A methodology to integrate solar thermal energy in district heating networks confronted with a Swedish real case study

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Abstract

Among other solutions, the integration of solar energy in district heating networks can contribute significantly to the increase of the renewable energy fraction in an urban area. This article describes the methodology developed in the framework of IEA Task 52 to help stakeholders during early phases of new or refurbishments projects. This methodology integrates a tool which is capable to assess the main solar indicators of the project with only two inputs: the solar installation area and the building heated area. The tool outputs are compared to the measured values of a Swedish case study.

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1. Introduction

Incoming solar radiation is a renewable, universal and freely available energy resource. As global consumption for space heating and domestic hot water is rising, it is essential to develop and propose energy systems relying more on renewable energies in general and solar energy in particular [1-2]. This article presents a study answering the following question: how to integrate solar energy in a built environment especially in the frame of district heating networks? This study was conducted as part of the Task 52 of the International Energy Agency SHC research program [3].

Even if today solar thermal energy is considered as a mature technology, the energy efficiency and economic viability of its integration in energy systems has still to be analyzed for each case. For new or existing district heating networks, a methodological approach is proposed to assist the stakeholders in their initial choices. This methodology eases the early stage decision-making process of users by quantifying parameters such as solar fraction, CO2 emissions decrease as a function of alternative nonrenewable resources or cost of solar system. This quantification is based on values taken from 46 existing best practice examples analyzed in the project.

A real case study is presented. In operation since 2014, this project was developed in a suburban area of a Swedish city near Goteborg. The new residential building area is composed of single and multi-family buildings and an elderly home. The heat supply of this district is provided by a combination of wood pellets and solar heat with an exemplary solar fraction of 37%. The latter is reached by using a pioneering combination of solar thermal technology panels and multistage thermal storage.

2. Methodology description

2.1. Methodology

In order to guide stakeholders in the elaboration of their energy concept, a methodological approach is developed. The graphical representation of the process is represented in the Figure 1 with the main following steps:

1. Project owner is either obliged or interested to elaborate an energy concept with a solar or renewable fraction in the energy mix. In order to pre-determine a solar concept, the initial constraints have to be determined. These constraints are varying a lot from a project to another depending for example on the country legislation, the type of needs or the owner’s financial capacity. These indicators are classified in three groups related to the framework, the boundary conditions and the energy system design.

2. Based on the initial constraints of the concept, a decision path is elaborated to guide the stakeholder in the pre-selection of an energy system. The decision path links the initial constraints, the available area for solar panel and main energy system classification presented in the next section.

3. An Excel-tool calculates the solar indicators. Based on heated floor area and available area for solar panels, some relevant indicators can be calculated at a very early stage of the project. The tool can provide valuable estimations of the solar fraction, costs expected for the solar system or gains in the CO2 emissions. Moreover, in order to help the stakeholder in his choices, commercial simulation tools are proposed to address some specific questions.

4. During this process, new solutions more efficient or more adapted to the situation, can be highlighted. The initial energy concept can be refined and a new run for the determination of the solar indicator can be realized.
2.2. Tool description

In order to provide a quantitative estimation of the solar indicators, an Excel-tool has been elaborated. From basic data of a new project, this tool can quantify the following indicators: the solar fraction, the energy costs or the CO2 emissions variation. The strength of this tool lies in the few inputs needed. These two indicators are needed: the heated surface area and the available area that could be dedicated to solar thermal installation. With these information, the solar indicators are derived from a benchmark realized on 46 solar thermal systems in operation in Austria, Denmark and Germany [4]. Solar integrated energy systems are classified in the following categories (Fig. 2): solar assisted heating of individual or multifamily house buildings, solar assisted heating of building blocks or urban quarters and solar assisted district heating (with or without seasonal storage).

From these two inputs, estimated or measured by the stakeholder, the thermal needs and the solar yields are assessed. The thermal needs are the addition of the needs for space heating and domestic hot water production. For domestic hot water quantification, the Swiss norm values [5] are applied. For the space heating, values are based on literature for the following countries: Austria, Denmark, France, Germany, Italy, Spain and Sweden. The data basis used to extract specific values is the Tabula WebTool [6]. This databases, developed within the framework of the Intelligent Energy Europe projects Tabula and Episcope, allows this estimation for a wide range of residential buildings. This consumption depends on the building constructions year, the country and the size of the building that can be distributed in three basic typologies: single family house, multifamily house and apartment block. The annual solar energy production is calculated by multiplying the available gross area by the annual solar energy yield $SE_{\text{var}}$ for a given country. The solar energy yield $SE$ taken from our benchmark [4], is valid for average Northern and Central European climate which correspond to a global solar irradiation of $G_{0,\text{incl}} = 1'343 \text{ kWh/(m}^2\text{.a)}$. The solar energy yield $SE_{\text{var}}$ is thus derived from the specific global solar irradiation $G_{0,\text{incl,\text{var}}}$ [7] and expressed as:

$$SE_{\text{var}} = SE \cdot (G_{0,\text{incl,\text{var}}}/G_{0,\text{incl}})$$

(1)

The outputs of the tool provide information on the energy system. Different scenarios can be then evaluated on a basis of quantified indicators comparison. The indicators that can be quantified are the following:

- The maximum solar fraction. This indicator is defined as the ratio between the annual solar production and the thermal needs for space heating and domestic hot water production.
- Volume requested for the hot water tank when a diurnal storage is planned.
- Specific solar thermal system cost [€/m²]. This indicator refers to the end-user costs for ready-installed (turnkey) systems (absorbers and storage) excluding taxes or subsidies.
- Energy cost [€/year] and [€/kWh]. This output represents the levelized cost for solar energy system in Central Europe countries. Costs are given for diurnal or seasonal storages.
- Saved CO₂ emissions [ton-CO₂]. By using solar heat in an energy system instead of non-renewable resources, a part of the CO₂ emissions can be avoided. This output quantify these avoided emissions in tons of CO₂.

Fig. 2. Classification solar thermal energy system (from left to right): solar assisted heating of individuals or multifamily house buildings, solar assisted heating of building blocks or urban quarters and solar assisted district heating (with or without seasonal storage).

3. Case study: Solar-assisted residential area “Vallda Heberg” in Kungsbacka

The construction of the Vallda Heberg residential area began in 2011 and the last building was finished in 2016. It is a suburban area outside the city of Kungsbacka (south of Gothenburg) on the Swedish west coast. The conceptual approach was to build a number of single-family houses for sale, in addition to several multi-family buildings and an elderly home with apartments for rent. Main objectives for the project include:
- 100% renewable heating solution
- 40% solar fraction (based on useful building thermal energy heating demand)
- Passive house standard (near zero energy)
- Reduction of heat distribution cost

Fig. 3. Vallda Heberg solar heat district. On the left an aerial view of the area [8]. On the right a schematic representation where the areas of solar thermal panel are indicated - Reproduced with permission [9]

This project is a well-known case study for solar district heating [10-12]. The main approach to meet these challenges was to implement novel heat distribution (Fig. 4). A central wood-pellet boiler supplies a primary distribution network (insulated steel pipes), delivering heat to four substations containing a decentralized storage. The substations are connected to a secondary distribution network utilizing extruded polyethylene (PEX) insulated pipes. In this secondary network, the hot water circulation serves the space heating and domestic hot water demands. Roof integrated flat plate collectors on the larger buildings deliver solar heat that are used for the pre-heating of domestic hot water in the substations. In addition, evacuated solar tube collectors are installed at the central boiler house with steeper inclination angles for optimized solar energy yields in winter (as well as reduced overheating in summer).
The solar active surfaces represent 570 m²\textsubscript{gross} of Flat plate collectors (FPC) and 108 m²\textsubscript{gross} of Evacuated tube collectors (ETC). These installations are able to provide 37% of the useful thermal energy demand of the 14'000 m² heated floor area. These numbers are even more impressive when considered that no seasonal storage are needed to reach this high solar fraction. The thermal storage volumes are distributed between the 13 substations and represent 75 m³. The drawback of such optimized system is it sensitivity in running phase. If a technical issue occurs, the whole system can be affected.

In regards with these achievements, it is anticipated that the majority of solutions will be transferred to future projects, if applicable. In particular the PEX system for heat distribution has proven to be economically and technically preferable, with lower overall cost and higher practicality due to a shorter installation time than conventional steel pipes. Furthermore, it has been shown that the investment cost for a renewable energy system has a negligible influence on the attractiveness of the residential area and the housing offered. The implementation of such a system becomes much more feasible when the energy system cost is considered in relation to the overall system cost – the additional cost for a renewable energy solution is such a small fraction, that it is considered irrelevant for all involved parties.

![Diagram](image)

**Fig. 4.** Energy system description - Reproduced with permission [13].

### 4. Discussion and conclusion

On the one hand, this article details a methodology to assess the main indicators during the early stage of development of an energy system. This methodology provides to the stakeholders a guideline to progress in the development of this type of projects. Based on a survey of existing solar energy systems, it integrates a tool that is able to quantify some crucial indicators. Comparison of these indicators can ease decision making.

On the other hand, an interesting Swedish solar district heating concept is detailed. This case study shows an existing district heating where more than 35% of the needed energy can be covered by solar energy. This substantial fraction can be reached without any seasonal storage facilities. The hot water is distributed to the consumers through innovative PEX pipes. Additional costs for such a system are considered irrelevant in regards to the overall cost.

In order to challenge the developed methodology and the Excel-Tool, the results can be compared to the measured data of the case study. The inputs parameters are the heated floor area, the solar thermal area and the thermal needs. The indicators compared are the solar fraction, the annual solar energy yield and the solar heating system cost. Others case studies were analyzed and the results will be included in IEA Task 52 final report.

For this case study, the values obtained with the tool are in good agreement with the measured values. This comparison is shown in the Figure 4. This example is encouraging but doesn’t bring a final proof of its accuracy. Nevertheless, this example shows that solar indicators can be roughly estimated by this method at very early stage of a project. The strength of the method relies on the wide range of countries and solar energy system types that can be evaluated on the basis of only two surfaces estimations.
Fig. 5. Solar indicators of the Vallda Heberg case study. On each graph, the left value is measured and the right value is calculated from the Excel-Tool.

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[13] Adapted from Markgren Arkitektur AB and Mats Abrahamsons Arkitektkontor AB.