_B$	Cooling load due to illumination heat	W
$\dot{Q}_C$	Other heat supply and removal (e.g. chemical reactions).	W
$\dot{Q}_{cool}$	Rate of cooling energy removed from space	W
$\dot{Q}_{Eq}$	Heat emission from equipment	W
$\dot{Q}_{FL}$	Infiltration loses	W

$\dot{Q}_G$	Heat absorption or emission in the event of material throughput through the room (e.g. cooling water for machines)	W
$\dot{Q}_{gain}$	Time variant heat gains	W
$\dot{Q}_I$	Internal cooling load	W
$\dot{Q}_L$	Instantaneous heating load	W
$\dot{Q}_{lat}$	Rate of cooling used to reduce room humidity	W
$\dot{Q}_M$	Machine and appliance heat	W
$\dot{Q}_N$	Heating losses	W
$\dot{Q}_P$	Heat emission from persons	W
$\dot{Q}_R$	Heat flowing in from adjacent rooms via the internal surface	W
$\dot{Q}_S$	Cooling load due to radiation through windows	W
$\dot{Q}_{sens}$	Rate of sensible cooling load	W
$\dot{Q}_T$	Transmission losses	W
$\dot{Q}_{TW}$	Cooling load due to transmission through windows	W
$\dot{Q}_W$	Cooling load through external walls and roofs	W
r	Pearson correlation coefficient	-
R^2	R-square, coefficient of determination	-
RC	Regional conversion factor	kg CO_2/kWh
RFA	Room floor area	m^2
S_a	Cooling load factor for external radiation load	-
S_i	Cooling load factor for internal loads	-
SSR	Variance by regression model	-
SS_{yy}	Total variation	-
U	Heat transfer coefficient	W/m^2K
U_F	Heat transfer coefficient of the window	W/m^2K

$U \cdot A$	Overall conductance for heat loss from house	W/K
$\dot{V}$	Air flow	m^3/s
$\hat{y}$	Regression function	-
$\overline{y}$	Mean value of the function	-

Greek

γ	Forcing function	--
η	Mean motor efficiency	-
ϑ_a	Ambient temperature	^oC
ϑ_A	Outlet temperature	^oC
$\vartheta_{DC\ indoor}$	Design indoor temperature for cooling season	^oC
$\vartheta_{DC\ out}$	Design outdoor temperature for cooling season	^oC
$\vartheta_{DH\ indoor}$	Design indoor temperature for heating season	^oC
$\vartheta_{DH\ out}$	Design outdoor temperature for heating season	^oC
ϑ_E	Inlet temperature	^oC
ϑ_i	Temperature of the fluid from heat source	^oC
$\vartheta_{\max}$	Room set temperature for cooling	^oC
$\vartheta_{\min}$	Room set temperature for heating	^oC
ϑ_o	Temperature of the fluid returning to heat source	^oC
ϑ_R	Room temperature	^oC
$\overline{\vartheta}_R$	Average room temperature	^oC
ϑ_{RI}	Initial room temperature	^oC
$\Delta\vartheta_{eq}$	Equivalent temperature difference	^oC
κ	Recycling factor	-
μ_{aj}	Load factor of the machine *j* at the time in question	-
μ_B	Room load factor due to lighting	-

ρ	Density	kg/m^3

Subscripts

a	Ambient
aux	Auxiliary
cool	Cooling
B	Lighting
CRO-NS	Non seasonal hotels in Croatia
CRO3-NS	Non seasonal hotels with 3 stars in Croatia
CRO-S	Seasonal hotels in Croatia
CRO2-S	Seasonal hotels with 2 stars in Croatia
CRO3-S	Seasonal hotels with 3 stars in Croatia
CRO5&4-S	Seasonal hotels with 5 and 4 stars in Croatia
DC indoor	Design cooling indoor temperature
DC out	Design cooling outdoor temperature
DH indoor	Design heating indoor temperature
DH out	Design heating outdoor temperature
D-NS	Non seasonal hotels in Dubrovnik region
D-S	Seasonal hotels in Dubrovnik region
D3-S	Seasonal hotels with 3 stars in Dubrovnik region
E	External
Eq	Equipment
eq	Equivalent
f	Fluid
gain	Gains
i	Inlet
I	Internal
I-S	Seasonal hotels in Istria region

L	Load
Lat	Latent
M	Machine
o	Outlet
P	Person
R	Room
RI	Initial room
R-NS	Non seasonal hotels in Rijeka region
R-S	Seasonal hotels in Rijeka region
sens	Sensible
S-NS	Non seasonal hotels in Split region
S-S	Seasonal hotels in Split region
T	Transferred
W	Walls

APPENDIX I: ENERGY AUDIT QUESTIONNARIE

FSB Sveučilište u Zagrebu
Fakultet strojarstva i brodogradnje

May, 2003

Questionnaire: ENERGY USE IN HOTELS

1. GENERAL INFORMATION

1.1 Hotel

Name
Address
Phone | Fax.
Web site | E-mail
Contact person

Seasonal hotel — Yes ☐ No ☐
Open from ____ to ____

1.2 Category

DELUXE 5 * — 5* ☐ 4* ☐ 3* ☐ 2* ☐ 1* ☐

1.3 Location

City centre ☐ Suburb ☐
Close to the shore ☐ Distance from the sea ____ m

1.4 Building characteristics

	Year of constr.	Year of latest adaptation	Number of floors	Number of rooms/ number of beds	Average room area, (m2)	Average window area in the room, (m2)	Total floor area of the building (m2)	Flat or sloped roof?
Main building				/				
building 2				/				
building 3				/				
building 4				/				
Total				/				

1.6 Additional facilities

Restaurant — Yes ☐ No ☐

	Capacity (persons)	Average number of meals in season (meal/day)	Installed stoves capacity (kW)	Installed power of dishwashers (kW)	Floor area of the restaurant (m2)	Space cooling (Yes/No)	Refrigerators capacity/ refrigerant, (kW/R...)
Restaurant 1							
Restaurant 2							
Restaurant 3							
Total							

Swimming pool — Yes ☐ No ☐

Type	Closed	Open air
Number of pools		
Area, m2/ depth, m or volume, m3	/	/
Seawater of fresh water?		
Open	from to	from to
Water is heated (Yes/No)		
Heater capacity, kW		
Water consumption, m3/day		

Sports facilities — Sauna ☐ Fitness ☐ Other ____

Laundry — Yes ☐ No ☐

Installed power of laundry machines ____ kW
Water consumption ____ m3/month
Average operational time ____ h/day

Elevators

Number of elevators ____
Wight limit ____ kg
Average occupancy ____ h/day

2. ENERGY CONSUMPTION

Electricity	months	1	2	3	4	5	6	7	8	9	10	11	12	Total
Purchased power	kW													
Electricity consumption	kWh													
Cost (VAT included)	KN													

Fuel	months	1	2	3	4	5	6	7	8	9	10	11	12	Total
LPG	m3													
	KN													
Natural gas	m3													
	KN													
Diesel	Litres													
	KN													
Heating oil	Litres													
	KN													
Heat	kWh													
	KN													
Other (specify)														
	KN													

Purchased electricity covers 100% needs for electricity Yes ☐ No ☐

Tariff model:

One-tariff model ☐ Two-tariff model ☐ Three-tariff model ☐

In house production of electricity

Back up system for electricity production

diesel generator ☐ Power ___ kW

gas generator ☐ Power ___ kW

other ___

Additional production of heat Yes No ☐

Water consumption	month	1	2	3	4	5	6	7	8	9	10	11	12	Total
Fresh water	m3													
	KN													

3.COOLING SYSTEM

Is the building mechanically cooled? Yes ☐ No ☐
If answer is Yes, than answer following questions

3.1 Cooling system
Technical data

Unit		Total cooling capacity (kW)	Number of units	Producer/ production year	Model	Refrigerant
a. Centralized cold water production						
3.1	Chiller					
3.2	Heat pump					
3.3	Absorption chiller powered by gas					
3.4.	Absorption chiller powered by solar en.					
3.5.	Other (specify)					
b. Centralized cold air production						
4.1	Air handling unit					
4.2	Split units					
4.3	Window units					

Energy source

- electricity ☐
- district heating ☐
- vapour ☐
- natural gas ☐
- LPG ☐
- heating oil ☐
- solar energy ☐

Automatic regulation

Manual ☐ Combined ☐ Automatic ☐
Room temperature control ____ oC-summer ____ oC - winter
Humidity control Yes ☐ No ☐
Is there any system with cold water storage Yes ☐ No ☐
If answer is Yes, what is storage volume and capacity ____ m3 ____ kW

a) Cold water system Yes ☐ No ☐
If Yes, than answer following questions
Centralized cold water production Yes ☐ No ☐
Cold water is distributed to:

- fan coils Yes ☐ No ☐
- air handling unit Yes ☐ No ☐
- radiant panels Yes ☐ No ☐
- other ____

Condenser:

Type

- Air cooled ☐ Power ____ kW
- Evaporative ☐ Power ____ kW
- Water cooled ☐ Power ____ kW
  - Cooling tower ☐ Power ____ kW
  - Fresh water ☐ Power ____ kW
  - Seawater ☐ Power ____ kW

Waste heat utilization for:

- DHW preheating Yes ☐ No ☐
- Swimming pool heating Yes ☐ No ☐
- Other ____

b) Air cooling system Yes ☐ No

If answer is Yes then answer following questions

Air handling unit is used for:

Ventilation	Yes	☐	No	☐
Space cooling	Yes	☐	No	☐
Space heating	Yes	☐	No	☐
Humidity regulation	Yes	☐	No	☐

	Air flow, (m3/h)	Cooling capacity, (kW)	Heating capacity, (kW)	Ventilator power, (kW)	Ratio of air mixing (fresh/ return) %	Heat recovery (Yes/No)	Producer/ year of production
AHU 1							
AHU 2							
AHU 3							
AHU 4							
AHU 5							
Ventilation unit - supply							
Ventilation unit - exhaust							

Supply air temperature, oC	summer		winter	
Room temperature, oC	summer		winter	

Conditioned floor area		m2	Location	
Ventilated floor area		m2	Location	

Tape of system

One zone	☐		
Multi zone	☐	Room ventilator	☐
VAV	☐	Fan coils	☐
2-pipe	☐	Other (specify)	
4-pipe	☐		

Operation 24 h ☐ According to needs ☐

Automatic regulation

Room temperature sensor	☐	Occupancy sensor	☐
Ambient temperature sensor	☐	Economical operation	☐
Time control	☐	Heat recovery from exhaust air	☐
		Other (specify)	

4. SPACE HEATING

Heating system Yes ☐ No ☐

If answer is Yes, answer following questions

Type of system: Heating+DHW ☐ Only heating; Heating+Cooling ☐

Energy source: solar ☐ heat pump ☐ biomass ☐; LPG ☐ natural gas ☐ electricity ☐; heating oil ☐ coal ☐ other ____

Central heating Yes ☐ No ☐

Heating devices: radiators ☐ fan coils ☐

Heating season starts: ____ Ends: ____

Heat recovery? Yes ☐ No ☐

Heat storage tank Yes ☐ No ☐

Tank volume ____ m3 Storage temperature ____ oC

Possibilities for solar collectors installation? Yes ☐ No ☐

Boiler

Boiler	1	2	3	4	5	6
Model						
Capacity, kW						
Year of installation						
Fuel						

Electrical heating

Producer ____ Model ____ Year ____

Heater power ____ kW Storage tank volume ____ m3

Solar heating Yes ☐ No ☐

Producer ____ Year of production ____

Used for: space heating ☐ heating + DHW ☐; DHW ☐

Collector type: flat ☐ vacuum pipe ☐; concentrated ☐ other ☐

Collector area ____ m2

Heat storage Yes ☐ No ☐

Storage tank volume ____ m3

Heat pump

Producer ____ Model ____ Year ____

Type: air/air ☐ water/water ☐ air/water ☐

Heating capacity ____ kW

Electrical power ____ kW

5. DOMESTIC HOT WATER - DHW

Hot water is produced for:

Hotel ☐ Rooms ☐ Restaurant ☐

Other (specify) ____

Energy source:

electricity ☐ heating oil ☐ LPG ☐

other (specify) ☐ natural gas ☐ solar energy ☐

Number of units for DHW

Unit	Power, kW	Number	Volume, l	Producer	Type	Powered by:	

Type of storage tank

Electrical boiler ☐

Storage tank ☐

Storage tank with additional heater ☐

Storage tank capacity ____ m3 Number of tanks ____

Set temperature in the storage tank ____ oC

Is there any hot water consumption measurements?

Yes ☐ No ☐

DHW consumption ____ m3/h or ____ m3/day (m3/month)

6. ENVIRONMENTAL ACTIVITIES

1. Are you using renewable energy sources (solar, biomass)?
Yes No ☐
If Yes, specify which

2. Have you initiated any energy savings measures?
Yes ☐ No ☐
If Yes, specify which

3. Have you initiated any water savings measures?
Yes ☐ No ☐
If Yes, specify which

4. Waste water is discharged to:
City waste water system ☐ To the sea ☐
To the sea after treatment ☐

5. If you posses waste water treatment system, which waste water do you treat (from the kitchen, toilettes)?

6. Are you using seawater in hotel?
As a cooling water ☐ m3/year
For the swimming pool ☐ m3/year
Other (specify)

7. Do you treat swimming pool water with chlorine ?
Yes ☐ No ☐
If answer is Yes, specify how much (g/l) ?

8. If you do not use chlorine, how do you treat water in the swimming pool?

9. Did you stop using some substances harmful to the environment?
Yes ☐ No ☐
If Yes, specify which

10. Are you familiar with regulation regarding phase out of CFC and HCFC refrigerants?
Yes ☐ No ☐
Which refrigerants are you using in refrigeration and cooling equipment?

11. Do you sort a waste?
Yes ☐ No ☐
If answer is Yes, what are the categories?

12. Have you been in contact with local authorities regarding waste sorting, or some other environmental action?
Yes ☐ No ☐
Specify

13. Do you have experience with energy or environmental programme?
ISO 14000 ☐ Environmental Label ☐
Blue flag ☐ Green Globe Programme ☐

14. Do you measure and record energy consumption in the hotel?
Yes ☐ No ☐

15. Can you provide us with these information? Yes ☐ No ☐

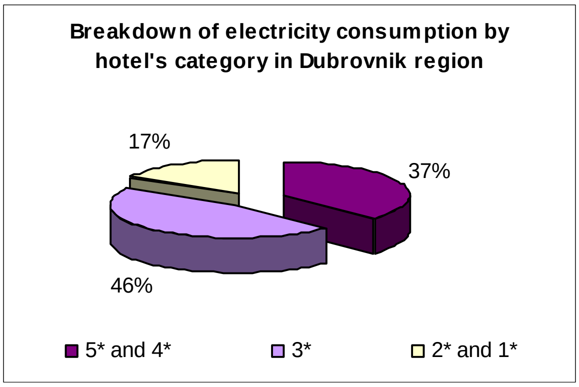
16. Are you interested in specialized courses "Energy management in hotels"?
Yes ☐ No ☐

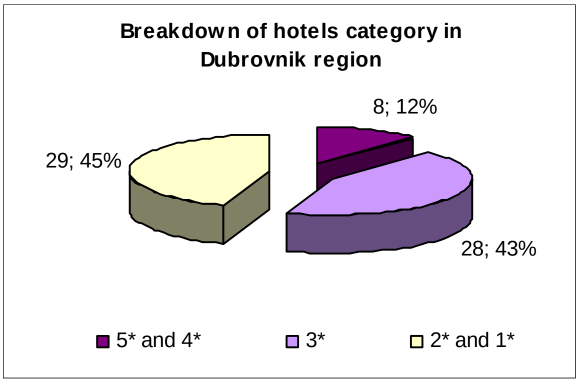
17. Are you interested in results of this research? Yes ☐ No ☐

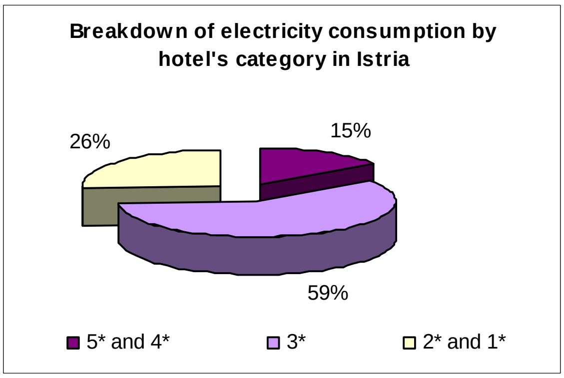
If you have any questions, please contact:

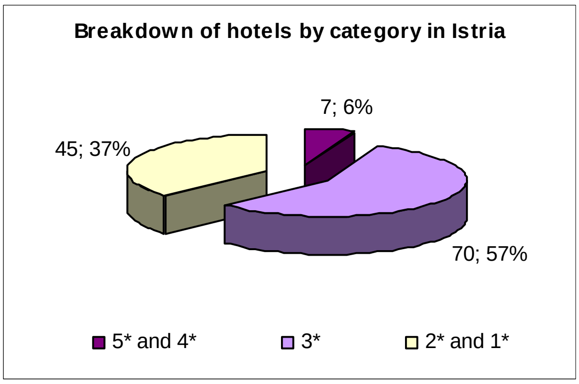
Vlasta Zanki, MSc, M.E.
Faculty of Mechanical Engineering and Naval Architecture, Ivana Lučića 5, 10000 Zagreb, e-mail: vlasta.zanki@fsb.hr

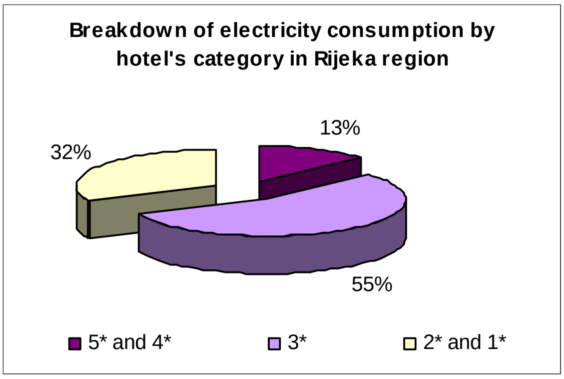
APPENDIX II: BREAKDOWN OF ELECTRICITY, OIL AND GAS CONSUMPTION BY REGION

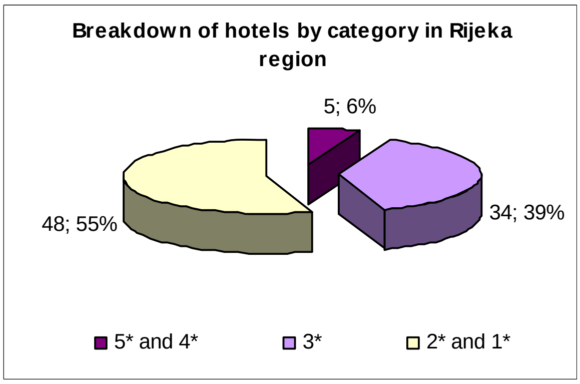


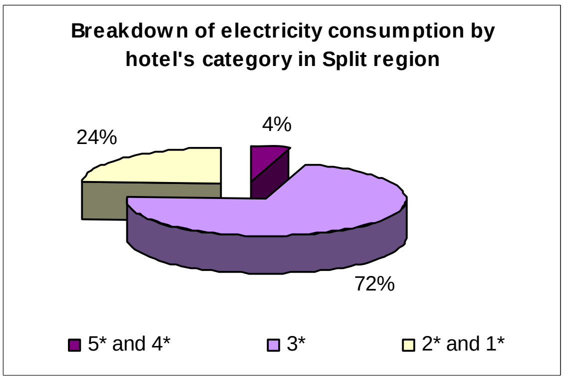


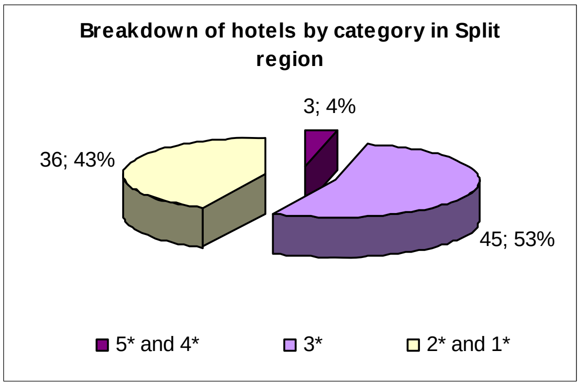


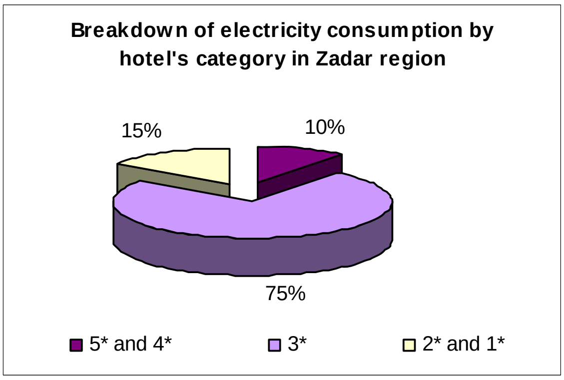


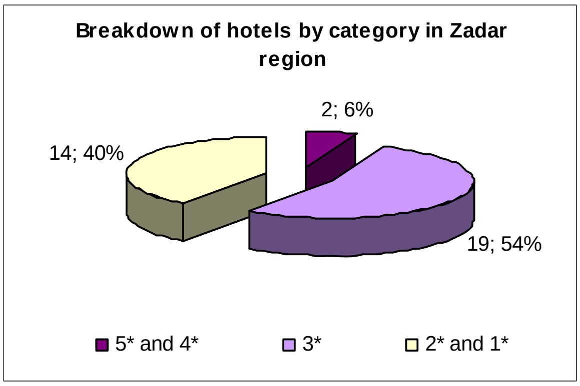

Breakdown of electricity consumption by hotel's category in Rijeka region
13%
32%
55%
5* and 4*
3*
2* and 1*

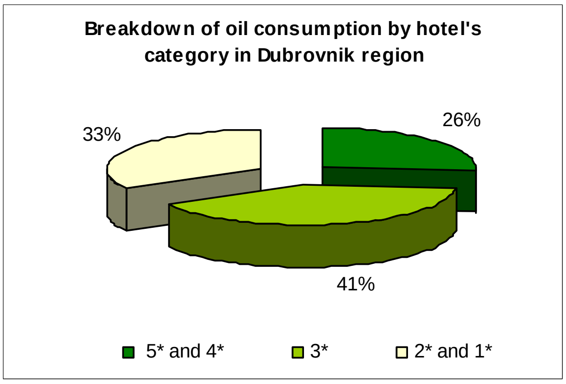

Breakdown of hotels by category in Rijeka region
5; 6%
48; 55%
34; 39%
5* and 4*
3*
2* and 1*

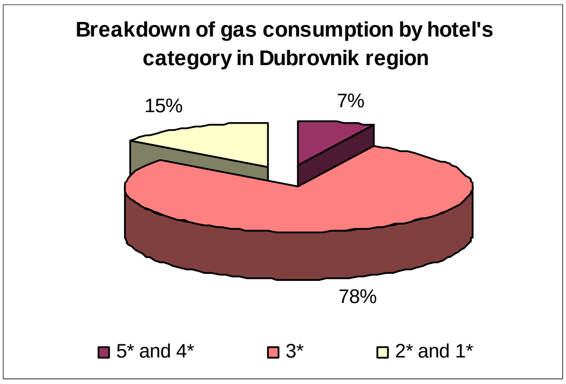

Breakdown of electricity consumption by hotel's category in Split region
4%
24%
72%
5* and 4*
3*
2* and 1*

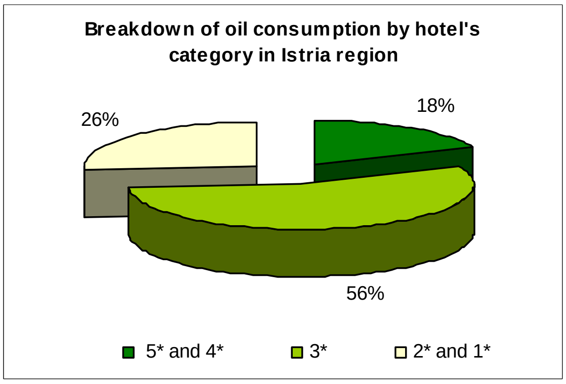

Breakdown of hotels by category in Split region
3; 4%
36; 43%
45; 53%
5* and 4*
3*
2* and 1*

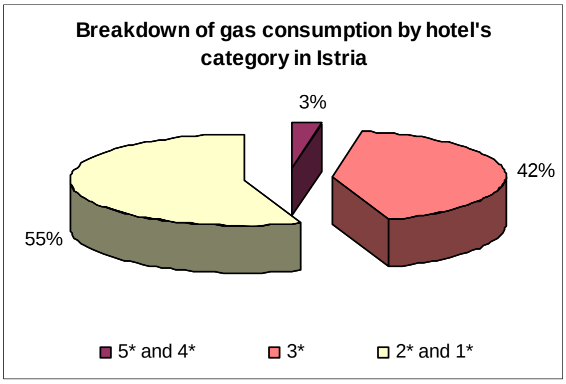

Breakdown of electricity consumption by hotel's category in Zadar region
15%
10%
75%
5* and 4*
3*
2* and 1*

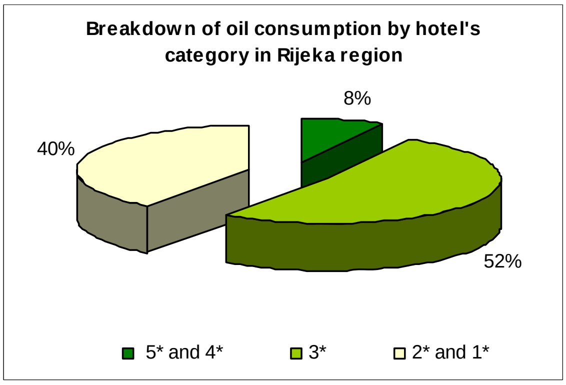

Breakdown of hotels by category in Zadar region
2; 6%
14; 40%
19; 54%
5* and 4*
3*
2* and 1*

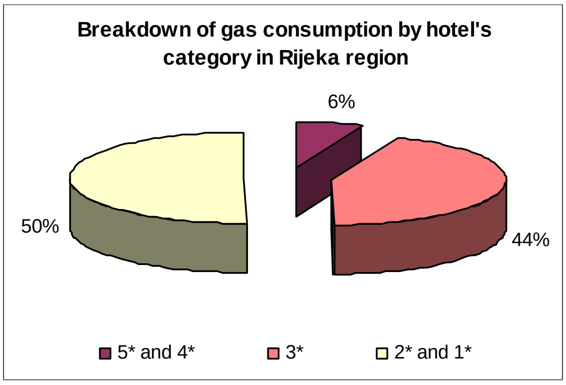

Breakdown of oil consumption by hotel's category in Dubrovnik region
33%
26%
41%
5* and 4*
3*
2* and 1*

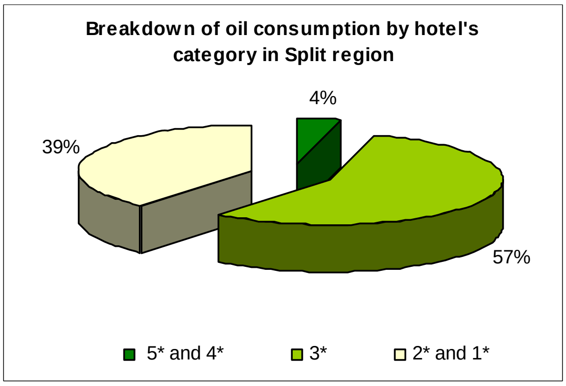

Breakdown of gas consumption by hotel's category in Dubrovnik region
15%
7%
78%
5* and 4*
3*
2* and 1*

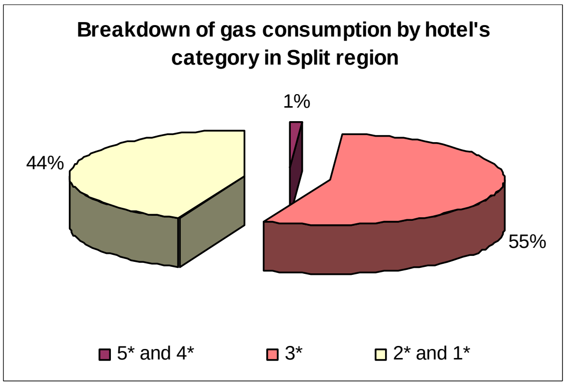

Breakdown of oil consumption by hotel's category in Istria region
26%
18%
56%
5* and 4*
3*
2* and 1*

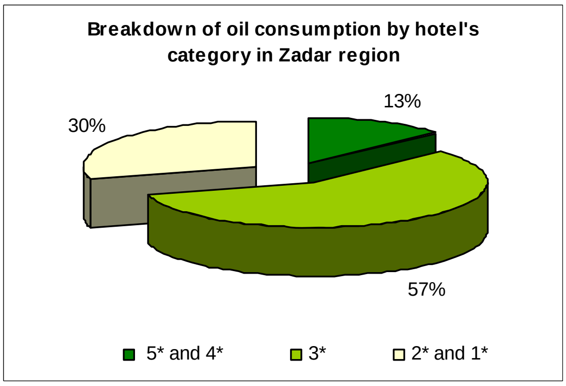

Breakdown of gas consumption by hotel's category in Istria
3%
42%
55%
5* and 4*
3*
2* and 1*

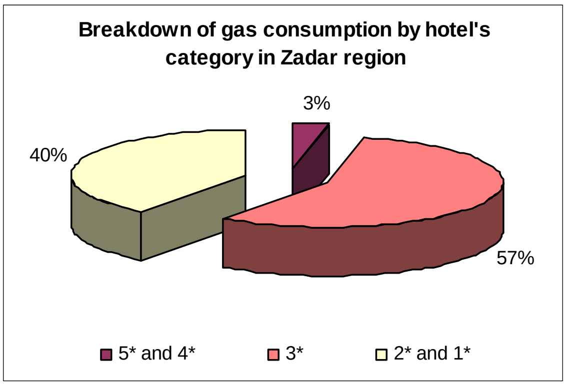

Breakdown of oil consumption by hotel's category in Rijeka region
8%
40%
52%
5* and 4*
3*
2* and 1*


Breakdown of gas consumption by hotel's category in Rijeka region
6%
50%
44%
5* and 4*
3*
2* and 1*


Breakdown of oil consumption by hotel's category in Split region
4%
39%
57%
5* and 4*
3*
2* and 1*


Breakdown of gas consumption by hotel's category in Split region
1%
44%
55%
5* and 4*
3*
2* and 1*


Breakdown of oil consumption by hotel's category in Zadar region
13%
30%
57%
5* and 4*
3*
2* and 1*


Breakdown of gas consumption by hotel's category in Zadar region
3%
40%
57%
5* and 4*
3*
2* and 1*

APPENDIX III: TRNSYS COMPONENTS USED IN THE DEVELOPMENT OF THE MODELS

TYPE 1: Solar Collector; Quadratic Efficiency, 2nd Order Incidence Angle Modifiers

This component models the thermal performance of a flat-plate solar collector. The solar collector array may consist of collectors connected in series and in parallel. The thermal performance of the collector array is determined by the number of modules in series and the characteristics of each module. The user must provide results from standard tests of collector efficiency versus a ratio of fluid temperature minus ambient temperature to solar radiation. The fluid temperature may be the inlet temperature, the average temperature, or the outlet temperature. In TYPE 1, there are 5 possibilities for considering the effects of off-normal solar incidence. In this instance of TYPE 1, a second order quadratic function is used to compute the incidence angle modifier. The coefficients of the function are supplied by an ASHRAE or equivalent test.

TYPE 2: On-off differential controller

The on/off differential controller generates a control function γ_o that can take values of 0 or 1. The value of γ_o is chosen as a function of the difference between upper and lower temperatures, T_H and T_L, compared with two dead band temperature differences, ΔT_H and ΔT_L. The new value of γ_o is dependent on whether γ_i is equal to 0 ot to 1. Usually, γ_o is connected to γ_i giving a hysteresis effect.

TYPE 3: Pump/ventilator

The pump model computes a mass flow rate using a variable control function, which must be between 0 and 1, and a fixed maximum flow capacity. Pump power consumption is also calculated, either as a linear function of mass flow rate or by a user-defined relationship between mass flow rate and power consumption. In many systems, there is no continuous flow modulation and the control function is either 0 or 1. In that case, the outlet flow rate and the power used are either both zero or both at their maximum values. Pump or fan power consumption may also be calculated.

TYPE 4: Stratified hot water storage tank

The thermal performance of a fluid – filled stratified storage tank is modelled by assuming that the tank consists of N $(N \leq 15)$ fully mixed equal volume segments. The degree of stratification is determined by the value N. If N is equal 1, the storage tank is modelled as a fully-mixed tank with no stratification effects. Options of fixed or variable inlets, unequal size nodes, temperature dead band at heater thermostats, incremental loss coefficients, and losses to flue gas of auxiliary heater are all available.

The mode that describes the height of inlet and outlet node is chosen. Two electric resistance-heating elements that are subject to temperature and time control are included in model as a back up system. The control option allows their utilization during selected periods. The electric resistance heaters may operate in two modes. The first mode, a master/slave relationship, allows the bottom heating element to be enabled only when the top element is satisfied. In this control mode, it is impossible for both electric heaters to be on simultaneously. The second mode allows both heaters to be on. This allows quicker heating of the storage tank, but at a significantly higher electrical demand. If no electric heating elements are present in the tank to be modelled, the maximum auxiliary heating rate is set to zero.

The auxiliary heaters employ a temperature dead band. The heater is enabled if the temperature of the node containing the thermostat is less than T_{set} -ΔT_{db} or if it was on for the previous interval and the thermostat temperature is less than T_{set}. If the lower heater meets these criteria and the master/slave relationship is employed, a check will be made to see if the upper electric heater is on before enabling the second heating element.

In order to take into account boiling effects, the boiling temperature of the fluid should be supplied, that is calculated with model of a pressure relief valve. Venting will release sufficient energy to keep the tank at the boiling temperature. The loss of mass due to venting has been neglected.

The model calculates the overall loss from any node above and including auxiliary heater occurs from the exterior and interior of the tank. The overall conductance for a heat loss to the flue when the heater is not operating, $(UA)_f$ is based upon an temperature of the environment. This conductance is divided among the nodes above and including the heater. An assumption, employed in this model, is to assume that the fluid streams flowing up and down from each node are fully mixed before they enter each segment.

TYPE 5: Counter Flow Heat Exchanger

A zero capacitance sensible heat exchanger is modelled in various configurations (parallel, counter, various cross flow configurations and shell and tube models). In this instance, a counter flow heat exchanger is modelled. Given the hot and cold side inlet temperatures and flow rates, the effectiveness is calculated for a given fixed value of the overall heat transfer coefficient.

TYPE 6: On-Off Auxiliary Heater

An auxiliary heater is modelled to elevate the temperature of a flow stream using either internal control, external control or a combination of both types of control. The heater is designed to add heat to the flow stream at a user-designated rate (Q_{max}) whenever the external control input γ is equal to 1 and the heater outlet temperature is less than a user-specified maximum (T_{set}). By specifying a constant value of the control function of γ equal 1 and specifying a sufficiently large value of Q_{max}, this routine will perform like a domestic hot water auxiliary with internal control to maintain an outlet temperature of T_{set}. By providing a control function of 0 or 1 from a thermostat or controller, TYPE 6 routine will perform like a furnace adding heat at a rate of Q_{max} but not exceeding an outlet temperature of T_{set}.

TYPE 8: Three-stage Room Thermostat

A three stage room thermostat is modelled to output three on/off control functions that can be used to control a system having a solar heat source, an auxiliary heater, and a cooling system. This controller is to be used to control systems on temperature levels and is compatible with the TYPE 12 mode 4 and the TYPE 19 mode 2 loads. The controller commands cooling at high room temperatures, first stage (solar source) heating at lower room temperatures, and second stage (auxiliary source) heating at even lower room temperatures. The user has the option, through parameter ISTG, to disable first stage heating during second stage heating and the capability, through parameter T_{min}, to disable first stage heating whenever the source temperature is too low. Although solar heating is specified in the description of this component, any three-stage heating system may be controlled using the TYPE 8 routine.

In many heating applications, the desired room temperature may depend on the time of day or the day of the week. This variation of the heating on/off temperatures is modelled in this instance of TYPE 8 using an optional "set back" control function γ_{set} and "set back" temperature difference ΔT_{set} . When this option is used, the usual temperatures at which first and second stage heating are commanded are both reduced by γ_{set} x ΔT_{set}. Typically, γ_{set} is calculated by a TYPE 14 time-dependent function generator.

In this instance, a hysteresis effects can be included in the model by supplying the optional dead band temperature difference ΔT_{db}. A single value of ΔT_{db}, if supplied, is applied to all three output control functions.

TYPE 11: Tee Piece, Flow Diverter, Flow Mixer, Tempering Valve

The use of pipe tee-pieces, mixers, and diverters which are subject to external control is often necessary in thermal systems. This component has ten modes of operation. Modes 1 through 5 are normally used for fluids with only one important property, such as temperature. Modes 6 through 10 are for fluids, such as moist air, with two important properties, such as temperature and humidity.

Tee Piece: This instance of the TYPE 11 model uses mode 1 to model a tee piece in which two inlet liquid streams are mixed together into a single liquid outlet stream.

Tempering Valve: This variant of the TYPE 11 model uses mode 4 or mode 5 to model a temperature controlled liquid flow diverter. In mode 4 the entire flow stream is sent through outlet 1 when $T_h < T_i$. In mode 5, the entire flow stream is sent through outlet 2 under these circumstances.

TYPE 12: Energy/Degree-Hour House: Temperature Level Control

The energy/(degree-day) concept has been shown to be useful in estimating the monthly heating load of a structure (ASHRAE). In this space heating load model, the energy/(degree-day), or more appropriately the energy/(degree-hour), concept is extended to estimate the hour by hour heating load of a structure. The model provides an estimate of the space heating load with minimal computational effort.

There are four modes of operation in TYPE 12. Models 1,2, and 3 are compatible with energy rate control. Mode 4 used in this thesis models a single lumped capacitance house compatible with temperature level control. Normally heating and/or cooling equipment and a controller are used in conjunction with this mode.

TYPE 14: Time Dependent Forcing Function

In a transient simulation, it is sometimes convenient to employ a time dependent forcing function which has a behaviour characterized by a repeated pattern. The pattern of the forcing function is established by a set of discrete data points indicating the value of the function at various times throughout one cycle. Linear interpolation is provided in order to generate a continuous forcing function from the discrete data. The cycle will repeat every N hours where N is the last value of time specified.

TYPE 24: Quantity Integrator

This component integrates a series of quantities over a period of time. Each quantity integrator can have up to, but no more than 500 inputs. TYPE 24 is able to reset periodically throughout the simulation either after a specified number of hours or after each month of the year.

TYPE 53: Parallel Chillers

This component models the thermal performance and power requirements of identical motor driven chillers that are installed in parallel. Each of the operating chillers is assumed to be controlled to maintain a specified chilled water supply temperature through modulation of the compressor capacity (either vane control or variable speed). The inputs to the component are the temperatures and total flow rates of the evaporator and condenser water, the desired chilled water set point, and the total number of chillers operating. The flow rates are divided equally between each of the operating chillers so as to give identical loading and heat rejection for each chiller.

The model relies on an empirical curve-fit to performance data. The user must create an external file containing performance data for a single chiller. The component parameter list specifies the Fortran logical unit associated with the data file and the number of operating points in the file. Each line of input in the data file has three items. "X" the ratio of chiller load to a specified design load, "Y" the ratio of the temperature difference between the condenser water outlet and the evaporator water outlet relative to a specified design temperature difference, and "Z", the ratio of the measured power relative to the power at the specified design conditions.

TYPE 65: Online graphical plotter with output file

The online graphics component is used to display selected system variables while the simulation is progressing. This component is highly recommended and widely used since it provides valuable variable information and allows users to immediately see if the system is not performing as desired. The selected variables will be displayed in a separate plot window on the screen.

TYPE 107: Hot Water-Fired Single-Effect Absorption Chiller

Type107 uses a normalized catalogue data lookup approach to model a single-effect hot-water fired absorption chiller. “Hot Water-Fired” indicates that the energy supplied to the machine’s generator comes from a hot water stream. Because the data files are normalized, the user may model any size chiller using a given set of data files.

TYPE 109: Data Reader and Radiation Processor

This component serves the main purpose of reading weather data at regular time intervals from a data file, converting it to a desired system of units and processing the solar radiation data to obtain tilted surface radiation and angle of incidence for an arbitrary number of surfaces.

In this mode, TYPE 109 reads a weather data file in the standard TMY2 format. The TMY2 format is used by the National Solar Radiation Data Base (USA) but TMY2 files can be generated from many programs, such as Meteonorm (REF).

APPENDIX IV: TRNSYS DECK FILES

Conventional cooling system (CS)

```
VERSION 16
*******************************************************************************
*** TRNSYS input file (deck) generated by Trnsys Studio
*******************************************************************************
*** Control cards
*******************************************************************************
* START, STOP and STEP
CONSTANTS 3
START=3624
STOP=6192
STEP=0.027777778
* User defined CONSTANTS

SIMULATION      START    STOP     STEP     ! Start time        End time  Time step
TOLERANCES 0.001 0.001                     ! Integration        Convergence
LIMITS 30 30 30                            ! Max iterations     Max warnings      Trace limit
DFQ 1                                      ! TRNSYS numerical integration solver method
WIDTH 80                                   ! TRNSYS output file width, number of characters
LIST                                       ! NOLIST statement
                                           ! MAP statement
SOLVER 0 1 1                               ! Solver statement   Minimum relaxation factor   Maximum
relaxation factor
NAN_CHECK 0                                ! Nan DEBUG statement
OVERWRITE_CHECK 0                          ! Overwrite DEBUG statement
EQSOLVER 0                                 ! EQUATION SOLVER statement

* Model "TMY" (Type 109)
*
UNIT 2 TYPE 109    TMY
*$UNIT_NAME TMY
*$MODEL .\Weather Data Reading and Processing\Standard Format\TMY2\Type109-TMY2.tmf
*$POSITION 107 181
*$LAYER Main #
PARAMETERS 4
2                   ! 1 Data Reader Mode
65                  ! 2 Logical unit
4                   ! 3 Sky model for diffuse radiation
1                   ! 4 Tracking mode
INPUTS 3
0,0                 ! [unconnected] Ground reflectance
0,0                 ! [unconnected] Slope of surface
0,0                 ! [unconnected] Azimuth of surface
*** INITIAL INPUT VALUES
0.2 45 0.0
*** External files
ASSIGN "D:\Vlasta 2005\PhD Vlasta\SimTRNSYS\PhD\HR-Split-133340.tm2" 65
*|? Weather data file |1000
*------------------------------------------------------------------------------
```

```
* Model "Hotel" (Type 12)
*
UNIT 3 TYPE 12      Hotel
*$UNIT_NAME Hotel
*$MODEL .\Loads and Structures\Single Zone Models\Energy (Degree Day) Space Load (Type12)\Temperature
Level Control\Type12c.tmf
*$POSITION 258 181
*$LAYER Main #
PARAMETERS 7
4                   ! 1 Temperature level control
125999.996662             ! 2 Overall conductance of house
750000              ! 3 House thermal capacitance
10                  ! 4 Initial room temperature
4.19                ! 5 Specific heat of source fluid
3599.999905               ! 6 Effectiveness-Cmin product
0.23                ! 7 Latent heat ratio
INPUTS 6
0,0                 ! [unconnected] Inlet temperature
0,0                 ! [unconnected] Inlet flow rate
2,1                 ! TMY:Ambient temperature ->Ambient temperature
0,0                 ! [unconnected] Internal gains
0,0                 ! [unconnected] Auxiliary heat input
10,5                ! Chillers:Chilled water load ->Cooling input
*** INITIAL INPUT VALUES
0 0 10 0.0 0.0 0.0
*------------------------------------------------------------------------------

* Model "Thermostat" (Type 8)
*
UNIT 4 TYPE 8       Thermostat
*$UNIT_NAME Thermostat
*$MODEL .\Controllers\3-Stage Room Thermostat\w_ heating set back and temp deadband\Type8b.tmf
*$POSITION 393 181
*$LAYER Main #
PARAMETERS 8
5                   ! 1 Nb. of oscillations permitted
0                   ! 2 1st stage heating in 2nd stage?
20.00               ! 3 Minimum primary source temperature
26                  ! 4 Temperature for cooling
21                  ! 5 1st stage heating temperature
15                  ! 6 2nd stage heating temperature
0                   ! 7 Heating set back temperature difference
0                   ! 8 Temperature dead band
INPUTS 3
3,4                 ! Hotel: Average house temperature ->Room temperature
0,0                 ! [unconnected] 1st stage source temperature
0,0                 ! [unconnected] Set back control function
*** INITIAL INPUT VALUES
20.0 30 0
*------------------------------------------------------------------------------

* Model "Ventilator" (Type 3)
*
UNIT 5 TYPE 3       Ventilator
*$UNIT_NAME Ventilator
*$MODEL .\Hydronics\Pumps\Single Speed\Type3b.tmf
*$POSITION 171 405
*$LAYER Main #
PARAMETERS 5
108000              ! 1 Maximum flow rate
```

```
1.005                   ! 2 Fluid specific heat
21599.999428                    ! 3 Maximum power
0.05                    ! 4 Conversion coefficient
0.5                     ! 5 Power coefficient
INPUTS 3
2,1                     ! TMY:Ambient temperature ->Inlet fluid temperature
0,0                     ! [unconnected] Inlet mass flow rate
4,3                     ! Thermostat:Control signal for cooling ->Control signal
*** INITIAL INPUT VALUES
10 100.0 1.0
*------------------------------------------------------------------------------


* Model "Pump-cold water" (Type 3)
*
UNIT 6 TYPE 3    Pump-cold water
*$UNIT_NAME Pump-cold water
*$MODEL .\Hydronics\Pumps\Single Speed\Type3b.tmf
*$POSITION 319 287
*$LAYER Main #
PARAMETERS 5
56160.001373                    ! 1 Maximum flow rate
4.190                   ! 2 Fluid specific heat
14126.399626                    ! 3 Maximum power
0.05                    ! 4 Conversion coefficient
0.5                     ! 5 Power coefficient
INPUTS 3
0,0                     ! [unconnected] Inlet fluid temperature
0,0                     ! [unconnected] Inlet mass flow rate
4,3                     ! Thermostat:Control signal for cooling ->Control signal
*** INITIAL INPUT VALUES
20.0 100.0 1.0
*------------------------------------------------------------------------------

* Model "Chillers" (Type 53)
*
UNIT 10 TYPE 53   Chillers
*$UNIT_NAME Chillers
*$MODEL .\HVAC\Parallel Chillers\Type53.tmf
*$POSITION 257 352
*$LAYER Main #
PARAMETERS 11
0.85                    ! 1 Overall motor efficiency
3599999.733642                  ! 2 Single chiller capacity
1799.999867                     ! 3 Chiller surge limit
67                      ! 4 Logical unit
17                      ! 5 Number of data points
349199.974163                   ! 6 Design load for data
31.36                   ! 7 Design temperature difference
35.2                    ! 8 Design power consumption
1.005                   ! 9 Condenser water specific heat
4.190                   ! 10 Evaporator water specific heat
1                       ! 11 Print indicator
INPUTS 6
0,0                     ! [unconnected] Chilled water set temperature
0,0                     ! [unconnected] Evaporator inlet temperature
0,0                     ! [unconnected] Evaporator flow rate
5,1                     ! Ventilator: Outlet fluid temperature ->Condenser inlet temperature
5,2                     ! Ventilator: Outlet flow rate ->Condenser flow rate
0,0                     ! [unconnected] Number of operating chillers
```

```
*** INITIAL INPUT VALUES
7 12 56160.001373 10 108000 3
*** External files
ASSIGN "ChillerAirCarrierAquaSnap30RA100.dat.txt" 67
*|? Which file contains the chiller performance data? |1000
*------------------------------------------------------------------------------

* EQUATIONS "Sum"
*
EQUATIONS 2
PSumm = [5,3]+[6,3]
QoSumm = [3,8]+[3,7]
*$UNIT_NAME Sum
*$LAYER Main
*$POSITION 431 266

*------------------------------------------------------------------------------

* Model "Integrator" (Type 24)
*
UNIT 8 TYPE 24       Integrator
*$UNIT_NAME Integrator
*$MODEL .\Utility\Integrators\Quantity Integrator\Type24.tmf
*$POSITION 541 265
*$LAYER Main #
PARAMETERS 2
STOP                    ! 1 Integration period
0                       ! 2 Relative or absolute start time
INPUTS 4
PSumm                   ! Sum:PSumm ->Input to be integrated-1
10,6                    ! Chillers:Total chiller power ->Input to be integrated-2
10,5                    ! Chillers:Chilled water load ->Input to be integrated-3
QoSumm                  ! Sum:QoSumm ->Input to be integrated-4
*** INITIAL INPUT VALUES
0.0 0.0 0.0 0.0
*------------------------------------------------------------------------------

* Model "Monitoring-1" (Type 65)
*
UNIT 11 TYPE 65     Monitoring-1
*$UNIT_NAME Monitoring-1
*$MODEL .\Output\Online Plotter\Online Plotter With File\TRNSYS-Supplied Units\Type65a.tmf
*$POSITION 502 171
*$LAYER Main #
PARAMETERS 12
2                       ! 1 Nb. of left-axis variables
1                       ! 2 Nb. of right-axis variables
0                       ! 3 Left axis minimum
40                      ! 4 Left axis maximum
0.0                     ! 5 Right axis minimum
8                       ! 6 Right axis maximum
1                       ! 7 Number of plots per simulation
12                      ! 8 X-axis gridpoints
0                       ! 9 Shut off Online w/o removing
68                      ! 10 Logical Unit for output file
2                       ! 11 Output file units
0                       ! 12 Output file delimiter
INPUTS 3
2,1                     ! TMY:Ambient temperature ->Left axis variable-1
3,4                     ! Hotel:Average house temperature ->Left axis variable-2
```

```
10,8                    ! Chillers:COP ->Right axis variable
*** INITIAL INPUT VALUES
Tamb Troom COP
LABELS  3
""
""
"Graph 1"
*** External files
ASSIGN "House.plt" 68
*|? What file should the online print to? |1000
*------------------------------------------------------------------------------

* Model "Monitoring-2" (Type 65)
*
UNIT 12 TYPE 65     Monitoring-2
*$UNIT_NAME Monitoring-2
*$MODEL .\Output\Online Plotter\Online Plotter With File\TRNSYS-Supplied Units\Type65a.tmf
*$POSITION 460 396
*$LAYER Main #
PARAMETERS 12
2                       ! 1 Nb. of left-axis variables
1                       ! 2 Nb. of right-axis variables
0.0                     ! 3 Left axis minimum
60                      ! 4 Left axis maximum
0.0                     ! 5 Right axis minimum
8                       ! 6 Right axis maximum
1                       ! 7 Number of plots per simulation
12                      ! 8 X-axis gridpoints
0                       ! 9 Shut off Online w/o removing
69                      ! 10 Logical Unit for output file
2                       ! 11 Output file units
0                       ! 12 Output file delimiter
INPUTS 3
10,1                    ! Chillers:Evaporator outlet temperature ->Left axis variable-1
10,3                    ! Chillers:Condenser outlet temperature ->Left axis variable-2
0,0                     ! [unconnected] Right axis variable
*** INITIAL INPUT VALUES
Evaporator Condenser COP
LABELS  3
"Temperatures"
"Heat transfer rates"
"Graph 1"
*** External files
ASSIGN "Evap.plt" 69
*|? What file should the online print to? |1000
*------------------------------------------------------------------------------

* Model "Ploter" (Type 25)
*
UNIT 7 TYPE 25       Ploter
*$UNIT_NAME Ploter
*$MODEL .\Output\Printer\TRNSYS-Supplied Units\Type25a.tmf
*$POSITION 630 266
*$LAYER Main #
PARAMETERS 10
1                       ! 1 Printing interval
START                   ! 2 Start time
STOP                    ! 3 Stop time
66                      ! 4 Logical unit
2                       ! 5 Units printing mode
```

```
0                       ! 6 Relative or absolute start time
-1                      ! 7 Overwrite or Append
-1                      ! 8 Print header
0                       ! 9 Delimiter
1                       ! 10 Print labels
INPUTS 4
8,3                     ! Integrator:Result of integration-3 ->Input to be printed-1
8,1                     ! Integrator:Result of integration-1 ->Input to be printed-2
8,2                     ! Integrator:Result of integration-2 ->Input to be printed-3
8,4                     ! Integrator:Result of integration-4 ->Input to be printed-4
*** INITIAL INPUT VALUES
CollingEnergyEvap PPump PChiller CollingEnergyHouse
*** External files
ASSIGN "EnergijeHladenja.out" 66
*|? Output File for printed results |1000
*------------------------------------------------------------------------------

END
```

Conventional heating system (CS)

```
*******************************************************************************
*** TRNSYS input file (deck) generated by Trnsys Studio
*******************************************************************************
*** Control cards
*******************************************************************************
* START, STOP and STEP
CONSTANTS 3
START=0
STOP=8760
STEP=0.055555557
* User defined CONSTANTS

SIMULATION        START    STOP      STEP      ! Start time             End time  Time step
TOLERANCES 0.001 0.001                         ! Integration            Convergence
LIMITS 30 30 30                                ! Max iterations       Max warnings        Trace limit
DFQ 1                                          ! TRNSYS numerical integration solver method
WIDTH 80                                       ! TRNSYS output file width, number of characters
LIST                                           ! NOLIST statement
                                               ! MAP statement
SOLVER 0 1 1                                   ! Solver statement    Minimum relaxation factor      Maximum
relaxation factor
NAN_CHECK 0                                    ! Nan DEBUG statement
OVERWRITE_CHECK 0                              ! Overwrite DEBUG statement
EQSOLVER 0                                     ! EQUATION SOLVER statement

* Model "Hotel" (Type 12)
*
UNIT 16 TYPE 12     Hotel
*$UNIT_NAME Hotel
*$MODEL .\Loads and Structures\Single Zone Models\Energy (Degree Day) Space Load (Type12)\Temperature
Level Control\Type12c.tmf
*$POSITION 279 160
*$LAYER Main #
PARAMETERS 7
4                    ! 1 Temperature level control
89999.997616                 ! 2 Overall conductance of house
750000               ! 3 House thermal capacitance
10                   ! 4 Initial room temperature
4.19                 ! 5 Specific heat of source fluid
68745.598179                 ! 6 Effectiveness-Cmin product
0.23                 ! 7 Latent heat ratio
INPUTS 6
26,1                 ! Pump-1:Outlet fluid temperature ->Inlet temperature
26,2                 ! Pump-1:Outlet flow rate ->Inlet flow rate
19,1                 ! TMY: Ambient temperature ->Ambient temperature
0,0                  ! [unconnected] Internal gains
0,0                  ! [unconnected] Auxiliary heat input
0,0                  ! [unconnected] Cooling input
*** INITIAL INPUT VALUES
0 0 10 0.0 0.0 0.0
*------------------------------------------------------------------------------

* Model "Thermostat-1" (Type 8)
*
UNIT 17 TYPE 8       Thermostat-1
*$UNIT_NAME Thermostat-1
*$MODEL .\Controllers\3-Stage Room Thermostat\w_ heating set back and temp deadband\Type8b.tmf
```

```
*$POSITION 415 161
*$LAYER Main #
PARAMETERS 8
5                    ! 1 Nb. of oscillations permitted
0                    ! 2 1st stage heating in 2nd stage?
20.0                 ! 3 Minimum primary source temperature
32                   ! 4 Temperature for cooling
24                   ! 5 1st stage heating temperature
20                   ! 6 2nd stage heating temperature
0                    ! 7 Heating set back temperature difference
2                    ! 8 Temperature dead band
INPUTS 3
16,4                 ! Hotel:Average house temperature ->Room temperature
0,0                  ! [unconnected] 1st stage source temperature
0,0                  ! [unconnected] Set back control function
*** INITIAL INPUT VALUES
20.0 30 0
*------------------------------------------------------------------------------

* Model "Monitoring" (Type 65)
*
UNIT 18 TYPE 65     Monitoring
*$UNIT_NAME Monitoring
*$MODEL .\Output\Online Plotter\Online Plotter With File\TRNSYS-Supplied Units\Type65a.tmf
*$POSITION 556 169
*$LAYER Main #
PARAMETERS 12
2                    ! 1 Nb. of left-axis variables
2                    ! 2 Nb. of right-axis variables
-10                  ! 3 Left axis minimum
30                   ! 4 Left axis maximum
0.0                  ! 5 Right axis minimum
200000               ! 6 Right axis maximum
1                    ! 7 Number of plots per simulation
12                   ! 8 X-axis gridpoints
0                    ! 9 Shut off Online w/o removing
69                   ! 10 Logical Unit for output file
2                    ! 11 Output file units
0                    ! 12 Output file delimiter
INPUTS 4
19,1                 ! TMY:Ambient temperature ->Left axis variable-1
16,4                 ! Hotel:Average house temperature ->Left axis variable-2
22,1                 ! Integrator-1:Result of integration ->Right axis variable-1
23,1                 ! Integrator-2:Result of integration ->Right axis variable-2
*** INITIAL INPUT VALUES
Tamb Troom EnergyHeater EnergyPump
LABELS  3
"Temperatures"
""
"Grijanje_Kotlom"
*** External files
ASSIGN "GrijanjeKotlomSustav2.plt" 69
*|? What file should the online print to? |1000
*------------------------------------------------------------------------------

* Model "TMY" (Type 109)
*
UNIT 19 TYPE 109   TMY
*$UNIT_NAME TMY
*$MODEL .\Weather Data Reading and Processing\Standard Format\TMY2\Type109-TMY2.tmf
```

```
*$POSITION 169 161
*$LAYER Main #
PARAMETERS 4
2                    ! 1 Data Reader Mode
70                   ! 2 Logical unit
4                    ! 3 Sky model for diffuse radiation
1                    ! 4 Tracking mode
INPUTS 3
0,0                  ! [unconnected] Ground reflectance
0,0                  ! [unconnected] Slope of surface
0,0                  ! [unconnected] Azimuth of surface
*** INITIAL INPUT VALUES
0.2 45 0.0
*** External files
ASSIGN "C:\Program Files\Trnsys16\Weather\Meteonorm\Europe\HR-Split-133340.tm2" 70
*|? Weather data file |1000
*------------------------------------------------------------------------------

* Model "Pump-2" (Type 3)
*
UNIT 20 TYPE 3     Pump-2
*$UNIT_NAME Pump-2
*$MODEL .\Hydronics\Pumps\Single Speed\Type3b.tmf
*$POSITION 458 371
*$LAYER Main #
PARAMETERS 5
72000                ! 1 Maximum flow rate
4.190                ! 2 Fluid specific heat
8999.999762                    ! 3 Maximum power
0.05                 ! 4 Conversion coefficient
0.5                  ! 5 Power coefficient
INPUTS 3
24,1                 ! Storage tank:Temperature to heat source ->Inlet fluid temperature
24,2                 ! Storage tank:Flowrate to heat source ->Inlet mass flow rate
25,2                 ! Thermostat-2:Control signal for 2nd stage heating ->Control signal
*** INITIAL INPUT VALUES
12 5000 0
*------------------------------------------------------------------------------

* Model "Boiler" (Type 6)
*
UNIT 21 TYPE 6     Boiler
*$UNIT_NAME Boiler
*$MODEL .\HVAC\Auxiliary Heaters\Type6.tmf
*$POSITION 555 371
*$LAYER Main #
PARAMETERS 4
1979999.853503                 ! 1 Maximum heating rate
4.19                 ! 2 Specific heat of fluid
0.0                  ! 3 Overall loss coefficient for heater during operation
1                    ! 4 Efficiency of auxiliary heater
INPUTS 5
20,1                 ! Pump-2:Outlet fluid temperature ->Inlet fluid temperature
20,2                 ! Pump-2:Outlet flow rate ->Fluid mass flow rate
25,2                 ! Thermostat-2:Control signal for 2nd stage heating ->Control Function
0,0                  ! [unconnected] Set point temperature
0,0                  ! [unconnected] Temperature of surroundings
*** INITIAL INPUT VALUES
20.0 100.0 1 55 20.0
*------------------------------------------------------------------------------
```

```
* Model "Integrator-1" (Type 24)
*
UNIT 22 TYPE 24     Integrator-1
*$UNIT_NAME Integrator-1
*$MODEL .\Utility\Integrators\Quantity Integrator\Type24.tmf
*$POSITION 489 475
*$LAYER Main #
PARAMETERS 2
STOP                ! 1 Integration period
0                   ! 2 Relative or absolute start time
INPUTS 1
21,5                ! Boiler:Rate of energy delivery to fluid stream ->Input to be integrated
*** INITIAL INPUT VALUES
0.0
*------------------------------------------------------------------------------

* Model "Integrator-2" (Type 24)
*
UNIT 23 TYPE 24     Integrator-2
*$UNIT_NAME Integrator-2
*$MODEL .\Utility\Integrators\Quantity Integrator\Type24.tmf
*$POSITION 489 534
*$LAYER Main #
PARAMETERS 2
STOP                ! 1 Integration period
0                   ! 2 Relative or absolute start time
INPUTS 1
SumPump12                   ! Sum:SumPump12 ->Input to be integrated
*** INITIAL INPUT VALUES
0.0
*------------------------------------------------------------------------------

* Model "Storage tank" (Type 4)
*
UNIT 24 TYPE 4      Storage tank
*$UNIT_NAME Storage tank
*$MODEL .\Thermal Storage\Stratified Storage Tank\Variable Inlets\Uniform Losses\Type4c.tmf
*$POSITION 371 328
*$LAYER Main #
PARAMETERS 22
2                   ! 1 Variable inlet positions
0.3                 ! 2 Tank volume
4.190               ! 3 Fluid specific heat
1000.0              ! 4 Fluid density
2.52                ! 5 Tank loss coefficient
0.5                 ! 6 Height of node-1
0.5                 ! 7 Height of node-2
0.5                 ! 8 Height of node-3
1                   ! 9 Auxiliary heater mode
1                   ! 10 Node containing heating element -1
1                   ! 11 Node containing thermostat -1
60.0                ! 12 Set point temperature for element-1
5.0                 ! 13 Deadband for heating element-1
0                   ! 14 Maximum heating rate of element -1
1                   ! 15 Node containing heating element -2
1                   ! 16 Node containing thermostat -2
60.0                ! 17 Set point temperature for element-2
5.0                 ! 18 Deadband for heating element-2
0                   ! 19 Maximum heating rate of element -2
```

```
0.0                     ! 20 Not used (Flue UA)
20.0                    ! 21 Not used (Tflue)
100.0                   ! 22 Boiling point
INPUTS 7
21,1                    ! Boiler:Outlet fluid temperature ->Hot-side temperature
21,2                    ! Boiler:Outlet fluid flow rate ->Hot-side flowrate
16,1                    ! Hotel:Temperature to heat source ->Cold-side temperature
16,2                    ! Hotel:Flow rate to heat source ->Cold-side flowrate
0,0                     ! [unconnected] Environment temperature
0,0                     ! [unconnected] Control signal for element-1
0,0                     ! [unconnected] Control signal for element-2
*** INITIAL INPUT VALUES
45.0 100.0 20.0 0 22.0 0.0 0.0
DERIVATIVES 3
10                      ! 1 Initial temperature of node-1
10                      ! 2 Initial temperature of node-2
10                      ! 3 Initial temperature of node-3
*------------------------------------------------------------------------------

* Model "Thermostat-2" (Type 8)
*
UNIT 25 TYPE 8      Thermostat-2
*$UNIT_NAME Thermostat-2
*$MODEL .\Controllers\3-Stage Room Thermostat\w_ heating set back and temp deadband\Type8b.tmf
*$POSITION 479 264
*$LAYER Main #
PARAMETERS 8
5                       ! 1 Nb. of oscillations permitted
0                       ! 2 1st stage heating in 2nd stage?
20.0                    ! 3 Minimum primary source temperature
65                      ! 4 Temperature for cooling
60                      ! 5 1st stage heating temperature
55                      ! 6 2nd stage heating temperature
0                       ! 7 Heating set back temperature difference
2                       ! 8 Temperature dead band
INPUTS 3
24,3                    ! Storage tank:Temperature to load ->Room temperature
0,0                     ! [unconnected] 1st stage source temperature
0,0                     ! [unconnected] Set back control function
*** INITIAL INPUT VALUES
20.0 30 0
*------------------------------------------------------------------------------

* Model "Pump-1" (Type 3)
*
UNIT 26 TYPE 3      Pump-1
*$UNIT_NAME Pump-1
*$MODEL .\Hydronics\Pumps\Single Speed\Type3b.tmf
*$POSITION 318 267
*$LAYER Main #
PARAMETERS 5
59400                   ! 1 Maximum flow rate
4.190                   ! 2 Fluid specific heat
14565.599614                    ! 3 Maximum power
0.05                    ! 4 Conversion coefficient
0.5                     ! 5 Power coefficient
INPUTS 3
24,3                    ! Storage tank:Temperature to load ->Inlet fluid temperature
24,4                    ! Storage tank:Flowrate to load ->Inlet mass flow rate
17,2                    ! Thermostat-1:Control signal for 2nd stage heating ->Control signal
```

```
*** INITIAL INPUT VALUES
12 5000 0
*------------------------------------------------------------------------------
* EQUATIONS "Sum"
EQUATIONS 1
SumPump12 = [26,3]+[20,3]
*$UNIT_NAME Sum
*$LAYER Main
*$POSITION 399 535

*------------------------------------------------------------------------------

END
```

Seawater cooling system (SWC)

```
*******************************************************************************
*** TRNSYS input file (deck) generated by Trnsys Studio

*******************************************************************************
*** Control cards
*******************************************************************************
* START, STOP and STEP
CONSTANTS 3
START=3624
STOP=6192
STEP=0.027777778
* User defined CONSTANTS

SIMULATION      START   STOP    STEP    ! Start time    End time  Time step
TOLERANCES 0.001 0.001                  ! Integration   Convergence
LIMITS 30 30 30                         ! Max iterations   Max warnings   Trace limit
DFQ 1                                   ! TRNSYS numerical integration solver method
WIDTH 80                                ! TRNSYS output file width, number of characters
LIST                                    ! NOLIST statement
                                        ! MAP statement
SOLVER 0 1 1                            ! Solver statement   Minimum relaxation factor   Maximum
relaxation factor
NAN_CHECK 0                             ! Nan DEBUG statement
OVERWRITE_CHECK 0                       ! Overwrite DEBUG statement
EQSOLVER 0                              ! EQUATION SOLVER statement

* Model "TMY" (Type 109)
*
UNIT 2 TYPE 109   TMY
*$UNIT_NAME TMY
*$MODEL .\Weather Data Reading and Processing\Standard Format\TMY2\Type109-TMY2.tmf
*$POSITION 137 168
*$LAYER Main #
PARAMETERS 4
2               ! 1 Data Reader Mode
55              ! 2 Logical unit
4               ! 3 Sky model for diffuse radiation
1               ! 4 Tracking mode
INPUTS 3
0,0             ! [unconnected] Ground reflectance
0,0             ! [unconnected] Slope of surface
0,0             ! [unconnected] Azimuth of surface
*** INITIAL INPUT VALUES
0.2 45 0.0
*** External files
ASSIGN "C:\Program Files\Trnsys16\Weather\Meteonorm\Europe\HR-Split-133340.tm2" 55
*|? Weather data file |1000
*------------------------------------------------------------------------------

* Model "Hotel" (Type 12)
*
UNIT 3 TYPE 12    Hotel
*$UNIT_NAME Hotel
*$MODEL .\Loads and Structures\Single Zone Models\Energy (Degree Day) Space Load (Type12)\Temperature
Level Control\Type12c.tmf
*$POSITION 278 168
*$LAYER Main #
```

```
PARAMETERS 7
4                   ! 1 Temperature level control
125999.996662               ! 2 Overall conductance of house
1000000             ! 3 House thermal capacitance
10                  ! 4 Initial room temperature
4.19                ! 5 Specific heat of source fluid
7199.99981                  ! 6 Effectiveness-Cmin product
0.23                ! 7 Latent heat ratio
INPUTS 6
0,0                 ! [unconnected] Inlet temperature
0,0                 ! [unconnected] Inlet flow rate
2,1                 ! TMY:Ambient temperature ->Ambient temperature
0,0                 ! [unconnected] Internal gains
0,0                 ! [unconnected] Auxiliary heat input
8,5                 ! Heat exchanger:Heat transfer rate ->Cooling input
*** INITIAL INPUT VALUES
0 0 10 0.0 0.0 0.0
*------------------------------------------------------------------------------

* Model "Thermostat" (Type 8)
*
UNIT 4 TYPE 8       Thermostat
*$UNIT_NAME Thermostat
*$MODEL .\Controllers\3-Stage Room Thermostat\w_ heating set back and temp deadband\Type8b.tmf
*$POSITION 458 168
*$LAYER Main #
PARAMETERS 8
5                   ! 1 Nb. of oscillations permitted
0                   ! 2 1st stage heating in 2nd stage?
120                 ! 3 Minimum primary source temperature
26                  ! 4 Temperature for cooling
20                  ! 5 1st stage heating temperature
20                  ! 6 2nd stage heating temperature
0                   ! 7 Heating set back temperature difference
0                   ! 8 Temperature dead band
INPUTS 3
3,4                 ! Hotel:Average house temperature ->Room temperature
0,0                 ! [unconnected] 1st stage source temperature
0,0                 ! [unconnected] Set back control function
*** INITIAL INPUT VALUES
20.0 30 0
*------------------------------------------------------------------------------

* Model "Seawater pump" (Type 3)
*
UNIT 7 TYPE 3       Seawater pump
*$UNIT_NAME Seawater pump
*$MODEL .\Hydronics\Pumps\Single Speed\Type3b.tmf
*$POSITION 135 369
*$LAYER Water Loop #
PARAMETERS 5
219203.997803               ! 1 Maximum flow rate
4.190               ! 2 Fluid specific heat
80639.997864                ! 3 Maximum power
0.05                ! 4 Conversion coefficient
0.5                 ! 5 Power coefficient
INPUTS 3
0,0                 ! [unconnected] Inlet fluid temperature
0,0                 ! [unconnected] Inlet mass flow rate
4,3                 ! Thermostat: Control signal for cooling ->Control signal
```

```
*** INITIAL INPUT VALUES
15 100.0 1.0
*-------------------------------------------------------------------------------

* Model "Cold water pump" (Type 3)
*
UNIT 9 TYPE 3        Cold water pump
*$UNIT_NAME Cold water pump
*$MODEL .\Hydronics\Pumps\Single Speed\Type3b.tmf
*$POSITION 133 275
*$LAYER Main #
PARAMETERS 5
215100               ! 1 Maximum flow rate
4.190                ! 2 Fluid specific heat
79127.997904                 ! 3 Maximum power
0.05                 ! 4 Conversion coefficient
0.5                  ! 5 Power coefficient
INPUTS 3
8,1                  ! Heat exchanger:Hot-side outlet temperature ->Inlet fluid temperature
8,2                  ! Heat exchanger:Hot-side flow rate ->Inlet mass flow rate
4,3                  ! Thermostat:Control signal for cooling ->Control signal
*** INITIAL INPUT VALUES
20.0 100.0 1.0
*-------------------------------------------------------------------------------

* Model "Heat exchanger" (Type 5)
*
UNIT 8 TYPE 5        Heat exchanger
*$UNIT_NAME Heat exchanger
*$MODEL .\Heat Exchangers\Counter Flow\Type5b.tmf
*$POSITION 278 349
*$LAYER Main #
PARAMETERS 4
2                    ! 1 Counter flow mode
4.19                 ! 2 Specific heat of hot side fluid
4.19                 ! 3 Specific heat of cold side fluid
0                    ! 4 Not used
INPUTS 5
0,0                  ! [unconnected] Hot side inlet temperature
0,0                  ! [unconnected] Hot side flow rate
7,1                  ! Seawater pump:Outlet fluid temperature ->Cold side inlet temperature
7,2                  ! Seawater pump:Outlet flow rate ->Cold side flow rate
0,0                  ! [unconnected] Overall heat transfer coefficient of exchanger
*** INITIAL INPUT VALUES
19 215100 20.0 100.0 899999.976158
*-------------------------------------------------------------------------------

* EQUATIONS "Sum"
*
EQUATIONS 2
PSumm = [7,3]+[9,3]
QoSumm = [3,8]+[3,7]
*$UNIT_NAME Sum
*$LAYER Main
*$POSITION 461 253

*-------------------------------------------------------------------------------
```

```
* Model "Integrator" (Type 24)
*
UNIT 11 TYPE 24     Integrator
*$UNIT_NAME Integrator
*$MODEL .\Utility\Integrators\Quantity Integrator\Type24.tmf
*$POSITION 563 253
*$LAYER Main #
PARAMETERS 2
STOP                ! 1 Integration period
0                   ! 2 Relative or absolute start time
INPUTS 3
8,5                 ! Heat exchanger:Heat transfer rate ->Input to be integrated-1
PSumm               ! Sum:PSumm ->Input to be integrated-2
QoSumm              ! Sum:QoSumm ->Input to be integrated-3
*** INITIAL INPUT VALUES
0.0 0.0 0.0
*------------------------------------------------------------------------------

* Model "Ploter" (Type 25)
*
UNIT 10 TYPE 25     Ploter
*$UNIT_NAME Ploter
*$MODEL .\Output\Printer\TRNSYS-Supplied Units\Type25a.tmf
*$POSITION 667 253
*$LAYER Outputs #
PARAMETERS 10
1                   ! 1 Printing interval
START               ! 2 Start time
STOP                ! 3 Stop time
57                  ! 4 Logical unit
2                   ! 5 Units printing mode
0                   ! 6 Relative or absolute start time
-1                  ! 7 Overwrite or Append
-1                  ! 8 Print header
0                   ! 9 Delimiter
1                   ! 10 Print labels
INPUTS 3
11,1                ! Integrator:Result of integration-1 ->Input to be printed-1
11,2                ! Integrator:Result of integration-2 ->Input to be printed-2
11,3                ! Integrator:Result of integration-3 ->Input to be printed-3
*** INITIAL INPUT VALUES
CollingEnergyOnHX PPump CollingEnergyOnHouse
*** External files
ASSIGN "EnergijeHladenja.out" 57
*|? Output File for printed results |1000
*------------------------------------------------------------------------------

* Model "Monitoring" (Type 65)
*
UNIT 6 TYPE 65      Monitoring
*$UNIT_NAME Monitoring
*$MODEL .\Output\Online Plotter\Online Plotter With File\TRNSYS-Supplied Units\Type65a.tmf
*$POSITION 660 178
*$LAYER Main #
PARAMETERS 12
2                   ! 1 Nb. of left-axis variables
0                   ! 2 Nb. of right-axis variables
```

```
0                 ! 3 Left axis minimum
40                ! 4 Left axis maximum
0                 ! 5 Right axis minimum
40                ! 6 Right axis maximum
1                 ! 7 Number of plots per simulation
12                ! 8 X-axis gridpoints
0                 ! 9 Shut off Online w/o removing
56                ! 10 Logical Unit for output file
2                 ! 11 Output file units
0                 ! 12 Output file delimiter
INPUTS 2
2,1               ! TMY:Ambient temperature ->Left axis variable-1
3,4               ! Hotel:Average house temperature ->Left axis variable-2
*** INITIAL INPUT VALUES
Tamb Troom
LABELS  3
""
""
"Kuca"
*** External files
ASSIGN "KucaHladenje.plt" 56
*|? What file should the online print to? |1000
*------------------------------------------------------------------------------

* Model "Monitoring-2" (Type 65)
*
UNIT 13 TYPE 65     Monitoring-2
*$UNIT_NAME Monitoring-2
*$MODEL .\Output\Online Plotter\Online Plotter With File\TRNSYS-Supplied Units\Type65a.tmf
*$POSITION 276 477
*$LAYER Main #
PARAMETERS 12
3                 ! 1 Nb. of left-axis variables
0                 ! 2 Nb. of right-axis variables
0.0               ! 3 Left axis minimum
30                ! 4 Left axis maximum
0.0               ! 5 Right axis minimum
30                ! 6 Right axis maximum
1                 ! 7 Number of plots per simulation
12                ! 8 X-axis gridpoints
0                 ! 9 Shut off Online w/o removing
58                ! 10 Logical Unit for output file
2                 ! 11 Output file units
0                 ! 12 Output file delimiter
INPUTS 3
8,3               ! Heat exchanger:Cold-side outlet temperature ->Left axis variable-1
3,1               ! Hotel:Temperature to heat source ->Left axis variable-2
8,1               ! Heat exchanger:Hot-side outlet temperature ->Left axis variable-3
*** INITIAL INPUT VALUES
TempMoreIzlaz TempFromHotel TempToHotel
LABELS  3
""
""
"Izmjenjivac"
*** External files
ASSIGN "TempIzmjenivac.plt" 58
*|? What file should the online print to? |1000
*------------------------------------------------------------------------------

END
```

Solar heating system (SWC - SH)

```
***************************************************************************
*** TRNSYS input file (deck) generated by TrnsysStudio

***************************************************************************
*** Control cards
***************************************************************************
* START, STOP and STEP
CONSTANTS 3
START=0
STOP=8760
STEP=0.002777778
* User defined CONSTANTS

SIMULATION      START    STOP     STEP     ! Start time          End time  Time step
TOLERANCES 0.001 0.001                     ! Integration         Convergence
LIMITS 30 30 30                            ! Max iterations      Max warnings       Trace limit
DFQ 1                                      ! TRNSYS numerical integration solver method
WIDTH 80                                   ! TRNSYS output file width, number of characters
LIST                                       ! NOLIST statement
                                           ! MAP statement
SOLVER 0 1 1                               ! Solver statement   Minimum relaxation factor    Maximum
relaxation factor
NAN_CHECK 0                                ! Nan DEBUG statement
OVERWRITE_CHECK 0                          ! Overwrite DEBUG statement
EQSOLVER 0                                 ! EQUATION SOLVER statement

* Model "Thermostat" (Type 8)
*
UNIT 4 TYPE 8      Thermostat
*$UNIT_NAME Thermostat
*$MODEL .\Controllers\3-Stage Room Thermostat\w_ heating set back and temp deadband\Type8b.tmf
*$POSITION 417 145
*$LAYER Main #
PARAMETERS 8
5                 ! 1 Nb. of oscillations permitted
0                 ! 2 1st stage heating in 2nd stage?
20.0              ! 3 Minimum primary source temperature
32                ! 4 Temperature for cooling
24                ! 5 1st stage heating temperature
21                ! 6 2nd stage heating temperature
0                 ! 7 Heating set back temperature difference
0                 ! 8 Temperature dead band
INPUTS 3
3,4               ! Hotel:Average house temperature ->Room temperature
0,0               ! [unconnected] 1st stage source temperature
0,0               ! [unconnected] Set back control function
*** INITIAL INPUT VALUES
20.0 30 0
*------------------------------------------------------------------------------

* Model "TMY" (Type 109)
*
UNIT 6 TYPE 109    TMY
*$UNIT_NAME TMY
*$MODEL .\Weather Data Reading and Processing\Standard Format\TMY2\Type109-TMY2.tmf
*$POSITION 173 145
```

```
*$LAYER Main #
PARAMETERS 4
2                ! 1 Data Reader Mode
67               ! 2 Logical unit
4                ! 3 Sky model for diffuse radiation
1                ! 4 Tracking mode
INPUTS 3
0,0              ! [unconnected] Ground reflectance
0,0              ! [unconnected] Slope of surface
0,0              ! [unconnected] Azimuth of surface
*** INITIAL INPUT VALUES
0.2 45 0.0
*** External files
ASSIGN "C:\Program Files\Trnsys16\Weather\Meteonorm\Europe\HR-Split-133340.tm2" 67
*|? Weather data file |1000
*------------------------------------------------------------------------------

* Model "Hotel" (Type 12)
*
UNIT 3 TYPE 12     Hotel
*$UNIT_NAME Hotel
*$MODEL .\Loads and Structures\Single Zone Models\Energy (Degree Day) Space Load (Type12)\Temperature
Level Control\Type12c.tmf
*$POSITION 301 145
*$LAYER Main #
PARAMETERS 7
4                ! 1 Temperature level control
89999.997616             ! 2 Overall conductance of house
750000           ! 3 House thermal capacitance
10               ! 4 Initial room temperature
4.19             ! 5 Specific heat of source fluid
142559.996223            ! 6 Effectiveness-Cmin product
0.23             ! 7 Latent heat ratio
INPUTS 6
13,1             ! Pump-1:Outlet fluid temperature ->Inlet temperature
13,2             ! Pump-1:Outlet flow rate ->Inlet flow rate
6,1              ! TMY:Ambient temperature ->Ambient temperature
0,0              ! [unconnected] Internal gains
0,0              ! [unconnected] Auxiliary heat input
0,0              ! [unconnected] Cooling input
*** INITIAL INPUT VALUES
0 0 10 0.0 0.0 0.0
*------------------------------------------------------------------------------

* Model "Storage tank" (Type 4)
*
UNIT 11 TYPE 4     Storage tank
*$UNIT_NAME Storage tank
*$MODEL .\Thermal Storage\Stratified Storage Tank\Variable Inlets\Uniform Losses\Type4c.tmf
*$POSITION 406 325
*$LAYER Main #
PARAMETERS 22
2                ! 1 Variable inlet positions
24               ! 2 Tank volume
4.190            ! 3 Fluid specific heat
1000.0           ! 4 Fluid density
2.52             ! 5 Tank loss coefficient
1                ! 6 Height of node-1
1                ! 7 Height of node-2
1                ! 8 Height of node-3
```

```
1                       ! 9 Auxiliary heater mode
2                       ! 10 Node containing heating element -1
1                       ! 11 Node containing thermostat -1
42.5                    ! 12 Set point temperature for element-1
0                       ! 13 Deadband for heating element-1
2519999.813549                  ! 14 Maximum heating rate of element -1
1                       ! 15 Node containing heating element -2
1                       ! 16 Node containing thermostat -2
60.0                    ! 17 Set point temperature for element-2
5.0                     ! 18 Deadband for heating element-2
0                       ! 19 Maximum heating rate of element -2
0.0                     ! 20 Not used (Flue UA)
20.0                    ! 21 Not used (Tflue)
100.0                   ! 22 Boiling point
INPUTS 7
12,1                    ! Solar collectors:Outlet temperature ->Hot-side temperature
12,2                    ! Solar collectors:Outlet flowrate ->Hot-side flowrate
24,1                    ! Mixing-2:Outlet temperature ->Cold-side temperature
24,2                    ! Mixing-2:Outlet flow rate ->Cold-side flowrate
0,0                     ! [unconnected] Environment temperature
0,0                     ! [unconnected] Control signal for element-1
0,0                     ! [unconnected] Control signal for element-2
*** INITIAL INPUT VALUES
0 0 0 0 22.0 1 0.0
DERIVATIVES 3
12                      ! 1 Initial temperature of node-1
12                      ! 2 Initial temperature of node-2
12                      ! 3 Initial temperature of node-3
*------------------------------------------------------------------------------

* Model "Solar collectors" (Type 1)
*
UNIT 12 TYPE 1       Solar collectors
*$UNIT_NAME Solar collectors
*$MODEL .\Solar Thermal Collectors\Quadratic Efficiency Collector\2nd-Order Incidence Angle
Modifiers\Type1b.tmf
*$POSITION 225 305
*$LAYER Main #
PARAMETERS 11
1                       ! 1 Number in series
350                     ! 2 Collector area
4.190                   ! 3 Fluid specific heat
1                       ! 4 Efficiency mode
40.0                    ! 5 Tested flow rate
0.80                    ! 6 Intercept efficiency
13.0                    ! 7 Efficiency slope
0.05                    ! 8 Efficiency curvature
2                       ! 9 Optical mode 2
0.2                     ! 10 1st-order IAM
0.0                     ! 11 2nd-order IAM
INPUTS 9
15,1                    ! Pump-2:Outlet fluid temperature ->Inlet temperature
15,2                    ! Pump-2:Outlet flow rate ->Inlet flowrate
6,1                     ! TMY:Ambient temperature ->Ambient temperature
6,18                    ! TMY:total radiation on tilted surface ->Incident radiation
6,12                    ! TMY:total radiation on horizontal ->Total horizontal radiation
6,14                    ! TMY:sky diffuse radiation on horizontal ->Horizontal diffuse radiation
0,0                     ! [unconnected] Ground reflectance
6,22                    ! TMY:angle of incidence for tilted surface  ->Incidence angle
6,23                    ! TMY:slope of tilted surface ->Collector slope
```

```
*** INITIAL INPUT VALUES
0 0 10.0 0. 0 0.0 0.2 45.0 0.
*------------------------------------------------------------------------------

* Model "Mixing valve" (Type 11)
*
UNIT 22 TYPE 11     Mixing valve
*$UNIT_NAME Mixing valve
*$MODEL .\Hydronics\Tempering Valve\Other Fluids\Type11b.tmf
*$POSITION 651 369
*$LAYER Main #
PARAMETERS 2
4                    ! 1 Tempering valve mode
7                    ! 2 Nb. of oscillations allowed
INPUTS 4
0,0                  ! [unconnected] Inlet temperature
21,1                 ! Histogram DHW:Average value of function ->Inlet flow rate
11,3                 ! Storage tank:Temperature to load ->Heat source temperature
0,0                  ! [unconnected] Set point temperature
*** INITIAL INPUT VALUES
10.0 100 0 40
*------------------------------------------------------------------------------

* Model "Mixing-2" (Type 11)
*
UNIT 24 TYPE 11     Mixing-2
*$UNIT_NAME Mixing-2
*$MODEL .\Hydronics\Tee-Piece\Other Fluids\Type11h.tmf
*$POSITION 546 369
*$LAYER Water Loop #
PARAMETERS 1
1                    ! 1 Tee piece mode
INPUTS 4
3,1                  ! Hotel:Temperature to heat source ->Temperature at inlet 1
3,2                  ! Hotel:Flow rate to heat source ->Flow rate at inlet 1
22,1                 ! Mixing valve:Temperature at outlet 1 ->Temperature at inlet 2
22,2                 ! Mixing valve:Flowrate at outlet 1 ->Flow rate at inlet 2
*** INITIAL INPUT VALUES
20.0 100.0 20.0 100.0
*------------------------------------------------------------------------------

* Model "Regulator" (Type 2)
*
UNIT 18 TYPE 2      Regulator
*$UNIT_NAME Regulator
*$MODEL .\Controllers\Differential Controller w_ Hysteresis\for Temperatures\Solver 0 (Successive Substitution)
Control Strategy\Type2b.tmf
*$POSITION 132 390
*$LAYER Main #
*$# NOTE: This control strategy can only be used with solver 0 (Successive substitution)
*$#
PARAMETERS 2
5                    ! 1 No. of oscillations
100.0                ! 2 High limit cut-out
INPUTS 6
12,1                 ! Solar collectors:Outlet temperature ->Upper input temperature Th
11,1                 ! Storage tank:Temperature to heat source ->Lower input temperature Tl
11,3                 ! Storage tank:Temperature to load ->Monitoring temperature Tin
18,1                 ! Regulator:Output control function ->Input control function
0,0                  ! [unconnected] Upper dead band dT
```

```
0,0                    ! [unconnected] Lower dead band dT
*** INITIAL INPUT VALUES
60 20 20 0 10.0 2.0
*------------------------------------------------------------------------------

* EQUATIONS "Sum"
*
EQUATIONS 1
Mout = [11,4]-[13,2]
*$UNIT_NAME Sum
*$LAYER Main
*$POSITION 558 267

*------------------------------------------------------------------------------


* Model "Mixing-1" (Type 11)
*
UNIT 23 TYPE 11     Mixing-1
*$UNIT_NAME Mixing-1
*$MODEL .\Hydronics\Tee-Piece\Other Fluids\Type11h.tmf
*$POSITION 651 305
*$LAYER Main #
PARAMETERS 1
1                      ! 1 Tee piece mode
INPUTS 4
11,3                   ! Storage tank:Temperature to load ->Temperature at inlet 1
Mout                   ! Sum:Mout ->Flow rate at inlet 1
22,3                   ! Mixing valve:Temperature at outlet 2 ->Temperature at inlet 2
22,4                   ! Mixing valve:Flow rate at outlet 2 ->Flow rate at inlet 2
*** INITIAL INPUT VALUES
20.0 100.0 20.0 100.0
*------------------------------------------------------------------------------

* Model "Pump-1" (Type 3)
*
UNIT 13 TYPE 3       Pump-1
*$UNIT_NAME Pump-1
*$MODEL .\Hydronics\Pumps\Single Speed\Type3b.tmf
*$POSITION 352 244
*$LAYER Main #
PARAMETERS 5
50400                  ! 1 Maximum flow rate
4.190                  ! 2 Fluid specific heat
18539.999509                 ! 3 Maximum power
0.05                   ! 4 Conversion coefficient
0.5                    ! 5 Power coefficient
INPUTS 3
11,3                   ! Storage tank:Temperature to load ->Inlet fluid temperature
11,4                   ! Storage tank:Flowrate to load ->Inlet mass flow rate
4,2                    ! Thermostat:Control signal for 2nd stage heating ->Control signal
*** INITIAL INPUT VALUES
12 5000 0
*------------------------------------------------------------------------------

* EQUATIONS "Sum-2"
*
EQUATIONS 1
SumPump12 = [13,3]+[15,3]
*$UNIT_NAME Sum-2
```

```
*$LAYER Main
*$POSITION 397 546

*------------------------------------------------------------------------------


* Model "Pump-2" (Type 3)
*
UNIT 15 TYPE 3      Pump-2
*$UNIT_NAME Pump-2
*$MODEL .\Hydronics\Pumps\Single Speed\Type3b.tmf
*$POSITION 90 305
*$LAYER Main #
PARAMETERS 5
10800               ! 1 Maximum flow rate
4.190               ! 2 Fluid specific heat
2915.999923                 ! 3 Maximum power
0.05                ! 4 Conversion coefficient
0.5                 ! 5 Power coefficient
INPUTS 3
11,1                ! Storage tank:Temperature to heat source ->Inlet fluid temperature
11,2                ! Storage tank:Flowrate to heat source ->Inlet mass flow rate
18,1                ! Regulator:Output control function ->Control signal
*** INITIAL INPUT VALUES
10 100.0 1.0
*------------------------------------------------------------------------------

* Model "Integrator-2" (Type 24)
*
UNIT 9 TYPE 24      Integrator-2
*$UNIT_NAME Integrator-2
*$MODEL .\Utility\Integrators\Quantity Integrator\Type24.tmf
*$POSITION 553 546
*$LAYER Main #
PARAMETERS 2
STOP                ! 1 Integration period
0                   ! 2 Relative or absolute start time
INPUTS 3
SumPump12                   ! Sum-2:SumPump12 ->Input to be integrated-1
23,2                ! Mixing-1:Outlet flow rate ->Input to be integrated-2
3,5                 ! Hotel:Heat transfer rate across HX ->Input to be integrated-3
*** INITIAL INPUT VALUES
0.0 0.0 0.0
*------------------------------------------------------------------------------

* Model "Integrator-1" (Type 24)
*
UNIT 10 TYPE 24     Integrator-1
*$UNIT_NAME Integrator-1
*$MODEL .\Utility\Integrators\Quantity Integrator\Type24.tmf
*$POSITION 553 465
*$LAYER Main #
PARAMETERS 2
STOP                ! 1 Integration period
0                   ! 2 Relative or absolute start time
INPUTS 2
11,8                ! Storage tank:Auxiliary heating rate ->Input to be integrated-1
12,3                ! Solar collectors:Useful energy gain ->Input to be integrated-2
*** INITIAL INPUT VALUES
0.0 0.0
```

```
*------------------------------------------------------------------------------

* Model "Ploter" (Type 25)
*
UNIT 17 TYPE 25     Ploter
*$UNIT_NAME Ploter
*$MODEL .\Output\Printer\TRNSYS-Supplied Units\Type25a.tmf
*$POSITION 680 505
*$LAYER Outputs #
PARAMETERS 10
1                    ! 1 Printing interval
START                ! 2 Start time
STOP                 ! 3 Stop time
69                   ! 4 Logical unit
2                    ! 5 Units printing mode
0                    ! 6 Relative or absolute start time
-1                   ! 7 Overwrite or Append
-1                   ! 8 Print header
0                    ! 9 Delimiter
1                    ! 10 Print labels
INPUTS 5
10,1                 ! Integrator-1:Result of integration-1 ->Input to be printed-1
9,1                  ! Integrator-2:Result of integration-1 ->Input to be printed-2
10,2                 ! Integrator-1:Result of integration-2 ->Input to be printed-3
9,2                  ! Integrator-2:Result of integration-2 ->Input to be printed-4
9,3                  ! Integrator-2:Result of integration-3 ->Input to be printed-5
*** INITIAL INPUT VALUES
AuxHeaterEnergy PumpEnergy EnergyFromColl PTVConsumption_kg HeatTransferedToHouse

*** External files
ASSIGN "EnergyConsumptionSustav1.out" 69
*|? Output File for printed results |1000
*------------------------------------------------------------------------------

* Model "Monitoring-1" (Type 65)
*
UNIT 19 TYPE 65     Monitoring-1
*$UNIT_NAME Monitoring-1
*$MODEL .\Output\Online Plotter\Online Plotter Without File\Type65d.tmf
*$POSITION 684 126
*$LAYER Main #
PARAMETERS 12
2                    ! 1 Nb. of left-axis variables
0                    ! 2 Nb. of right-axis variables
-10                  ! 3 Left axis minimum
30                   ! 4 Left axis maximum
0.0                  ! 5 Right axis minimum
50                   ! 6 Right axis maximum
1                    ! 7 Number of plots per simulation
12                   ! 8 X-axis gridpoints
0                    ! 9 Shut off Online w/o removing
-1                   ! 10 Logical unit for output file
0                    ! 11 Output file units
0                    ! 12 Output file delimiter
INPUTS 2
6,1                  ! TMY:Ambient temperature ->Left axis variable-1
3,4                  ! Hotel:Average house temperature ->Left axis variable-2
*** INITIAL INPUT VALUES
Tamb Troom
LABELS  3
```

```
""
""
"House"
*------------------------------------------------------------------------------

* Model "Monitoring-2" (Type 65)
*
UNIT 20 TYPE 65     Monitoring-2
*$UNIT_NAME Monitoring-2
*$MODEL .\Output\Online Plotter\Online Plotter Without File\Type65d.tmf
*$POSITION 135 522
*$LAYER Main #
PARAMETERS 12
6                 ! 1 Nb. of left-axis variables
0                 ! 2 Nb. of right-axis variables
-5                ! 3 Left axis minimum
60                ! 4 Left axis maximum
0.0               ! 5 Right axis minimum
1000.0            ! 6 Right axis maximum
1                 ! 7 Number of plots per simulation
12                ! 8 X-axis gridpoints
0                 ! 9 Shut off Online w/o removing
-1                ! 10 Logical unit for output file
0                 ! 11 Output file units
0                 ! 12 Output file delimiter
INPUTS 6
11,1              ! Storage tank:Temperature to heat source ->Left axis variable-1
11,3              ! Storage tank:Temperature to load ->Left axis variable-2
11,12             ! Storage tank:Average tank temperature ->Left axis variable-3
11,13             ! Storage tank:Temperature of node 1+ ->Left axis variable-4
12,1              ! Solar collectors:Outlet temperature ->Left axis variable-5
23,1              ! Mixing-1:Outlet temperature ->Left axis variable-6
*** INITIAL INPUT VALUES
TToHeatSource TToLoad TAverageTank TMidleTank TFromColl TToConsumers

LABELS  3
""
""
"Graph 1"
*------------------------------------------------------------------------------

* Model "Histogram DHW" (Type 14)
*
UNIT 21 TYPE 14     Histogram DHW
*$UNIT_NAME Histogram DHW
*$MODEL .\Utility\Forcing Functions\General\Type14h.tmf
*$POSITION 675 211
*$LAYER Main #
PARAMETERS 44
0                 ! 1 Initial value of time
50                ! 2 Initial value of function
1                 ! 3 Time at point-1
100               ! 4 Value at point -1
4                 ! 5 Time at point-2
150               ! 6 Value at point -2
5                 ! 7 Time at point-3
100               ! 8 Value at point -3
6                 ! 9 Time at point-4
1500              ! 10 Value at point -4
7                 ! 11 Time at point-5
```

```
2000                ! 12 Value at point -5
8                   ! 13 Time at point-6
2500                ! 14 Value at point -6
9                   ! 15 Time at point-7
3000                ! 16 Value at point -7
10                  ! 17 Time at point-8
2000                ! 18 Value at point -8
11                  ! 19 Time at point-9
500                 ! 20 Value at point -9
13                  ! 21 Time at point-10
500                 ! 22 Value at point -10
14                  ! 23 Time at point-11
750                 ! 24 Value at point -11
15                  ! 25 Time at point-12
1000                ! 26 Value at point -12
16                  ! 27 Time at point-13
1250                ! 28 Value at point -13
17                  ! 29 Time at point-14
2000                ! 30 Value at point -14
18                  ! 31 Time at point-15
2500                ! 32 Value at point -15
19                  ! 33 Time at point-16
3000                ! 34 Value at point -16
20                  ! 35 Time at point-17
1500                ! 36 Value at point -17
21                  ! 37 Time at point-18
1000                ! 38 Value at point -18
22                  ! 39 Time at point-19
500                 ! 40 Value at point -19
23                  ! 41 Time at point-20
250                 ! 42 Value at point -20
24                  ! 43 Time at point-21
50                  ! 44 Value at point -21
*-----------------------------------------------------------------------------

END
```

Chiller – seawater cooled condenser (HPS)

```
*******************************************************************************
*** TRNSYS input file (deck) generated by TrnsysStudio
*******************************************************************************
*** Control cards
*******************************************************************************
* START, STOP and STEP
CONSTANTS 3
START=3624
STOP=6192
STEP=0.013888889
* User defined CONSTANTS

SIMULATION     START   STOP    STEP     ! Start time        End time  Time step
TOLERANCES 0.001 0.001                  ! Integration        Convergence
LIMITS 30 30 30                         ! Max iterations    Max warnings     Trace limit
DFQ 1                                   ! TRNSYS numerical integration solver method
WIDTH 80                                ! TRNSYS output file width, number of characters
LIST                                    ! NOLIST statement
                                        ! MAP statement
SOLVER 0 1 1                            ! Solver statement   Minimum relaxation factor    Maximum
relaxation factor
NAN_CHECK 0                             ! Nan DEBUG statement
OVERWRITE_CHECK 0                       ! Overwrite DEBUG statement
EQSOLVER 0                              ! EQUATION SOLVER statement

* Model "TMY" (Type 109)
*
UNIT 2 TYPE 109    TMY
*$UNIT_NAME TMY
*$MODEL .\Weather Data Reading and Processing\Standard Format\TMY2\Type109-TMY2.tmf
*$POSITION 116 128
*$LAYER Main #
PARAMETERS 4
2                  ! 1 Data Reader Mode
59                 ! 2 Logical unit
4                  ! 3 Sky model for diffuse radiation
1                  ! 4 Tracking mode
INPUTS 3
0,0                ! [unconnected] Ground reflectance
0,0                ! [unconnected] Slope of surface
0,0                ! [unconnected] Azimuth of surface
*** INITIAL INPUT VALUES
0.2 45 0.0
*** External files
ASSIGN "C:\Program Files\Trnsys16\Weather\Meteonorm\Europe\HR-Split-133340.tm2" 59
*|? Weather data file |1000
*------------------------------------------------------------------------------

* Model "Hotel" (Type 12)
*
UNIT 3 TYPE 12     Hotel
*$UNIT_NAME Hotel
*$MODEL .\Loads and Structures\Single Zone Models\Energy (Degree Day) Space Load (Type12)\Temperature
Level Control\Type12c.tmf
*$POSITION 269 128
*$LAYER Main #
PARAMETERS 7
```

```
4                       ! 1 Temperature level control
125999.996662                 ! 2 Overall conductance of house
750000                  ! 3 House thermal capacitance
10                      ! 4 Initial room temperature
4.19                    ! 5 Specific heat of source fluid
3599.999905                   ! 6 Effectiveness-Cmin product
0.23                    ! 7 Latent heat ratio
INPUTS 6
0,0                     ! [unconnected] Inlet temperature
0,0                     ! [unconnected] Inlet flow rate
2,1                     ! TMY:Ambient temperature ->Ambient temperature
0,0                     ! [unconnected] Internal gains
0,0                     ! [unconnected] Auxiliary heat input
12,5                    ! Chillers:Chilled water load ->Cooling input
*** INITIAL INPUT VALUES
0 0 10 0.0 0.0 0.0
*------------------------------------------------------------------------------

* Model "Monitoring-1" (Type 65)
*
UNIT 13 TYPE 65     Monitoring-1
*$UNIT_NAME Monitoring-1
*$MODEL .\Output\Online Plotter\Online Plotter With File\TRNSYS-Supplied Units\Type65a.tmf
*$POSITION 513 118
*$LAYER Main #
PARAMETERS 12
2                       ! 1 Nb. of left-axis variables
0                       ! 2 Nb. of right-axis variables
10                      ! 3 Left axis minimum
40                      ! 4 Left axis maximum
0.0                     ! 5 Right axis minimum
6                       ! 6 Right axis maximum
1                       ! 7 Number of plots per simulation
12                      ! 8 X-axis gridpoints
0                       ! 9 Shut off Online w/o removing
63                      ! 10 Logical Unit for output file
2                       ! 11 Output file units
0                       ! 12 Output file delimiter
INPUTS 2
2,1                     ! TMY:Ambient temperature ->Left axis variable-1
3,4                     ! Hotel:Average house temperature ->Left axis variable-2
*** INITIAL INPUT VALUES
Tamb Troom
LABELS  3
""
""
"Graph 1"
*** External files
ASSIGN "House.plt" 63
*|? What file should the online print to? |1000
*------------------------------------------------------------------------------

* EQUATIONS "Sum"
*
EQUATIONS 2
PSumm = [7,3]+[8,3]
QoSumm = [3,8]+[3,7]
*$UNIT_NAME Sum
*$LAYER Main
*$POSITION 443 213
```

```
*-------------------------------------------------------------------------------

* Model "Thermostat" (Type 8)
*
UNIT 4 TYPE 8      Thermostat
*$UNIT_NAME Thermostat
*$MODEL .\Controllers\3-Stage Room Thermostat\w_ heating set back and temp deadband\Type8b.tmf
*$POSITION 404 128
*$LAYER Main #
PARAMETERS 8
5                 ! 1 Nb. of oscillations permitted
0                 ! 2 1st stage heating in 2nd stage?
20.00             ! 3 Minimum primary source temperature
26                ! 4 Temperature for cooling
21                ! 5 1st stage heating temperature
15                ! 6 2nd stage heating temperature
0                 ! 7 Heating set back temperature difference
0                 ! 8 Temperature dead band
INPUTS 3
3,4               ! Hotel:Average house temperature ->Room temperature
0,0               ! [unconnected] 1st stage source temperature
0,0               ! [unconnected] Set back control function
*** INITIAL INPUT VALUES
20.0 30 0
*-------------------------------------------------------------------------------

* Model "Integrator" (Type 24)
*
UNIT 10 TYPE 24    Integrator
*$UNIT_NAME Integrator
*$MODEL .\Utility\Integrators\Quantity Integrator\Type24.tmf
*$POSITION 552 213
*$LAYER Main #
PARAMETERS 2
STOP              ! 1 Integration period
0                 ! 2 Relative or absolute start time
INPUTS 4
PSumm             ! Sum:PSumm ->Input to be integrated-1
12,6              ! Chillers:Total chiller power ->Input to be integrated-2
12,5              ! Chillers:Chilled water load ->Input to be integrated-3
QoSumm            ! Sum:QoSumm ->Input to be integrated-4
*** INITIAL INPUT VALUES
0.0 0.0 0.0 0.0
*-------------------------------------------------------------------------------

* Model "Pump-cold water" (Type 3)
*
UNIT 8 TYPE 3      Pump-cold water
*$UNIT_NAME Pump-cold water
*$MODEL .\Hydronics\Pumps\Single Speed\Type3b.tmf
*$POSITION 210 235
*$LAYER Main #
PARAMETERS 5
90000             ! 1 Maximum flow rate
4.190             ! 2 Fluid specific heat
33109.199123             ! 3 Maximum power
0.05              ! 4 Conversion coefficient
0.5               ! 5 Power coefficient
```

```
INPUTS 3
0,0                 ! [unconnected] Inlet fluid temperature
0,0                 ! [unconnected] Inlet mass flow rate
4,3                 ! Thermostat:Control signal for cooling ->Control signal
*** INITIAL INPUT VALUES
20.0 100.0 1.0
*------------------------------------------------------------------------------

* Model "Seawater pump" (Type 3)
*
UNIT 7 TYPE 3     Seawater pump
*$UNIT_NAME Seawater pump
*$MODEL .\Hydronics\Pumps\Single Speed\Type3b.tmf
*$POSITION 182 352
*$LAYER Main #
PARAMETERS 5
130000              ! 1 Maximum flow rate
4.190               ! 2 Fluid specific heat
45982.798782                ! 3 Maximum power
0.05                ! 4 Conversion coefficient
0.5                 ! 5 Power coefficient
INPUTS 3
0,0                 ! [unconnected] Inlet fluid temperature
0,0                 ! [unconnected] Inlet mass flow rate
4,3                 ! Thermostat:Control signal for cooling ->Control signal
*** INITIAL INPUT VALUES
20 100.0 1.0
*------------------------------------------------------------------------------

* Model "Chillers" (Type 53)
*
UNIT 12 TYPE 53   Chillers
*$UNIT_NAME Chillers
*$MODEL .\HVAC\Parallel Chillers\Type53.tmf
*$POSITION 268 299
*$LAYER Water Loop #
PARAMETERS 11
0.85                ! 1 Overall motor efficiency
539999.960046               ! 2 Single chiller capacity
1799.999867                 ! 3 Chiller surge limit
62                  ! 4 Logical unit
21                  ! 5 Number of data points
169343.990766               ! 6 Design load for data
32.5                ! 7 Design temperature difference
15.16               ! 8 Design power consumption
4.190               ! 9 Condenser water specific heat
4.190               ! 10 Evaporator water specific heat
1                   ! 11 Print indicator
INPUTS 6
0,0                 ! [unconnected] Chilled water set temperature
0,0                 ! [unconnected] Evaporator inlet temperature
0,0                 ! [unconnected] Evaporator flow rate
7,1                 ! Seawater pump:Outlet fluid temperature ->Condenser inlet temperature
7,2                 ! Seawater pump:Outlet flow rate ->Condenser flow rate
0,0                 ! [unconnected] Number of operating chillers
*** INITIAL INPUT VALUES
7 12 90000 0 0 5
*** External files
ASSIGN "ChillerTraneEXWA240WToW.dat" 62
*|? Which file contains the chiller performance data? |1000
```

```
*------------------------------------------------------------------------------

* Model "Monitoring-2" (Type 65)
*
UNIT 14 TYPE 65     Monitoring-2
*$UNIT_NAME Monitoring-2
*$MODEL .\Output\Online Plotter\Online Plotter With File\TRNSYS-Supplied Units\Type65a.tmf
*$POSITION 439 342
*$LAYER Main #
PARAMETERS 12
2                    ! 1 Nb. of left-axis variables
1                    ! 2 Nb. of right-axis variables
0.0                  ! 3 Left axis minimum
30                   ! 4 Left axis maximum
0.0                  ! 5 Right axis minimum
10                   ! 6 Right axis maximum
1                    ! 7 Number of plots per simulation
12                   ! 8 X-axis gridpoints
0                    ! 9 Shut off Online w/o removing
64                   ! 10 Logical Unit for output file
2                    ! 11 Output file units
0                    ! 12 Output file delimiter
INPUTS 3
12,1                 ! Chillers:Evaporator outlet temperature ->Left axis variable-1
12,3                 ! Chillers:Condenser outlet temperature ->Left axis variable-2
12,8                 ! Chillers:COP ->Right axis variable
*** INITIAL INPUT VALUES
Evaporator Condenser COP
LABELS  3
"Temperatures"
"Heat transfer rates"
"COP"
*** External files
ASSIGN "Evap.plt" 64
*|? What file should the online print to? |1000
*------------------------------------------------------------------------------

* Model "Ploter" (Type 25)
*
UNIT 9 TYPE 25       Ploter
*$UNIT_NAME Ploter
*$MODEL .\Output\Printer\TRNSYS-Supplied Units\Type25a.tmf
*$POSITION 633 213
*$LAYER Main #
PARAMETERS 10
1                    ! 1 Printing interval
START                ! 2 Start time
STOP                 ! 3 Stop time
61                   ! 4 Logical unit
2                    ! 5 Units printing mode
0                    ! 6 Relative or absolute start time
-1                   ! 7 Overwrite or Append
-1                   ! 8 Print header
0                    ! 9 Delimiter
1                    ! 10 Print labels
INPUTS 4
10,3                 ! Integrator:Result of integration-3 ->Input to be printed-1
10,1                 ! Integrator:Result of integration-1 ->Input to be printed-2
10,2                 ! Integrator:Result of integration-2 ->Input to be printed-3
10,4                 ! Integrator:Result of integration-4 ->Input to be printed-4
```

```
*** INITIAL INPUT VALUES
CollingEnergyEvap PPump PChiller CollingEnergyHouse
*** External files
ASSIGN "EnergijeHladenja.out" 61
*|? Output File for printed results |1000
*-------------------------------------------------------------------------------

END
```

Heat pump heating system (HPS)

```
*******************************************************************************
*** TRNSYS input file (deck) generated by TrnsysStudio
*******************************************************************************
*** Control cards
*******************************************************************************
* START, STOP and STEP
CONSTANTS 3
START=0
STOP=8760
STEP=0.027777778
* User defined CONSTANTS
EQUATIONS 1
STARTDAY=INT(START/24)+1
SIMULATION     START   STOP    STEP     ! Start time    End time  Time step
TOLERANCES 0.001 0.001                  ! Integration    Convergence
LIMITS 30 30 30                         ! Max iterations   Max warnings    Trace limit
DFQ 1                                   ! TRNSYS numerical integration solver method
WIDTH 80                                ! TRNSYS output file width, number of characters
LIST                                    ! NOLIST statement
                                        ! MAP statement
SOLVER 0 1 1                            ! Solver statement   Minimum relaxation factor    Maximum
relaxation factor
NAN_CHECK 0                             ! Nan DEBUG statement
OVERWRITE_CHECK 0                       ! Overwrite DEBUG statement
EQSOLVER 0                              ! EQUATION SOLVER statement

* Model "TMY" (Type 109)
*

UNIT 20 TYPE 109   TMY
*$UNIT_NAME TMY
*$MODEL .\Weather Data Reading and Processing\Standard Format\TMY2\Type109-TMY2.tmf
*$POSITION 84 117
*$LAYER Weather - Data Files #
PARAMETERS 4
2            ! 1 Data Reader Mode
54           ! 2 Logical unit
4            ! 3 Sky model for diffuse radiation
1            ! 4 Tracking mode
INPUTS 3
0,0          ! [unconnected] Ground reflectance
0,0          ! [unconnected] Slope of surface
0,0          ! [unconnected] Azimuth of surface
*** INITIAL INPUT VALUES
0.2 45 0.0
*** External files
ASSIGN "C:\Program Files\Trnsys16\Weather\Meteonorm\Europe\HR-Split-133340.tm2" 54
*|? Weather data file |1000
*------------------------------------------------------------------------------

* Model "Thermostat-1" (Type 8)
*
UNIT 4 TYPE 8      Thermostat-1
*$UNIT_NAME Thermostat-1
*$MODEL .\Controllers\3-Stage Room Thermostat\w_ heating set back and temp deadband\Type8b.tmf
*$POSITION 393 123
*$LAYER Main #
```

```
PARAMETERS 8
5                   ! 1 Nb. of oscillations permitted
0                   ! 2 1st stage heating in 2nd stage?
20.0                ! 3 Minimum primary source temperature
32                  ! 4 Temperature for cooling
26                  ! 5 1st stage heating temperature
21                  ! 6 2nd stage heating temperature
0                   ! 7 Heating set back temperature difference
0                   ! 8 Temperature dead band
INPUTS 3
3,4                 ! Hotel:Average house temperature ->Room temperature
0,0                 ! [unconnected] 1st stage source temperature
0,0                 ! [unconnected] Set back control function
*** INITIAL INPUT VALUES
20.0 30 0
*------------------------------------------------------------------------------

* Model "Thermostat-2" (Type 8)
*
UNIT 31 TYPE 8      Thermostat-2
*$UNIT_NAME Thermostat-2
*$MODEL .\Controllers\3-Stage Room Thermostat\w_ heating set back and temp deadband\Type8b.tmf
*$POSITION 396 221
*$LAYER Main #
PARAMETERS 8
5                   ! 1 Nb. of oscillations permitted
0                   ! 2 1st stage heating in 2nd stage?
20.0                ! 3 Minimum primary source temperature
70                  ! 4 Temperature for cooling
50                  ! 5 1st stage heating temperature
42                  ! 6 2nd stage heating temperature
0                   ! 7 Heating set back temperature difference
0                   ! 8 Temperature dead band
INPUTS 3
29,3                ! Storage tank:Temperature to load ->Room temperature
0,0                 ! [unconnected] 1st stage source temperature
0,0                 ! [unconnected] Set back control function
*** INITIAL INPUT VALUES
20.0 0 0
*------------------------------------------------------------------------------

* Model "Hotel" (Type 12)
*
UNIT 3 TYPE 12      Hotel
*$UNIT_NAME Hotel
*$MODEL .\Loads and Structures\Single Zone Models\Energy (Degree Day) Space Load (Type12)\Temperature
Level Control\Type12c.tmf
*$POSITION 212 117
*$LAYER Main #
PARAMETERS 7
4                   ! 1 Temperature level control
89999.997616                  ! 2 Overall conductance of house
7500000             ! 3 House thermal capacitance
10                  ! 4 Initial room temperature
4.19                ! 5 Specific heat of source fluid
68745.598179                  ! 6 Effectiveness-Cmin product
0.23                ! 7 Latent heat ratio
INPUTS 6
34,1                ! Pump-1:Outlet fluid temperature ->Inlet temperature
34,2                ! Pump-1:Outlet flow rate ->Inlet flow rate
```

```
20,1                    ! TMY:Ambient temperature ->Ambient temperature
0,0                     ! [unconnected] Internal gains
0,0                     ! [unconnected] Auxiliary heat input
0,0                     ! [unconnected] Cooling input
*** INITIAL INPUT VALUES
0 0 10 0.0 0.0 0.0
*------------------------------------------------------------------------------

* Model "Pump-2" (Type 3)
*
UNIT 27 TYPE 3     Pump-2
*$UNIT_NAME Pump-2
*$MODEL .\Hydronics\Pumps\Single Speed\Type3b.tmf
*$POSITION 396 371
*$LAYER Main #
PARAMETERS 5
169999.996948           ! 1 Maximum flow rate
4.190                   ! 2 Fluid specific heat
41691.598896            ! 3 Maximum power
0.05                    ! 4 Conversion coefficient
0.5                     ! 5 Power coefficient
INPUTS 3
29,1                    ! Storage tank:Temperature to heat source ->Inlet fluid temperature
29,2                    ! Storage tank:Flowrate to heat source ->Inlet mass flow rate
31,2                    ! Thermostat-2:Control signal for 2nd stage heating ->Control signal
*** INITIAL INPUT VALUES
20.0 100.0 1
*------------------------------------------------------------------------------

* Model "Pump" (Type 3)
*
UNIT 32 TYPE 3     Pump
*$UNIT_NAME Pump
*$MODEL .\Hydronics\Pumps\Single Speed\Type3b.tmf
*$POSITION 590 415
*$LAYER Main #
PARAMETERS 5
119999.995422           ! 1 Maximum flow rate
4.190                   ! 2 Fluid specific heat
44143.198831            ! 3 Maximum power
0.05                    ! 4 Conversion coefficient
0.5                     ! 5 Power coefficient
INPUTS 3
0,0                     ! [unconnected] Inlet fluid temperature
0,0                     ! [unconnected] Inlet mass flow rate
31,2                    ! Thermostat-2:Control signal for 2nd stage heating ->Control signal
*** INITIAL INPUT VALUES
12 100.0 1
*------------------------------------------------------------------------------

* Model "Heat pump" (Type 53)
*
UNIT 28 TYPE 53    Heat pump
*$UNIT_NAME Heat pump
*$MODEL .\HVAC\Parallel Chillers\TYPE53.tmf
*$POSITION 492 371
*$LAYER Main #
*$#
*$#
*$#
```

```
*$#
PARAMETERS 11
0.85                    ! 1 Overall motor efficiency
539999.960046           ! 2 Single chiller capacity
35999.997336            ! 3 Chiller surge limit
60                      ! 4 Logical unit
10                      ! 5 Number of data points
186731.982339           ! 6 Design load for data
42                      ! 7 Design temperature difference
22.68                   ! 8 Design power consumption
4.190                   ! 9 Condenser water specific heat
4.190                   ! 10 Evaporator water specific heat
1                       ! 11 Print indicator
INPUTS 6
0,0                     ! [unconnected] Chilled water set temperature
32,1                    ! Pump:Outlet fluid temperature ->Evaporator inlet temperature
32,2                    ! Pump:Outlet flow rate ->Evaporator flow rate
27,1                    ! Pump-2:Outlet fluid temperature ->Condenser inlet temperature
27,2                    ! Pump-2:Outlet flow rate ->Condenser flow rate
0,0                     ! [unconnected] Number of operating chillers
*** INITIAL INPUT VALUES
9 0 0 0 0 8
*** External files
ASSIGN "HeatPumpTraneEXWA240WToW.dat" 60
*|? Which file contains the chiller performance data? |1000
*------------------------------------------------------------------------------

* Model "Storage tank" (Type 4)
*
UNIT 29 TYPE 4     Storage tank
*$UNIT_NAME Storage tank
*$MODEL .\Thermal Storage\Stratified Storage Tank\Variable Inlets\Uniform Losses\Type4c.tmf
*$POSITION 316 309
*$LAYER Main #
PARAMETERS 22
2                       ! 1 Variable inlet positions
400                     ! 2 Tank volume
4.190                   ! 3 Fluid specific heat
1000.0                  ! 4 Fluid density
2.52                    ! 5 Tank loss coefficient
0.5                     ! 6 Height of node-1
0.5                     ! 7 Height of node-2
0.5                     ! 8 Height of node-3
1                       ! 9 Auxiliary heater mode
1                       ! 10 Node containing heating element -1
1                       ! 11 Node containing thermostat -1
60.0                    ! 12 Set point temperature for element-1
5.0                     ! 13 Deadband for heating element-1
0                       ! 14 Maximum heating rate of element -1
1                       ! 15 Node containing heating element -2
1                       ! 16 Node containing thermostat -2
60.0                    ! 17 Set point temperature for element-2
5.0                     ! 18 Deadband for heating element-2
0                       ! 19 Maximum heating rate of element -2
0.0                     ! 20 Not used (Flue UA)
20.0                    ! 21 Not used (Tflue)
100.0                   ! 22 Boiling point
INPUTS 7
28,3                    ! Heat pump:Condenser outlet temperature ->Hot-side temperature
28,4                    ! Heat pump:Condenser outlet flow rate ->Hot-side flowrate
```

```
3,1                    ! Hotel:Temperature to heat source ->Cold-side temperature
3,2                    ! Hotel:Flow rate to heat source ->Cold-side flowrate
0,0                    ! [unconnected] Environment temperature
0,0                    ! [unconnected] Control signal for element-1
0,0                    ! [unconnected] Control signal for element-2
*** INITIAL INPUT VALUES
0 0 0 0 22.0 0.0 0.0
DERIVATIVES 3
40                     ! 1 Initial temperature of node-1
40                     ! 2 Initial temperature of node-2
40                     ! 3 Initial temperature of node-3
*------------------------------------------------------------------------------

* Model "Pump-1" (Type 3)
*
UNIT 34 TYPE 3      Pump-1
*$UNIT_NAME Pump-1
*$MODEL .\Hydronics\Pumps\Single Speed\Type3b.tmf
*$POSITION 266 232
*$LAYER Main #
PARAMETERS 5
180000                 ! 1 Maximum flow rate
4.190                  ! 2 Fluid specific heat
58269.598456                    ! 3 Maximum power
0.05                   ! 4 Conversion coefficient
0.5                    ! 5 Power coefficient
INPUTS 3
29,3                   ! Storage tank:Temperature to load ->Inlet fluid temperature
29,4                   ! Storage tank:Flowrate to load ->Inlet mass flow rate
4,2                    ! Thermostat-1:Control signal for 2nd stage heating ->Control signal
*** INITIAL INPUT VALUES
20.0 100.0 0
*------------------------------------------------------------------------------

* EQUATIONS "Sum"
*
EQUATIONS 1
SumPump = [34,3]+[32,3]+[27,1]
*$UNIT_NAME Sum
*$LAYER Main
*$POSITION 358 477

*------------------------------------------------------------------------------

* Model "Integrator" (Type 24)
*
UNIT 14 TYPE 24     Integrator
*$UNIT_NAME Integrator
*$MODEL .\Utility\Integrators\Quantity Integrator\Type24.tmf
*$POSITION 436 477
*$LAYER Main #
PARAMETERS 2
STOP                   ! 1 Integration period
0                      ! 2 Relative or absolute start time
INPUTS 2
SumPump                         ! Sum:SumPump ->Input to be integrated-1
28,6                   ! Heat pump:Total chiller power ->Input to be integrated-2
*** INITIAL INPUT VALUES
0.0 0.0
*------------------------------------------------------------------------------
```

```
* Model "Monitoring" (Type 65)
*
UNIT 12 TYPE 65     Monitoring
*$UNIT_NAME Monitoring
*$MODEL .\Output\Online Plotter\Online Plotter Without File\Type65d.tmf
*$POSITION 546 125
*$LAYER Main #
PARAMETERS 12
2                    ! 1 Nb. of left-axis variables
0                    ! 2 Nb. of right-axis variables
-5                   ! 3 Left axis minimum
30                   ! 4 Left axis maximum
0.0                  ! 5 Right axis minimum
8                    ! 6 Right axis maximum
1                    ! 7 Number of plots per simulation
12                   ! 8 X-axis gridpoints
0                    ! 9 Shut off Online w/o removing
-1                   ! 10 Logical unit for output file
0                    ! 11 Output file units
0                    ! 12 Output file delimiter
INPUTS 2
20,1                 ! TMY:Ambient temperature ->Left axis variable-1
3,4                  ! Hotel:Average house temperature ->Left axis variable-2
*** INITIAL INPUT VALUES
Tamb THouse
LABELS  3
""
""
"gr"
*------------------------------------------------------------------------------

* Model "Ploter" (Type 25)
*
UNIT 13 TYPE 25     Ploter
*$UNIT_NAME Ploter
*$MODEL .\Output\Printer\TRNSYS-Supplied Units\Type25a.tmf
*$POSITION 535 477
*$LAYER Outputs #
PARAMETERS 10
1                    ! 1 Printing interval
START                ! 2 Start time
STOP                 ! 3 Stop time
61                   ! 4 Logical unit
2                    ! 5 Units printing mode
0                    ! 6 Relative or absolute start time
-1                   ! 7 Overwrite or Append
-1                   ! 8 Print header
0                    ! 9 Delimiter
1                    ! 10 Print labels
INPUTS 2
14,1                 ! Integrator:Result of integration-1 ->Input to be printed-1
14,2                 ! Integrator:Result of integration-2 ->Input to be printed-2
*** INITIAL INPUT VALUES
QPump QChiller
*** External files
ASSIGN "Energy.out" 61
*|? Output File for printed results |1000
*------------------------------------------------------------------------------
END
```

Solar absorption cooling system + domestic hot water (ACS)

```
*******************************************************************************
*** TRNSYS input file (deck) generated by TrnsysStudio
*******************************************************************************
*** Control cards
*******************************************************************************
* START, STOP and STEP
CONSTANTS 3
START=2520
STOP=6936
STEP=0.027777778
* User defined CONSTANTS

SIMULATION        START    STOP      STEP      ! Start time           End time  Time step
TOLERANCES 0.001 0.001                         ! Integration          Convergence
LIMITS 30 30 30                                ! Max iterations       Max warnings       Trace limit
DFQ 1                                          ! TRNSYS numerical integration solver method
WIDTH 80                                       ! TRNSYS output file width, number of characters
LIST                                           ! NOLIST statement
                                               ! MAP statement
SOLVER 0 1 1                                   ! Solver statement   Minimum relaxation factor     Maximum
relaxation factor
NAN_CHECK 0                                    ! Nan DEBUG statement
OVERWRITE_CHECK 0                              ! Overwrite DEBUG statement
EQSOLVER 0                                     ! EQUATION SOLVER statement

* Model "TMY" (Type 109)
*
UNIT 17 TYPE 109   TMY
*$UNIT_NAME TMY
*$MODEL .\Weather Data Reading and Processing\Standard Format\TMY2\Type109-TMY2.tmf
*$POSITION 102 83
*$LAYER Main #
PARAMETERS 4
2                ! 1 Data Reader Mode
68               ! 2 Logical unit
4                ! 3 Sky model for diffuse radiation
1                ! 4 Tracking mode
INPUTS 3
0,0              ! [unconnected] Ground reflectance
0,0              ! [unconnected] Slope of surface
0,0              ! [unconnected] Azimuth of surface
*** INITIAL INPUT VALUES
0.2 45 0.0
*** External files
ASSIGN "C:\Program Files\Trnsys16\Weather\Meteonorm\Europe\HR-Split-133340.tm2" 68
*|? Weather data file |1000
*------------------------------------------------------------------------------

* Model "Hotel" (Type 12)
*
UNIT 3 TYPE 12       Hotel
*$UNIT_NAME Hotel
*$MODEL .\Loads and Structures\Single Zone Models\Energy (Degree Day) Space Load (Type12)\Temperature
Level Control\Type12c.tmf
*$POSITION 226 83
*$LAYER Main #
PARAMETERS 7
```

```
4                      ! 1 Temperature level control
125999.996662                  ! 2 Overall conductance of house
750000                 ! 3 House thermal capacitance
10                     ! 4 Initial room temperature
4.19                   ! 5 Specific heat of source fluid
3599.999905                    ! 6 Effectiveness-Cmin product
0.23                   ! 7 Latent heat ratio
INPUTS 6
0,0                    ! [unconnected] Inlet temperature
0,0                    ! [unconnected] Inlet flow rate
17,1                   ! TMY:Ambient temperature ->Ambient temperature
0,0                    ! [unconnected] Internal gains
0,0                    ! [unconnected] Auxiliary heat input
12,7                   ! Absorption chiller:Chilled water energy ->Cooling input
*** INITIAL INPUT VALUES
0 0 10 0.0 0.0 0.0
*------------------------------------------------------------------------------

* Model "Thermostat" (Type 8)
*
UNIT 4 TYPE 8     Thermostat
*$UNIT_NAME Thermostat
*$MODEL .\Controllers\3-Stage Room Thermostat\w_ heating set back and temp deadband\Type8b.tmf
*$POSITION 361 83
*$LAYER Main #
PARAMETERS 8
5                      ! 1 Nb. of oscillations permitted
0                      ! 2 1st stage heating in 2nd stage?
20.00                  ! 3 Minimum primary source temperature
26                     ! 4 Temperature for cooling
21                     ! 5 1st stage heating temperature
21                     ! 6 2nd stage heating temperature
0                      ! 7 Heating set back temperature difference
0                      ! 8 Temperature dead band
INPUTS 3
3,4                    ! Hotel:Average house temperature ->Room temperature
0,0                    ! [unconnected] 1st stage source temperature
0,0                    ! [unconnected] Set back control function
*** INITIAL INPUT VALUES
20.0 30 0
*------------------------------------------------------------------------------

* Model "Pump-1" (Type 3)
*
UNIT 8 TYPE 3     Pump-1
*$UNIT_NAME Pump-1
*$MODEL .\Hydronics\Pumps\Single Speed\Type3b.tmf
*$POSITION 274 168
*$LAYER Main #
PARAMETERS 5
86400                  ! 1 Maximum flow rate
4.190                  ! 2 Fluid specific heat
31784.399158                   ! 3 Maximum power
0.05                   ! 4 Conversion coefficient
0.5                    ! 5 Power coefficient
INPUTS 3
0,0                    ! [unconnected] Inlet fluid temperature
0,0                    ! [unconnected] Inlet mass flow rate
4,3                    ! Thermostat:Control signal for cooling ->Control signal
*** INITIAL INPUT VALUES
```

```
20.0 100.0 1.0
*------------------------------------------------------------------------------

* Model "Pump-3" (Type 3)
*
UNIT 7 TYPE 3         Pump-3
*$UNIT_NAME Pump-3
*$MODEL .\Hydronics\Pumps\Single Speed\Type3b.tmf
*$POSITION 135 340
*$LAYER Main #
PARAMETERS 5
180000                ! 1 Maximum flow rate
4.190                 ! 2 Fluid specific heat
44143.198831                  ! 3 Maximum power
0.05                  ! 4 Conversion coefficient
0.5                   ! 5 Power coefficient
INPUTS 3
0,0                   ! [unconnected] Inlet fluid temperature
0,0                   ! [unconnected] Inlet mass flow rate
4,3                   ! Thermostat:Control signal for cooling ->Control signal
*** INITIAL INPUT VALUES
20 100.0 1.0
*------------------------------------------------------------------------------

* Model "Boiler" (Type 6)
*
UNIT 22 TYPE 6        Boiler
*$UNIT_NAME Boiler
*$MODEL .\HVAC\Auxiliary Heaters\Type6.tmf
*$POSITION 326 307
*$LAYER Water Loop #
PARAMETERS 4
3419999.74696                 ! 1 Maximum heating rate
4.19                  ! 2 Specific heat of fluid
0.0                   ! 3 Overall loss coefficient for heater during operation
1.0                   ! 4 Efficiency of auxiliary heater
INPUTS 5
18,3                  ! Storage tank:Temperature to load ->Inlet fluid temperature
18,4                  ! Storage tank:Flowrate to load ->Fluid mass flow rate
4,3                   ! Thermostat:Control signal for cooling ->Control Function
0,0                   ! [unconnected] Set point temperature
0,0                   ! [unconnected] Temperature of surroundings
*** INITIAL INPUT VALUES
0 0 1 90.0 20.0
*------------------------------------------------------------------------------

* Model "Pump-2" (Type 3)
*
UNIT 20 TYPE 3        Pump-2
*$UNIT_NAME Pump-2
*$MODEL .\Hydronics\Pumps\Single Speed\Type3b.tmf
*$POSITION 432 341
*$LAYER Water Loop #
PARAMETERS 5
90000                 ! 1 Maximum flow rate
4.190                 ! 2 Fluid specific heat
22071.599415                  ! 3 Maximum power
0.05                  ! 4 Conversion coefficient
0.5                   ! 5 Power coefficient
INPUTS 3
```

```
12,5                    ! Absorption chiller:Hot water outlet temperature ->Inlet fluid temperature
12,6                    ! Absorption chiller:Hot water flow rate ->Inlet mass flow rate
4,3                     ! Thermostat:Control signal for cooling ->Control signal
*** INITIAL INPUT VALUES
20.0 100.0 1.0
*------------------------------------------------------------------------------

* Model "Absorption chiller" (Type 107)
*
UNIT 12 TYPE 107    Absorption chiller
*$UNIT_NAME Absorption chiller
*$MODEL .\HVAC\Absorption Chiller (Hot-Water Fired, Single Effect)\Type107.tmf
*$POSITION 225 244
*$LAYER Main #
PARAMETERS 11
5380000                 ! 1 Rated capacity
0.53                    ! 2 Rated C.O.P.
65                      ! 3 Logical unit for S1 data file
5                       ! 4 Number of HW temperatures in S1 data file
3                       ! 5 Number of CW steps in S1 data file
7                       ! 6 Number of CHW set points in S1 data file
11                      ! 7 Number of load fractions in S1 data file
4.190                   ! 8 HW fluid specific heat
4.190                   ! 9 CHW fluid specific heat
4.190                   ! 10 CW fluid specific heat
20000.0                 ! 11 Auxiliary electrical power
INPUTS 8
0,0                     ! [unconnected] Chilled water inlet temperature
0,0                     ! [unconnected] Chilled water flow rate
7,1                     ! Pump-3:Outlet fluid temperature ->Cooling water inlet temperature
7,2                     ! Pump-3:Outlet flow rate ->Cooling water flow rate
22,1                    ! Boiler:Outlet fluid temperature ->Hot water inlet temperature
22,2                    ! Boiler:Outlet fluid flow rate ->Hot water flow rate
0,0                     ! [unconnected] CHW set point
4,3                     ! Thermostat:Control signal for cooling ->Chiller control signal
*** INITIAL INPUT VALUES
12 86400 0 0 0 0 7 1.0
*** External files
ASSIGN "C:\Program Files\Trnsys16\Examples\Data Files\Type107-HotWaterFiredAbsorptionChiller.dat" 65
*|? File with fraction of design energy input data |1000
*------------------------------------------------------------------------------

* Model "Solar collectors" (Type 1)
*
UNIT 15 TYPE 1      Solar collectors
*$UNIT_NAME Solar collectors
*$MODEL .\Solar Thermal Collectors\Quadratic Efficiency Collector\2nd-Order Incidence Angle
Modifiers\Type1b.tmf
*$POSITION 159 414
*$LAYER Main #
PARAMETERS 11
1                       ! 1 Number in series
2000                    ! 2 Collector area
4.190                   ! 3 Fluid specific heat
1                       ! 4 Efficiency mode
40.0                    ! 5 Tested flow rate
0.80                    ! 6 Intercept efficiency
13.0                    ! 7 Efficiency slope
0.05                    ! 8 Efficiency curvature
2                       ! 9 Optical mode 2
```

```
0.2                    ! 10 1st-order IAM
0.0                    ! 11 2nd-order IAM
INPUTS 9
16,1                   ! Pump-4:Outlet fluid temperature ->Inlet temperature
16,2                   ! Pump-4:Outlet flow rate ->Inlet flowrate
17,1                   ! TMY:Ambient temperature ->Ambient temperature
17,18                  ! TMY:total radiation on tilted surface ->Incident radiation
17,12                  ! TMY:total radiation on horizontal ->Total horizontal radiation
17,14                  ! TMY:sky diffuse radiation on horizontal ->Horizontal diffuse radiation
0,0                    ! [unconnected] Ground reflectance
17,22                  ! TMY:angle of incidence for tilted surface  ->Incidence angle
17,23                  ! TMY:slope of tilted surface ->Collector slope
*** INITIAL INPUT VALUES
0 0 0 0. 0 0.0 0.2 45.0 0.
*------------------------------------------------------------------------------

* Model "Pump-4" (Type 3)
*
UNIT 16 TYPE 3      Pump-4
*$UNIT_NAME Pump-4
*$MODEL .\Hydronics\Pumps\Single Speed\Type3b.tmf
*$POSITION 52 414
*$LAYER Main #
PARAMETERS 5
90000                  ! 1 Maximum flow rate
4.190                  ! 2 Fluid specific heat
14713.19961                     ! 3 Maximum power
0.05                   ! 4 Conversion coefficient
0.5                    ! 5 Power coefficient
INPUTS 3
18,1                   ! Storage tank:Temperature to heat source ->Inlet fluid temperature
18,2                   ! Storage tank:Flowrate to heat source ->Inlet mass flow rate
19,1                   ! Regulator:Output control function ->Control signal
*** INITIAL INPUT VALUES
10 100.0 1.0
*------------------------------------------------------------------------------

* Model "Storage tank" (Type 4)
*
UNIT 18 TYPE 4      Storage tank
*$UNIT_NAME Storage tank
*$MODEL .\Thermal Storage\Stratified Storage Tank\Variable Inlets\Uniform Losses\Type4c.tmf
*$POSITION 286 434
*$LAYER Main #
PARAMETERS 22
2                      ! 1 Variable inlet positions
200                    ! 2 Tank volume
4.190                  ! 3 Fluid specific heat
1000.0                 ! 4 Fluid density
2.52                   ! 5 Tank loss coefficient
2                      ! 6 Height of node-1
2                      ! 7 Height of node-2
2                      ! 8 Height of node-3
1                      ! 9 Auxiliary heater mode
2                      ! 10 Node containing heating element -1
1                      ! 11 Node containing thermostat -1
70                     ! 12 Set point temperature for element-1
0                      ! 13 Deadband for heating element-1
0                      ! 14 Maximum heating rate of element -1
2                      ! 15 Node containing heating element -2
```

```
2                       ! 16 Node containing thermostat -2
60.0                    ! 17 Set point temperature for element-2
5.0                     ! 18 Deadband for heating element-2
0                       ! 19 Maximum heating rate of element -2
0.0                     ! 20 Not used (Flue UA)
20.0                    ! 21 Not used (Tflue)
150                     ! 22 Boiling point
INPUTS 7
15,1                    ! Solar collectors:Outlet temperature ->Hot-side temperature
15,2                    ! Solar collectors:Outlet flowrate ->Hot-side flowrate
27,1                    ! Mixing point-1:Outlet temperature ->Cold-side temperature
27,2                    ! Mixing point-1:Outlet flow rate ->Cold-side flowrate
0,0                     ! [unconnected] Environment temperature
0,0                     ! [unconnected] Control signal for element-1
0,0                     ! [unconnected] Control signal for element-2
*** INITIAL INPUT VALUES
0 0 0 0 22.0 0 0
DERIVATIVES 3
10                      ! 1 Initial temperature of node-1
10                      ! 2 Initial temperature of node-2
10                      ! 3 Initial temperature of node-3
*------------------------------------------------------------------------------

* Model "Regulator" (Type 2)
*
UNIT 19 TYPE 2       Regulator
*$UNIT_NAME Regulator
*$MODEL .\Controllers\Differential Controller w_ Hysteresis\for Temperatures\Solver 0 (Successive Substitution)
Control Strategy\Type2b.tmf
*$POSITION 96 493
*$LAYER Main #
*$# NOTE: This control strategy can only be used with solver 0 (Successive substitution)
*$#
PARAMETERS 2
5                       ! 1 No. of oscillations
100.0                   ! 2 High limit cut-out
INPUTS 6
15,1                    ! Solar collectors:Outlet temperature ->Upper input temperature Th
18,1                    ! Storage tank:Temperature to heat source ->Lower input temperature Tl
18,3                    ! Storage tank:Temperature to load ->Monitoring temperature Tin
19,1                    ! Regulator:Output control function ->Input control function
0,0                     ! [unconnected] Upper dead band dT
0,0                     ! [unconnected] Lower dead band dT
*** INITIAL INPUT VALUES
60 20 20 0 10.0 2.0
*------------------------------------------------------------------------------

* EQUATIONS "Sum-1"
*
EQUATIONS 2
PPumpSum = [7,3]+[8,3]+[20,3]+[16,3]
QoSum = [3,8]+[3,7]
*$UNIT_NAME Sum-1
*$LAYER Main
*$POSITION 459 168

*------------------------------------------------------------------------------
```

```
* Model "Integrator" (Type 24)
*
UNIT 10 TYPE 24     Integrator
*$UNIT_NAME Integrator
*$MODEL .\Utility\Integrators\Quantity Integrator\Type24.tmf
*$POSITION 555 167
*$LAYER Main #
PARAMETERS 2
STOP                ! 1 Integration period
0                   ! 2 Relative or absolute start time
INPUTS 7
PPumpSum                    ! Sum-1:PPumpSum ->Input to be integrated-1
12,9                ! Absorption chiller:Hot water energy ->Input to be integrated-2
15,3                ! Solar collectors:Useful energy gain ->Input to be integrated-3
12,7                ! Absorption chiller:Chilled water energy ->Input to be integrated-4
QoSum               ! Sum-1:QoSum ->Input to be integrated-5
12,10               ! Absorption chiller:Electrical energy required ->Input to be integrated-6
22,5                ! Boiler:Rate of energy delivery to fluid stream ->Input to be integrated-7
*** INITIAL INPUT VALUES
0.0 0.0 0.0 0.0 0.0 0.0 0.0
*------------------------------------------------------------------------------

* Model "Ploter" (Type 25)
*
UNIT 9 TYPE 25      Ploter
*$UNIT_NAME Ploter
*$MODEL .\Output\Printer\TRNSYS-Supplied Units\Type25a.tmf
*$POSITION 662 168
*$LAYER Main #
PARAMETERS 10
1                   ! 1 Printing interval
START               ! 2 Start time
STOP                ! 3 Stop time
61                  ! 4 Logical unit
2                   ! 5 Units printing mode
0                   ! 6 Relative or absolute start time
-1                  ! 7 Overwrite or Append
-1                  ! 8 Print header
0                   ! 9 Delimiter
1                   ! 10 Print labels
INPUTS 7
10,4                ! Integrator:Result of integration-4 ->Input to be printed-1
10,1                ! Integrator:Result of integration-1 ->Input to be printed-2
10,2                ! Integrator:Result of integration-2 ->Input to be printed-3
10,5                ! Integrator:Result of integration-5 ->Input to be printed-4
10,3                ! Integrator:Result of integration-3 ->Input to be printed-5
10,6                ! Integrator:Result of integration-6 ->Input to be printed-6
10,7                ! Integrator:Result of integration-7 ->Input to be printed-7
*** INITIAL INPUT VALUES
CollingEnergyEvap PPump HotWaterEnergyChiller CollingEnergyHouse
EnergyFromColl ElecticalEnergyRequiChiller AuxHeaterEnergy
*** External files
ASSIGN "EnergijeHladenjaApsorp.out" 61
*|? Output File for printed results |1000
*------------------------------------------------------------------------------

* Model "Monitoring-1" (Type 65)
*
UNIT 21 TYPE 65     Monitoring-1
*$UNIT_NAME Monitoring-1
```

```
*$MODEL .\Output\Online Plotter\Online Plotter Without File\Type65d.tmf
*$POSITION 546 83
*$LAYER Main #
PARAMETERS 12
2                    ! 1 Nb. of left-axis variables
0                    ! 2 Nb. of right-axis variables
0.0                  ! 3 Left axis minimum
40                   ! 4 Left axis maximum
0.0                  ! 5 Right axis minimum
1000.0               ! 6 Right axis maximum
1                    ! 7 Number of plots per simulation
12                   ! 8 X-axis gridpoints
0                    ! 9 Shut off Online w/o removing
-1                   ! 10 Logical unit for output file
0                    ! 11 Output file units
0                    ! 12 Output file delimiter
INPUTS 2
17,1                 ! TMY:Ambient temperature ->Left axis variable-1
3,4                  ! Hotel:Average house temperature ->Left axis variable-2
*** INITIAL INPUT VALUES
Ambient Average
LABELS  3
""
""
"House"
*------------------------------------------------------------------------------

* Model "Monitoring-3" (Type 65)
*
UNIT 23 TYPE 65     Monitoring-3
*$UNIT_NAME Monitoring-3
*$MODEL .\Output\Online Plotter\Online Plotter Without File\Type65d.tmf
*$POSITION 361 553
*$LAYER Main #
PARAMETERS 12
6                    ! 1 Nb. of left-axis variables
0                    ! 2 Nb. of right-axis variables
0.0                  ! 3 Left axis minimum
150                  ! 4 Left axis maximum
0.0                  ! 5 Right axis minimum
1000.0               ! 6 Right axis maximum
1                    ! 7 Number of plots per simulation
12                   ! 8 X-axis gridpoints
0                    ! 9 Shut off Online w/o removing
-1                   ! 10 Logical unit for output file
0                    ! 11 Output file units
0                    ! 12 Output file delimiter
INPUTS 6
18,3                 ! Storage tank:Temperature to load ->Left axis variable-1
18,1                 ! Storage tank:Temperature to heat source ->Left axis variable-2
18,12                ! Storage tank:Average tank temperature ->Left axis variable-3
18,13                ! Storage tank:Temperature of node 1+ ->Left axis variable-4
15,1                 ! Solar collectors:Outlet temperature ->Left axis variable-5
28,1                 ! Mixing point-2:Outlet temperature ->Left axis variable-6
*** INITIAL INPUT VALUES
TToLoad TToColl TTankAverage TTankMidle TCollOut TToConsumers
LABELS  3
""
""
"Collector"
```

```
*------------------------------------------------------------------------------

* Model "Monitoring-2" (Type 65)
*
UNIT 24 TYPE 65     Monitoring-2
*$UNIT_NAME Monitoring-2
*$MODEL .\Output\Online Plotter\Online Plotter Without File\Type65d.tmf
*$POSITION 662 244
*$LAYER Main #
PARAMETERS 12
3                   ! 1 Nb. of left-axis variables
0                   ! 2 Nb. of right-axis variables
0.0                 ! 3 Left axis minimum
110                 ! 4 Left axis maximum
0.0                 ! 5 Right axis minimum
1000.0              ! 6 Right axis maximum
1                   ! 7 Number of plots per simulation
12                  ! 8 X-axis gridpoints
0                   ! 9 Shut off Online w/o removing
-1                  ! 10 Logical unit for output file
0                   ! 11 Output file units
0                   ! 12 Output file delimiter
INPUTS 3
12,1                ! Absorption chiller:Chilled water temperature ->Left axis variable-1
12,3                ! Absorption chiller:Cooling water temperature ->Left axis variable-2
12,5                ! Absorption chiller:Hot water outlet temperature ->Left axis variable-3
*** INITIAL INPUT VALUES
Chilled Cooling Hot
LABELS  3
""
""
"Absorption"
*------------------------------------------------------------------------------

* Model "Histogram DHW" (Type 14)
*
UNIT 25 TYPE 14     Histogram DHW
*$UNIT_NAME Histogram DHW
*$MODEL .\Utility\Forcing Functions\General\Type14h.tmf
*$POSITION 657 500
*$LAYER Main #
PARAMETERS 44
0                   ! 1 Initial value of time
100                 ! 2 Initial value of function
1                   ! 3 Time at point-1
200                 ! 4 Value at point -1
4                   ! 5 Time at point-2
300                 ! 6 Value at point -2
5                   ! 7 Time at point-3
200                 ! 8 Value at point -3
6                   ! 9 Time at point-4
3000                ! 10 Value at point -4
7                   ! 11 Time at point-5
4000                ! 12 Value at point -5
8                   ! 13 Time at point-6
5000                ! 14 Value at point -6
9                   ! 15 Time at point-7
6000                ! 16 Value at point -7
10                  ! 17 Time at point-8
4000                ! 18 Value at point -8
```

```
11                  ! 19 Time at point-9
1000                ! 20 Value at point -9
13                  ! 21 Time at point-10
1000                ! 22 Value at point -10
14                  ! 23 Time at point-11
1500                ! 24 Value at point -11
15                  ! 25 Time at point-12
2000                ! 26 Value at point -12
16                  ! 27 Time at point-13
2500                ! 28 Value at point -13
17                  ! 29 Time at point-14
4000                ! 30 Value at point -14
18                  ! 31 Time at point-15
5000                ! 32 Value at point -15
19                  ! 33 Time at point-16
6000                ! 34 Value at point -16
20                  ! 35 Time at point-17
3000                ! 36 Value at point -17
21                  ! 37 Time at point-18
2000                ! 38 Value at point -18
22                  ! 39 Time at point-19
1000                ! 40 Value at point -19
23                  ! 41 Time at point-20
500                 ! 42 Value at point -20
24                  ! 43 Time at point-21
100                 ! 44 Value at point -21
*------------------------------------------------------------------------------

* Model "Mixing valve" (Type 11)
*
UNIT 26 TYPE 11     Mixing valve
*$UNIT_NAME Mixing valve
*$MODEL .\Hydronics\Tempering Valve\Other Fluids\Type11b.tmf
*$POSITION 534 500
*$LAYER Main #
PARAMETERS 2
4                   ! 1 Tempering valve mode
7                   ! 2 Nb. of oscillations allowed
INPUTS 4
0,0                 ! [unconnected] Inlet temperature
0,0                 ! [unconnected] Inlet flow rate
18,3                ! Storage tank:Temperature to load ->Heat source temperature
0,0                 ! [unconnected] Set point temperature
*** INITIAL INPUT VALUES
10.0 100 0 40
*------------------------------------------------------------------------------

* Model "Mixing point-1" (Type 11)
*
UNIT 27 TYPE 11     Mixing point-1
*$UNIT_NAME Mixing point-1
*$MODEL .\Hydronics\Tee-Piece\Other Fluids\Type11h.tmf
*$POSITION 432 500
*$LAYER Main #
PARAMETERS 1
1                   ! 1 Tee piece mode
INPUTS 4
20,1                ! Pump-2:Outlet fluid temperature ->Temperature at inlet 1
20,2                ! Pump-2:Outlet flow rate ->Flow rate at inlet 1
26,1                ! Mixing valve:Temperature at outlet 1 ->Temperature at inlet 2
```

```
26,2                    ! Mixing valve:Flowrate at outlet 1 ->Flow rate at inlet 2
*** INITIAL INPUT VALUES
20.0 100.0 20.0 100.0
*------------------------------------------------------------------------------

* Model "Mixing point-2" (Type 11)
*
UNIT 28 TYPE 11     Mixing point-2
*$UNIT_NAME Mixing point-2
*$MODEL .\Hydronics\Tee-Piece\Other Fluids\Type11h.tmf
*$POSITION 534 414
*$LAYER Main #
PARAMETERS 1
1                       ! 1 Tee piece mode
INPUTS 4
18,3                    ! Storage tank:Temperature to load ->Temperature at inlet 1
Mout                    ! Sum-2:Mout ->Flow rate at inlet 1
26,3                    ! Mixing valve:Temperature at outlet 2 ->Temperature at inlet 2
26,4                    ! Mixing valve:Flow rate at outlet 2 ->Flow rate at inlet 2
*** INITIAL INPUT VALUES
20.0 100.0 20.0 100.0
*------------------------------------------------------------------------------

* EQUATIONS "Sum-2"
*
EQUATIONS 1
Mout = [18,4]-[20,2]
*$UNIT_NAME Sum-2
*$LAYER Main
*$POSITION 535 341

*------------------------------------------------------------------------------


END
```

Solar heating system + domestic hot water (ACS)

```
*******************************************************************************
*** TRNSYS input file (deck) generated by TrnsysStudio
*******************************************************************************
*** Control cards
*******************************************************************************
* START, STOP and STEP
CONSTANTS 3
START=0
STOP=2520
STEP=0.005555556
* User defined CONSTANTS

SIMULATION     START   STOP   STEP      ! Start time      End time  Time step
TOLERANCES 0.001 0.001                  ! Integration      Convergence
LIMITS 30 30 30                         ! Max iterations    Max warnings     Trace limit
DFQ 1                                   ! TRNSYS numerical integration solver method
WIDTH 80                                ! TRNSYS output file width, number of characters
LIST                                    ! NOLIST statement
                                        ! MAP statement
SOLVER 0 1 1                            ! Solver statement   Minimum relaxation factor    Maximum
relaxation factor
NAN_CHECK 0                             ! Nan DEBUG statement
OVERWRITE_CHECK 0                       ! Overwrite DEBUG statement
EQSOLVER 0                              ! EQUATION SOLVER statement

* Model "TMY" (Type 109)
*

UNIT 17 TYPE 109   TMY
*$UNIT_NAME TMY
*$MODEL .\Weather Data Reading and Processing\Standard Format\TMY2\Type109-TMY2.tmf
*$POSITION 108 83
*$LAYER Main #
PARAMETERS 4
2             ! 1 Data Reader Mode
68            ! 2 Logical unit
4             ! 3 Sky model for diffuse radiation
1             ! 4 Tracking mode
INPUTS 3
0,0           ! [unconnected] Ground reflectance
0,0           ! [unconnected] Slope of surface
0,0           ! [unconnected] Azimuth of surface
*** INITIAL INPUT VALUES
0.2 45 0.0
*** External files
ASSIGN "C:\Program Files\Trnsys16\Weather\Meteonorm\Europe\HR-Split-133340.tm2" 68
*|? Weather data file |1000
*------------------------------------------------------------------------------

* Model "Hotel" (Type 12)
*
UNIT 3 TYPE 12      Hotel
*$UNIT_NAME Hotel
*$MODEL .\Loads and Structures\Single Zone Models\Energy (Degree Day) Space Load (Type12)\Temperature
Level Control\Type12c.tmf
*$POSITION 226 83
*$LAYER Main #
```

```
PARAMETERS 7
4                ! 1 Temperature level control
89999.997616                ! 2 Overall conductance of house
750000           ! 3 House thermal capacitance
10               ! 4 Initial room temperature
4.19             ! 5 Specific heat of source fluid
68745.598179                ! 6 Effectiveness-Cmin product
0.23             ! 7 Latent heat ratio
INPUTS 6
20,1             ! Pump-1:Outlet fluid temperature ->Inlet temperature
20,2             ! Pump-1:Outlet flow rate ->Inlet flow rate
17,1             ! TMY:Ambient temperature ->Ambient temperature
0,0              ! [unconnected] Internal gains
0,0              ! [unconnected] Auxiliary heat input
0,0              ! [unconnected] Cooling input
*** INITIAL INPUT VALUES
0 0 10 0.0 0.0 0.0
*------------------------------------------------------------------------------

* Model "Histogram DHW" (Type 14)
*
UNIT 22 TYPE 14     Histogram DHW
*$UNIT_NAME Histogram DHW
*$MODEL .\Utility\Forcing Functions\General\Type14h.tmf
*$POSITION 681 498
*$LAYER Main #
PARAMETERS 44
0                ! 1 Initial value of time
50               ! 2 Initial value of function
1                ! 3 Time at point-1
100              ! 4 Value at point -1
4                ! 5 Time at point-2
150              ! 6 Value at point -2
5                ! 7 Time at point-3
100              ! 8 Value at point -3
6                ! 9 Time at point-4
1500             ! 10 Value at point -4
7                ! 11 Time at point-5
2000             ! 12 Value at point -5
8                ! 13 Time at point-6
2500             ! 14 Value at point -6
9                ! 15 Time at point-7
3000             ! 16 Value at point -7
10               ! 17 Time at point-8
2000             ! 18 Value at point -8
11               ! 19 Time at point-9
500              ! 20 Value at point -9
13               ! 21 Time at point-10
500              ! 22 Value at point -10
14               ! 23 Time at point-11
750              ! 24 Value at point -11
15               ! 25 Time at point-12
1000             ! 26 Value at point -12
16               ! 27 Time at point-13
1250             ! 28 Value at point -13
17               ! 29 Time at point-14
2000             ! 30 Value at point -14
18               ! 31 Time at point-15
2500             ! 32 Value at point -15
19               ! 33 Time at point-16
```

```
3000                    ! 34 Value at point -16
20                      ! 35 Time at point-17
1500                    ! 36 Value at point -17
21                      ! 37 Time at point-18
1000                    ! 38 Value at point -18
22                      ! 39 Time at point-19
500                     ! 40 Value at point -19
23                      ! 41 Time at point-20
250                     ! 42 Value at point -20
24                      ! 43 Time at point-21
50                      ! 44 Value at point -21
*------------------------------------------------------------------------------

* Model "Thermostat" (Type 8)
*
UNIT 4 TYPE 8      Thermostat
*$UNIT_NAME Thermostat
*$MODEL .\Controllers\3-Stage Room Thermostat\w_ heating set back and temp deadband\Type8b.tmf
*$POSITION 361 83
*$LAYER Main #
PARAMETERS 8
5                       ! 1 Nb. of oscillations permitted
0                       ! 2 1st stage heating in 2nd stage?
20.00                   ! 3 Minimum primary source temperature
35                      ! 4 Temperature for cooling
21                      ! 5 1st stage heating temperature
21                      ! 6 2nd stage heating temperature
0                       ! 7 Heating set back temperature difference
0                       ! 8 Temperature dead band
INPUTS 3
3,4                     ! Hotel:Average house temperature ->Room temperature
0,0                     ! [unconnected] 1st stage source temperature
0,0                     ! [unconnected] Set back control function
*** INITIAL INPUT VALUES
20.0 30 0
*------------------------------------------------------------------------------

* Model "Solar collectors" (Type 1)
*
UNIT 15 TYPE 1     Solar collectors
*$UNIT_NAME Solar collectors
*$MODEL .\Solar Thermal Collectors\Quadratic Efficiency Collector\2nd-Order Incidence Angle
Modifiers\Type1b.tmf
*$POSITION 136 412
*$LAYER Main #
PARAMETERS 11
1                       ! 1 Number in series
1500                    ! 2 Collector area
4.190                   ! 3 Fluid specific heat
1                       ! 4 Efficiency mode
40.0                    ! 5 Tested flow rate
0.80                    ! 6 Intercept efficiency
13.0                    ! 7 Efficiency slope
0.05                    ! 8 Efficiency curvature
2                       ! 9 Optical mode 2
0.2                     ! 10 1st-order IAM
0.0                     ! 11 2nd-order IAM
INPUTS 9
16,1                    ! Pump-2:Outlet fluid temperature ->Inlet temperature
16,2                    ! Pump-2:Outlet flow rate ->Inlet flowrate
```

```
17,1                    ! TMY:Ambient temperature ->Ambient temperature
17,18                   ! TMY:total radiation on tilted surface ->Incident radiation
17,12                   ! TMY:total radiation on horizontal ->Total horizontal radiation
17,14                   ! TMY:sky diffuse radiation on horizontal ->Horizontal diffuse radiation
0,0                     ! [unconnected] Ground reflectance
17,22                   ! TMY:angle of incidence for tilted surface  ->Incidence angle
17,23                   ! TMY:slope of tilted surface ->Collector slope
*** INITIAL INPUT VALUES
0 0 0 0. 0 0.0 0.2 45.0 0.
*------------------------------------------------------------------------------

* EQUATIONS "Sum-2"
*
EQUATIONS 1
Mout = [18,4]-[20,2]
*$UNIT_NAME Sum-2
*$LAYER Main
*$POSITION 544 328

*------------------------------------------------------------------------------

* Model "Mixing valve" (Type 11)
*
UNIT 26 TYPE 11     Mixing valve
*$UNIT_NAME Mixing valve
*$MODEL .\Hydronics\Tempering Valve\Other Fluids\Type11b.tmf
*$POSITION 582 498
*$LAYER Main #
PARAMETERS 2
4                       ! 1 Tempering valve mode
7                       ! 2 Nb. of oscillations allowed
INPUTS 4
0,0                     ! [unconnected] Inlet temperature
22,1                    ! Histogram DHW:Average value of function ->Inlet flow rate
18,3                    ! Storage tank:Temperature to load ->Heat source temperature
0,0                     ! [unconnected] Set point temperature
*** INITIAL INPUT VALUES
10.0 100 0 40
*------------------------------------------------------------------------------

* Model "Mixing place-2" (Type 11)
*
UNIT 27 TYPE 11     Mixing place-2
*$UNIT_NAME Mixing place-2
*$MODEL .\Hydronics\Tee-Piece\Other Fluids\Type11h.tmf
*$POSITION 482 498
*$LAYER Main #
PARAMETERS 1
1                       ! 1 Tee piece mode
INPUTS 4
3,1                     ! Hotel:Temperature to heat source ->Temperature at inlet 1
3,2                     ! Hotel:Flow rate to heat source ->Flow rate at inlet 1
26,1                    ! Mixing valve:Temperature at outlet 1 ->Temperature at inlet 2
26,2                    ! Mixing valve:Flowrate at outlet 1 ->Flow rate at inlet 2
*** INITIAL INPUT VALUES
20.0 100.0 20.0 100.0
*------------------------------------------------------------------------------
```

```
* Model "Mixing place-3" (Type 11)
*
UNIT 28 TYPE 11     Mixing place-3
*$UNIT_NAME Mixing place-3
*$MODEL .\Hydronics\Tee-Piece\Other Fluids\Type11h.tmf
*$POSITION 582 412
*$LAYER Main #
PARAMETERS 1
1                    ! 1 Tee piece mode
INPUTS 4
18,3                 ! Storage tank:Temperature to load ->Temperature at inlet 1
Mout                 ! Sum-2:Mout ->Flow rate at inlet 1
26,3                 ! Mixing valve:Temperature at outlet 2 ->Temperature at inlet 2
26,4                 ! Mixing valve:Flow rate at outlet 2 ->Flow rate at inlet 2
*** INITIAL INPUT VALUES
20.0 100.0 20.0 100.0
*------------------------------------------------------------------------------

* Model "Pump-1" (Type 3)
*
UNIT 20 TYPE 3      Pump-1
*$UNIT_NAME Pump-1
*$MODEL .\Hydronics\Pumps\Single Speed\Type3b.tmf
*$POSITION 337 244
*$LAYER Water Loop #
PARAMETERS 5
79200                ! 1 Maximum flow rate
4.190                ! 2 Fluid specific heat
29350.799222                 ! 3 Maximum power
0.05                 ! 4 Conversion coefficient
0.5                  ! 5 Power coefficient
INPUTS 3
18,3                 ! Storage tank:Temperature to load ->Inlet fluid temperature
0,0                  ! [unconnected] Inlet mass flow rate
4,2                  ! Thermostat:Control signal for 2nd stage heating ->Control signal
*** INITIAL INPUT VALUES
20.0 100.0 1.0
*------------------------------------------------------------------------------

* Model "Pump-2" (Type 3)
*
UNIT 16 TYPE 3      Pump-2
*$UNIT_NAME Pump-2
*$MODEL .\Hydronics\Pumps\Single Speed\Type3b.tmf
*$POSITION 51 412
*$LAYER Main #
PARAMETERS 5
59760.001373                 ! 1 Maximum flow rate
4.190                ! 2 Fluid specific heat
14713.19961                  ! 3 Maximum power
0.05                 ! 4 Conversion coefficient
0.5                  ! 5 Power coefficient
INPUTS 3
18,1                 ! Storage tank:Temperature to heat source ->Inlet fluid temperature
0,0                  ! [unconnected] Inlet mass flow rate
19,1                 ! Regulator:Output control function ->Control signal
*** INITIAL INPUT VALUES
10 100.0 1.0
*------------------------------------------------------------------------------
```

```
* EQUATIONS "Sum"
*
EQUATIONS 2
PPumpSum = [20,3]+[16,3]
QoSum = [3,8]+[3,7]
*$UNIT_NAME Sum
*$LAYER Main
*$POSITION 399 168

*------------------------------------------------------------------------------

* Model "Storage tank" (Type 4)
*
UNIT 18 TYPE 4     Storage tank
*$UNIT_NAME Storage tank
*$MODEL .\Thermal Storage\Stratified Storage Tank\Variable Inlets\Uniform Losses\Type4c.tmf
*$POSITION 285 432
*$LAYER Main #
PARAMETERS 22
2                   ! 1 Variable inlet positions
150                 ! 2 Tank volume
4.190               ! 3 Fluid specific heat
1000.0              ! 4 Fluid density
2.52                ! 5 Tank loss coefficient
2                   ! 6 Height of node-1
2                   ! 7 Height of node-2
2                   ! 8 Height of node-3
1                   ! 9 Auxiliary heater mode
2                   ! 10 Node containing heating element -1
1                   ! 11 Node containing thermostat -1
42                  ! 12 Set point temperature for element-1
0                   ! 13 Deadband for heating element-1
2339999.826867              ! 14 Maximum heating rate of element -1
2                   ! 15 Node containing heating element -2
2                   ! 16 Node containing thermostat -2
60.0                ! 17 Set point temperature for element-2
5.0                 ! 18 Deadband for heating element-2
0                   ! 19 Maximum heating rate of element -2
0.0                 ! 20 Not used (Flue UA)
20.0                ! 21 Not used (Tflue)
100                 ! 22 Boiling point
INPUTS 7
15,1                ! Solar collectors:Outlet temperature ->Hot-side temperature
15,2                ! Solar collectors:Outlet flowrate ->Hot-side flowrate
27,1                ! Mixing place-2:Outlet temperature ->Cold-side temperature
27,2                ! Mixing place-2:Outlet flow rate ->Cold-side flowrate
0,0                 ! [unconnected] Environment temperature
0,0                 ! [unconnected] Control signal for element-1
0,0                 ! [unconnected] Control signal for element-2
*** INITIAL INPUT VALUES
0 0 0 0 22.0 1 0
DERIVATIVES 3
40                  ! 1 Initial temperature of node-1
40                  ! 2 Initial temperature of node-2
40                  ! 3 Initial temperature of node-3
*------------------------------------------------------------------------------
```

```
* Model "Regulator" (Type 2)
*
UNIT 19 TYPE 2	Regulator
*$UNIT_NAME Regulator
*$MODEL .\Controllers\Differential Controller w_ Hysteresis\for Temperatures\Solver 0 (Successive Substitution)
Control Strategy\Type2b.tmf
*$POSITION 93 505
*$LAYER Main #
*$# NOTE: This control strategy can only be used with solver 0 (Successive substitution)
*$#
PARAMETERS 2
5		! 1 No. of oscillations
100.0		! 2 High limit cut-out
INPUTS 6
15,1		! Solar collectors:Outlet temperature ->Upper input temperature Th
18,1		! Storage tank:Temperature to heat source ->Lower input temperature Tl
18,3		! Storage tank:Temperature to load ->Monitoring temperature Tin
19,1		! Regulator:Output control function ->Input control function
0,0		! [unconnected] Upper dead band dT
0,0		! [unconnected] Lower dead band dT
*** INITIAL INPUT VALUES
60 20 20 0 10 2
*------------------------------------------------------------------------------

* Model "Integrator" (Type 24)
*
UNIT 10 TYPE 24	Integrator
*$UNIT_NAME Integrator
*$MODEL .\Utility\Integrators\Quantity Integrator\Type24.tmf
*$POSITION 513 168
*$LAYER Main #
PARAMETERS 2
STOP		! 1 Integration period
0		! 2 Relative or absolute start time
INPUTS 7
PPumpSum			! Sum:PPumpSum ->Input to be integrated-1
0,0		! [unconnected] Input to be integrated-2
15,3		! Solar collectors:Useful energy gain ->Input to be integrated-3
0,0		! [unconnected] Input to be integrated-4
QoSum		! Sum:QoSum ->Input to be integrated-5
0,0		! [unconnected] Input to be integrated-6
18,8		! Storage tank:Auxiliary heating rate ->Input to be integrated-7
*** INITIAL INPUT VALUES
0.0 0.0 0.0 0.0 0.0 0.0 0.0
*------------------------------------------------------------------------------

* Model "Ploter" (Type 25)
*
UNIT 9 TYPE 25	Ploter
*$UNIT_NAME Ploter
*$MODEL .\Output\Printer\TRNSYS-Supplied Units\Type25a.tmf
*$POSITION 622 168
*$LAYER Main #
PARAMETERS 10
1		! 1 Printing interval
START		! 2 Start time
STOP		! 3 Stop time
61		! 4 Logical unit
2		! 5 Units printing mode
0		! 6 Relative or absolute start time
```

```
-1                      ! 7 Overwrite or Append
-1                      ! 8 Print header
0                       ! 9 Delimiter
1                       ! 10 Print labels
INPUTS 7
10,4                    ! Integrator:Result of integration-4 ->Input to be printed-1
10,1                    ! Integrator:Result of integration-1 ->Input to be printed-2
10,2                    ! Integrator:Result of integration-2 ->Input to be printed-3
10,5                    ! Integrator:Result of integration-5 ->Input to be printed-4
10,3                    ! Integrator:Result of integration-3 ->Input to be printed-5
10,6                    ! Integrator:Result of integration-6 ->Input to be printed-6
10,7                    ! Integrator:Result of integration-7 ->Input to be printed-7
*** INITIAL INPUT VALUES
CollingEnergyEvap PPump HotWaterEnergyChiller CollingEnergyHouse
EnergyFromColl ElecticalEnergyRequiChiller AuxHeaterEnergy
*** External files
ASSIGN "EnergijeGrijanjaSustav2.out" 61
*|? Output File for printed results |1000
*------------------------------------------------------------------------------

* Model "Monitoring" (Type 65)
*
UNIT 21 TYPE 65     Monitoring
*$UNIT_NAME Monitoring
*$MODEL .\Output\Online Plotter\Online Plotter Without File\Type65d.tmf
*$POSITION 475 83
*$LAYER Main #
PARAMETERS 12
2                       ! 1 Nb. of left-axis variables
0                       ! 2 Nb. of right-axis variables
-5                      ! 3 Left axis minimum
30                      ! 4 Left axis maximum
0.0                     ! 5 Right axis minimum
1000.0                  ! 6 Right axis maximum
1                       ! 7 Number of plots per simulation
12                      ! 8 X-axis gridpoints
0                       ! 9 Shut off Online w/o removing
-1                      ! 10 Logical unit for output file
0                       ! 11 Output file units
0                       ! 12 Output file delimiter
INPUTS 2
17,1                    ! TMY:Ambient temperature ->Left axis variable-1
3,4                     ! Hotel:Average house temperature ->Left axis variable-2
*** INITIAL INPUT VALUES
Ambient Average
LABELS  3
""
""
"House"
*------------------------------------------------------------------------------

* Model "Monitoring-2" (Type 65)
*
UNIT 23 TYPE 65     Monitoring-2
*$UNIT_NAME Monitoring-2
*$MODEL .\Output\Online Plotter\Online Plotter Without File\Type65d.tmf
*$POSITION 397 551
*$LAYER Main #
PARAMETERS 12
6                       ! 1 Nb. of left-axis variables
```

```
0                    ! 2 Nb. of right-axis variables
0.0                  ! 3 Left axis minimum
90                   ! 4 Left axis maximum
0.0                  ! 5 Right axis minimum
1000.0               ! 6 Right axis maximum
2                    ! 7 Number of plots per simulation
12                   ! 8 X-axis gridpoints
0                    ! 9 Shut off Online w/o removing
-1                   ! 10 Logical unit for output file
0                    ! 11 Output file units
0                    ! 12 Output file delimiter
INPUTS 6
18,3                 ! Storage tank:Temperature to load ->Left axis variable-1
18,1                 ! Storage tank:Temperature to heat source ->Left axis variable-2
18,12                ! Storage tank:Average tank temperature ->Left axis variable-3
18,13                ! Storage tank:Temperature of node 1+ ->Left axis variable-4
15,1                 ! Solar collectors:Outlet temperature ->Left axis variable-5
28,1                 ! Mixing place-3:Outlet temperature ->Left axis variable-6
*** INITIAL INPUT VALUES
TToLoad TToColl TTankAverage TTankMidle TCollOut TToConsumers
LABELS  3
""
""
"Collector"
*------------------------------------------------------------------------------

END
```

Domestic hot water system – oil boiler (CS)

```
*******************************************************************************
*** TRNSYS input file (deck) generated by TrnsysStudio
*******************************************************************************
*** Control cards
*******************************************************************************
* START, STOP and STEP
CONSTANTS 3
START=0
STOP=8760
STEP=0.055555557
* User defined CONSTANTS

SIMULATION      START    STOP     STEP      ! Start time        End time  Time step
TOLERANCES 0.001 0.001                      ! Integration        Convergence
LIMITS 30 30 30                             ! Max iterations    Max warnings     Trace limit
DFQ 1                                       ! TRNSYS numerical integration solver method
WIDTH 80                                    ! TRNSYS output file width, number of characters
LIST                                        ! NOLIST statement
                                            ! MAP statement
SOLVER 0 1 1                                ! Solver statement   Minimum relaxation factor    Maximum
relaxation factor
NAN_CHECK 0                                 ! Nan DEBUG statement
OVERWRITE_CHECK 0                           ! Overwrite DEBUG statement
EQSOLVER 0                                  ! EQUATION SOLVER statement

* Model "Storage tank" (Type 4)
*
UNIT 2 TYPE 4      Storage tank
*$UNIT_NAME Storage tank
*$MODEL .\Thermal Storage\Stratified Storage Tank\Variable Inlets\Uniform Losses\Type4c.tmf
*$POSITION 207 279
*$LAYER Main #
PARAMETERS 22
2                   ! 1 Variable inlet positions
36                  ! 2 Tank volume
4.190               ! 3 Fluid specific heat
1000.0              ! 4 Fluid density
2.52                ! 5 Tank loss coefficient
1                   ! 6 Height of node-1
1                   ! 7 Height of node-2
1                   ! 8 Height of node-3
1                   ! 9 Auxiliary heater mode
2                   ! 10 Node containing heating element -1
1                   ! 11 Node containing thermostat -1
42.5                ! 12 Set point temperature for element-1
0                   ! 13 Deadband for heating element-1
539999.960046               ! 14 Maximum heating rate of element -1
3                   ! 15 Node containing heating element -2
3                   ! 16 Node containing thermostat -2
60                  ! 17 Set point temperature for element-2
5.0                 ! 18 Deadband for heating element-2
0                   ! 19 Maximum heating rate of element -2
0.0                 ! 20 Not used (Flue UA)
20.0                ! 21 Not used (Tflue)
100.0               ! 22 Boiling point
INPUTS 7
0,0                 ! [unconnected] Hot-side temperature
```

```
0,0                     ! [unconnected] Hot-side flowrate
9,1                     ! Mixing valve:Temperature at outlet 1 ->Cold-side temperature
9,2                     ! Mixing valve:Flowrate at outlet 1 ->Cold-side flowrate
0,0                     ! [unconnected] Environment temperature
0,0                     ! [unconnected] Control signal for element-1
0,0                     ! [unconnected] Control signal for element-2
*** INITIAL INPUT VALUES
45.0 0 10 0 22.0 1 0
DERIVATIVES 3
10                      ! 1 Initial temperature of node-1
10                      ! 2 Initial temperature of node-2
10                      ! 3 Initial temperature of node-3
*------------------------------------------------------------------------------

* Model "Histogram DHW" (Type 14)
*
UNIT 3 TYPE 14     Histogram DHW
*$UNIT_NAME Histogram DHW
*$MODEL .\Utility\Forcing Functions\General\Type14h.tmf
*$POSITION 499 323
*$LAYER Main #
PARAMETERS 44
0                       ! 1 Initial value of time
100                     ! 2 Initial value of function
1                       ! 3 Time at point-1
200                     ! 4 Value at point -1
4                       ! 5 Time at point-2
300                     ! 6 Value at point -2
5                       ! 7 Time at point-3
200                     ! 8 Value at point -3
6                       ! 9 Time at point-4
3000                    ! 10 Value at point -4
7                       ! 11 Time at point-5
4000                    ! 12 Value at point -5
8                       ! 13 Time at point-6
5000                    ! 14 Value at point -6
9                       ! 15 Time at point-7
6000                    ! 16 Value at point -7
10                      ! 17 Time at point-8
4000                    ! 18 Value at point -8
11                      ! 19 Time at point-9
1000                    ! 20 Value at point -9
13                      ! 21 Time at point-10
1000                    ! 22 Value at point -10
14                      ! 23 Time at point-11
1500                    ! 24 Value at point -11
15                      ! 25 Time at point-12
2000                    ! 26 Value at point -12
16                      ! 27 Time at point-13
2500                    ! 28 Value at point -13
17                      ! 29 Time at point-14
4000                    ! 30 Value at point -14
18                      ! 31 Time at point-15
5000                    ! 32 Value at point -15
19                      ! 33 Time at point-16
6000                    ! 34 Value at point -16
20                      ! 35 Time at point-17
3000                    ! 36 Value at point -17
21                      ! 37 Time at point-18
2000                    ! 38 Value at point -18
```

```
22                      ! 39 Time at point-19
1000                    ! 40 Value at point -19
23                      ! 41 Time at point-20
500                     ! 42 Value at point -20
24                      ! 43 Time at point-21
100                     ! 44 Value at point -21
*------------------------------------------------------------------------------

* Model "Monitoring-2" (Type 65)
*
UNIT 4 TYPE 65      Monitoring-2
*$UNIT_NAME Monitoring-2
*$MODEL .\Output\Online Plotter\Online Plotter With File\TRNSYS-Supplied Units\Type65a.tmf
*$POSITION 265 392
*$LAYER Main #
PARAMETERS 12
0                       ! 1 Nb. of left-axis variables
2                       ! 2 Nb. of right-axis variables
0                       ! 3 Left axis minimum
100                     ! 4 Left axis maximum
0.0                     ! 5 Right axis minimum
7000                    ! 6 Right axis maximum
1                       ! 7 Number of plots per simulation
12                      ! 8 X-axis gridpoints
0                       ! 9 Shut off Online w/o removing
72                      ! 10 Logical Unit for output file
2                       ! 11 Output file units
0                       ! 12 Output file delimiter
INPUTS 2
2,4                     ! Storage tank:Flowrate to load ->Right axis variable-1
2,2                     ! Storage tank:Flowrate to heat source ->Right axis variable-2
*** INITIAL INPUT VALUES
MassRateTankLOAD MassRateTankSOURCE
LABELS  3
"kg/s"
""
"MassFlowRates"
*** External files
ASSIGN "MassFlowRates.plt" 72
*|? What file should the online print to? |1000
*------------------------------------------------------------------------------

* Model "Monitoring-1" (Type 65)
*
UNIT 5 TYPE 65      Monitoring-1
*$UNIT_NAME Monitoring-1
*$MODEL .\Output\Online Plotter\Online Plotter With File\TRNSYS-Supplied Units\Type65a.tmf
*$POSITION 136 392
*$LAYER Main #
PARAMETERS 12
5                       ! 1 Nb. of left-axis variables
1                       ! 2 Nb. of right-axis variables
0                       ! 3 Left axis minimum
60                      ! 4 Left axis maximum
0.0                     ! 5 Right axis minimum
7000                    ! 6 Right axis maximum
1                       ! 7 Number of plots per simulation
12                      ! 8 X-axis gridpoints
0                       ! 9 Shut off Online w/o removing
73                      ! 10 Logical Unit for output file
```

```
2                     ! 11 Output file units
0                     ! 12 Output file delimiter
INPUTS 6
2,3                   ! Storage tank:Temperature to load ->Left axis variable-1
2,1                   ! Storage tank:Temperature to heat source ->Left axis variable-2
2,12                  ! Storage tank:Average tank temperature ->Left axis variable-3
2,13                  ! Storage tank:Temperature of node 1+ ->Left axis variable-4
8,1                   ! Mixing :Outlet temperature ->Left axis variable-5
8,2                   ! Mixing :Outlet flow rate ->Right axis variable
*** INITIAL INPUT VALUES
TempToLoad TempBotom TempAverage TempMidle TempToConsumer MassRateConsum

LABELS  3
"Temperatures"
""
"Tank"
*** External files
ASSIGN "Tank.plt" 73
*|? What file should the online print to? |1000
*------------------------------------------------------------------------------

* Model "Integrator" (Type 24)
*
UNIT 6 TYPE 24       Integrator
*$UNIT_NAME Integrator
*$MODEL .\Utility\Integrators\Quantity Integrator\Type24.tmf
*$POSITION 446 189
*$LAYER Main #
PARAMETERS 2
STOP                  ! 1 Integration period
0                     ! 2 Relative or absolute start time
INPUTS 2
8,2                   ! Mixing :Outlet flow rate ->Input to be integrated-1
2,8                   ! Storage tank:Auxiliary heating rate ->Input to be integrated-2
*** INITIAL INPUT VALUES
0.0 0.0
*------------------------------------------------------------------------------

* Model "Ploter" (Type 25)
*
UNIT 7 TYPE 25       Ploter
*$UNIT_NAME Ploter
*$MODEL .\Output\Printer\TRNSYS-Supplied Units\Type25a.tmf
*$POSITION 563 190
*$LAYER Main #
PARAMETERS 10
1                     ! 1 Printing interval
START                 ! 2 Start time
STOP                  ! 3 Stop time
74                    ! 4 Logical unit
2                     ! 5 Units printing mode
0                     ! 6 Relative or absolute start time
-1                    ! 7 Overwrite or Append
-1                    ! 8 Print header
0                     ! 9 Delimiter
1                     ! 10 Print labels
INPUTS 2
6,1                   ! Integrator:Result of integration-1 ->Input to be printed-1
6,2                   ! Integrator:Result of integration-2 ->Input to be printed-2
*** INITIAL INPUT VALUES
```

```
Consumption_Kg AuxEnergy_kJ
*** External files
ASSIGN "PTV.out" 74
*|? Output File for printed results |1000
*------------------------------------------------------------------------------

* Model "Mixing " (Type 11)
*
UNIT 8 TYPE 11	Mixing
*$UNIT_NAME Mixing
*$MODEL .\Hydronics\Tee-Piece\Other Fluids\Type11h.tmf
*$POSITION 350 259
*$LAYER Water Loop #
PARAMETERS 1
1			! 1 Tee piece mode
INPUTS 4
2,3			! Storage tank:Temperature to load ->Temperature at inlet 1
2,4			! Storage tank:Flowrate to load ->Flow rate at inlet 1
9,3			! Mixing valve:Temperature at outlet 2 ->Temperature at inlet 2
9,4			! Mixing valve:Flow rate at outlet 2 ->Flow rate at inlet 2
*** INITIAL INPUT VALUES
20.0 100.0 20.0 100.0
*------------------------------------------------------------------------------

* Model "Mixing valve" (Type 11)
*
UNIT 9 TYPE 11	Mixing valve
*$UNIT_NAME Mixing valve
*$MODEL .\Hydronics\Tempering Valve\Other Fluids\Type11b.tmf
*$POSITION 350 323
*$LAYER Water Loop #
PARAMETERS 2
4			! 1 Tempering valve mode
7			! 2 Nb. of oscillations allowed
INPUTS 4
0,0			! [unconnected] Inlet temperature
3,1			! Histogram DHW:Average value of function ->Inlet flow rate
2,3			! Storage tank:Temperature to load ->Heat source temperature
0,0			! [unconnected] Set point temperature
*** INITIAL INPUT VALUES
10 100.0 55.0 40
*------------------------------------------------------------------------------

END
```

Domestic hot water system – solar collectors (HPS)

```
*******************************************************************************
*** TRNSYS input file (deck) generated by TrnsysStudio
*******************************************************************************
*** Control cards
*******************************************************************************
* START, STOP and STEP
CONSTANTS 3
START=0
STOP=8760
STEP=0.055555557
* User defined CONSTANTS

SIMULATION     START   STOP    STEP     ! Start time      End time  Time step
TOLERANCES 0.001 0.001                  ! Integration      Convergence
LIMITS 30 30 30                         ! Max iterations   Max warnings    Trace limit
DFQ 1                                   ! TRNSYS numerical integration solver method
WIDTH 80                                ! TRNSYS output file width, number of characters
LIST                                    ! NOLIST statement
                                        ! MAP statement
SOLVER 0 1 1                            ! Solver statement   Minimum relaxation factor   Maximum
relaxation factor
NAN_CHECK 0                             ! Nan DEBUG statement
OVERWRITE_CHECK 0                       ! Overwrite DEBUG statement
EQSOLVER 0                              ! EQUATION SOLVER statement

* Model "TMY" (Type 109)
*
UNIT 9 TYPE 109    TMY
*$UNIT_NAME TMY
*$MODEL .\Weather Data Reading and Processing\Standard Format\TMY2\Type109-TMY2.tmf
*$POSITION 187 72
*$LAYER Main #
PARAMETERS 4
2            ! 1 Data Reader Mode
67           ! 2 Logical unit
4            ! 3 Sky model for diffuse radiation
1            ! 4 Tracking mode
INPUTS 3
0,0          ! [unconnected] Ground reflectance
0,0          ! [unconnected] Slope of surface
0,0          ! [unconnected] Azimuth of surface
*** INITIAL INPUT VALUES
0.2 45 0.0
*** External files
ASSIGN "C:\Program Files\Trnsys16\Weather\Meteonorm\Europe\HR-Split-133340.tm2" 67
*|? Weather data file |1000
*------------------------------------------------------------------------------

* Model "Regulator" (Type 2)
*
UNIT 11 TYPE 2    Regulator
*$UNIT_NAME Regulator
*$MODEL .\Controllers\Differential Controller w_ Hysteresis\for Temperatures\Solver 0 (Successive Substitution)
Control Strategy\Type2b.tmf
*$POSITION 128 288
*$LAYER Main #
*$# NOTE: This control strategy can only be used with solver 0 (Successive substitution)
```

```
*$#
PARAMETERS 2
5                   ! 1 No. of oscillations
100.0               ! 2 High limit cut-out
INPUTS 6
5,1                 ! Collectors:Outlet temperature ->Upper input temperature Th
10,1                ! Storage tank:Temperature to heat source ->Lower input temperature Tl
10,3                ! Storage tank:Temperature to load ->Monitoring temperature Tin
11,1                ! Regulator:Output control function ->Input control function
0,0                 ! [unconnected] Upper dead band dT
0,0                 ! [unconnected] Lower dead band dT
*** INITIAL INPUT VALUES
60 20 20 0 10.0 2.0
*------------------------------------------------------------------------------

* Model "Storage tank" (Type 4)
*
UNIT 10 TYPE 4      Storage tank
*$UNIT_NAME Storage tank
*$MODEL .\Thermal Storage\Stratified Storage Tank\Variable Inlets\Uniform Losses\Type4c.tmf
*$POSITION 336 232
*$LAYER Main #
PARAMETERS 22
2                   ! 1 Variable inlet positions
25                  ! 2 Tank volume
4.190               ! 3 Fluid specific heat
1000.0              ! 4 Fluid density
2.52                ! 5 Tank loss coefficient
1                   ! 6 Height of node-1
1                   ! 7 Height of node-2
1                   ! 8 Height of node-3
1                   ! 9 Auxiliary heater mode
1                   ! 10 Node containing heating element -1
2                   ! 11 Node containing thermostat -1
42.5                ! 12 Set point temperature for element-1
5.0                 ! 13 Deadband for heating element-1
359999.973364               ! 14 Maximum heating rate of element -1
2                   ! 15 Node containing heating element -2
2                   ! 16 Node containing thermostat -2
60.0                ! 17 Set point temperature for element-2
5.0                 ! 18 Deadband for heating element-2
0                   ! 19 Maximum heating rate of element -2
0.0                 ! 20 Not used (Flue UA)
20.0                ! 21 Not used (Tflue)
100.0               ! 22 Boiling point
INPUTS 7
5,1                 ! Collectors:Outlet temperature ->Hot-side temperature
5,2                 ! Collectors:Outlet flowrate ->Hot-side flowrate
13,1                ! Mixing valve:Temperature at outlet 1 ->Cold-side temperature
13,2                ! Mixing valve:Flowrate at outlet 1 ->Cold-side flowrate
0,0                 ! [unconnected] Environment temperature
0,0                 ! [unconnected] Control signal for element-1
0,0                 ! [unconnected] Control signal for element-2
*** INITIAL INPUT VALUES
45.0 100.0 13.5 0 22.0 1 0
DERIVATIVES 3
40                  ! 1 Initial temperature of node-1
40                  ! 2 Initial temperature of node-2
40                  ! 3 Initial temperature of node-3
*------------------------------------------------------------------------------
```

```
* Model "Pump" (Type 3)
*
UNIT 6 TYPE 3	 Pump
*$UNIT_NAME Pump
*$MODEL .\Hydronics\Pumps\Single Speed\Type3b.tmf
*$POSITION 87 212
*$LAYER Main #
PARAMETERS 5
7200		! 1 Maximum flow rate
4.190		! 2 Fluid specific heat
2757.599927		! 3 Maximum power
0.05		! 4 Conversion coefficient
0.5		! 5 Power coefficient
INPUTS 3
10,1		! Storage tank:Temperature to heat source ->Inlet fluid temperature
10,2		! Storage tank:Flowrate to heat source ->Inlet mass flow rate
11,1		! Regulator:Output control function ->Control signal
*** INITIAL INPUT VALUES
10 100.0 1.0
*------------------------------------------------------------------------------

* Model "Collectors" (Type 1)
*
UNIT 5 TYPE 1	 Collectors
*$UNIT_NAME Collectors
*$MODEL .\Solar Thermal Collectors\Quadratic Efficiency Collector\2nd-Order Incidence Angle
Modifiers\Type1b.tmf
*$POSITION 187 212
*$LAYER Main #
PARAMETERS 11
1		! 1 Number in series
350		! 2 Collector area
4.190		! 3 Fluid specific heat
1		! 4 Efficiency mode
40.0		! 5 Tested flow rate
0.80		! 6 Intercept efficiency
13.0		! 7 Efficiency slope
0.05		! 8 Efficiency curvature
2		! 9 Optical mode 2
0.2		! 10 1st-order IAM
0.0		! 11 2nd-order IAM
INPUTS 9
6,1		! Pump:Outlet fluid temperature ->Inlet temperature
6,2		! Pump:Outlet flow rate ->Inlet flowrate
9,1		! TMY:Ambient temperature ->Ambient temperature
9,18		! TMY:total radiation on tilted surface ->Incident radiation
9,12		! TMY:total radiation on horizontal ->Total horizontal radiation
9,14		! TMY:sky diffuse radiation on horizontal ->Horizontal diffuse radiation
0,0		! [unconnected] Ground reflectance
9,22		! TMY:angle of incidence for tilted surface  ->Incidence angle
9,23		! TMY:slope of tilted surface ->Collector slope
*** INITIAL INPUT VALUES
10 100.0 10.0 0. 0 0.0 0.2 45.0 0.
*------------------------------------------------------------------------------

* Model "Histogram DHW" (Type 14)
*
UNIT 21 TYPE 14	 Histogram DHW
*$UNIT_NAME Histogram DHW
```

```
*$MODEL .\Utility\Forcing Functions\General\Type14h.tmf
*$POSITION 624 315
*$LAYER Main #
PARAMETERS 44
0                  ! 1 Initial value of time
50                 ! 2 Initial value of function
1                  ! 3 Time at point-1
100                ! 4 Value at point -1
4                  ! 5 Time at point-2
150                ! 6 Value at point -2
5                  ! 7 Time at point-3
100                ! 8 Value at point -3
6                  ! 9 Time at point-4
1500               ! 10 Value at point -4
7                  ! 11 Time at point-5
2000               ! 12 Value at point -5
8                  ! 13 Time at point-6
2500               ! 14 Value at point -6
9                  ! 15 Time at point-7
3000               ! 16 Value at point -7
10                 ! 17 Time at point-8
2000               ! 18 Value at point -8
11                 ! 19 Time at point-9
500                ! 20 Value at point -9
13                 ! 21 Time at point-10
500                ! 22 Value at point -10
14                 ! 23 Time at point-11
750                ! 24 Value at point -11
15                 ! 25 Time at point-12
1000               ! 26 Value at point -12
16                 ! 27 Time at point-13
1250               ! 28 Value at point -13
17                 ! 29 Time at point-14
2000               ! 30 Value at point -14
18                 ! 31 Time at point-15
2500               ! 32 Value at point -15
19                 ! 33 Time at point-16
3000               ! 34 Value at point -16
20                 ! 35 Time at point-17
1500               ! 36 Value at point -17
21                 ! 37 Time at point-18
1000               ! 38 Value at point -18
22                 ! 39 Time at point-19
500                ! 40 Value at point -19
23                 ! 41 Time at point-20
250                ! 42 Value at point -20
24                 ! 43 Time at point-21
50                 ! 44 Value at point -21
*------------------------------------------------------------------------------

* Model "Mixing valve" (Type 11)
*
UNIT 13 TYPE 11     Mixing valve
*$UNIT_NAME Mixing valve
*$MODEL .\Hydronics\Tempering Valve\Other Fluids\Type11b.tmf
*$POSITION 478 315
*$LAYER Water Loop #
PARAMETERS 2
4                  ! 1 Tempering valve mode
7                  ! 2 Nb. of oscillations allowed
```

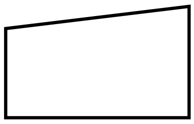
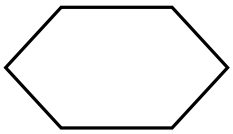
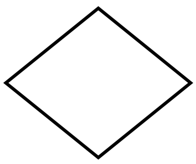
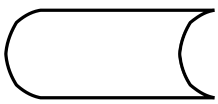
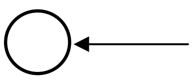
```
INPUTS 4
0,0                  ! [unconnected] Inlet temperature
21,1                 ! Histogram DHW:Average value of function ->Inlet flow rate
10,3                 ! Storage tank:Temperature to load ->Heat source temperature
0,0                  ! [unconnected] Set point temperature
*** INITIAL INPUT VALUES
10.0 100.0 55.0 40
*------------------------------------------------------------------------------

* Model "Mixing" (Type 11)
*
UNIT 14 TYPE 11     Mixing
*$UNIT_NAME Mixing
*$MODEL .\Hydronics\Tee-Piece\Other Fluids\Type11h.tmf
*$POSITION 478 222
*$LAYER Water Loop #
PARAMETERS 1
1                    ! 1 Tee piece mode
INPUTS 4
10,3                 ! Storage tank:Temperature to load ->Temperature at inlet 1
10,4                 ! Storage tank:Flowrate to load ->Flow rate at inlet 1
13,3                 ! Mixing valve:Temperature at outlet 2 ->Temperature at inlet 2
13,4                 ! Mixing valve:Flow rate at outlet 2 ->Flow rate at inlet 2
*** INITIAL INPUT VALUES
20.0 100.0 20.0 100.0
*------------------------------------------------------------------------------

* Model "Integrator" (Type 24)
*
UNIT 25 TYPE 24     Integrator
*$UNIT_NAME Integrator
*$MODEL .\Utility\Integrators\Quantity Integrator\Type24.tmf
*$POSITION 538 126
*$LAYER Main #
PARAMETERS 2
STOP                 ! 1 Integration period
0                    ! 2 Relative or absolute start time
INPUTS 4
14,2                 ! Mixing:Outlet flow rate ->Input to be integrated-1
5,3                  ! Collectors:Useful energy gain ->Input to be integrated-2
10,8                 ! Storage tank:Auxiliary heating rate ->Input to be integrated-3
6,3                  ! Pump:Power consumption ->Input to be integrated-4
*** INITIAL INPUT VALUES
0.0 0.0 0.0 0.0
*------------------------------------------------------------------------------

* Model "Ploter" (Type 25)
*
UNIT 12 TYPE 25     Ploter
*$UNIT_NAME Ploter
*$MODEL .\Output\Printer\TRNSYS-Supplied Units\Type25a.tmf
*$POSITION 645 126
*$LAYER Outputs #
PARAMETERS 10
1                    ! 1 Printing interval
START                ! 2 Start time
STOP                 ! 3 Stop time
71                   ! 4 Logical unit
2                    ! 5 Units printing mode
0                    ! 6 Relative or absolute start time
```

```
-1                  ! 7 Overwrite or Append
-1                  ! 8 Print header
0                   ! 9 Delimiter
1                   ! 10 Print labels
INPUTS 4
25,1                ! Integrator:Result of integration-1 ->Input to be printed-1
25,2                ! Integrator:Result of integration-2 ->Input to be printed-2
25,3                ! Integrator:Result of integration-3 ->Input to be printed-3
25,4                ! Integrator:Result of integration-4 ->Input to be printed-4
*** INITIAL INPUT VALUES
Consumption_Kg EnergyFromColl_kJ AuxHeatTank_kJ PPump
*** External files
ASSIGN "EnergijePTVSustav2.out" 71
*|? Output File for printed results |1000
*------------------------------------------------------------------------------

* Model "Monitoring-3" (Type 65)
*
UNIT 16 TYPE 65     Monitoring-3
*$UNIT_NAME Monitoring-3
*$MODEL .\Output\Online Plotter\Online Plotter With File\TRNSYS-Supplied Units\Type65a.tmf
*$POSITION 534 402
*$LAYER Main #
PARAMETERS 12
1                   ! 1 Nb. of left-axis variables
1                   ! 2 Nb. of right-axis variables
0.0                 ! 3 Left axis minimum
50                  ! 4 Left axis maximum
0.0                 ! 5 Right axis minimum
10000               ! 6 Right axis maximum
2                   ! 7 Number of plots per simulation
12                  ! 8 X-axis gridpoints
0                   ! 9 Shut off Online w/o removing
72                  ! 10 Logical Unit for output file
2                   ! 11 Output file units
0                   ! 12 Output file delimiter
INPUTS 2
14,1                ! Mixing:Outlet temperature ->Left axis variable
14,2                ! Mixing:Outlet flow rate ->Right axis variable
*** INITIAL INPUT VALUES
TVentToLoad MVentToLoad
LABELS  3
""
""
"Ventili"
*** External files
ASSIGN "Ventili.plt" 72
*|? What file should the online print to? |1000
*------------------------------------------------------------------------------

* Model "Monitoring-2" (Type 65)
*
UNIT 22 TYPE 65     Monitoring-2
*$UNIT_NAME Monitoring-2
*$MODEL .\Output\Online Plotter\Online Plotter With File\TRNSYS-Supplied Units\Type65a.tmf
*$POSITION 336 402
*$LAYER Main #
PARAMETERS 12
0                   ! 1 Nb. of left-axis variables
5                   ! 2 Nb. of right-axis variables
```

```
0                       ! 3 Left axis minimum
100                     ! 4 Left axis maximum
0.0                     ! 5 Right axis minimum
7000                    ! 6 Right axis maximum
2                       ! 7 Number of plots per simulation
12                      ! 8 X-axis gridpoints
0                       ! 9 Shut off Online w/o removing
70                      ! 10 Logical Unit for output file
2                       ! 11 Output file units
0                       ! 12 Output file delimiter
INPUTS 5
5,2                     ! Collectors:Outlet flowrate ->Right axis variable-1
10,2                    ! Storage tank:Flowrate to heat source ->Right axis variable-2
0,0                     ! [unconnected] Right axis variable-3
10,4                    ! Storage tank:Flowrate to load ->Right axis variable-4
0,0                     ! [unconnected] Right axis variable-5
*** INITIAL INPUT VALUES
MassRateCollOUT MassRateTankSOURCE MassRatePumpOUT MassRateTankLOAD
AuxHeatRate
LABELS  3
""
""
"MassFlowRates"
*** External files
ASSIGN "MassFlowRatesSustav2.plt" 70
*|? What file should the online print to? |1000
*------------------------------------------------------------------------------

* Model "Monitoring-1" (Type 65)
*
UNIT 8 TYPE 65       Monitoring-1
*$UNIT_NAME Monitoring-1
*$MODEL .\Output\Online Plotter\Online Plotter With File\TRNSYS-Supplied Units\Type65a.tmf
*$POSITION 157 402
*$LAYER Main #
PARAMETERS 12
6                       ! 1 Nb. of left-axis variables
0                       ! 2 Nb. of right-axis variables
0                       ! 3 Left axis minimum
100                     ! 4 Left axis maximum
0.0                     ! 5 Right axis minimum
7000                    ! 6 Right axis maximum
2                       ! 7 Number of plots per simulation
12                      ! 8 X-axis gridpoints
0                       ! 9 Shut off Online w/o removing
66                      ! 10 Logical Unit for output file
2                       ! 11 Output file units
0                       ! 12 Output file delimiter
INPUTS 6
5,1                     ! Collectors:Outlet temperature ->Left axis variable-1
10,1                    ! Storage tank:Temperature to heat source ->Left axis variable-2
6,1                     ! Pump:Outlet fluid temperature ->Left axis variable-3
10,12                   ! Storage tank:Average tank temperature ->Left axis variable-4
10,13                   ! Storage tank:Temperature of node 1+ ->Left axis variable-5
10,3                    ! Storage tank:Temperature to load ->Left axis variable-6
*** INITIAL INPUT VALUES
TCollOut TTankToColl TCollIn AverageTankTemp TempTopNode TTankToLoad

LABELS  3
""
```

```
""
"Collector"
*** External files
ASSIGN "CollectorSustav2.plt" 66
*|? What file should the online print to? |1000
*-----------------------------------------------------------------------------

END
```

APPENDIX V: FLOWCHARTS SYMBOLISM

	Beginning or end of the flow chart
	Manual input
	Input or output operation
	Computer model
	Decision. A choice is made between two alternatives
	Computational process
	Application
	Display information
	Flow chart connector

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