KTH Byggvetenskap

Samhällsbyggnad
Kungliga Tekniska Högskolan

Low Exergy Supermarket in a Mediterranean Climate

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Javier Arrué Ballester

Handledare
Gudni Jóhannesson, KTH Byggvetenskap

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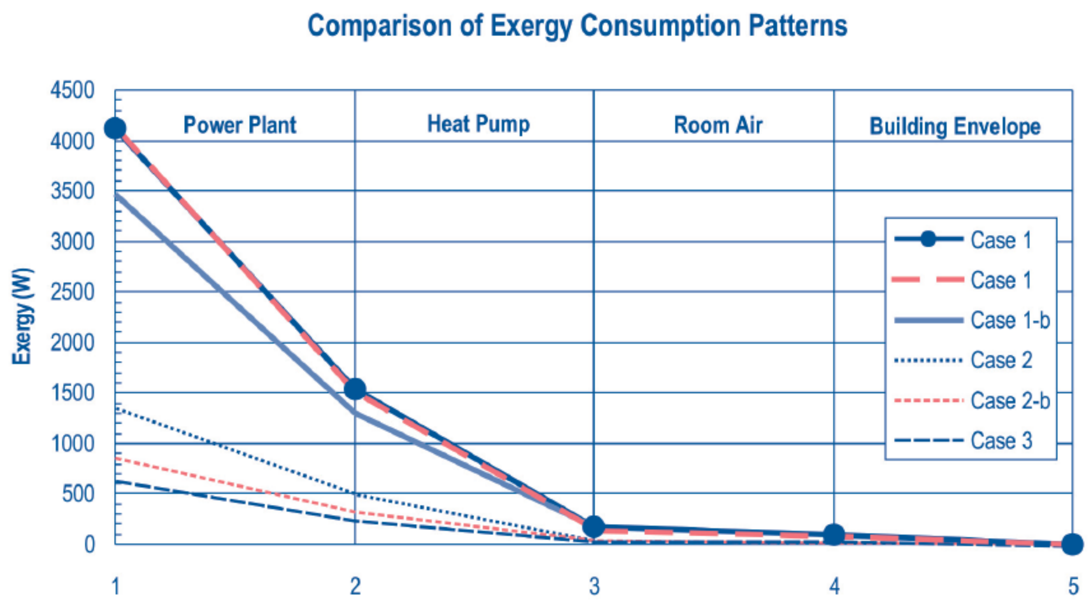
1. INTRODUCTION

This Study is the result of Master Thesis Degree at the Royal Institute of Technology in Stockholm (KTH) in the Division of Building of Building Technology, over Erasmus programme. The objective of this project is to develop a low energy/exergy industrial building: a supermarket, which has an intensive energy need, was considered. Particular attention was paid to cold needs in warm climates and for this reason the supermarket is located in Valencia (Spain), representing a Mediterranean Climate.

The idea of the project is to study exergy consumption in the different steps of the energy production chain. Some studies have already been done with reference to the energy needs in houses using solar airborne collectors and energy heat storage [Noguera, 2007].
In this way, this study is focused in this area but in the opposite side, using a cold collector in order to accumulate low-temperature energy during winter time in a ground storage and to use it and in warms seasons in order to reduce the energy/exergy needs.

One of the organizations which promote researches and tools to improve the exergy efficiency in buildings is the International Energy Agency, which also receives the support of others organizations in many studies. One of them studies is the IEA ECBCS Annex 37 “Low Exergy Systems for Heating and Cooling of Buildings). The Guidebook of Annex 37 has a lot of information about systems that reduce the exergy consumption in buildings. However there is still a great potential for improving.

Figure 1 represents a comparison of the different ways to improve aspects in a building with the purpose of reducing the exergy needs. The extension of the exergy losses in each subsystem can be inferred from the figure. .



Case 1	Base Case - Moderate Thermal Insulation of Building Envelope, Internal Shading Devices
Case 1-b	Improved COP Coefficient
Case 2	Improved Thermal Insulation, External Shading Devices
Case 2-b	Improved Thermal Insulation, External Shading Devices, Improved Electric Lighting
Case 3	Improved Thermal Insulation, COP and Electric Lighting, External Shading Deivices

Figure 1: Example of output of the Pre-design tool. Annex 37.

The figure is an example of how is possible to improve the exergy efficiency using thermal insulation and controlling the COP or the electric lighting.
But on the other hand different kinds of buildings exist, and the variety is bigger in industrial buildings: therefore is mandatory to study of the processes that are present in a specific building and choose which parameters are necessary to improve.

1.1. Background

Nowadays there is a great concern about energetic systems and these worries could be roughly divided into three kinds; economical, political and environmental.
It is worth noticing that these have a close relation between each other: for instance, a political choice affects environment and also economy.

Governments are making efforts trying to save energy and impulse ways to do it. As an example in Spain the new normative obliges to use solar panels on the roof in residential buildings with the purpose of warming water that later will be used for hot water supply.

The purposes of these initiatives are clearly to reduce the gasses that produce the Greenhouse Effect, by lessening the consumption of fossil fuels which produce these gasses, and also reduce the dependence of fossil fuels that in recent years have had influence in the economy of many countries.

In order to obtain an accurate model, knowledge in different areas have been developed; In particular they are:

Introduction to Layout supermarkets
Introduction to "CasaBona System"
Introduction to Daylight analysis and necessary software
Introduction to Building energy/exergy needs
Introduction to Processes in supermarkets
Training in some necessary computer tools
Introduction to exergy concept

1.2. Purpose

The main objective of this project is to model an industrial building like a supermarket and apply different techniques to develop a low exergy building. In this way some techniques have been selected, as passive methods like insulated system and day light approach, and also active methods like cold air system which benefits will be studied.

1.3. Method

In order to obtain a real model to study it is necessary as first step to understand the building and its processes. It is not easy at all to find information about supermarkets, their layouts, methods of calculating their energy needs and needs of different devices. For these reasons a time-demanding task is to obtain information.

In the first time a new model of layout is defined as a building that will be studied. This building is thought to be built in Spain,and thus it is necessary to calculate the structure of the building according to the Spanish normative "Codigo Técnico de la Edificación".

Day light approach has a great importance in this project: the idea is trying to obtain a good daylight building design to save luminance energy and then to study the interaction with the indoor climate.

The supermarket energy needs is another point developed in this study: in that chapter it has been necessary some focused knowledge in supermarket processes and understanding the different models to make it.

Once the mentioned techniques have been applied, an energy and exergy analysis has been carried out to find the processes that still need a special improvement.

The last step is the study of the cold system, by which is possible to obtain a temperature reduction.

Different computer tools have been necessary to develop the thesis. The training in these tools has required enough time to understand the concepts and get the software work. These tools have been namely:

- AutoCAD 2007 (2D and 3D drawing software)
- Google Sketch Up (3D drawing software)
- Daysim (Daylight simulation software)
- SAP 2000 8 Nonlinear (to calculate structure efforts)
- CyberMart (Supermarkets needs software)
- Comsol Multiphysics (finite element analysis software)
- Consolis Energy + (MS Excel energy calculations software)

2. LAYOUT

Layout in supermarkets has a huge importance in our days. Interior design of supermarkets has changed during recent years. The new layout supermarkets are focused on making shopping easier and inducing the customer to buy additional merchandise through long distances between products and check out. The following map [IEA Annex 26.Supermarket Refrigeration/Heat Recovery Systems] shows a typical layout of a modern supermarket: it helps to get a preliminary idea about supermarket layout.

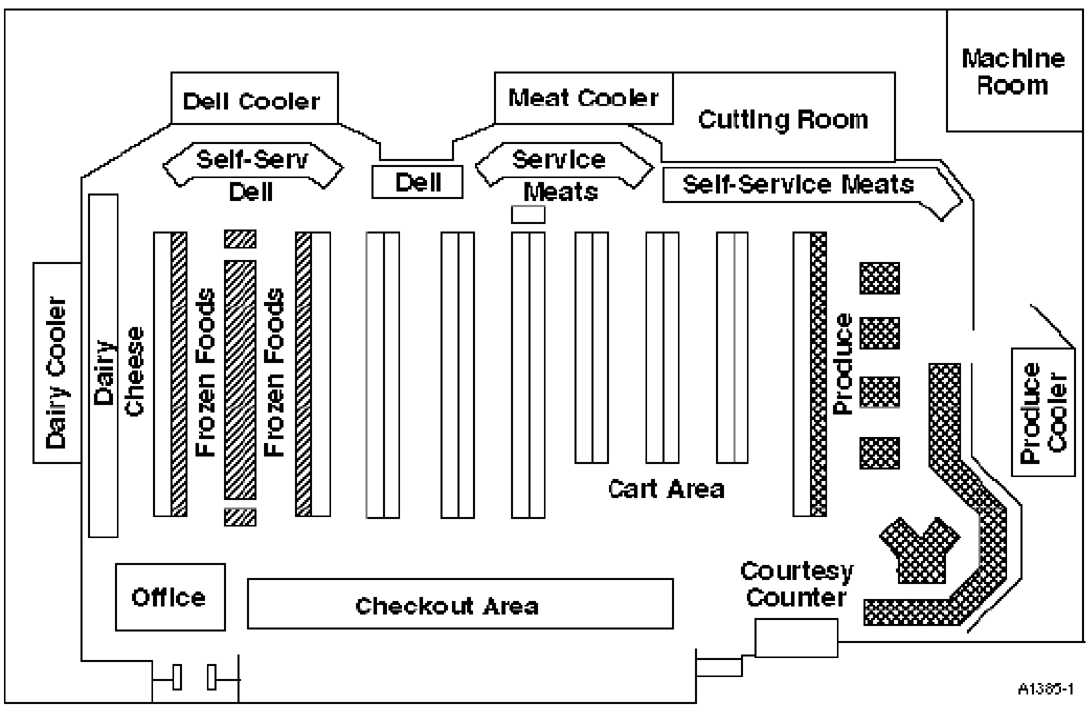


Figure 2: IEA Annex 26. Typical layout in a modern supermarket

After a survey of different supermarket chains in Spain and in Sweden, it has been necessary to develop a supermarket layout: the way to get it has been visiting a lot of supermarkets in both countries before mentioned, taking measures of distances, look at different distribution of different food, and taking pictures.

By doing this, data showed in this thesis in all of the chapters are close to real situation with a great degree of accuracy.

The supermarket under consideration is located in Valencia (Spain), where there is another culture alimentation compared with Sweden: Mediterranean diet is also reflected in supermarkets in a bigger amount of fresh food and less prepared food: this fact may have a certain importance in energy needs.

The supermarket under consideration has a total area of 1000 m^2 corresponding to a medium size supermarket. The supermarket is divided into sales area, store area and service area. In the store area, that is approximately 150 m^2, walk-in coolers are located, for conservation and freezing of food; this area is also used to store dry food.
In the service area, approximately 100 m^2, there are meeting rooms and lunch room, changing rooms, and an office room. The sales zone has an area of 750 m^2.
Layout plane in Figure 3 shows with a great accuracy dimensions and details of the supermarket layout.

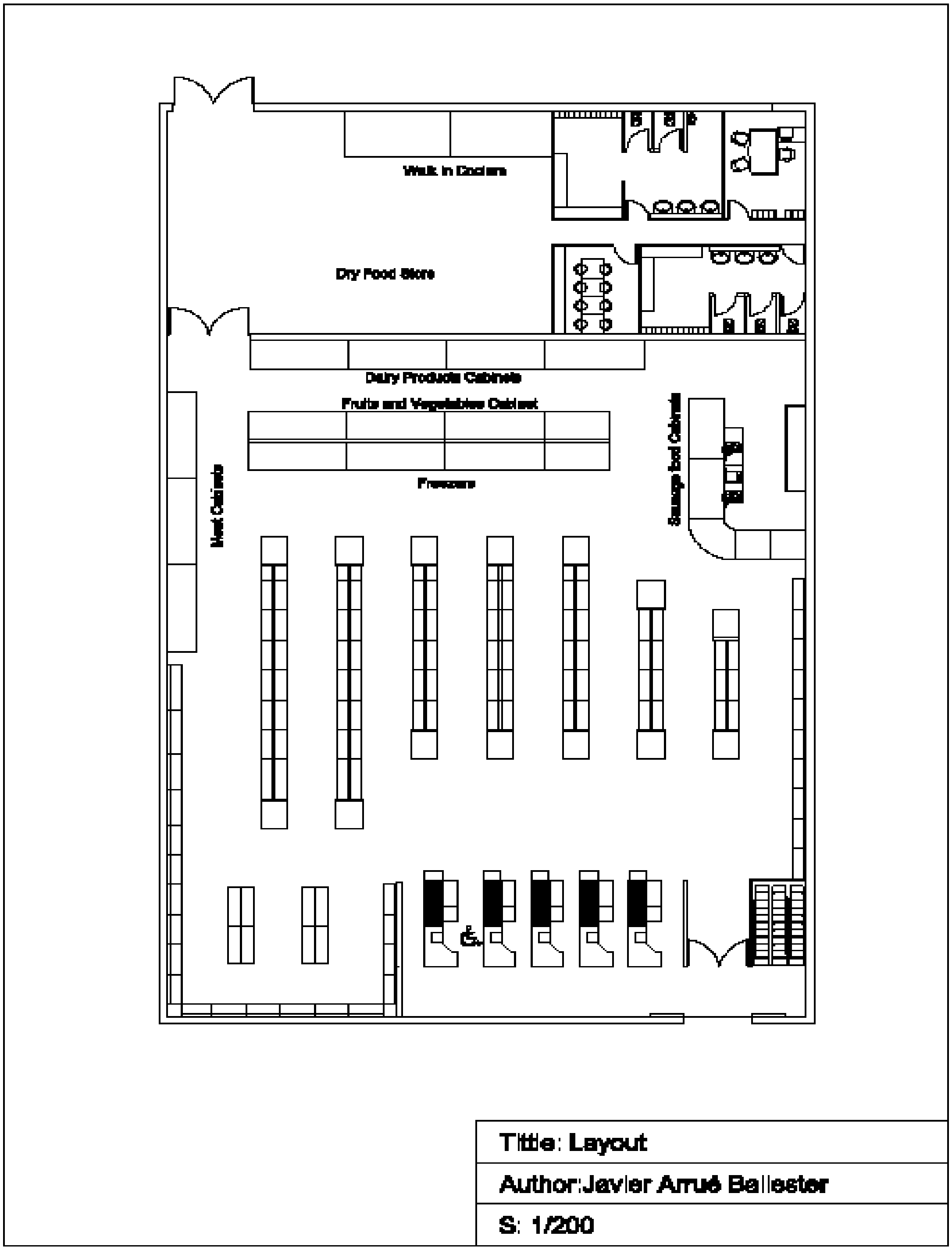


Figure 3: Supermarket layout

3. STRUCTURE

3.1 Introduction

The main aspect of this Project is not to calculate with great accuracy the structure system; even though, by following the Spanish normative “Codigo Técnico de la Edificación”, realistic dimensioning values have been calculated.

A simple industrial building has been chosen: these kinds of buildings are usually located in an industrial area because of size, dimensions and shape. Dimensions of building are 25 m of span, 40 m of depth, and ridge height of 5,125 m, with a maximum pillar height of 4 meters.

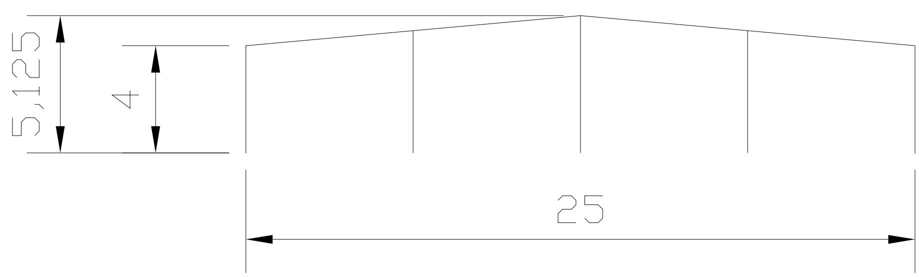


Figure 4: Façade plane

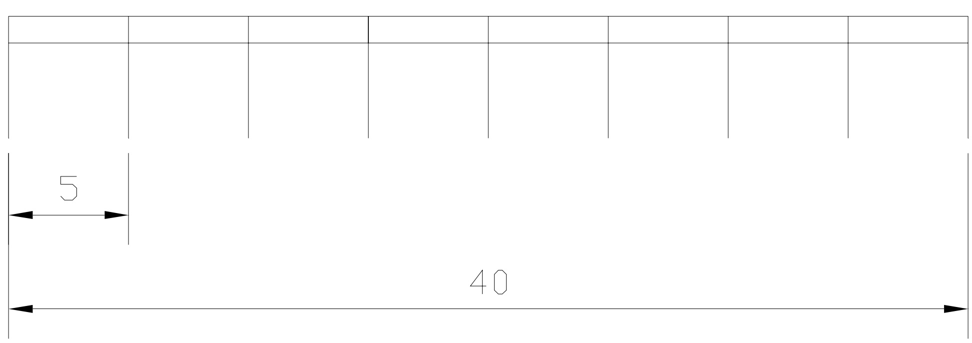


Figure 5: Side plane

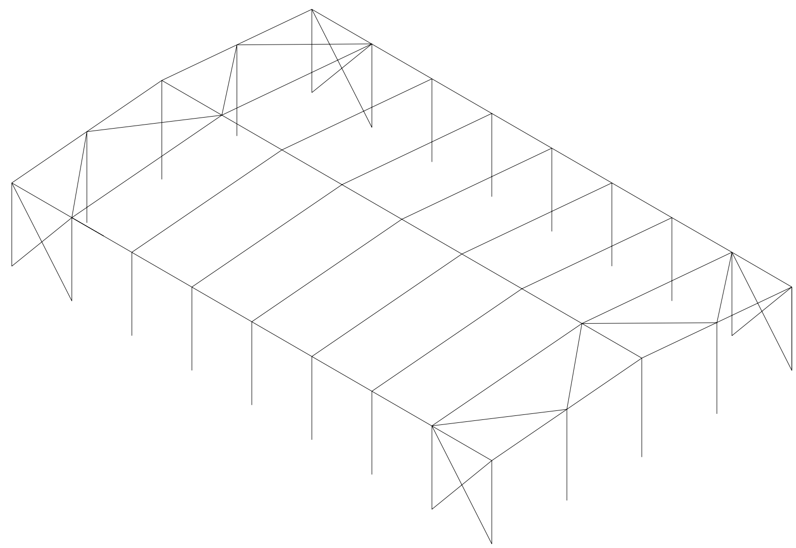


Figure 6: **3D distribution plane**

The building is located in Valencia (Spain): therefore the structure has been calculated according to new "Código Técnico de la Edificación", that was introduced in Spain in March 2007, which is compulsory to carry out for steel structures in Spain.

3.2. Stress Calculation

In order to obtain the main frames of the structure system the Spanish normative will be used:it is necessary to carry out the different State Limit of the structure that are obtained by different load combination. In a first time it is necessary to calculate the parameters of the structure which depend on where the structure is placed and the characteristics of this place as wind conditions and climate conditions (snow).

Stress calculations have been calculated with SAP 2000: the inputs of SAP 2000 are the geometric of the structure, the profile that is used in each beam and the load conditions of different portals. The outputs are the efforts that there are in each beam under the different load combinations. Once the efforts are obtained for each beam, the next step is to carry out the different State Limits that are compulsory by Spanish normative.

As a first attempt an IPE 330 profile has been introduced as a minimum profile, then with results of this profile it has been checked whether it was necessary to increase the steel profile.

The building is situated in Valencia at 0 m. over sea level in an urban/industrial and the material of steel profile is S275JR.

3.2.1. Load Action Calculation

The procedure to calculate the loads taken into account over the structure has been divided into two groups: permanents and variables. Between permanent ones are the weight of different parts of the building that are always present as load. Variables loads are the ones that depend on different parameters as climate. The importance to put the loads in the correct group is quite important even if the parameters are corrected by different coefficients in every State Limit. There are two groups of state limits: Ultimate Limit State (ULS) and Serviceability Limit State (SLS), and in every group it is compulsory to carry out with different conditions as

<u>**3.2.1.1. Permanents**</u>

Own weight: 0.25 KN/m
Roof weight: 0,15KN/m

<u>**3.2.1.2. Variables**</u>

3.2.1.2.1 Snow:

The building is located at 0 m over sea level, in a climatic zone 5 and since the slope of the ceiling is little, the shape coefficient can be approximated to μ =1; with these parameters is:

$$S_k=0.2 \qquad q_n = \mu . s_k = 1.0.2 = 0.2 KN/m^2$$

Figura E.2 Zonas climáticas de invierno

Tabla E.1 Temperatura mínima del aire exterior (ºC)

Altitud (m)	Zona de clima invernal, (según figura E.2)						
	1	2	3	4	5	6	7
0	-7	-11	-11	-6	-5	-6	6
200	-10	-13	-12	-8	-8	-8	5
400	-12	-15	-14	-10	-11	-9	3
600	-15	-16	-15	-12	-14	-11	2
800	-18	-18	-17	-14	-17	-13	0
1.000	-20	-20	-19	-16	-20	-14	-2
1.200	-23	-21	-20	-18	-23	-16	-3
1.400	-26	-23	-22	-20	-26	-17	-5
1.600	-28	-25	-23	-22	-29	-19	-7
1.800	-31	-26	-25	-24	-32	-21	-8
2.000	-33	-28	-27	-26	-35	-22	-10

Figure 7: Climatic Zones Parameters. CTE

3.2.1.2.2. Wind:

$$q_e(z) = q_b.C_e(z).C_p$$

With:

q_e: static pressure
q_b: dynamic pressure
C_e: exposition coefficient
C_p: pressure coefficient

As regards wind calculation, the building is located in the zone A, so that:

q_b=0.42KN/m^2

Figura D.1 Valor básico de la velocidad del viento, v_b

Figure 8: Wind Zones Parameters and Rough Parameters. CTE

Tabla D.2 Coeficientes para tipo de entorno

	Grado de aspereza del entorno	Parámetro		
		k	L (m)	Z (m)
I	Borde del mar o de un lago, con una superficie de agua en la dirección del viento de al menos 5 km de longitud	0,15	0,003	1,0
II	Terreno rural llano sin obstáculos ni arbolado de importancia	0,17	0,01	1,0
III	Zona rural accidentada o llana con algunos obstáculos aislados, como árboles o construcciones pequeñas	0,19	0,05	2,0
IV	Zona urbana en general, industrial o forestal	0,22	0,3	5,0
V	Centro de negocios de grandes ciudades, con profusión de edificios en altura	0,24	1,0	10,0

The exposition coefficient has been obtained through a table D.2 (Figure 8) with coping height of the building equal to 5,125 m and how is located in an urban zone the roughness parameter is IV, with this we obtain:

$$C_e(g,z) = F(g,z).[F(g,z) + 7.k(g)$$

$$F(g,z) = k(g).\ln\left(\frac{\max(z, Z(g)}{L(g)}\right)$$

Being:

k(g):terrain factor
L(g):Rough lenght
With this, it results:

Ce=1.66

The next step is to calculate the pressure coefficients for all parts of the structure.
The structure is divided in four areas.

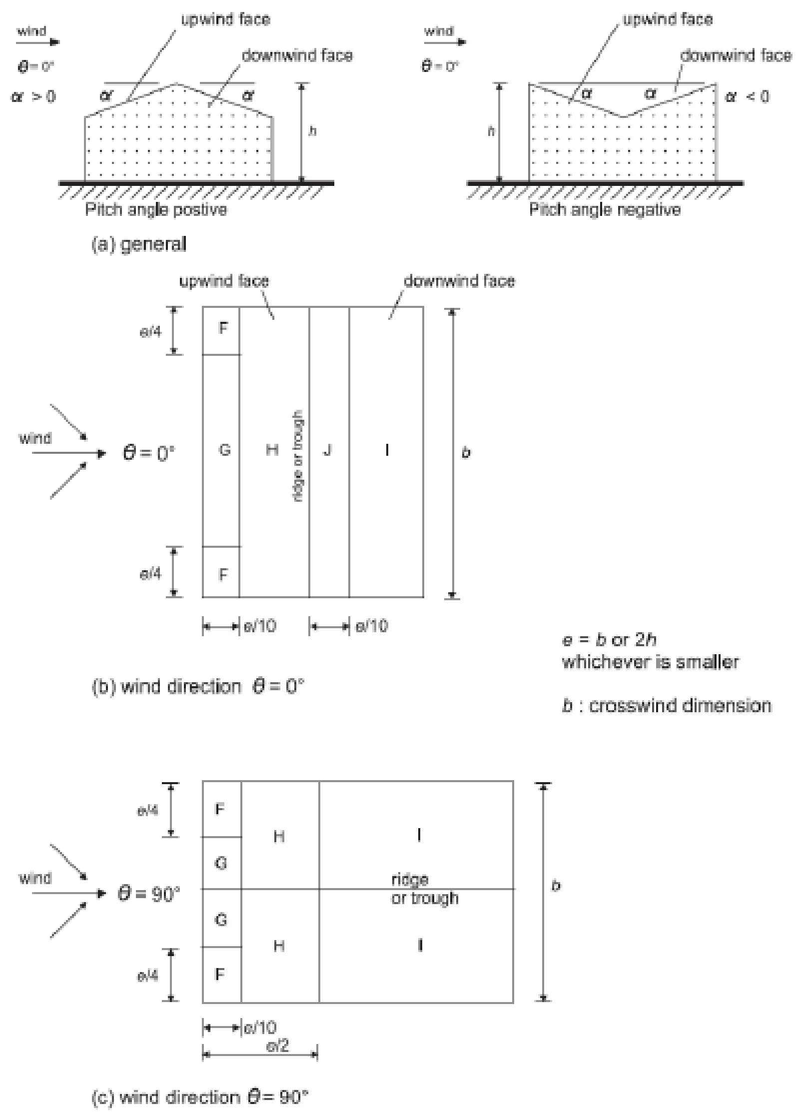


Figure 10: Wind zones in buildings. CTE

In the following drawings it is shown how the wind affects the structure, in particular portal GHJI area (Portal that include GHIJ areas, see figure 10); these wind model loads have been obtained taking into account the different directions of wind.

Wind 1D:

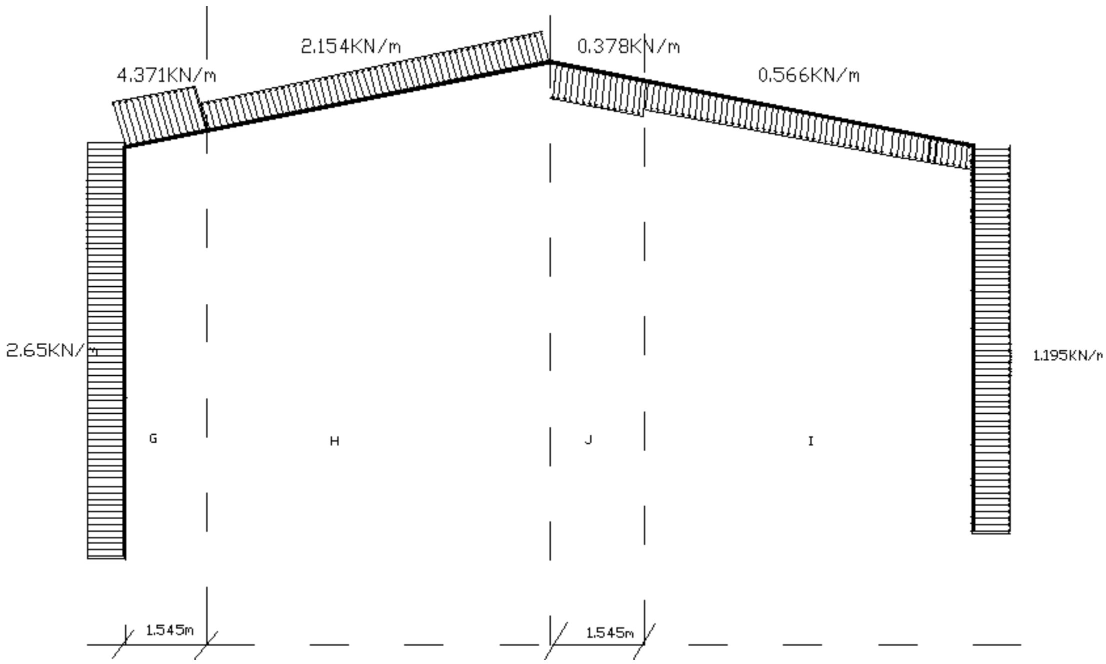


Figure 11: Wind 1D stress. CTE

Wind 2D:

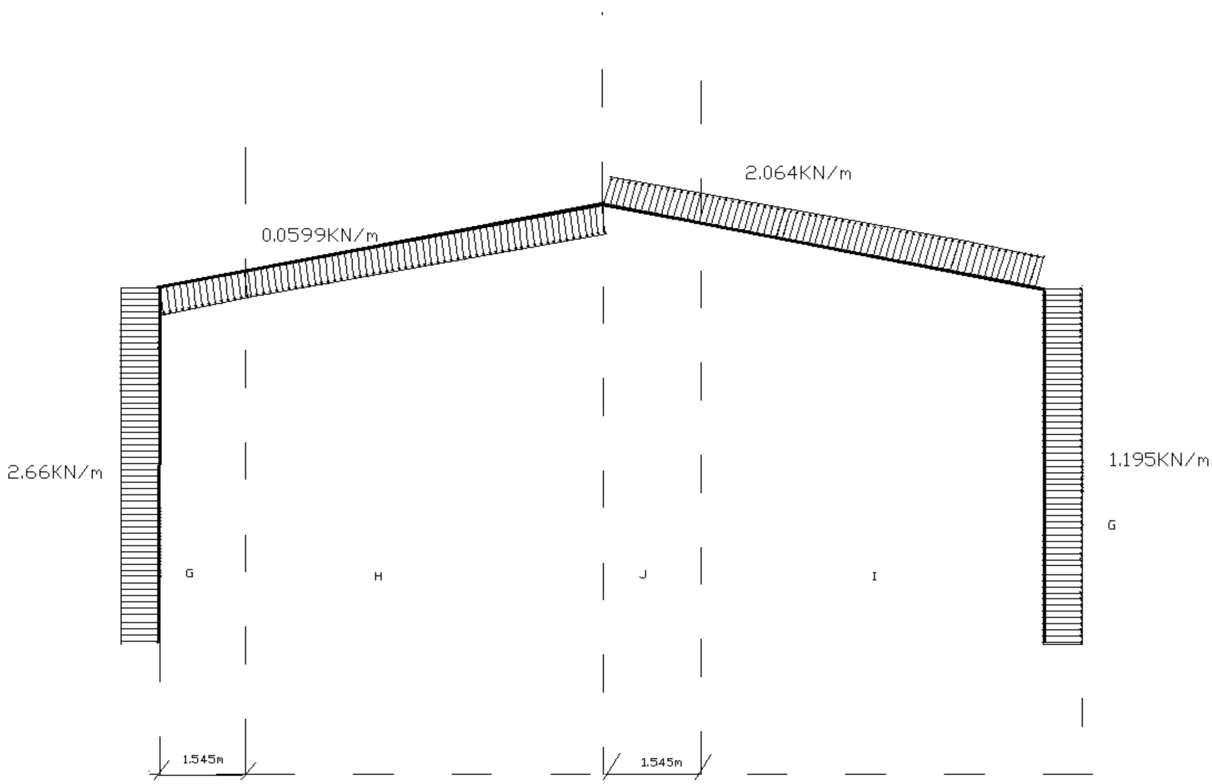


Figure 12: Wind 2D stress. CTE

Interior wind of suction:

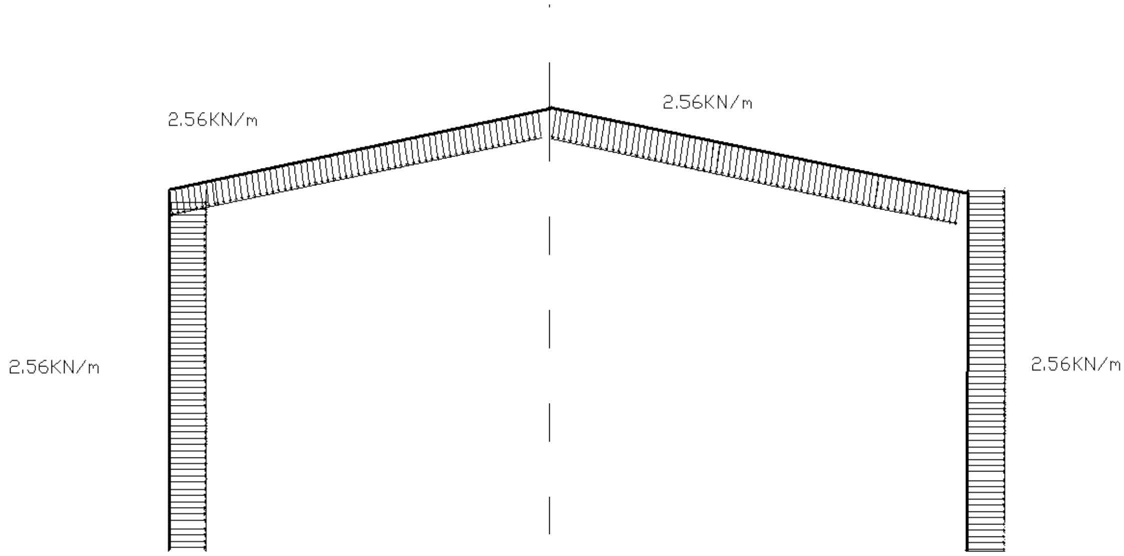


Figure 13: Interior wind suction stress. CTE

Interior wind pressure:

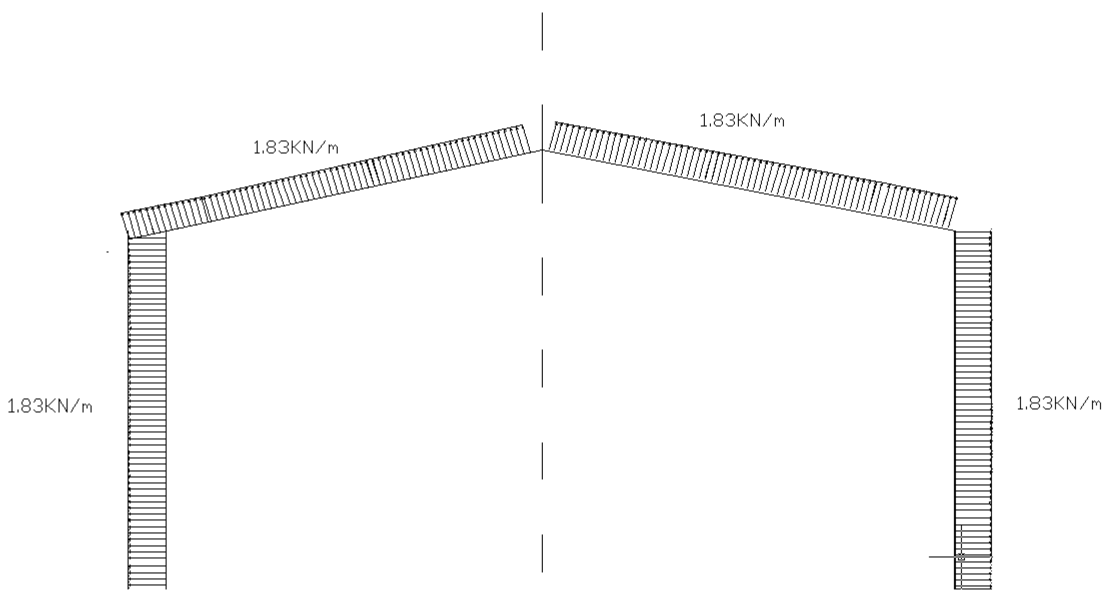


Figure 14: Interior wind pressure stress. CTE

3.3. Calculations

3.3.1. Interior portal

As first step an IPE-330 profile for pillars and beams has been used. Then, the displacements that have been calculated by SAP 2000 with properties of IPE-330. The detailed calculations to check the hypotheses of displacement, integrity, resistance and buckling are showed following: this check has to be made for a building with one height.

3.3.1.1. Pillar

Pillars have to carry out the next limits states:

Serviceability Limit State: Displacement, Integrity

Ultimate Limit State: Buckling, Resistance

- **SLS (Serviceability Limit State) Displacement**

The most demanding loads for displacement calculations of pillars are the following:

$$\boldsymbol{1 \times Permanents}$$

Maximum relative displacement should not exceed of the value $1/250$.

With the software calculation a displacement value at the head of pillars equal to 0,007685 m has been obtained, so that the relative displacement is:

$$f/L = 0.007685/6.5 = 1/845.8 < 1/250$$

Therefore the **IPE 330** carries out displacement criterion.

- **SLS (Serviceability Limit State) Integrity**

The most demanding combination with respect to integrity calculations is the following:

1× Frontal wind (2D) + 1×Interior pressure wind

Maximum relative displacement must not exceed the value of $1/250$.

With the software calculation is obtained a value of displacement at the head of pillars that is 0,007685 m., obtaining a relative displacement of:

$$f/L = 0.0206/6.5 = 1/315.54 < 1/250$$

Therefore **IPE 330** carries out displacement criterion.

- **ULS (Ultimate Limit State) Buckling**

The most demanding loads for buckling calculations of pillar are the following:

1,35×Permanents + 1.5×Snow + 0.9× Frontal wind (1D) + 0,9×interior suction pressure

Pillar must not buckle in any direction:

<u>-Portal plane</u>

$$\eta_i = 0$$

$$\eta_s = \frac{1/L_{pilar}}{1/L_{pilar} + 1{,}5/L_{jácena}} = \frac{1/4}{1/4 + 1{,}5/25} = 0{,}804$$

$$\beta_1 = \sqrt{\frac{1 - 0{,}2(\eta_s + \eta_i) - 0{,}12 \cdot \eta_i \cdot \eta_s}{1 - 0{,}8(\eta_s + \eta_i) + 0{,}6 \cdot \eta_i \cdot \eta_s}} = 1{,}537$$

$$L_{k,1} = \beta_1 \cdot L = 1{,}537 \cdot 4 = 6{,}149\,\mathrm{m}$$

$$i_{IPE-330,ejefuerte} = 0{,}1371\,\mathrm{m}$$

$$\lambda_1 = L_{k,1} / i_{IPE-330,ejefuerte} = 44{,}85$$

$$\lambda_{\lim} = \sqrt{\frac{\pi^2 \cdot E}{f_y}} = \sqrt{\frac{\pi^2 \cdot 210000}{275}} = 86{,}8147$$

$$\overline{\lambda}_1 = \lambda_1 / \lambda_{\lim} = 0{,}516 < 2$$

Buckling curve: a (Strong axis)

Imperfection coefficient: α=0,21

$$\phi_1 = 0{,}5 \cdot (1 + \alpha \cdot (\overline{\lambda}_1 - 0{,}2) + \overline{\lambda}_1{}^2) = 0{,}5 \cdot (1 + 0{,}21 \cdot (0{,}516 - 0{,}2) + 0{,}516^2) = 0{,}5611$$

$$\chi_1 = \frac{1}{\phi_1 + \sqrt{\phi_1^2 - \overline{\lambda}_1{}^2}} = 0{,}8195$$

-Façade plane

$\beta_2 = 0{,}7$ (Build in base, supported in head pillar, without horizontal displacement)

$$L_{k,2} = \beta_2 \cdot L = 0{,}7 \cdot 4 = 2{,}8\ \text{m}$$

$$i_{IPE-330,ejedebil} = 0{,}0355\ \text{m}$$

$$\lambda_1 = L_{k,1} / i_{IPE-330,ejedebil} = 78{,}87$$

$$\lambda_{\lim} = \sqrt{\frac{\pi^2 \cdot E}{f_y}} = \sqrt{\frac{\pi^2 \cdot 210000}{275}} = 86{,}8147$$

$$\overline{\lambda}_1 = \lambda_1 / \lambda_{\lim} = 0{,}90 < 2$$

Buckling curve: b (weak axis)

Coefficient of imperfection: α=0,34

$$\phi_1 = 0{,}5 \cdot (1 + \alpha \cdot (\overline{\lambda}_1 - 0{,}2) + \overline{\lambda}_1{}^2) = 0{,}5 \cdot (1 + 0{,}34 \cdot (0{,}9086 - 0{,}2) + 0{,}9086^2) = 1{,}806$$

$$\chi_1 = \frac{1}{\phi_1 + \sqrt{\phi_1^2 - \overline{\lambda}_1{}^2}} = 0{,}29656$$

-Check:

Condition:

$$\begin{Bmatrix} 1/\chi_y \\ 1/\chi_z \end{Bmatrix} \cdot \frac{N_{Ed}}{A \cdot f_{yd}} + \begin{pmatrix} 1 \\ \alpha_y \end{pmatrix} \cdot \frac{k_y \cdot c_{m,y} \cdot M_{y,Ed}}{W_y \cdot f_{yd}} \leq \begin{Bmatrix} 1 \\ 1 \end{Bmatrix}$$

The following figures have been calculated:

N_{ed}= 70,92 KN

$M_{y,ed}$= 211,25 KN m

Over the most demanding load hypotheses.

$$c_{my} = 0{,}9(traslational, \beta > 1)$$

$$\alpha_y = 0{,}8(clase3)$$

$$N_{c,rd} = A_{IPE-330} \cdot f_{yd} = 1639{,}523 \text{ KN}$$

$$k_y = 1 + 0{,}6 \cdot \overline{\lambda}_1 \, {N_{ED}}\big/{\chi_1 \cdot N_{C,RD}} = 1{,}025$$

$$W_{y,el} = 713100 \text{ mm}^3$$

Replacing these values in the conditions it is obtained:

$$\{1{,}016;0{,}97\} > \{1;1\}$$

Therefore buckling hypotheses are not carried out with IPE-330 and the profile has to be changed with an IPE 360

$$i_{IPE-36O,ejefuerte} = 0{,}1495m$$
$$i_{IPE-36O,ejedebil} = 0{,}0379m$$
$$A_{IPE-360} = 72700mm^2$$

$W_{y,el}$=903600 mm^3

Repeating the same procedure as before the following replacement values are obtained:

$$\{0{,}8625;0{,}7505\} < \{1;1\}$$

Therefore buckling hypotheses are carried out with **IPE-360.**

- **ULS Resistance**

The most demanding loads for the pillar calculations are the following:

1,35×Permanents + 1.5×snow + 0.9×frontal wind(1D) + 0,9×interior suction wind

The efforts obtained with the most demanding load must not exceed maximum admissible value.

Via software calculations the following values are obtained: the structural behaviour is represented by the following formulas.

$V_{ed,i}$ = -54,64 KN
$V_{ed,j}$ = -50,93 KN
$M_{ed,i}$ = -211,25 KN m
$M_{ed,j}$ = 131,86 KN m

$$P_d = (V_{ed,i} - V_{ed,j}) / L = -0{,}571$$
$$V_{ed} = V_{ed,i} - P_d \cdot x = -54{,}64 + 0{,}571 \cdot x$$
$$M_{ed} = M_{ed,i} - V_{ed,i} \cdot x + P_d \cdot \frac{x^2}{2} = -211{,}25 + 54{,}64 \cdot x - 0{,}571 \cdot \frac{x^2}{2}$$

Taking into account the new IPE360 profile, it has to be checked whether there are interactions between shearing and bending.

$V_{ed} < 0{,}5\ V_{pl,rd}$

$$V_{pl,rd} = A_{v,IPE-360} \cdot \frac{f_{yd}}{\sqrt{3}} = 3514 \cdot \frac{261{,}9}{\sqrt{3}} = 531345{,}04N = 531{,}345KN$$
V_{ed}=54,64KN

54,64 KN < $0{,}5 \cdot 531{,}345$ = 265,67 KN

Therefore the relation is carried out and interaction with shearing stress does not exist.
Conditions of reinforcement:

$M_{ed} \leq M_{u,rd}$

$M_{u,rd} = W_{el,y}\ (f_{yd}-N_{Eed}/A)$ = 903600 (261,9-70920/72700) = 235771360 N mm = 235,77 KN m

Applying the condition, it is:

$$\left| -211{,}25 + 54{,}64 \cdot x - 0{,}571 \cdot \frac{x^2}{2} \right| \leq 235{,}77$$

$$x = -0{,}4;8{,}4 \notin [0 - 6{,}5]m$$

Then, reinforcement is not needed and **IPE-360** profile is enough for all conditions.

3.3.1.2. Girder

The hypotheses of displacement, integrity, resistance and buckling have been checked for the pillars; as next step the same procedure has to be done for the girder.

- **ELS Displacement**

The most demanding loads for displacement calculations of pillar are the following:

$$\boldsymbol{1 \times Permanents}$$

This combination is symmetric and it has been calculated in the first part of girder. The maximum relative displacement must not exceed the value of 1/300.

With software calculations of interior portal the following laws of efforts for the girder are obtained.

V_{edi} = -22,15 KN
V_{edj} = 2,03 KN
M_{edi} = -77,96 KN m
M_{edj} = 43,42 KN m

$$P_d = (V_{ed,i} - V_{ed,j}) / L = -2$$
$$V_{ed} = V_{ed,i} - P_d \cdot x = -22{,}15 + 2 \cdot x$$
$$M_{ed} = M_{ed,i} - V_{ed,i} \cdot x + P_d \cdot \frac{x^2}{2} = -77{,}96 + 22{,}15 \cdot x - 2 \cdot \frac{x^2}{2}$$

Now with these laws the displacement equation is obtained, and the maximum and minimum displacement in the girder is:

$$y^{//} = -\frac{M_{ed}}{E \cdot I} = \frac{77{,}96 - 22{,}15 \cdot x + 2 \cdot \frac{x^2}{2}}{E \cdot I}$$

Solving the equation and giving the boundary values [y(0)=0,y(12,06)=0]:

$$y = \frac{0{,}0833 \cdot x^4 - 3{,}69 \cdot x^3 + 38{,}98 \cdot x^2 - 79{,}52 \cdot x}{E \cdot I}$$

Maximum and minimum values of displacement in the girder are:

x = [1,225;8,168].
E = 210000 N/mm^2
$I_{IPE\ 330}$= 117700000 m^4
E $I_{IPE\ 330}$= 24717 KN m

y(1,225) = -0,0018415 m
y(8,168) = 0,01255 m

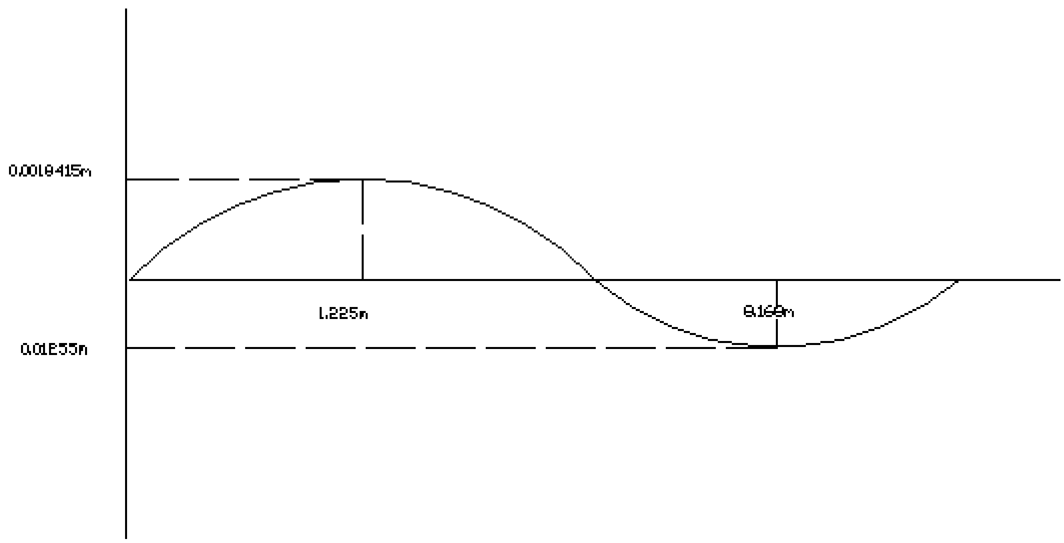


Figure 15: Girder displacement

Checking the three relative displacement in different intervals of beams; [0;1,225],[1,225;8,168],[8,168;12,06].

$$f_{r,ij} = \frac{|f_i - f_j|}{2 \cdot |x_i - x_j|}$$

$$f_{r,o-x1} = \frac{0,001845}{2 \cdot 1,225} = 0,000753 = \frac{1}{1327,91} \leq \frac{1}{300} = f_{r,adm}$$

$$f_{r,x1-x2} = \frac{0,014395}{2 \cdot 6,943} = 0,0010366 = \frac{1}{964,64} \leq \frac{1}{300} = f_{r,adm}$$

$$f_{r,x2-L} = \frac{0,01255}{2 \cdot 3,892} = 0,0016122 = \frac{1}{620,24} \leq \frac{1}{300} = f_{r,adm}$$

Therefore **IPE 330** carries out displacement criterion for the girder.

- **SLS Integrity**

The most demanding loads for calculations for this case are the following:

1×Snow+ 0, 6×Frontal Wind (2D) + 0,6×Interior wind suction

The maximum relative displacement must not exceed the value of 1/300.

With software calculations of interior portal the following laws of efforts for the girder are obtained in the second part (part where displacements are bigger)

V_{edi} = 3,03 KN
V_{edj} = 13,66 KN
M_{edi} = 34,33 KN m
M_{edj} = -66,32 KN m

$$P_d = (V_{ed,i} - V_{ed,j}) / L = -0,881$$

$$V_{ed} = V_{ed,i} - P_d \cdot x = 3,03 + 0,881 \cdot x$$

$$M_{ed} = M_{ed,i} - V_{ed,i} \cdot x + P_d \cdot \frac{x^2}{2} = 34,33 - 3,03 \cdot x - 0,881 \cdot \frac{x^2}{2}$$

Now with these equations is obtained the displacement equation: with it is obtained the maximum and minimum displacement in the girder.

$$y^{//} = -\frac{M_{ed}}{E \cdot I} = \frac{-34,33 + 3,03 \cdot x + 0,881 \cdot \frac{x^2}{2}}{E \cdot I}$$

Solving the equation and taking the bounder values [y(0)=0,y(12,06)=0].

$$y = \frac{0,0367 \cdot x^4 + 0,505 \cdot x^3 - 17,165 \cdot x^2 + 69,187 \cdot x}{E \cdot I}$$

The maximum and minimum values of displacement in the girder are:

x = [2,3;9,33]
E = 210000 N/mm^2
$I_{IPE\ 330}$= 117700000 m^4
E $I_{IPE\ 330}$= 24717 KN m

y(2,3) = 0,0031 m
y(9,33) = -0,0065 m

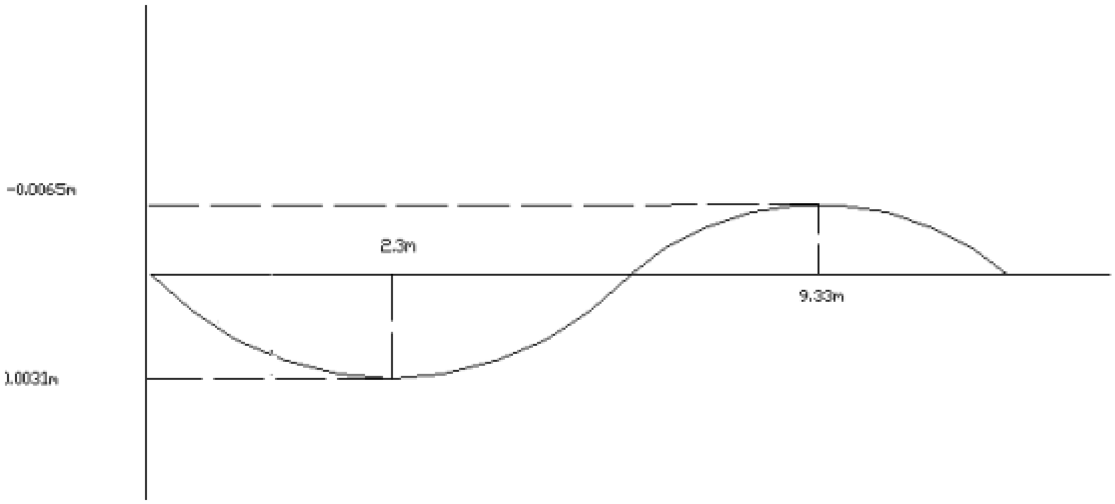


Figure 16: Girder Displacement. CTE

Checking the three relative displacement in different intervals of bean [0;2,3],[2,3;9,33],[9,33;12,06].

$$f_{r,ij} = \frac{|f_i - f_j|}{2 \cdot |x_i - x_j|}$$

$$f_{r,o-x1} = \frac{0,0031}{2 \cdot 2,3} = 0,0006739 = \frac{1}{1483,871} \leq \frac{1}{300} = f_{r,adm}$$

$$f_{r,x1-x2} = \frac{0,0096}{2 \cdot 7,03} = 0,0006827 = \frac{1}{1464,58} \leq \frac{1}{300} = f_{r,adm}$$

$$f_{r,x2-L} = \frac{0,0065}{2 \cdot 2,73} = 0,0011904 = \frac{1}{840} \leq \frac{1}{300} = f_{r,adm}$$

Therefore IPE 330 carries out integrity criterion for the girder.

- **ULS Buckling**

The most demanding loads for this case are:

1,35*Permanents + 1.5*Snow + 0.9*Frontal Wind (1D) + 0,9*Interior suction wind

The beam does not have to buckle in any direction.

<u>-Portal plane</u>

$\beta_1 = 1$ (Non translational, elastic join connected in both extremes)

$$L_{k,1} = \beta_1 \cdot L = 1 \cdot 25 = 25\,\text{m}$$
$$i_{IPE-330,ejefuerte} = 0{,}1371\,\text{m}$$
$$\lambda_1 = L_{k,1} / i_{IPE-330,ejefuerte} = 25/0{,}1371 = 182{,}34$$
$$\lambda_{\lim} = \sqrt{\frac{\pi^2 \cdot E}{f_y}} = \sqrt{\frac{\pi^2 \cdot 210000}{275}} = 86{,}8147$$
$$\overline{\lambda}_1 = \lambda_1 / \lambda_{\lim} = 2{,}010 > 2 \text{ (principal element)}$$

Since IPE-330 does not carry out the condition it is necessary to increase the profile to **IPE-360**

$\beta_1 = 1$ (Non translational, elastic join connected in both extremes)

$$L_{k,1} = \beta_1 \cdot L = 1 \cdot 25 = 25\,\text{m}$$
$$i_{IPE-330,ejefuerte} = 0{,}1495\,\text{m}$$
$$\lambda_1 = L_{k,1} / i_{IPE-330,ejefuerte} = 24/0{,}1495 = 167{,}22$$
$$\lambda_{\lim} = \sqrt{\frac{\pi^2 \cdot E}{f_y}} = \sqrt{\frac{\pi^2 \cdot 210000}{275}} = 86{,}8147$$
$$\overline{\lambda}_1 = \lambda_1 / \lambda_{\lim} = 1{,}926 < 2 \text{ (principal element)}$$

Buckling curve: a (strong axis)

Imperfection coefficient: α=0,21

$$\phi_1 = 0{,}5 \cdot (1 + \alpha \cdot (\overline{\lambda}_1 - 0{,}2) + \overline{\lambda}_1{}^2) = 0{,}5 \cdot (1 + 0{,}21 \cdot (1{,}849 - 0{,}2) + 1{,}849^2) = 2{,}3825$$
$$\chi_1 = \frac{1}{\phi_1 + \sqrt{\phi_1{}^2 - \overline{\lambda}_1{}^2}} = 0{,}25735$$

-Roof plane:

$\chi_2 = 1$ (Displacement stopped for purling)

-Checking

Condition:

$$\begin{Bmatrix} 1/\chi_y \\ 1/\chi_z \end{Bmatrix} \cdot \frac{N_{Ed}}{A \cdot f_{yd}} + \begin{pmatrix} 1 \\ \alpha_y \end{pmatrix} \cdot \frac{k_y \cdot c_{m,y} \cdot M_{y,Ed}}{W_y \cdot f_{yd}} \leq \begin{Bmatrix} 1 \\ 1 \end{Bmatrix}$$

Values obtained with software simulations N_{ED} = 61,56 KN and $M_{y,ED}$= 211,25 KN.m

$$c_{my} = 0,1 - 0,8 \cdot (\alpha) = 0,1 - 0,8 \cdot (-0,5103) = 0,5082$$

$$\alpha_y = 0,8(clase3)$$

$$N_{C,RD} = A_{IPE-360} \cdot f_{yd} = 1904,048 \text{ KN}$$

$$k_y = 1 + 0,6 \cdot \overline{\lambda}_1 \, {N_{ED}} \big/ {\chi_1 \cdot N_{C,RD}} = 1,0139$$

$W_{y,el}$= 903600 mm^3

Replacing values in the condition, it is are obtained:

$$\{0,6423;0,44595\} < \{1;1\}$$

Therefore is carried out with **IPE-360**.

- **ULS Resistance**

The most demanding loads for this case are:

1,35*Permanents + 1.5*Snow + 0.9*Frontal Wind (1D) + 0,9*Interior suction wind

The efforts obtained with the most demanding load must not exceed maximum admissible value.

With software calculation are obtained the following values and stress laws:

$V_{ed,i}$ = -11,88 KN
$V_{ed,j}$ = 65,01 KN
$M_{ed,i}$ = 107,8 KN m
$M_{ed,j}$ = -211,25 KN m

$$P_d = (V_{ed,i} - V_{ed,j}) / L = -6,376$$

$$V_{ed} = V_{ed,i} - P_d \cdot x = -11,88 + 6,376 \cdot x$$

$$M_{ed} = M_{ed,i} - V_{ed,i} \cdot x + P_d \cdot \frac{x^2}{2} = 107,8 + 11,88 \cdot x - 6,376 \cdot \frac{x^2}{2}$$

$$V_{pl,rd} = A_{v,IPE-360} \cdot \frac{f_{yd}}{\sqrt{3}} = 3514 \cdot \frac{261,9}{\sqrt{3}} = 531345,04N = 531,345KN$$

V_{ed}= 65,01 KN
65,01 KN < $0,5 \cdot 531,345$ = 265,67 KN

Therefore the relation is carried out and there is not interaction with shearing stress.

Condition not to put reinforcement:

$M_{ed} \leq M_{u,rd}$
$M_{u,rd} = W_{el,y}\ (f_{yd}\text{-}N_{ed}/A) = 903600\ (261{,}9\text{-}65010/72700) = 235844820$ N mm = 235,84 KN m

Applying the condition is obtained:

$$\left|107{,}8 + 11{,}88 \cdot x - 6{,}376 \cdot \frac{x^2}{2}\right| \leq 235{,}84$$
$$x = -8{,}75;12{,}4 \notin [0 - 12{,}06]m$$

Therefore reinforcement is not necessary and IPE-360 is enough under all check criterions.

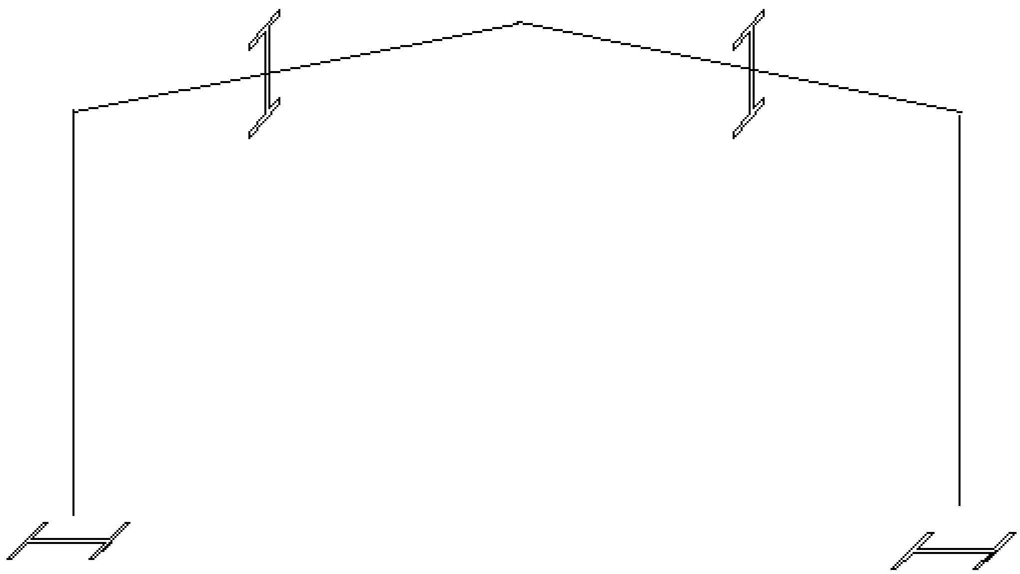


Figure 16: Beams direction

3.3.2. Façade Portal

3.3.2.1. Girder

In this portal the hypotheses that are necessary to check are the same of the girder in the interior portal, but the procedure and the efforts take into account in this case is different.

- **SLS integrity**

The way to carry out with this criterion is to calculate I_y minimum for support the most demanding hypothesis and then, with this inertia obtain the optimal profile.

The most demanding hypothesis is:

1×Frontal wind+ 1×interior pressure wind

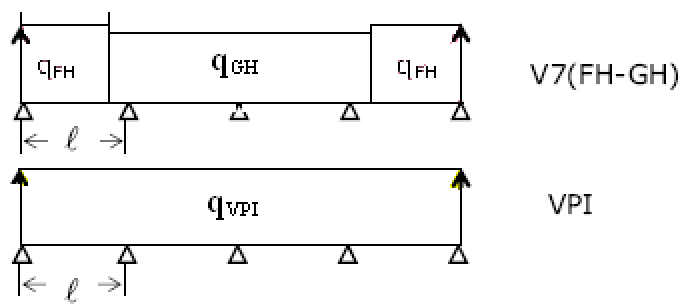


Figure 17: Efforts distribution on the girder

For simplified calculations, the following value is taken:

$$p_d = q_{FH} + q_{VPI}$$

Frontal wind:

$$q_{FH} = \frac{s}{2} \times q_b \times C_e = 0.708 KN/m^2 \times 1.4 \times \frac{5.25}{2} m = 2.6 KN/m$$

Interior pressure wind:

$$q_{VPI} = VPI \times \frac{s}{2} = 0.4956 KN/m^2 \times \frac{5.25}{2} = 1.29 KN/m$$

Therefore:

$$p_d = 2.6 KN/m + 1.29 KN/m = 3.89 KN/m$$

The values under consideration are: l=6,25m ; E=210000N/mm^2

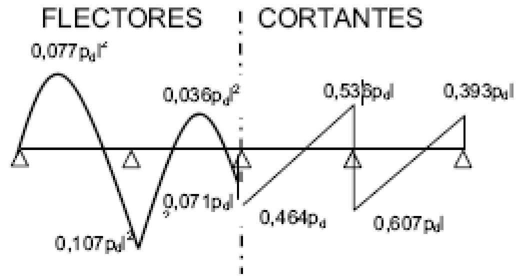


Figure 18: Efforts law distribution on the girder

Maximum displacement is in the first span, between pillars 1 and 2: calculating it, besides $f_{r,\max} \leq \frac{1}{300}$

$$M_{ed\,\max} = 0.077 \times p_d \times l^2$$

$$M_{ed}(x) = -0.393.p_d \times l.x + p_d.\frac{x^2}{2}$$

$$y'' = \frac{-M_{ed}(x)}{EI};$$

Solving the equation and applying boundary conditions y(0)=y(l)=0

$$y = -\frac{1}{384}.\frac{p_d.l^4}{EI}.\left(-0.393\times 64.\left(\frac{x}{l}\right)^3 + 16.\left(\frac{x}{l}\right)^4 + \frac{384}{p_d.l^4}.C_1.x\right)$$

With:

$$C_1 = 9.152 \times \frac{p_d \times l^3}{384}$$

Maximum displacement is y'(x) = 0. Solving the value obtained is $x_{max}=0.43984\times l$ (the unique point in the range), replacing x_{max} is obtained:

$$y_{\max} = y(x_{\max}) = \frac{-2.484.p_d.l^4}{384EI}$$

It is compulsory to carry out with the following expression:

$$f_r = \frac{y_{\max}}{\min[2.x_{\max};2(l-x_{\max})]} = \frac{y_{\max}}{2x_{\max}} = \frac{\frac{2.484}{384}\times\frac{p_d.l^4}{E.I_y}}{2x_{\max}} \leq \frac{1}{300}$$

$$I_y > \frac{300 \times 2.484}{384} \frac{p_d . l^4}{E \times 2 \times x_{\max}} = \frac{300 \times 2.484}{384} \times \frac{3.841 \times 6{,}25^4}{2.1 \times 10^8 \times 2 \times 0.43984 \times 6{,}25}$$

solving:

$$I_y > 871.55 \times 10^{-8} m^4 = 871.55 cm^4$$

Therefore it will be used an **IPE180.**

- **SLS displacement**

The way to carry out this criterion is to calculate I_y minimum for support the most demanding hypothesis and then, with this inertia obtain the optimal profile is obtained.

The most demanding hypothesis is:

$$\boldsymbol{1 \times Permanents}$$

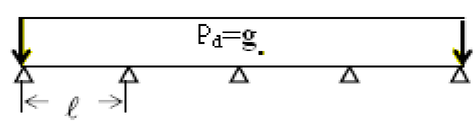


Figure 19: Efforts distribution on the girder in SLS displacement

$$p_d = 0.40 KN / m^2 . \frac{5}{2} m = 1.0075 KN / m$$

l=6,25m; E=210000N/mm^2

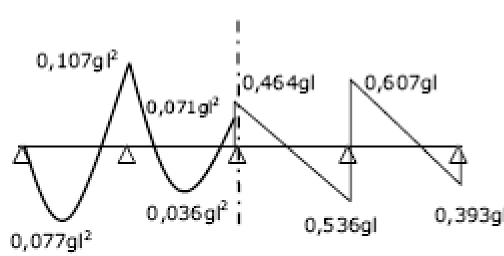


Figure 20: Efforts distribution law on the girder in SLS displacement

Maximum displacement is in the first span, between pillars 1 and 2: calculating it, besides $f_{r,\max} \leq \frac{1}{300}$.

Solving the equation and applying bounder conditions y(0)=y(l)=0

$$M_{ed\,\max} = 0.077 \times p_d \times l^2$$

$$M_{ed}(x) = -0.393.p_d \times l.x + p_d.\frac{x^2}{2}$$

$$y'' = \frac{-M_{ed}(x)}{EI};$$

$$y = -\frac{1}{384}.\frac{p_d.l^4}{EI}.\left(-0.393\times 64.\left(\frac{x}{l}\right)^3 + 16.\left(\frac{x}{l}\right)^4 + \frac{384}{p_d.l^4}.C_1.x\right)$$

With

$$C_1 = 9.152 \times \frac{p_d \times l^3}{384}$$

Maximum displacement will be in y'(x)=0. Solving the equation it is obtained $x_{max}=0.43984 \times l$ (the unique point in the range), replacing x_{max} is obtained:

$$y_{\max} = y(x_{\max}) = \frac{-2.484.p_d.l^4}{384EI}$$

It is compulsory to carry out the following conditions:

$$f_r = \frac{y_{\max}}{\min[2.x_{\max};2(l-x_{\max})]} = \frac{y_{\max}}{2x_{\max}} = \frac{\frac{2.484}{384}\times\frac{p_d.l^4}{E.I_y}}{2x_{\max}} \leq \frac{1}{300}$$

$$I_y > \frac{300\times 2.484}{384}\frac{p_d.l^4}{E\times 2\times x_{\max}} = \frac{300\times 2.484}{384}\times\frac{1.0075\times 6{,}25^4}{2.1\times 10^8\times 2\times 0.43984\times 6{,}25}$$

Solving:

$$I_y > 228.61\times 10^{-8} m^4 = 228.6cm^4$$

They are all carried out by using **IPE180**

- **ULS Resistance and stability**

The design girder criterion is based on the use of the same profile for all beams (without reinforcement): for this reason it has been considered the more loaded section (bigger M_{ed}).

The most demanding load in the girder is the following:

$$\mathbf{1.35\times Permanents + 1.5\times Snow}$$

$$q_{dg} = \frac{s}{2}\times(1.35\times0.40+1.5\times0.5)=2.135KN/m$$

$$\mathbf{0.8\times Permanents\text{-}1.5\times frontal\ wind\text{-}1.5\times interior\ wind\ pressure}$$

$$q_{ds} = \frac{s}{2}.(0.8\times0.40-1.5\times(0.708.1.4)-1.5\times0.4956)=-4.955KN/m$$

The second hypothesis is more demanding due to the fact that has more load module, therefore:

$$Pd=q_{ds}=-4.955KN/m$$

The maximum effort will be on bearing of the second pillar:

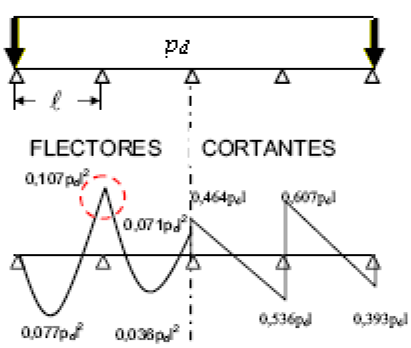


Figure 21: Efforts distribution on the girder in ULS Resistance

Applying condition to check resistance:

$$M_{ed,\max} = 0.107 \times p_d \times l^2 = 0.107 \times 4.955 \times 6{,}25^2 = 19.086KN \leq W_{y,el} \times f_{yd} = W_{y,el} \times \frac{275000}{1.05} = M_{c,rd}$$

Solving:

$W_{y,el} \geq 72.873 \times 10^{-6} = 72.873cm^3$ in this case we have enough with IPE140, but is less than I**PE180**, then will be used the last one.

Checking if there is interaction with shearing stress:

$$V_{ed} = 0.607 \times p_d \times l = 18.046KN \leq 0.5 \times Av \times {f_{yd}}/{\sqrt{3}} = 85.056KN$$

Then there is not interaction with shearing stress.

- **ULS buckling**

The girder of façade portal works in compression then is necessary to check the bucking efforts. For this hypothesis it is considered the frontal wind.

The hypotheses to consider for taking into account load p_d in the roof and q_d in pillars are the following:

Hypothesis to consider load p_d in the roof:

0.8×Permanents+1.5×Frontal Wind+1.5×interior wind suction

Where $p_d = \frac{5.25}{2}\left(0.8 \times 0.40 - 1.5(0.708 \times 1.4) - 1.5 \times 0.354\right) = -4.407KN/m$

1.35×Permanents + 0.5×1.5×Snow + 1.5×Frontal wind + 1.5×interior wind suction

Q_d is calculated for each pillar.

The buckling of the girder is stopped in the roof plane due to bridging of roof: then, making the following condition:

$$\frac{N_{ed,j}}{\chi_{yj} \times A \times f_{yd}} + \frac{k_{y,j} \times C_{my,j} \times M_{y,ed,j}}{W_y \times f_{yd}} \leq 1 \quad \forall \text{ j (no buckling condition)}$$

$\bar{\lambda}$ <2 (slenderness condition)

The possible buckling behaviour in the portal plane of the girder is then studied:

-<u>Slenderness condition of span j</u>

$\eta_i = \eta_s = 1$; Translation =0 then $\beta_j = \beta(1,1,0) = 1$ $\forall$ span j

$$L_{kyj} = l \times \beta = l \quad ; \qquad \lambda_{yj} = \lambda_y = \frac{L_{Ky}}{i_y} \quad ; \qquad \bar{\lambda} = \frac{\lambda}{\lambda_{\lim}} < 2$$

With l=6,25 m and solving is obtained i_y>0.03456m=3.456cm that corresponds to a profile IPE100 so that an IPE180 fits.

-<u>No buckling condition</u>

Compression in each span j of the girder is obtained with axils of wind bracing system.

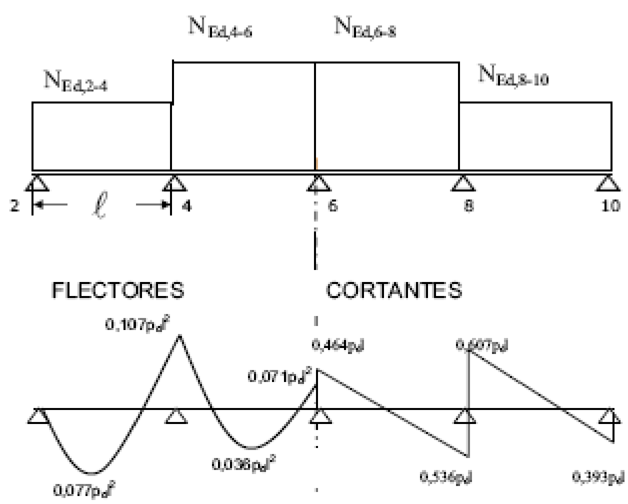
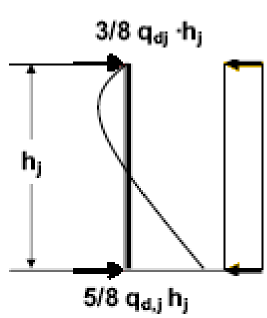


Figure 22: Efforts distribution on the girder in ULS Buckling

As first step an **IPE180** that carries out all the before conditions of demanding states is chosen: afterwards it will be checked if this profile carries out buckling conditions in the façade portal for all spans in the girder

xes in the wind bracing system are to be calculated, calculating the stresses that are transmitted in the pillars, connected in the base and supported in the superior girder.



$$q_{dj} = \gamma_Q \left[l(q_{ee} - q_{ei}) \right] \quad j \neq 1, n \text{ (interior pillar)}$$

$$q_{dj} = \gamma_Q \left[\frac{l}{2}(q_{ee} - q_{ei}) \right] \quad \text{j} = 1, n \text{ (extreme pillar)}$$

with $\gamma_Q = 1.5$

$$q_{ee} = q_b \times C_e(g,z) \times C_{pi} = 0.45KN/m^2 \times 1.3363 \times -0.5 = -0.301KN/m^2$$

$$q_{ee} = q_b \times C_e(g,h) \times C_{pe} = 0.45KN/m^2 \times 1.531 \times 0.7 = 0.4822KN/m$$

With h=5,125m; z=2m.

Then:

$$q_{dj} = 1.5 \times 6{,}25 \times (0.4822 + 0.301) = 7.05KN/m \quad j \neq 1, n \text{ (Interior pillar)}$$
$$q_{dj} = 1.5 \times \frac{6{,}25}{2} \times (0.4822 + 0.301) = 3.525KN/m \quad \mathrm{j} = 1, n \text{ (extreme pillar)}$$

Therefore actions again wind bracing system are the following:

$$Q_{ed,2} = Q_{ed,10} = \frac{3}{8} \times 3.525 \times 4 = 5{,}2875KN$$

$$Q_{ed,4} = Q_{ed,10} = \frac{3}{8} \times 7.05 \times 4{,}5625 = 12{,}06KN$$

$$Q_{ed,6} = \frac{3}{8} \times 7.05 \times 5{,}125 = 13{,}55KN$$

And reactions:

$$R_{ed,1} = R_{ed,2} = 24{,}1255KN$$

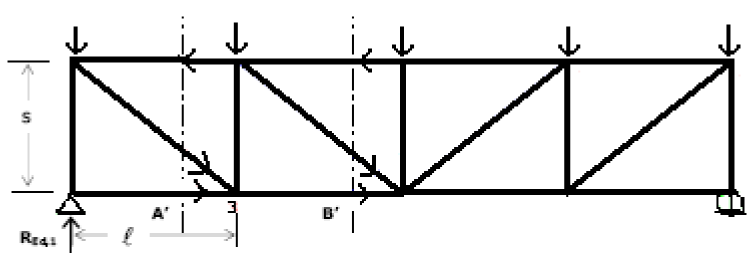


Figure 23: Axils efforts

Applying Ritter method (section method) it is obtained (taking moments in joins 3 and 5):

$$N_{ed,4-2} = \frac{1}{s}\left(R_{ed,1} \times l - Q_{ed,2} \times l\right) = \frac{1}{5}\left(24{,}12 \times 6{,}25 - 5{,}28 \times 6{,}25\right) = 18{,}88KN$$

$$N_{ed,6-4} = \frac{1}{s}\left(R_{ed,1} \times 2l - Q_{ed,2} \times 2l - Q_{ed,4} \times l\right)$$

$$N_{ed,6-4} = \frac{1}{5}\left(24{,}12 \times 2 \times 6{,}25 - 5{,}28 \times 2 \times 6{,}25 - 12{,}06 \times 6{,}25\right) = 30{,}5KN$$

Being the two compression axes, it is:

Span 1: $\alpha = {M_S}/{M_H} = -0.7196 \rightarrow C_{my} = 0.6757$

Span 2: $\alpha = {M_S}/{M_H} = -0.3364 \rightarrow C_{my} = 0.4$

$$\bar{\lambda}_y = \frac{l/i_y}{\lambda_{\lim}} = \frac{6{,}25/7.42 \times 10^{-2}}{86.815} = 0.931$$

$$N_{c,rd} = A \times f_{yd} = 2390mm^2 \times \frac{275KN/mm^2}{1.05} = 625.652KN$$

Buckling curve: a

Imperfection coefficient: α=0,21

$$\phi_1 = 0{,}5 \cdot (1 + \alpha \cdot (\bar{\lambda}_1 - 0{,}2) + \bar{\lambda}_1^{\,2}) = 0{,}5 \cdot (1 + 0{,}21 \cdot (0.931 - 0{,}2) + 0.931^2) = 1.0106$$

$$\chi_1 = \frac{1}{\phi_1 + \sqrt{\phi_1^{\,2} - \bar{\lambda}_1^{\,2}}} = 0.7129$$

$$k_y = 1 + 0{,}6 \cdot \bar{\lambda}_1 \, {N_{ED}}/{\chi_1 \cdot N_{C,RD}} = 1 + 0.6 \times 0.931 \, {N_{ed,j}}/{0.7129 \times 625.932}$$

Therefore $k_{y=}$1.04289 for span 1 y 1.057 for span 2

Applying no buckling condition:

Span 1:

$$\frac{18{,}88}{0.7129 \times 625.952} + \frac{1.04219 \times 0.6757 \times 16.975}{0.1463 \times 10^{-3} \times \dfrac{275000}{1.05}} = 0.3874 < 1$$

Span 2:

$$\frac{30,5}{0.7129\times 625.952}+\frac{1.057\times 0.4\times 16.975}{0.1463\times 10^{-3}\times \frac{275000}{1.05}}=0.289<1$$

W_y=0.1463×10^{-3} y $M_{ed,max}=0.107\,p_d\times l^2=16.975KN/m$

Therefore IPE180 carries out buckling and it is taken as girder profile.

3.3.2.2. Pillar

- **SLS Displacement**

It is not necessary to verify this combination in this case.

- **SLS Integrity**

Calculating the I_{nec} to carry out the criterion $\left(f_{r\max}=1/250\right)$

The most demanding load combination is:

1×Frontal wind(1D) + 1×Interior Suction Wind

Solving for the most demanding pillar, the central:

$$q_d=\frac{s}{2}\left(1\times VF+1\times VSI\right)=\frac{5}{2}\left(-1\times 0.708\times 1.4-1\times 0.5\times 0.708\right)=-3.475\,\text{KN/m}$$

Applying the condition for carrying out its integrity

$$\frac{f}{h}=f_r=\frac{2\times q_d\times l^3}{384\times E\times I}\leq\frac{1}{250}\rightarrow I\geq\frac{2\times 250\times 3.475\times 5{,}125^3}{384\times 2.1\times 10^8}=2{,}92x10^{-6}m^4=292cm^4$$

Then is used **IPE180**

- **ULS buckling**

To solve buckling due to the compression, the most demanding hypothesis to calculate buckling in the façade pillars are:

1.35 $\times$ Permanents +1.5 $\times$ Snow+0.6 $\times$ 1.5 $\times$ Interior pressure wind +0.6 $\times$ 1.5 $\times$ Frontal wind

To simplify calculations, it is assumed that façade portal is located in f zone: besides it is considered all pillars with the same A, W_y.

Applying condition of reduced slenderness:

$\lambda_y, \lambda_z < 2$ (Principal elements)

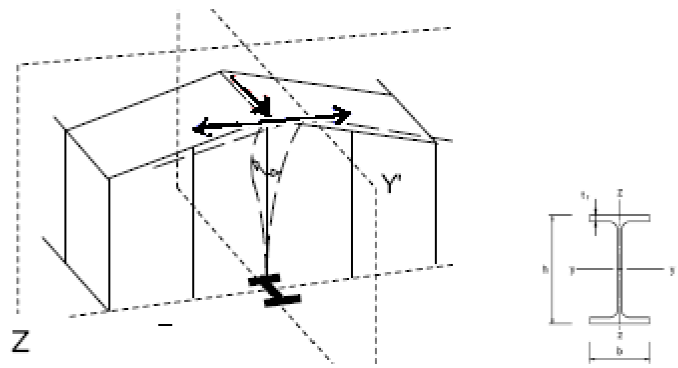


Figure 24: Buckling directions

-Façade portal plane:

Pillar is fixed connected-free and translational

$$\beta_y(0,1,1) = 2 \rightarrow \lambda_y = \frac{L_{ky}}{i_y} = \frac{\beta_y \times h_y}{i_y} = \frac{2 \times h_y}{i_y}$$

$$\bar{\lambda}_y = \frac{\lambda_y}{\lambda_{\lim}} = \frac{2 \times h_y}{i_y \times \lambda_{\lim}} < 2 \rightarrow i_y > \frac{h_y}{\lambda_{\lim}} = \frac{7.724}{86.815} = 0.08897m = 8.897cm$$

-Perpendicular plane to façade portal:

Pillar is fixed connected-free and (movement stopped by wind bracing system)

$$\beta_y(0,1,0) = 0.7 \rightarrow \lambda_y = \frac{L_{kz}}{i_z} = \frac{\beta_z \times h_z}{i_z} = \frac{0.7 \times h_z}{i_z}$$

$$\overline{\lambda}_z = \frac{\lambda_z}{\lambda_{\lim}} = \frac{0.7 \times h_z}{i_z \times \lambda_{\lim}} < 2 \rightarrow i_z > \frac{h_z}{\lambda_{\lim}} \times \frac{0.7}{2} = \frac{5{,}125}{86.815} \times \frac{0.7}{2} = 0.03114m = 3.114cm$$

Therefore is used IPE300 with:

i_y=12.46cm ; i_z=33.35cm ; $W_{el,y}$=557.1cm^3 ; A=53.8cm^2

<u>No buckling condition:</u>

Check whether IPE300 carries out this condition:

-Façade portal plane:

$$\overline{\lambda}_y = \frac{\lambda_y}{\lambda_{\lim}} = \frac{2 \times h_y}{i_y \times \lambda_{\lim}} = \frac{2 \times 5{,}125}{12.46 \times 10^{-2} \times 86.815} = 1.428 < 2$$

With buckling curve a:

$$\phi_y = 0{,}5 \cdot (1 + \alpha \cdot (\overline{\lambda}_1 - 0{,}2) + \overline{\lambda}_1{}^2) = 0{,}5 \cdot (1 + 0{,}23 \cdot (01.428 - 0{,}2) + 1.428^2) = 1.661$$

$$\chi_y = \frac{1}{\phi_y + \sqrt{\phi_y{}^2 - \overline{\lambda}_y{}^2}} = 0.3985$$

-Perpendicular plane to façade plane:

$$\overline{\lambda}_z = \frac{\lambda_z}{\lambda_{\lim}} = \frac{0.7 \times h_z}{i_z \times \lambda_{\lim}} = \frac{0.7 \times 5{,}125}{3.35 \times 10^{-2} \times 86.815} = 1.859 < 2$$

$$\phi_z = 0{,}5 \cdot (1 + \alpha \cdot (\overline{\lambda}_1 - 0{,}2) + \overline{\lambda}_1{}^2) = 0{,}5 \cdot (1 + 0{,}34 \cdot (1.859 - 0{,}2) + 1.859^2) = 2.51$$

$$\chi_z = \frac{1}{\phi_z + \sqrt{\phi_z{}^2 - \overline{\lambda}_z{}^2}} = 0.2383$$

$\alpha_y = 0.8(clase3)$; $C_{m,y} = 0.9$ (translational, β>1)

$$k_y = 1 + 0{,}6 \cdot \bar{\lambda}_y \, N_{ED} / \chi_y \cdot N_{C,RD}$$

Solving N_{ed}, is taking into account that central pillar is the most demanding:

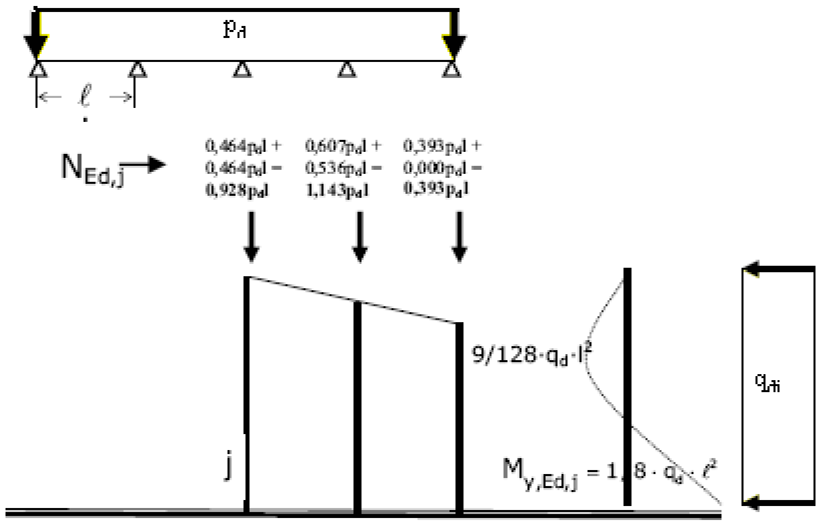


Figure 25: Axial efforts distribution on façade pillars

$$p_d = \frac{s}{2}\left(1.35 \times G + 1.5 \times N + 1.5 \times 0.6 \times VIS + 0.6 \times 1.5 \times VF(2D)\right) =$$

$$= \frac{5}{2}(1.35 \times 0.40 + 1.5 \times 0.2 + 1.5 \times 0.6 \times 0.354 + 0.6 \times 1.5 \times 0.0033) = 3.0125 KN/m$$

$$N_{ed} = 0.928 \times 3.0125 \times 6{,}25 = 16.77 KN$$

$$q_d = 1.5 \times h_z{}^2 (q_{ee} - q_{ei}) = 1.5 \times 5{,}125 \times (0.4822 + 0.301) = 9.074 KN/m$$

q_{ee} and q_{ei} (which we calculated for the girder)

$$M_{ed} = \frac{1}{8} \times q_d \times h_z{}^2 = \frac{1}{8} \times 9.074 \times 5{,}125^2 = 67.669 KNm$$

$$V_{ed} = \frac{5}{8} \times q_d \times h_z = \frac{5}{8} \times 9.074 \times 5{,}125 = 43.8 KN$$

$$\begin{Bmatrix} 1/\chi_y \\ 1/\chi_z \end{Bmatrix} \cdot \frac{N_{Ed}}{A \cdot f_{yd}} + \begin{pmatrix} 1 \\ \alpha_y \end{pmatrix} \cdot \frac{k_y \cdot c_{m,y} \cdot M_{y,Ed}}{W_y \cdot f_{yd}} \leq \begin{Bmatrix} 1 \\ 1 \end{Bmatrix}$$

Replacement:

$\{0.458, 0.392\} \leq \{1, 1\}$

Therefore this profile carries out the condition.

- **ULS Resistance**

Check whether IPE300 carries out resistance, the most demanding hypothesis is:

1.35×Permanents +1.5×snow+0.6×1.5×Interior wind of suction +0.6×1.5×frontal wind

Check if there are interactions with shearing stress:

$$V_{ed} = 43.8KN \leq 0.5 \times Av \times {f_{yd}}/{\sqrt{3}} = 203.86KN$$

Shearing stress action is not noticeable: there is not interaction.

$$M_{ed,\max} = 67.669KNm \leq M_{rd} = W_{el,y}\left(f_{yd} - \frac{N_{ed}}{A}\right) =$$

$$= 557.1 \times 10^{-6}\left(\frac{275000}{1.05} - \frac{16.77}{53.8 \times 10^{-4}}\right) = 144.14KNm$$

Then, profile carries out resistance condition and finally we choose it as pillar of façade portal.

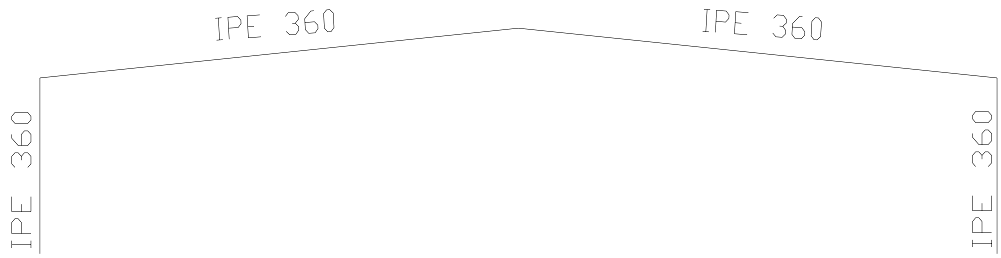


Figure 26: Section profiles in interior portal

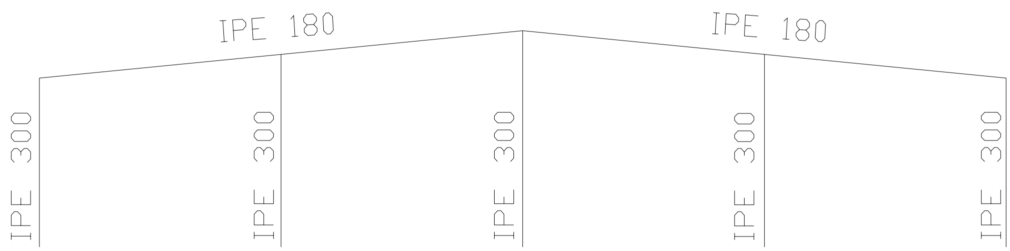


Figure 27: Section profiles in façade portal

4. DAYLIGHT CALCULATIONS

4.1. Introduction

With the objective of creating a building that consumes the minimum amount of energy, it is necessary to study day lighting. Light consumption in supermarkets is estimated to come to around 25% of the total energy consumption in a supermarket. So it is needed to design a building with enough windows and right orientation to use the daylight at best.

The building studied is a simple industrial hall that is used as a supermarket. It is situated in a place free of surrounded buildings or in other words, externally reflected components have been left out. The building is divided into two parts: storage area and supermarket. These parts are separated by an intermediate wall, affecting the daylight performances because the wall acts as a barrier that the light.

It is very important to consider also the height of the windows due to the fact that, in one hand a reduced height of windows produces glare inside the building, while windows with enough height produce more uniform light. This is one of the main reasons for what the building has a minimum height of 4 m. Air quality and need for storage space are other reasons for not making the building too low. On the other hand the height of the building conditioned the windows size.

It is also important to consider the connections between size of windows and the energy. When more light goes inside a building more refrigeration might be necessary.

The daylight analysis has been developed by DAYSIM 2.1. This software has been developed by National Research Council Canada, Institute for Research in Construction and partners.

4.2. Daysim

Daysim software is a tool to simulate the amount of day light that can be obtained in a building. This amount of energy is measured in different performance indicators, which will be later explained. This software provides very exhaustive control of daylight and a great deal of accuracy.

The following diagram shows the method to work with this software and the input data that is necessary to obtain simulation results.

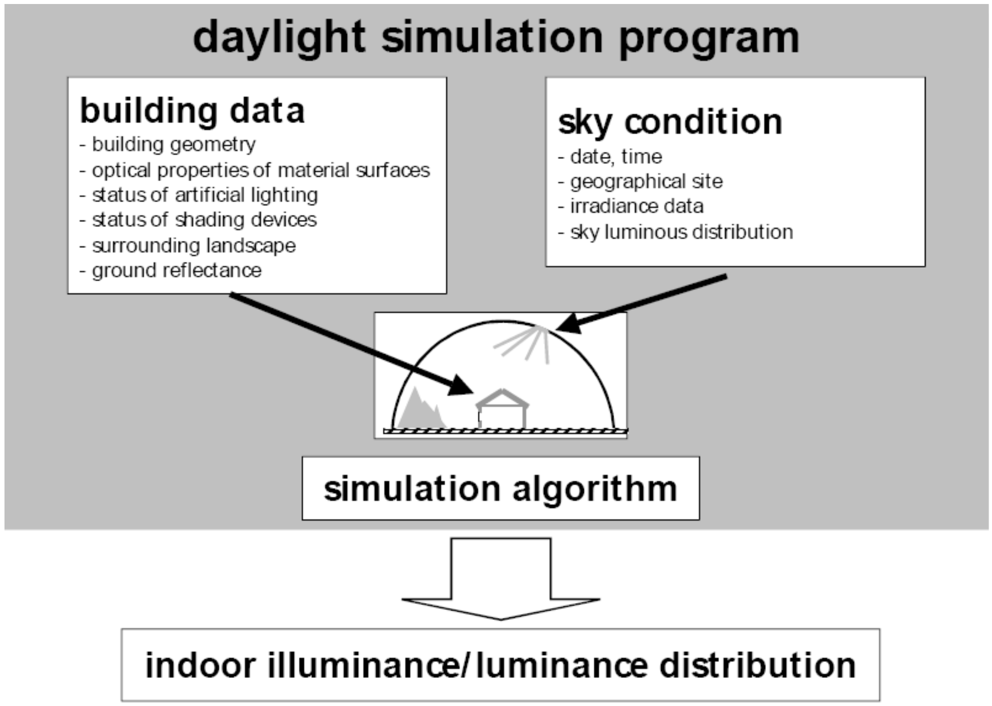


Figure 28: Simulation process

The building has been drawn in three dimensions and then imported to a 3Ds format after making some simulations and beginning to use Skecth up software, available as free trial version in internet.
A problem occurring at the beginning with Autocad 2007 has been solved: with Autocad it was impossible to obtain a good import in 3Ds format, because of materials properties of layers were not possible to be imported. The problem was then solved by using Sketch up.

The following step has been to provide the materials of different layers with its properties, such as, for instance, reflectance. Daysim has a material library where it is easy to find materials that are necessary in each kind of buildings.

Once the building has been imported into the software, it has been only necessary to choose options that are needed. The running of simulations has been done in order to obtain the required parameters.

Daylight factor:

It is defined as the ratio of the indoor luminance at a point of interest to the outdoor horizontal luminance under the overcast CIE sky (it is a sky model that is explained in the next pages). This indicator is widely used because it provides an idea of how bright or dark the interior of a giving building is.

The major weakness is that the orientation of the investigated building does not influence the daylight factor: for this cause luminance in side lit/top lit spaces are under/over predicted.

An experimentally recommended range is to use a daylight factor between **2%-5%**, that provides the building with satisfactory day lighting (British Standards Institution, BS 8206 part 2).

In Leadership in Energy & Environmental Design (LEED 2.1), (The US Green Building Council), it is recommended a minimum daylight factor of 2% to be achieved in 75% in all spaces occupied for critical visual tasks.

Electric Lighting use:

The annual electric energy demand is defined as the total electric energy to light a building. This value will depend on how to use dim system. When a dimmed lighting system is used, the energy demand system depends on the momentary dim level of the system. On the other hand for a manually control lighting system, this value depends on how and when buildings occupants are using their light switches.

Daylight Autonomy:

The daylight autonomy at a point in a building is defined as the percentage of occupied hours per year, when the minimum luminance level can be maintained by daylight alone. In contrast to the more commonly used daylight factor.

The main limitation of Daylight Autonomy is that this factor is relatively new and for this reason there aren't range indicators performance recommended. But in the other hand the main advantage of the daylight autonomy over daylight factor is that it takes façade orientation a user occupancy profile throughout the year.

Useful Daylight Autonomy:

Useful daylight Autonomy (UDI) is a dynamic daylight performance measure that is also based on work plane luminance. This performance determines when the daylight levels are 'useful' for the occupant. The suggested range is 100-2000 lux.

Continuous Daylight Autonomy:

Continuous Daylight Autonomy (DAcon). In contrast to conventional daylight autonomy, partial credit is attributed to time steps when the daylight luminance lies below the minimum luminance level. For example if 500 lux of luminance are needed but at this time only 400 lux can be obtained by day light, there is a partial credit of 400/500 lux=0.8.

Another parameter to consider is the widely appearance of glare, maximum Daylight Autonomy (DAmax): it is reported together with DAcon to indicate the percentage of the occupied hours when direct sunlight or exceedingly high daylight conditions are present. DAmax was defined to be a sliding level equal to ten times the design illuminance of a space, with this parameter a measure of how often and where large luminance contrasts appear in a space can be obtained.

4.3. Simulation Assumptions

Site Description: The investigated building is located in Valencia (Spain) (39.50 N/ 0.47 E).

User Description: The zone is continuously occupied from Monday to Saturday from 9:00 to 21:00. The occupant performs a task that requires a minimum luminance level of 300 lux.

Lighting and Blind Control: The electric lighting system has an installed lighting power density of 20.00 W/unit area and it is manually controlled with an on/off switch. The office has no dynamic shading device system installed.

4.4. Input Data

4.4.1. Building

In order to obtain a good daylight performance, results have been studied for four different building windows distributions:

Type 1:

In the option 1, an approach to give maximum façade area of windows has been used. The windows are placed as bands along the building:

Windows widths are:

Roof windows: 2 bands 1 m wide
Side windows: 1,5m.
Façade windows: 1,5m.

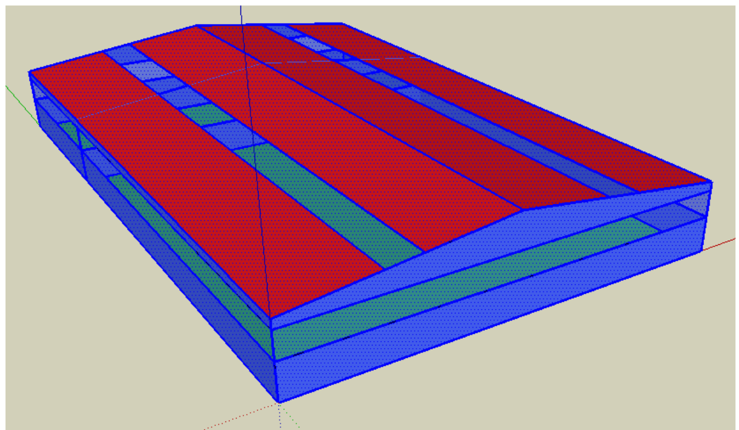


Figure 29: Building type 1

Type 2:

In this option only roof windows into rectangular windows have been changed, as it is shown in the figure.

Windows wide:

Roof windows: 6 windows a 3m2.
Side windows: 1,5m.
Façade windows: 1,5m.

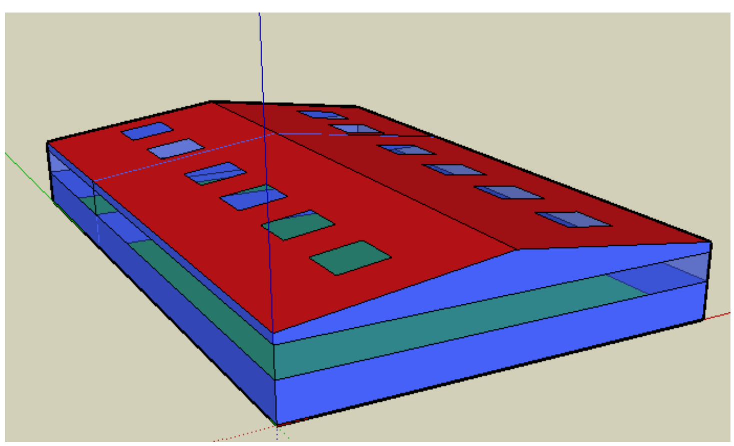


Figure 30: Building type 2

Type 3:

This option is the same as option 1 but without roof windows.

Windows wide:

Side windows: 1,5m.
Façade windows: 1,5m.

Type 4:

This option is the same as option 1 but without side windows.

Windows wide:

Roof windows: 2m.
Façade windows: 1,5m.

4.4.2. Materials

The materials selected have been chosen from Daysim material library, trying to choose the most similar materials of our building.

There are five different materials considered:

- Floor material
- Interior window material: single glass
- Exterior Window material: double glass
- Roof material
- Wall material

4.4.3. Work plane

It is required to define points that will be studied by the software; these points have been chosen every five meters inside building, at a height of 0,85m.

x(m)	y(m)	z(m)
5.000	5.000	0.850
5.000	10.000	0.850
5.000	15.000	0.850
5.000	20.000	0.850
5.000	25.000	0.850
5.000	30.000	0.850
5.000	35.000	0.850
10.000	5.000	0.850
10.000	10.000	0.850
10.000	15.000	0.850
10.000	20.000	0.850

10.000	25.000	0.850
10.000	30.000	0.850
10.000	35.000	0.850
15.000	5.000	0.850
15.000	10.000	0.850
15.000	15.000	0.850
15.000	20.000	0.850
15.000	25.000	0.850
15.000	30.000	0.850
15.000	35.000	0.850
20.000	5.000	0.850
20.000	10.000	0.850
20.000	15.000	0.850
20.000	20.000	0.850
20.000	25.000	0.850
20.000	30.000	0.850
20.000	35.000	0.850

Table 1: Work plane coordinates

In the figure 1, the X-axis is the red one or which is in façade plane, Y-axis is the depth axis and is located on the side building, and Z-axis is the height axis.

4.5. Daylight Results

In order to evaluate the different options of windows distribution it is necessary to determinate which parameter will be taken into account.

A “quality” parameter of light, which is obtained with the different model is the daylight factor (DF), studied considering an optimal range of 2%-5%.

The result is showed at different states along X axis which is the short side of the building and showed through the building (distance to North façade).

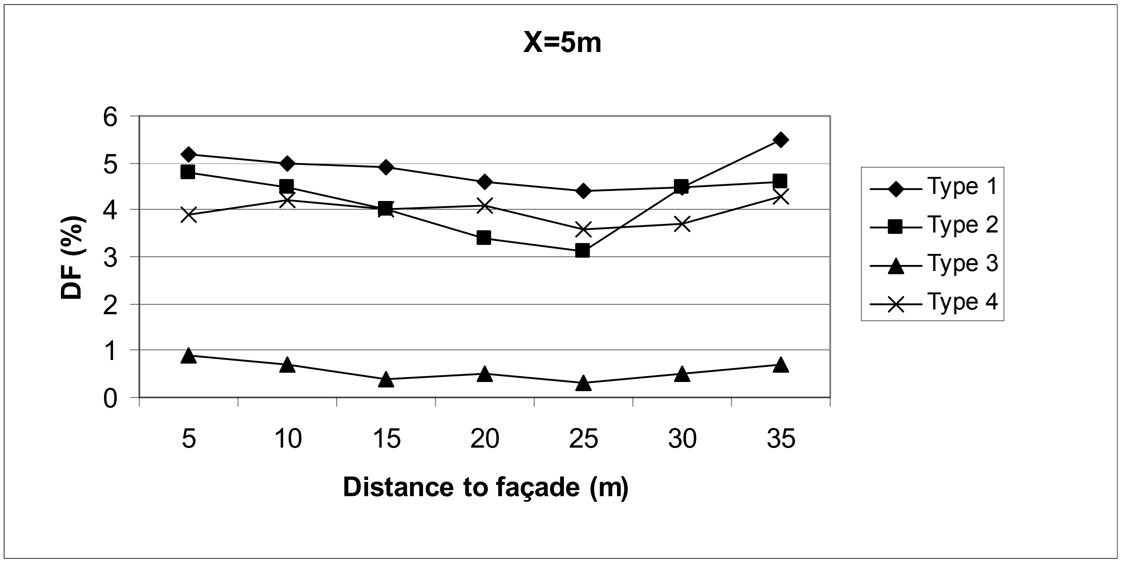


Figure 31: Daylight factor distribution X=5m.

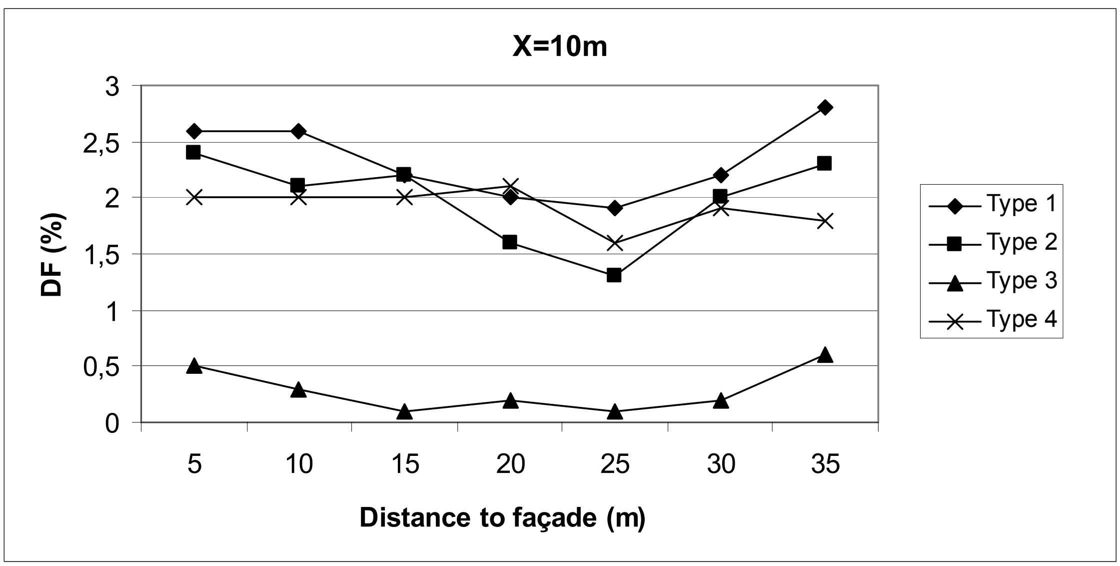


Figure 31: Daylight factor distribution X=10m.

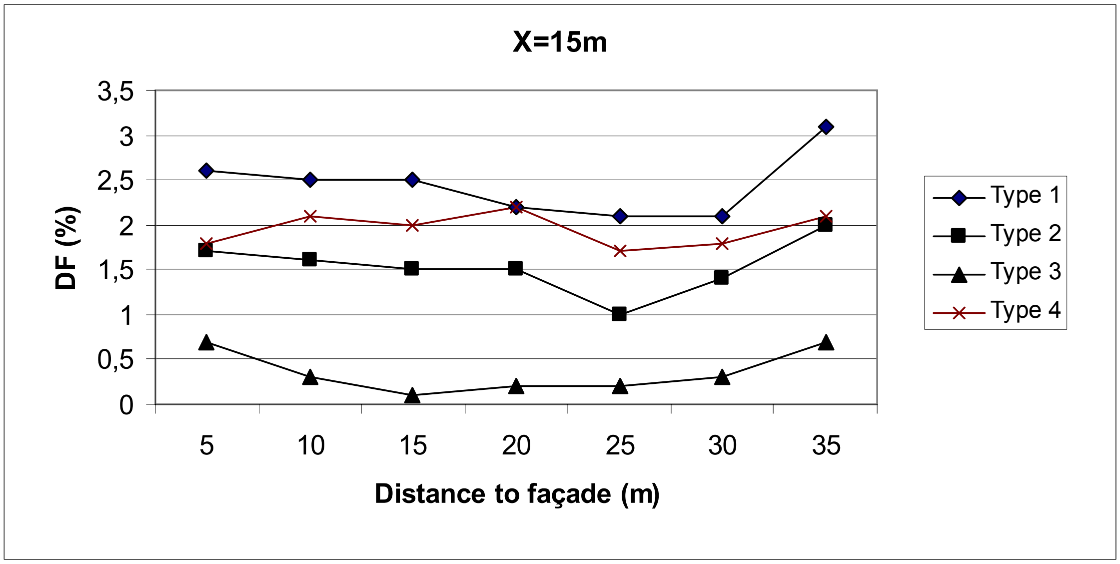


Figure 32: Daylight factor distribution X=15m.

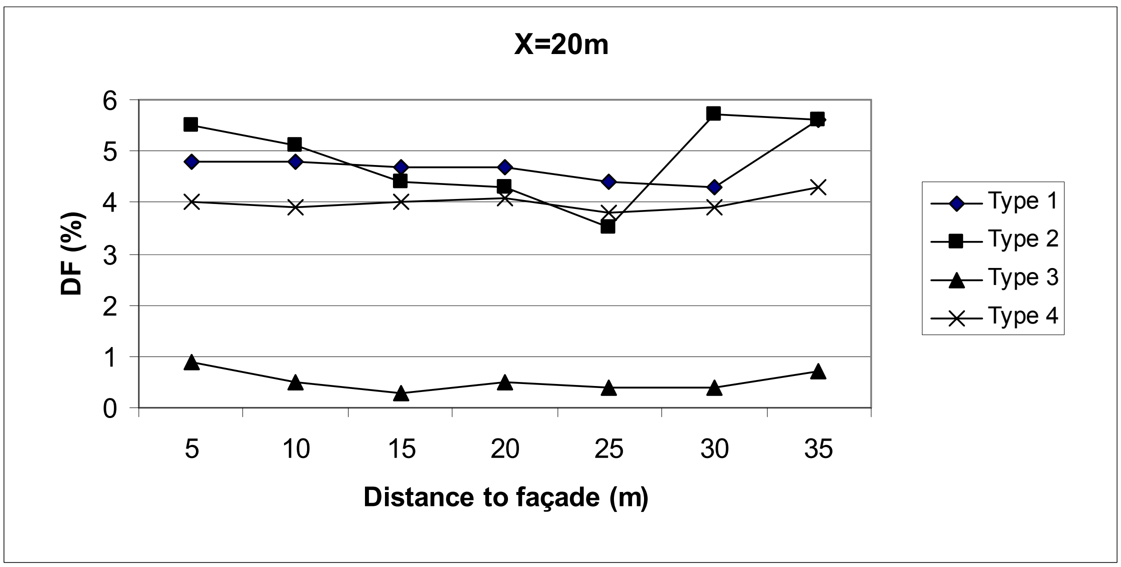


Figure 33: Daylight factor distribution X=20m.

As it is shown in the different diagrams there are two types of window distribution building that are in the range that is considered good and these are Type 1 and Type 4.

Type 1 carries on with the minimum limit of 2% of DF in all study points. On the other hand this is the type that has the biggest window space and therefore the higher thermal losses will take place in this model.

Critical DF distribution occurs at X=15m, where type 4 lies down 2% of DF value, which is considered as the minimum required; anyway, considering the recommendations of the US Green building Council this type also will be taken into account: these recommendations, in fact, are focused on office buildings and intensive needs of light. In supermarkets a good illumination is necessary but not as much as in an office, then type 4 can be considered passing the DF criterion.

As a consequence types 2 and 3 cannot be considered possible window distribution.

By studying the different performance parameters for these two options it is then possible to choose which one is better.

It is worth noticing that in the input data there are two possible options in the use of blinds:

- **Static shading device**: In this mode DAYSIM either assumes that the shading device is already part of the considered basic RADIANCE scene or that there is no shading device.

- **Dynamic shading device model (simple):** In this mode DAYSIM uses a simplified model to consider the effect of a generic venetian blinds system on the annual daylight availability: DAYSIM uses the basic RADIANCE scene to calculate indoor luminance when the blinds are retracted. In this method when blinds are lowered due to the glare, Daysim assumes that generic blind system blocks all direct sunlight and transmits 25% of all diffuse daylight. Note that with this method Daysim assume that there is a blind system, although it is not drawn in Sketch up model.

4.5.1. Static shading Device:

Now the average value in the X axis has been considered to show in an easy way the results.

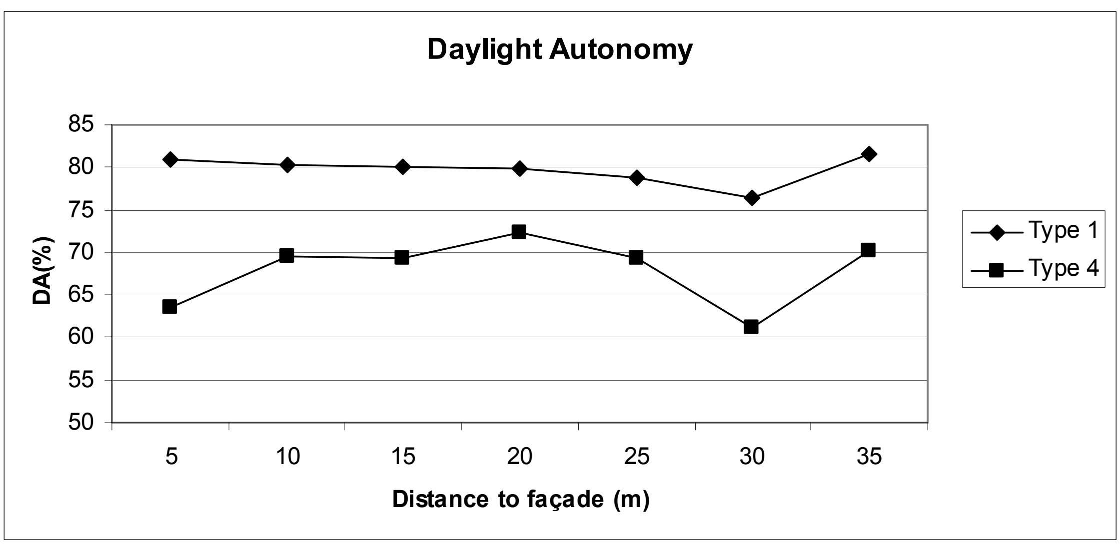


Figure 34: Daylight Autonomy distribution.

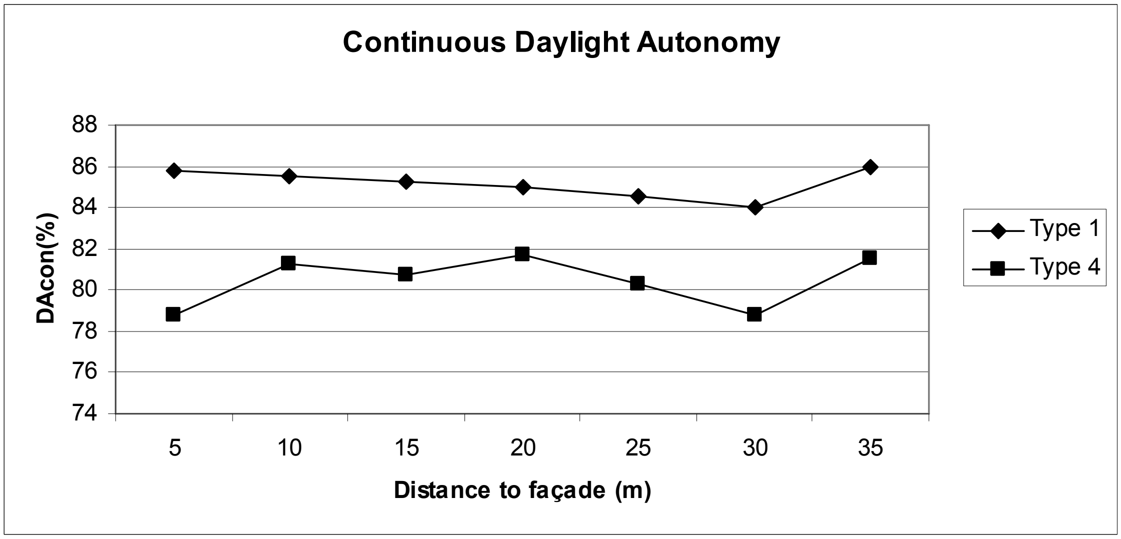


Figure 35: Continuous Daylight Autonomy Distribution.

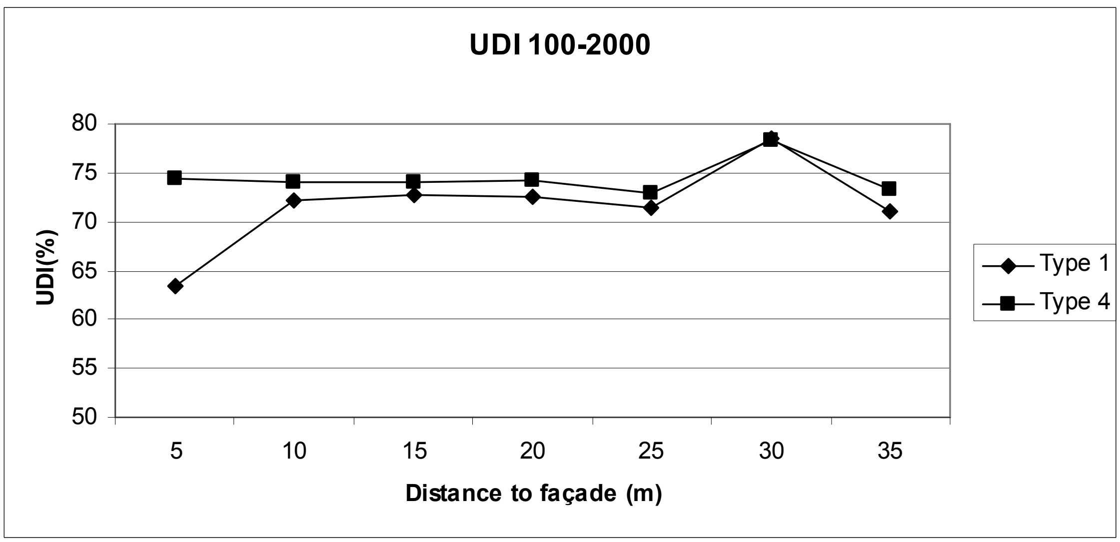


Figure 36: Useful Daylight Autonomy distribution.

4.5.2. Dynamic shading device model (simple):

In this model it is not possible to compare both types of window layout because type 4 only has roof windows without blinds. Then this kind of model is only capable to study type 1. Because it is not possible compare both types with this model it will not be used.

The predicted annual electric lighting energy use of 50.6 kWh/unit area with a building type 1 and 47,5 kWh/unit area with building type 4, corresponds to the mean energy use in a group of identical offices that are occupied by four user types:

- a user who operates the electric lighting in relation to ambient daylight conditions, opens the blinds in the morning, and lowers them when direct sunlight above 50 Wm^{-2} hits the seating position (to avoid direct glare)

- a user who operates the electric lighting in relation to ambient daylight conditions, and keeps the blinds lowered throughout the year to avoid direct sunlight

- a user who keeps the electric lighting on throughout the working day, opens the blinds in the morning, and lowers them when direct sunlight above 50 Wm^{-2} hits the seating position (to avoid direct glare)

- a user who keeps the electric lighting on throughout the working day, and keeps the blinds lowered throughout the year to avoid direct sunlight

The light needs in the supermarket under consideration are 47500 kWh/year for Type 1 and 50600 kWh/year for Type 4, saving in a first approximation 3100 kWh/year**.** Note that this value has to be studied with respect of other variables that are commented in the next paragraph.

It is possible to obtain a good daylight approach by adding more windows, but this also requires more energy to cool the supermarket. It is compulsory to study the cooling needs due to different kind of windows distribution, in order to obtain a good analysis and a good model. Otherwise the energy saving in daylight analysis might be lost in a higher cooling or heating demand For these reason the following step is to calculate the cooling needs with Consolis Energy +.

4.6. Consolis Energy+

This software has been developed by Prof. Gudni Jóhannesson at KTH (2007). This is a program for the calculation of yearly energy use in buildings.

The programme is based mainly upon the new EN standards for energy optimization in buildings:

- Annual energy used in buildings
- Ground heat loss
- Thermal bridges

European climates have been added to the programme, but no all climates have been included. On the other hand it is easy to introduce a new climate as Valencia, which has not been not included and for this task it is only necessary to have a database of the average monthly temperatures and number of cloudy days, partially cloudy days and sunny days in each month and then the program itself calculates all required dates.

It is also important to know that the program calculates the hourly temperature per month depending on the kind of the day before mentioned. These data are used after in the amount of energy/exergy that it is possible to store.

The picture below shows the way the program works and which energy flows that are taken into account.

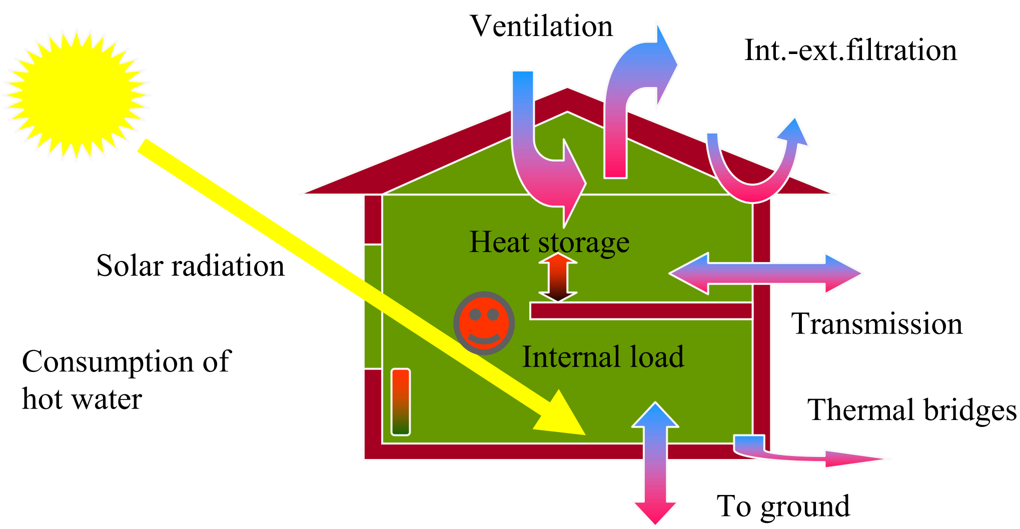


Figure 37: Thermal processes in buildings.

4.6.1. Input Data

Consolis+ can handle buildings divided into two parts, but it is also possible to compare two different buildings in a single simulation by joining two zones with no air flows or energy flows between them,

So a simulation has been done comparing in part 1 properties of building type1, and in part 2 properties of building type 4. Note that the following input data have been chosen to give a first assessment of the building behaviour with different window areas. Afterwards in the next chapters there will be a more accurate calculation.

Building type	type 1	type 4
Temperature inside Min	21 ºC	21 ºC
Temperature inside Min	25 ºC	25 ºC
H. solar screening angle	5 W/ m^2	5 W/ m^2

Mean effect of internal heat load	5 W/ m^2	5 W/ m^2
Internal heat load profile	3	3
Heated floor area	850m^2	850m^2
Ground area (Footprint)	1000m^2	1000m^2
Perimeter against the free	130m	130m
Ventilation flow in	850 l/s	850 l/s
Ventilation flow out	850 l/s	850 l/s
Air leakage at 50 Pa q_{50}	1056	1056
Temperature efficiency outlet air	0,21	0,21
Temperature efficiency inlet air	0,21	0,21
Electricity use for property and household	212kWh/y.m^2	212kWh/y.m^2
Climate	Valencia	Valencia
Ext. Walls (U=0.15;Ceff=25040)	784,5	974,5
Roof (U=0.12;Ceff=25270)	848	848
Windows (U-value=1.20; frame factor=0,8; g-value=0,25)	S:37,5 m^2 W:60 m^2 N:37,5 m^2 E:60 m^2 H: 160 m^2	H:160 m^2
Ground floor (R=13.95; Ceff=215500)	1000m^2	1000m^2
Intermediate construction (U=0.3)	100m^2	100m^2
Linear thermal bridges (ψ=0.04)	432m	224m
Linear thermal bridges (ψ=0.09)	130m	130m
Linear thermal bridges (ψ=0.17)	130m	130m
Linear thermal bridges (ψ=0.08)	16m	0

Table 2: Input Data Consolis Energy +.

4.6.2. Results

Building type 1:

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Average Ext. T	11,5	12,6	13,9	15,5	18,4	22,1	24,9	25,5	23,1	19,1	14,9	12,4	
Sun in	4911,7	5537,8	7800,4	9019,1	9755,3	10368,7	11540,7	9832,9	7545,3	6670,2	4875,7	4398,2	92255,9 kWh
Internal heat Load	3162,0	2856,0	3162,0	3060,0	3162,0	3060,0	3162,0	3162,0	3060,0	3162,0	3060,0	3162,0	37230 kWh
Total heat Gain	8073,7	8393,8	10962,4	12079,1	12917,3	13428,7	14702,7	12994,9	10605,3	9832,2	7935,7	7560,2	129485,9 kWh
Utilization Factor	0,9	0,8	0,7	0,5	0,2	0,0	0,0	0,0	0,0	0,2	0,7	0,9	
Ut. Factor Dyn calc	0,9	0,9	0,8	0,5	0,3	0,0	0,0	0,0	0,0	0,2	0,8	0,9	
Used free Heat	7320,5	6939,9	7518,9	6137,3	3184,9	0,0	0,0	0,0	0,0	2306,0	5924,7	6788,9	46121,2 kWh
Heat energy EN13790*	4417,5	2416,6	1178,1	331,2	14,2	0,0	0,0	0,0	0,0	8,5	1288,3	3813,2	13467,6 kWh
Do dynamic Method	4171,4	2167,4	461,6	52,2	0,0	0,0	0,0	0,0	0,0	0,0	717,7	3542,8	11113,0 kWh
Do steady State	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0 kWh
Cool energy ut f 1	0,0	0,0	0,0	560,9	4617,9	9845,1	14486,9	13542,8	8270,1	2462,5	0,0	0,0	53786,1 kWh
Do dynamic Method	0,0	25,6	589,3	2368,2	5405,6	10035,3	14523,2	13542,1	8361,3	3323,8	68,1	0,0	58242,4 kWh
El property Household	15304,7	13823,6	15304,7	14811,0	15304,7	14811,0	15304,7	15304,7	14811,0	15304,7	14811,0	15304,7	180200 kWh
Hot water Consumption	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0 kWh

Table 3: Results Building type 1.

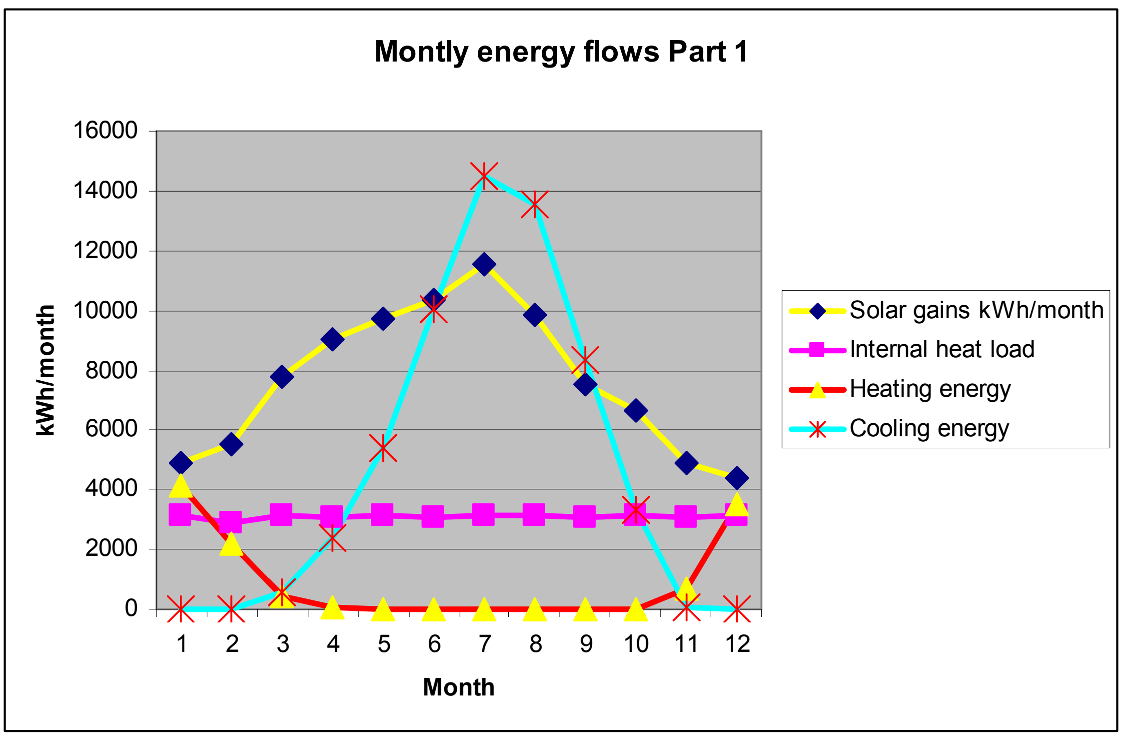


Figure 38: Results building type 1.

Building type 2:

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Average Ext. T	11,5	12,6	13,9	15,5	18,4	22,1	24,9	25,5	23,1	19,1	14,9	12,4	
Sun in	2190,2	2804,9	3988,8	4883,0	5524,3	5973,5	6606,7	5450,6	4005,1	3242,8	2229,0	1912,2	48811,2 kWh
Internal heat load	3162,0	2856,0	3162,0	3060,0	3162,0	3060,0	3162,0	3162,0	3060,0	3162,0	3060,0	3162,0	37230 kWh
Total heat gain	5352,2	5660,9	7150,8	7943,0	8686,3	9033,5	9768,7	8612,6	7065,1	6404,8	5289,0	5074,2	86041,2 kWh
Utilization factor	1,0	0,9	0,8	0,6	0,3	0,0	0,0	0,0	0,0	0,3	0,9	1,0	
Ut. Factor Dyn calc	1,0	0,9	0,9	0,7	0,3	0,0	0,0	0,0	0,0	0,3	0,9	1,0	
Used free heat	5181,9	5218,3	5925,1	5153,1	2769,0	0,0	0,0	0,0	0,0	2001,6	4596,8	4884,4	35730,1 kWh
Heat energy EN13790*	5106,2	2999,6	1733,3	520,7	19,0	0,0	0,0	0,0	0,0	12,4	1735,7	4404,7	16531,5 kWh
Do dynamic method	5050,0	3102,9	1419,7	77,5	0,0	0,0	0,0	0,0	0,0	0,0	1541,1	4327,9	15519,2 kWh
Cool energy ut f 1	0,0	0,0	0,0	0,0	1398,5	5880,0	9568,3	9083,8	5011,7	0,0	0,0	0,0	30942,3 kWh
Do dynamic method	0,0	0,0	0,0	268,7	2295,8	6048,6	9583,0	9054,6	5089,2	893,7	0,0	0,0	33233,6 kWh
El property household	15304,7	13823,6	15304,7	14811,0	15304,7	14811,0	15304,7	15304,7	14811,0	15304,7	14811,0	15304,7	180200 kWh
Hot water consumption	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0 kWh

Table 4: Results Building type 2.

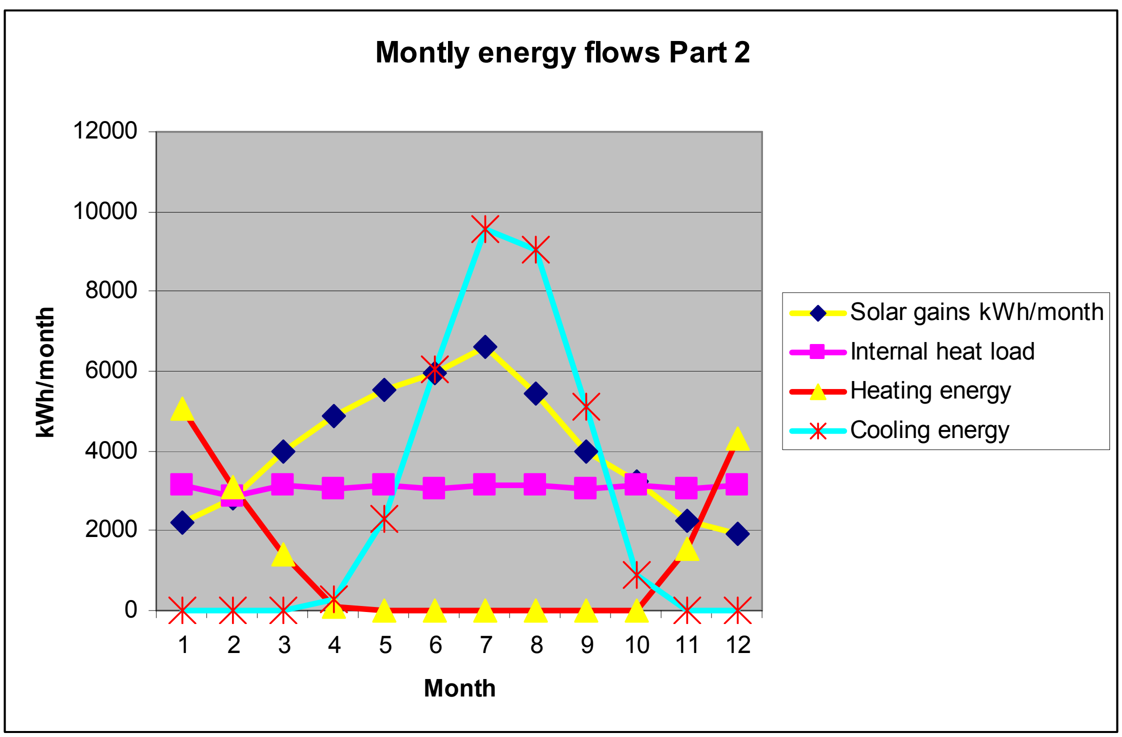


Figure 39: Results building type 2.

The following graph shows clearly the difference of climate energy needs between these two buildings.

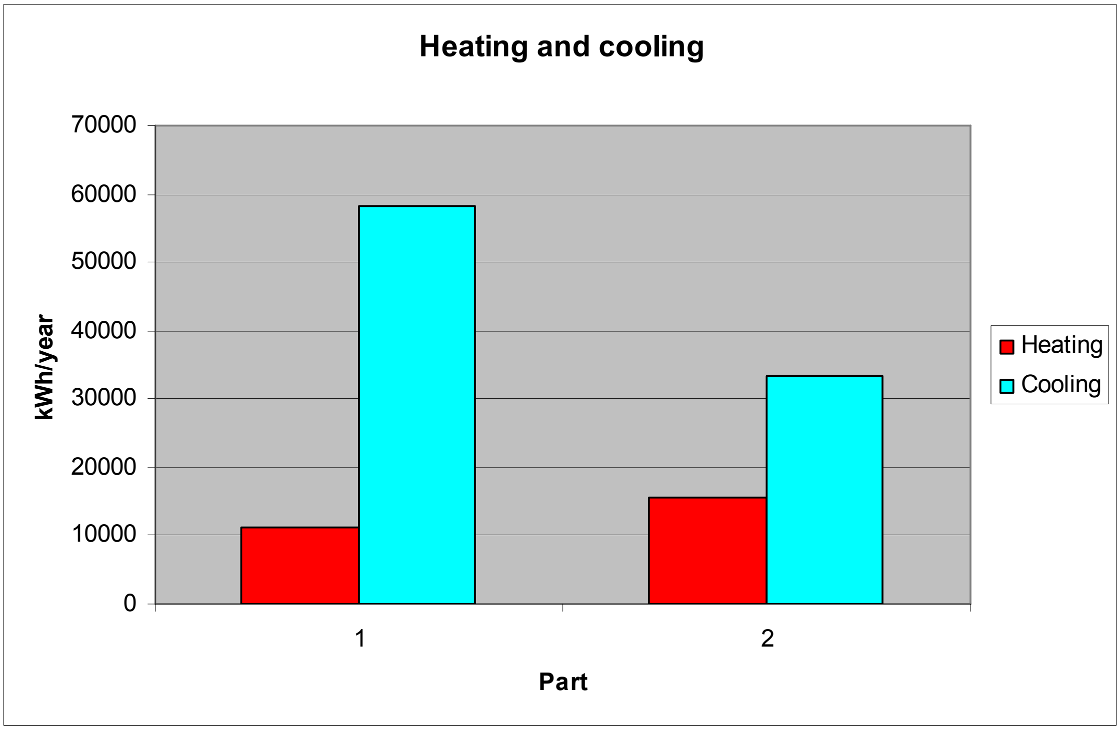


Figure 40: Comparison Heating and Cooling.

Finally, taking into account these results and making an approximation, it is feasible to save 20592 kWh/year with Type 2, meanwhile the difference between Type 1 in lighting needs is 3100 kWh/year.

	type 1	type 2	Save
Cold Energy Needs (kWh/year)	58242	33234	25008
Hot Energy Needs (kWh/year)	11103	15519	-4416
			20592
Lighting (electricity) (kWh/year)	47500	50600	-3100

Table 5: Save energy.

As a conclusion Type 2 gives better energy behaviour than Type 1, and it will be the windows distribution used in the study.

5. THE CASA BONA SYSTEM

5.1. Introduction

In the way to save energy in buildings, Professor Gudni Jóhanesson developed a new procedure to build walls and roofs. This procedure is called the Casa Bona System. The Casa Bona system was born combining the traditions of different countries to build walls. The main advantage of this procedure is that it offers a good thermal isolation only using few material layers, which results in lower cost of materials and workers.

The idea is to use a rigid foam of EPS (expanded polystyrene) which is relatively inexpensive, environmentally friendly and can be cut with enough accuracy. The goal is to create a site building structure based on standard structural elements with a minimum degree of prefabrication, good thermal isolation properties and also limited risk of moisture damages.

This idea has a precedent, in America: during a suburban project in Arizona, foam blocks were fitted between wooden frames which composed the structure of the wall. The fitting of the foam insulation was not perfect, therefore the insulation was poor. Moreover, the rigid foam did not contribute to the rigidity of the construction. If rigid foams fit into the frame it will have similar insulating properties as mineral wool and, at the same time, it will increase the load bearing capacity and the rigidity of the structure.

Developing this idea bore Casa Bona procedure, which is described below.

5.2. Casa Bona Elements

The basic components of this system are:

-Z-profiles, which consist on galvanized steel sheets with perforated web and oversized backward flanges.

- **Blocks of EPS**.

5.2.1. Z-Profile

In the production of Z-profiles the continuous sheet is cut and profiled and can then either be cold rolled or bent to the final shape. For vertical constructions, the profiles sizes are normally 60x60x150x60x60 or 60x60x200x60x60, with a Z-shape, with materials thickness 1.2 or 1.5 mm. The web is perforated with long narrows slots in the direction of the profile forming a pattern that gives a thermal bridge effect equal to a normal wooden stud.

At the top and at the bottom of the wall a U-profile is used, that has the same weight as Z-profile used in the wall.

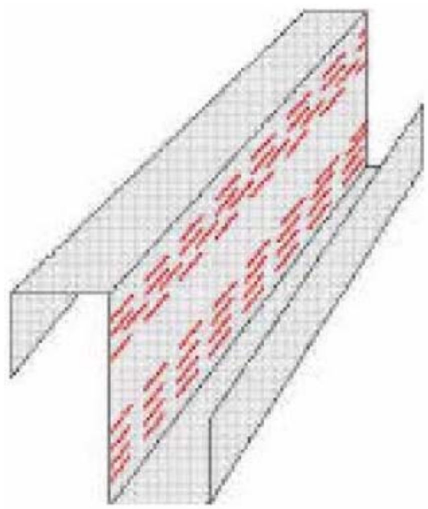


Figure 41 .Z-Profile

5.2.2. Blocks

The blocks are made of Expanded Polystyrene; this product is widely used for packaging and in building construction. In order to obtain a rigid system, the Casa Bona System uses EPS blocks with high density (30 kg/m), and other materials can be used for other specifications such as Rigid Mineral Wood (80 kg/m). EPS also has excellent iinsulation properties that provide this material as one of the best for saving energy in buildings.

The modular dimension of the system is defined by the nominal width of the polystyrene blocks. For a 900 mm module the exact width would be 898.5 mm. with 1.5 mm. thick profiles, thickness 150 mm and the blocks and the grooves is usually carried out at the polystyrene factory.

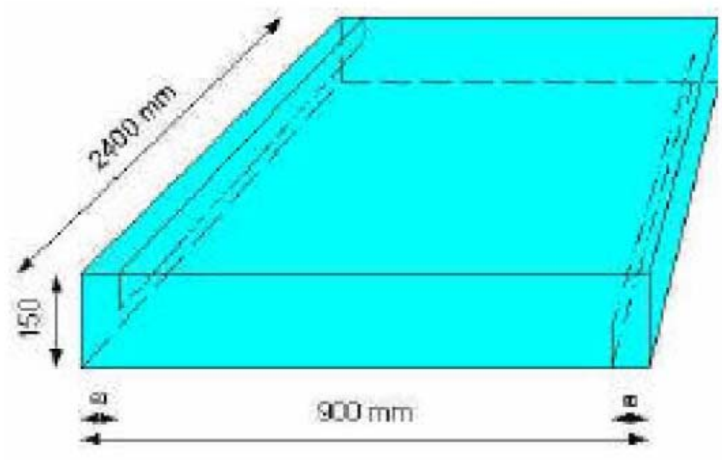


Figure 42.EPS blocks

Usually walls are finished at the bottom with a U profile 60x150x60, and a thickness of 1.0 mm with a slotted web. For moisture protection to obtain air tightness and to reduce the thermal bridges the wall is placed on neoprene gaskets: this is especially advisable when the walls are mounted to a highly conductive substrate like concrete.

The block has two deep grooves (60 or 45 mm) placed to fit the flanges in the Z-profiles.

The precise cutting blocks and the grooves are usually carried out at the polystyrene factory and the experience shows that this can be done with high accuracy.

The EPS blocks are manufactured with 2400 mm of height, but of course these dimensions can be modified to fit windows and doors. It is advisable to use block divisible with 300 mm. (Jóhanesson)

5.3. Assembly of components

The Z-profiles are attached to the EPS blocks simply by pressing the backward flange of the profile into the matching groove. In this way, a whole wall can be mounted very quickly.

The wall element can be prefabricated or built in situ; if the elements are prefabricated they can be mounted horizontally on a flat surface. When building is made in situ, the elements are usually mounted in the vertical position. Firstly, it is necessary to screw down the foot of the U-profile onto the substrate, and then press the first Z-profile into an EPS block, and put the first element in vertical position in the U-profile. After that, a temporary transversal support maintains the vertical position and the Z-profile is fixed to the U-profile with self-drilling screws. The consecutive Z-profiles and EPS blocks can now be added by gliding the components into the U-profile in a tilt position, so that the backward flanges and the grooves meet.

When additional elements are fixed, it is important to be careful about their position. They must be placed vertically with help of additional transversal supports, if it is necessary.

The modular dimension is completed by pressing the joints together.

Figure 43.The mounting of the wall starts with pushing the flange of the Z-profile into the groove in the polystyrene block. The foot profiles are screwed onto the floor edge along the perimeter of the building. Thereby the position of the walls is defined. (Francesca Aime 2005)

Figure 44.The wall blocks with the attached profiles can now be placed into the foot profile and fixed with screws. (Francesca Aime 2005)

Figure 45.Attaching the profiles special flat head screws are used in order to be able to mount board cladding directly to the surface. (Francesca Aime 2005)

Figure 46.The elements of the wall can in this way be mounted in sequence at a very high speed. Temporary supports sideways are mounted to keep the wall in an exact vertical

position during tills the intermediate floor or roof is put on top. At the corners construction will be self supporting. (Francesca Aime 2005)

5.4. Conclusions

The Casa Bona System is an economical alternative compared to wooden or masonry structures. It has a faster build-up and from a building physics point of view offers many advantages:

- The thermal bridge in correspondence to the profile is effectively broken by the perforations on the central flange.
- The air tightness of the joint seems to be well provided for by the labyrinth around the embedded flanges through which the air has to pass.
- Moisture diffusion through the EPS is relatively limited and moisture convection is a function of the air tightness.

According to what written above, Casa Bona System is a good choice to reduce the usually high initial costs of a low-energy house. Excellent isolated properties and low construction time makes this procedure feasible to be used to save energy among other properties.

6. PROCESSES

Energy needs in supermarkets are divided into different processes. These main processes are Refrigeration, HVAC and lighting between others. To study them it is necessary to take into account the relations between all processes, due to the fact that all processes in supermarkets have influence in the others and therefore it is necessary to take into account these relations and the interaction between them. In the following conceptual scheme different subsystems and their connections are shown (Jaime Arias 2005).

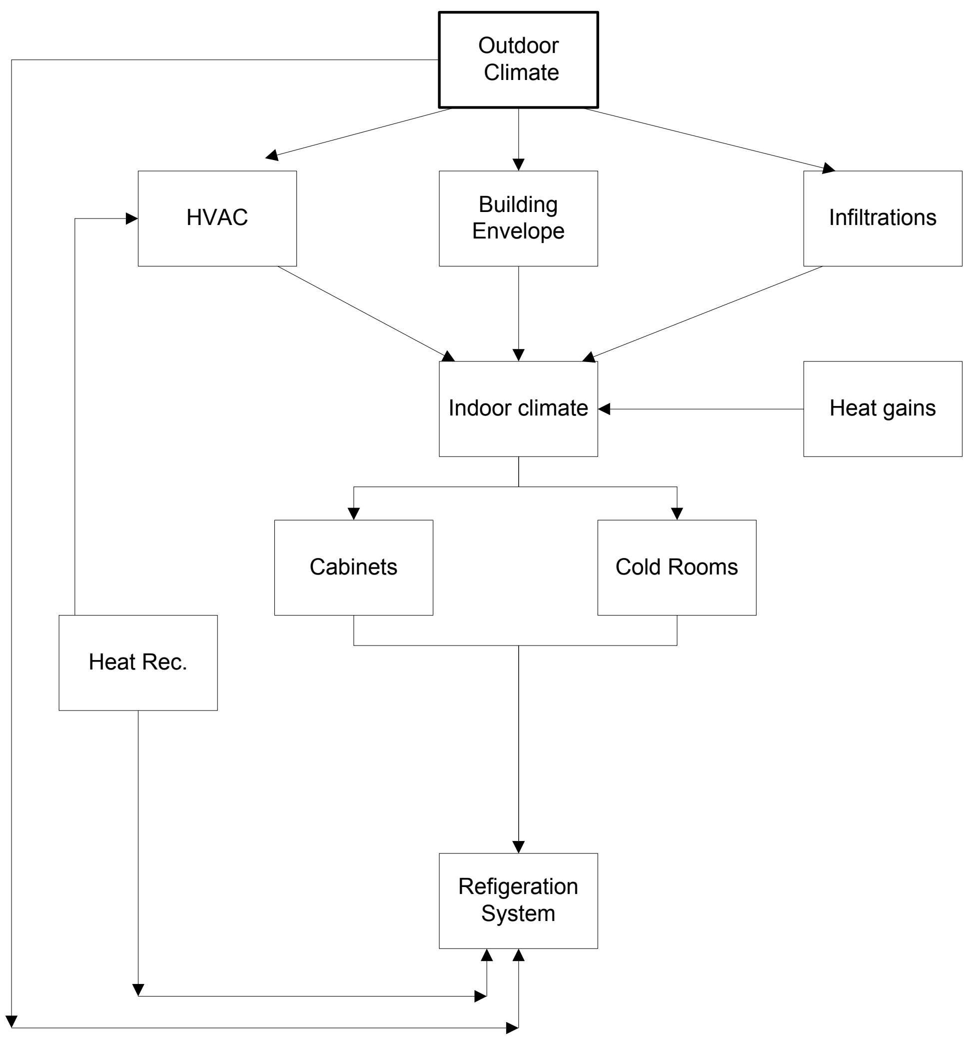


Figure 47: Supermarket Processes.

Outdoor climate and its properties (temperature, humidity, solar irradiation, wind speed) have great influence in the indoor climate and the performance of refrigeration.

6.1. Refrigeration

The purpose of refrigeration systems in supermarkets is to provide perishable food in display machines and its storage in walk in coolers. Perishable food can be divided into frozen food and chilled food. Besides, chilled food is also divided into different kinds of food and every kind needs different temperature storage. Then, in the supermarket there will be different display cases devices working in different temperature work range. Fruits, vegetables, meat and dairy products are the main subgroups of chilled food.

Chilled food is maintained between 1º and 14º, while frozen food is kept at -12ºC to -18ºC, but these values can vary depending on the country. Therefore evaporation temperature range for the first group is between -15ºC and 5ºC, and for frozen food the evaporation temperature range is -30ºC and -40ºC.

As an example the working temperature of every device is shown in the following table:

Cabinets	T(ºC) Minimum	T(ºC) Maximum
Meat	0	(+)2
Dairy products	(+)2	(+)4
Fruits, Vegetables	(+)5	(+)7
Sausage food	(-)1	(+)5

Table 6: Cabinets Temperature.

Walk in Coolers	T(ºC) Minimum	T(ºC) Maximum
Conservation	0	(+)5
Freezing	(-)25	(-)20

Table 7: Walk in Coolers Temperature.

Refrigeration System consists of basically of four components: a condenser, an evaporator, a compressor and an expansion device.

Usually in supermarkets, in order to improve the overall energetic performance, all these devices are assembled in a different way. The most commonly type is Centralised System:

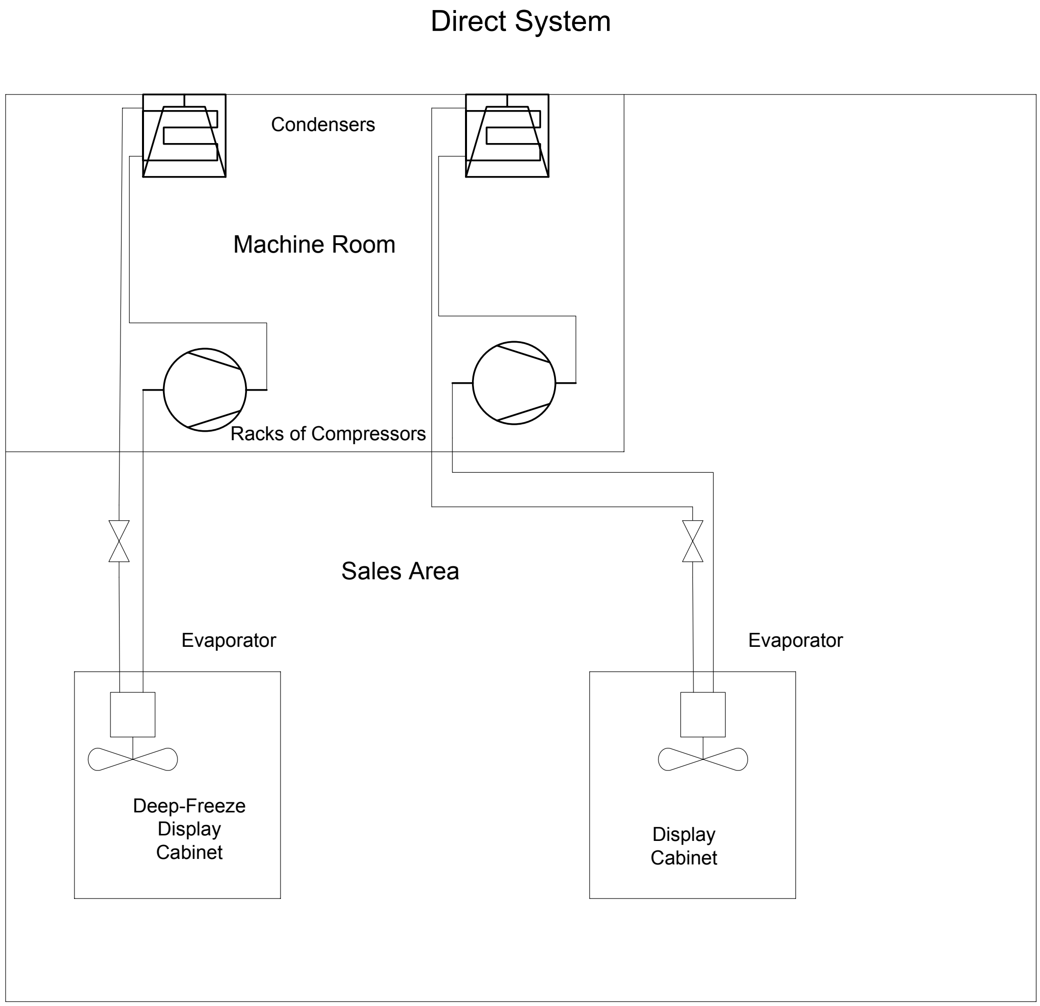


Figure 47: Direct System Refrigeration.

Condensers are installed on the roof or in a small machine room. These devices are small-size refrigeration equipment with one or two compressors.

Direct system, instead, consists of a central refrigeration unit located in a machine room. Racks of compressors are connected to the evaporators in the display cases and to the condensers on the roof by long pipes with refrigerant. The refrigerant circulates from the machine room to the display cases in the sales area where it evaporates and absorbs heat.

Cabinets needs a proper indoor condition in order to reduce cooling loses. The cold air providing the cabinets also affects to the heating and cooling needs.

6.2. HVAC

The main purposee of this system is to provide a comfort environment inside the building. In a supermarket HVAC system is affected by lighting, equipments, occupants, cabinets, ventilation requirements and outdoor climate.

In the study case this subsystem is going to be studied in the next chapters in order to find out which is the best way to approach the cold storage for HVAC system.

6.3. Lighting

Lighting represents in many times approximately 25% of energy needs in a supermarket. This value is relevant in a whole energy needs. For this reason lighting has been studied in a specific chapter in which simulations with Daysim simulations have been run and values of daylight analysis about daylight performance parameters have been obtained.

These are the main processes taken it account in the analysis systems. Other system and subsystems study has took it account with the study of main processes.

6.4. Heat Recovery System

Trying to improve performance in energy consumption, the supermarket under consideration has been provided with a Floating Condensing System as method of heat recovery. By this method, condensing temperature system changes with the ambient temperature and with lower outdoor temperature, condensing temperatures can float down properly. (Jaime Arias 2005).

This increases the coefficient performance, COP, and decreases the energy consumption of compressors. Note that the influence in COP parameter can be very important in the study approach the exergy need for supermarket needs.

6.5. CyberMart

Energy needs have been calculated with Cybermart software. Jaime Arias, member of Department of Energy Technology at the Royal Institute of Technology, developed this tool; a thorough explanation of the tool can be found in his Doctoral Thesis “Energy Usage in Supermarkets-Modelling and Field Measurements”.

In this software all processes that take place in a supermarket are linked, with the objective of obtaining a good model close to real supermarket consumption. All processes and interactions between them are explained in Jaime Arias Doctoral Thesis.

Input Data of this program are introduced in different windows. A real supermarket in Sweden similar to the studied supermarket has been taken as a model and only some parameters like climate and little differences have been changed.

The following steps are divided into different windows which provide user the possibility to introduce input data in an easy way and step by step. The windows are:

6.5.1. Main Program.

Here user decides which refrigeration system will use; Direct System, Completely Indirect System, Partially Indirect System, Cascade A, Cascade B, Parallel System with Subcooling, District Cooling or other.

6.5.2. Building

Requirements in this window are location, building and HVAC conditions.

- **Climatic Conditions**, to introduce Valencia's outdoor climate CyberMart use Meteonorm, which supplies climate data at any location in the hourly hours. Meteonorm uses the average values from the period 1961-1990 for different weather stations according to the World Meteorogical Institute (WMO).

- **Building envelope,** properties of walls, roof and ground. Sales area, building dimensions

- **Ventilation,** ventilation needs of building, infiltrations..

- **Heat sources,** lighting, equipments, service water, occupants.

- **Opening Hours,** define opening hours along the week.

- **Heating and Air conditioned**, Supermarket Temperature in summer, winter. Control temperature, heat recovery system.

6.5.3. Refrigeration system design

In this window properties of different refrigerator lines, low and medium temperature are described

- **Refrigerant**
- **Compressor**
- **Brine**
- **Cabinets, Deep Freeze Cabinets and Cold Stores properties**.

6.6. Results

The simulation has been done with the help of Jaime Arias. Results can be shown in month hours and days. First general results will be shown, while later results will be focused on the objective of the thesis. In other words, at the beginning the results are in electricity units, but as said before the main objective of this study is to obtain heat measures in order to study later a cold storage system and possible benefits in industrial buildings as supermarket under consideration.

Month	El. Fans. Vent kWh	El. Light kWh	El. Equip kWh	El. Comp kWh	El. Ref. Syst kWh	Total El. kWh	Total Heat kWh
1	7936	8210	7158	18516	25737	49041	7351
2	7168	7400	6456	16726	23322	44346	5529
3	7936	8190	7146	19016	26467	49744	4862
4	7680	7920	6912	18574	25916	48433	3521
5	7936	8210	7158	20463	28340	51662	2647
6	7680	7920	6912	20959	28838	51510	2167
7	7936	8190	7146	22583	30912	54692	2235
8	7936	8210	7158	22875	31223	55074	2245
9	7680	7900	6900	21042	28969	51702	2155
10	7936	8210	7158	20422	28325	51647	2620
11	7680	7940	6924	18398	25651	48196	4882
12	7936	8170	7134	18559	25819	49059	6870
Total	**93440**	**96470**	**84162**	**238133**	**329518**	**605105**	**47085**

Table 8: Results Supermarket needs.

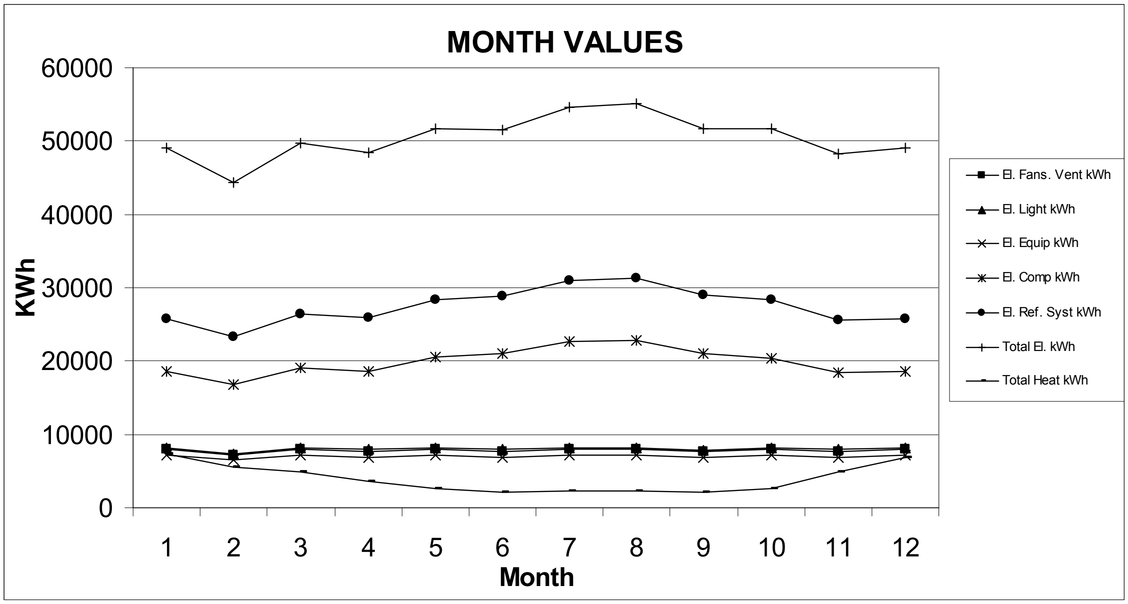


Figure 48: Results Supermarket needs.

As a conclusion of electricity consumption: the biggest consumption energy has been due to refrigeration system, and the most influence in this part has been because of compressor needs.

In similar range ha beens equipments consumption, fans and lighting system. In the equipment group cash machines, computers, ovens and other electrical devices have been considered.

Note that heat needs for indoor climate has been low in a first sight. The reason has been that Valencia has a warm climate, and then usually does not need heat energy for indoor climate. On the other hand, cool needs seemed also too low: in this case note that refrigeration systems have a great influence in indoor climate because cabinets emit a huge cold energy to the indoor environment. Then the big refrigeration consumption also helps to keep the indoor temperature between the comfort values in supermarkets.

In the Hourly Report of Results, CyberMart shows different parameters which have been combined in an Excel page in order to obtain some interesting values. In this way the following graph has been obtained combining these values.

Month	Heat Med (kWh)	Heat Low (kWh)	Heat building (kWh)	AC building (kWh)	Tot. Refrigeration (kWh)
1	28911	10352	5106	0	39263
2	26172	9345	3509	2	35517
3	29872	10572	2627	29	40444
4	29264	10289	1361	31	39553
5	32553	11213	402	103	43766
6	33834	11353	7	890	45187
7	36683	12133	0	2678	48815

8	37449	12376	0	2872	49825
9	33931	11360	5	1362	45291
10	32463	11213	374	99	43676
11	29797	10562	2812	3	40359
12	28126	10055	4546	0	38180

Table 9: Heat needs.

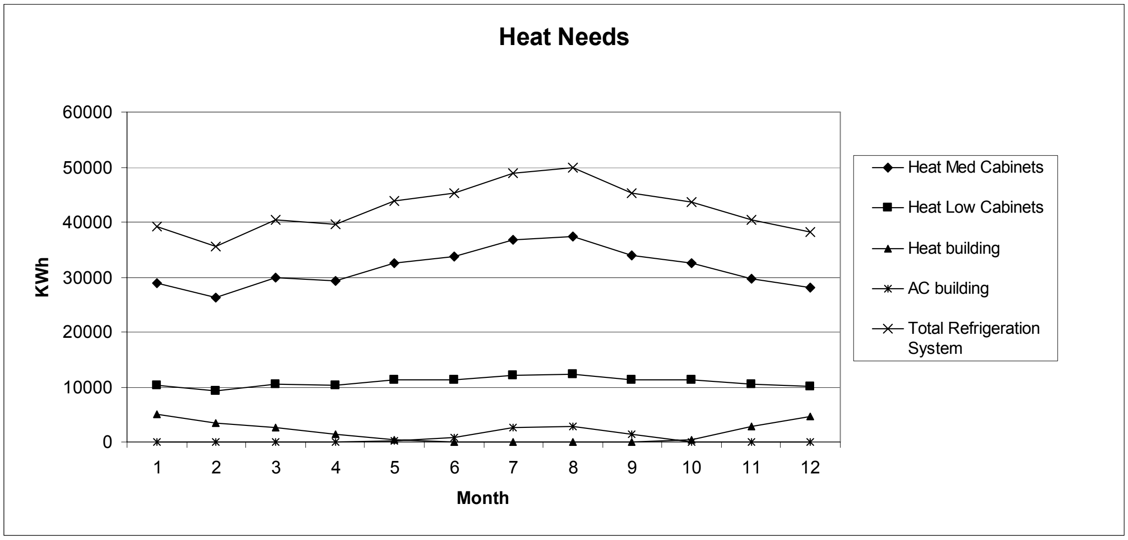


Figure 49: Heat needs.

An interesting figure is that COP of low temperature compressor line has been around 1,42 while COP of medium temperature compressor line is 2,58. (COP_{low}=1,42 ; COP_{medium}=2,58). Also note the temperatures in devices of refrigeration low and medium temperatures systems.

Device	T (ºC)
Condenser Temperature Medium	37
Evaporator Temperature Medium	-13
Condenser Temperature Low	36
Evaporator Temperature Low	-35

Table10: Temperature devices.

It has been necessary to separate Electricity needs from Heat needs in order to study the system and possibilities of cold storage: in the following, the electrical needs for the supermarket will be study

The Daylight analysis has been applied to evaluate the electrical consumption of light that is possible to save. In the correspondent chapter of Daylight analysis, the conclusion has that it is possible to save about 60% of light consumption in the worst case. This value corresponds to Daylight Autonomy factor and will be applied in the results of CyberMart.

Month	Light (kWh)	Equipment (kWh)	Others (kWh)	Tot. Elect.(kWh)
1	3282	7152	7925	18359
2	2960	6456	7168	16584
3	3276	7146	7941	18363
4	3168	6912	7686	17766
5	3284	7158	7954	18396
6	3168	6912	7840	17920
7	3276	7146	8444	18866
8	3284	7158	8483	18925
9	3160	6900	7933	17993
10	3284	7158	7954	18396
11	3276	7146	7936	18358
12	3168	6912	7680	17760

Table 11: Electricity Needs.

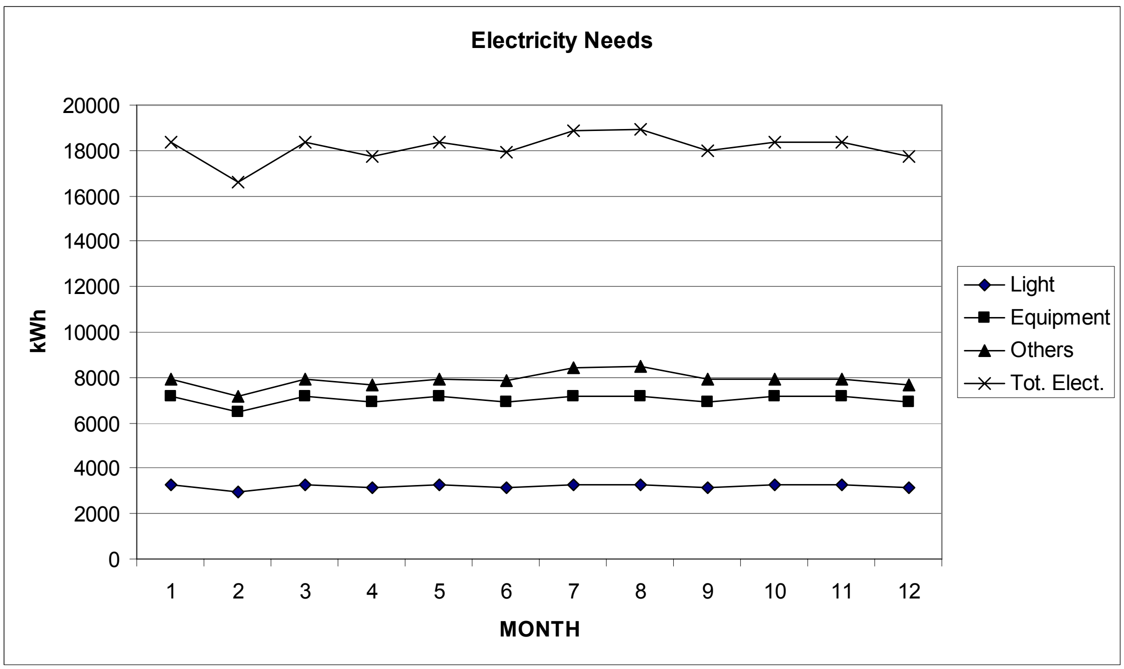


Figure 50: Electricity needs.

“Others” group have been calculated as total electricity value minus the consumption of compressors for refrigeration and minus Light consumption and minus Equipment consumption.

Then, in this group, electricity needs of cabinets as fans and lights, total fans of climate system consumption, defrosting system and condenser fans that are placed on the roof are included.

As a conclusion total needs of electricity and heat are shown in the following graph:

Month	Tot. Elect. (kWh)	Tot. Heating and Cooling (kWh)
1	18359	44369
2	16584	39027
3	18363	43100
4	17766	40945
5	18396	44271
6	17920	46085
7	18866	51493
8	18925	52697
9	17993	46658
10	18396	44149
11	18358	43174
12	17760	42726

Table 12: Total Needs.

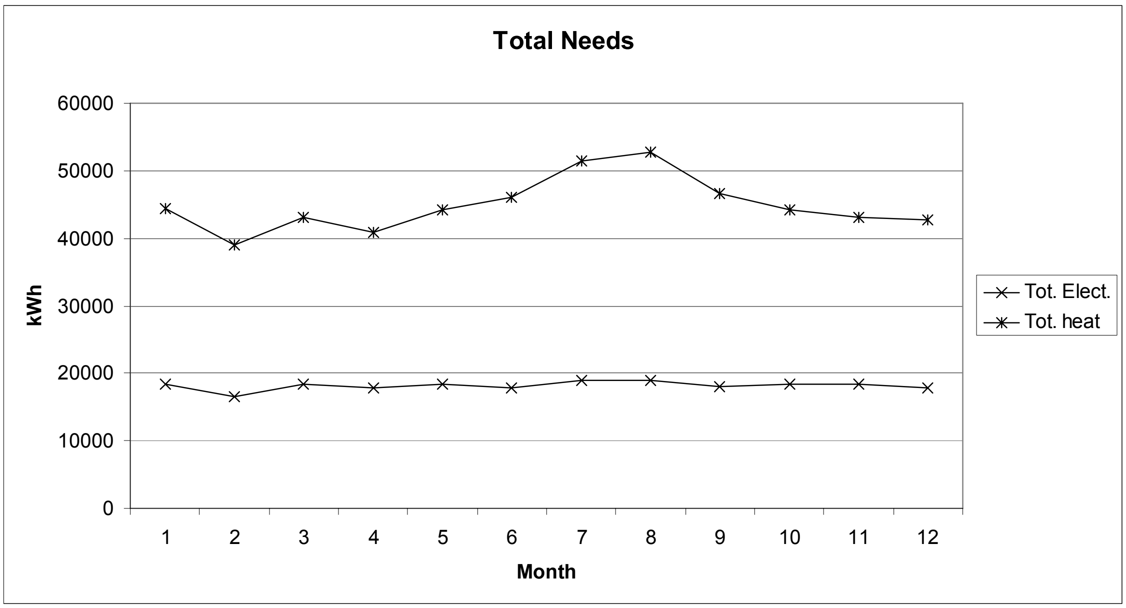


Figure 51: Total Needs.

7. ENERGY-EXERGY NEEDS

7.1. Introduction

The supermarket has been studied with CyberMart software, but once these results have been obtained, it can be observed that this program focuses on energy needs in devices and that it is impossible to introduce and study the effect that windows could have on indoor climate behaviour. Anyway it has been possible to study these influences with Consolis Energy +.

Note that the following results are an approximation, because many processes that are present in supermarkets are not taken into account in Consolis, so that an approximation is necessary.

These comments will be shown in comparison between results obtained with Consolis and with CyberMart, in relation to climate needs. Consolis graph has been obtained in chapter 3 "Daylight Calculations", when it has been studied the influence of windows in the indoor climate.

These results are shown in the following graphic.

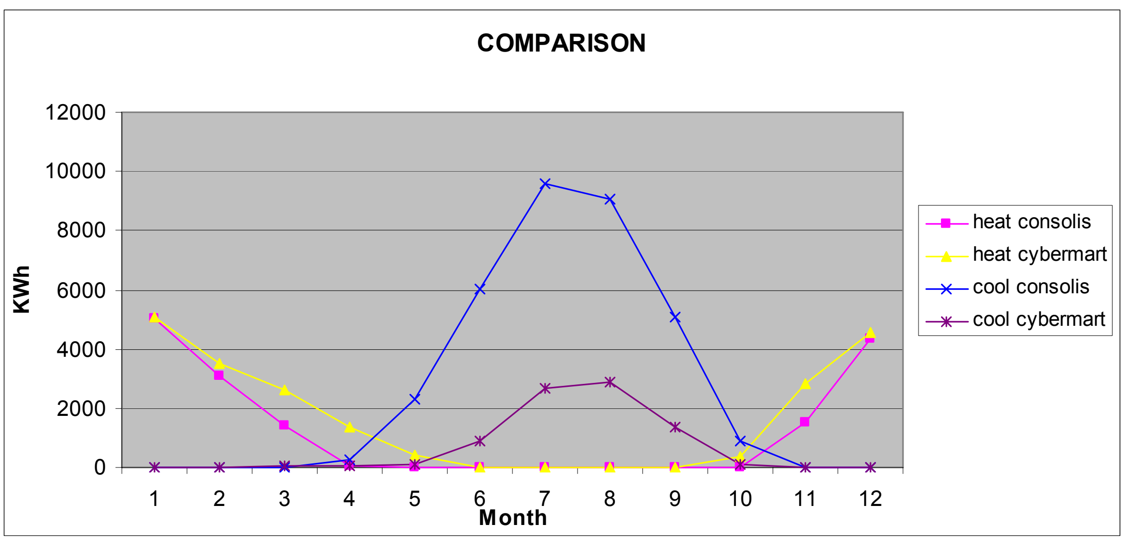


Figure 52: Comparison software results.

The cooling needs in Consolis are higher than in Cybermart, but it is necessary to understand how CyberMart works. This software takes into account all processes that take place in a supermarket: in others words, the main needs in supermarkets are used to refrigerate the low and medium temperature cabinets, when there are no panels or similar devices that shields the cabinets cooling losses, so that a lot of cold energy reaches the ambient and helps HVAC system to cool the ambient.

7.2. Energy needs

It has been necessary to modify Consolis Energy +, software in which it is possible to make changes. The model has been completed with windows properties and the influence of refrigeration system.

The way has been to change the parameter "Mean effect of internal head load", that is the internal heat gain consisting of heat that is emitted from domestic appliances, lighting, humans etc. The average heat gain has been assumed constant over the year and a recommended value for dwellings of 5 W per square meter of floor area has been given.

In the before mentioned Doctoral Thesis ofJaime Arias "Energy Usage in Supermarkets-Modelling and Field Measurements" is explained the methodology by which the influence of cabinets and its influence with the ambient have been taken into account to be run in CyberMart, making it possible to model the behaviour and apply in Consolis + Energy.

Energy balances of open vertical cabinets are divided into losses from infiltration, radiation, conduction, lighting, the fan, heating wires and defrost and their values are:

$Q_{wal}l= 7\%$
$Q_{infiltration}= 64\%$
$Q_{radiation}=11\%$
$Q_{lighting}=11\%$
$Q_{fan}=5\%$
$Q_{heating\ wires}=2\%$

Besides, these values have a proportional relation with indoor temperature, due to the effect of indoor temperature on refrigeration load in vertical display cases; this effect is 100% when indoor temperature is 25ºC and then as approximation this effect is not taken into account.

However if it is taking into account the heat radiation of medium temperature cabinets (that are the only one that are open: low temperature cabinets are usually closed), a medium value of medium refrigeration has to be obtained as sum all months divided in the twelve months.

Month	Heat Med (kWh)
1	28911
2	26172
3	29872
4	29264

5	32553
6	33834
7	36683
8	37449
9	33931
10	32463
11	29797
12	28126
sum	379054
Medium value (month)	31587,84

Table 13: Heat needs values.

Internal heat load is given in W/m^2, so that it is necessary to obtain the value in these units:

$$31587{,}84 kWh / month * \frac{1 month}{30 days * 24 h / 1 day} = 43{,}87 kW$$

The building has 1000 m^2 of area:

$$43{,}87 kW / 1000 m^2 = 43{,}87 W / m^2$$

Taking into account radiation losses:

$$43{,}87 W / m^2 * 0{,}11 = 4{,}4 W / m^2$$

Then, the modified original value of internal heat load 5 W/m^2 is 5-4,4=0,6 W/m^2.

As a conclusion a value of **0,6 W/m^2** of internal heat load has been used. The other input data has been kept with respect to the first estimations made in the Daylight chapter.

In the following graphs the differences that have been taken into consideration and how this has changed the results obtained by Consolis Energy+ are shown.
Part 1 is the first model and Part 2 is the model with heat load changed.

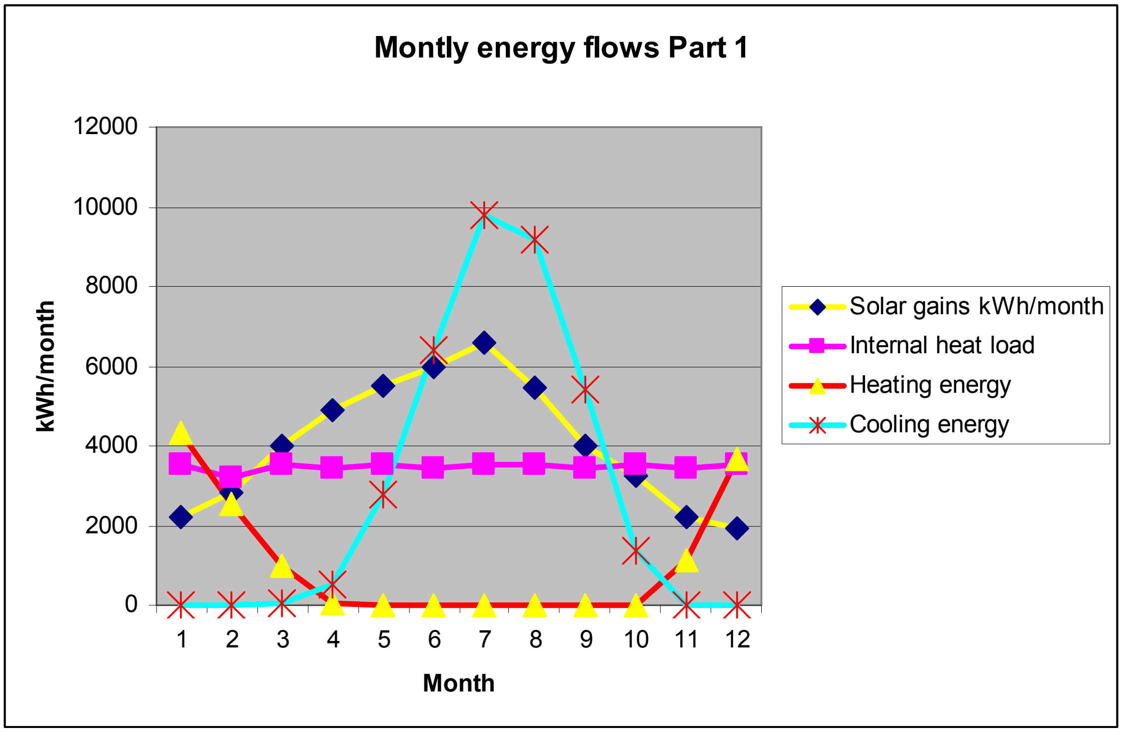


Figure 53: Energy Needs with Internal heat load=5 W/m^2.

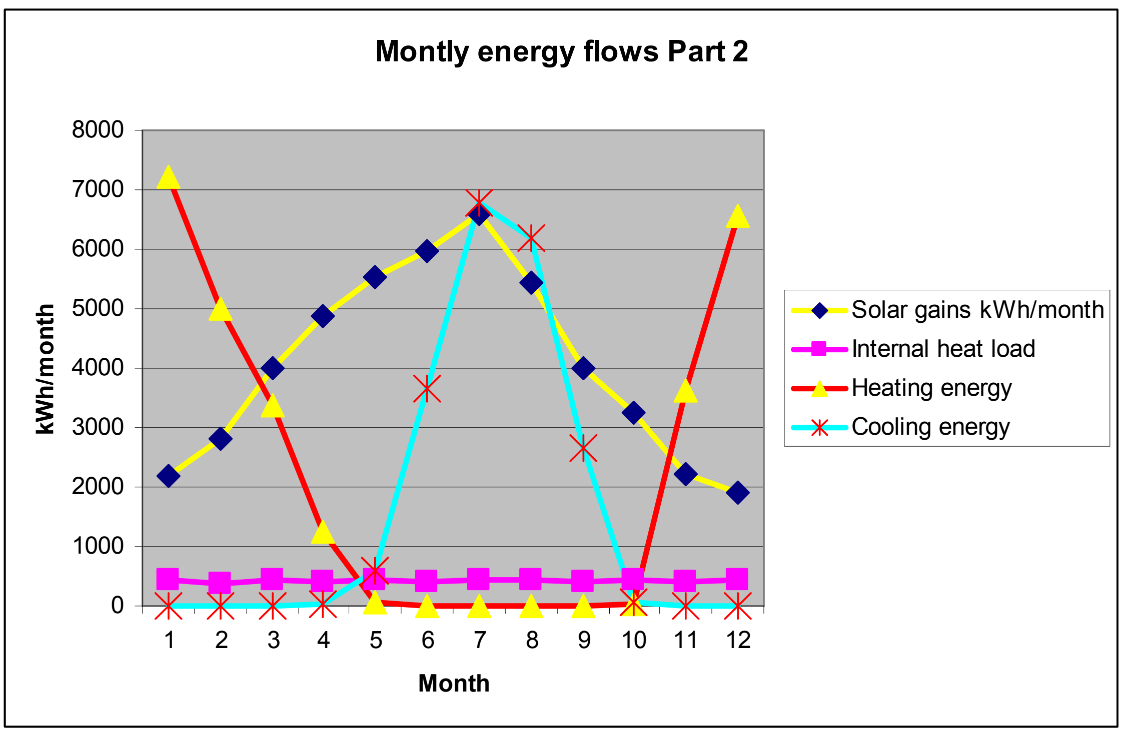


Figure 54: Energy Needs with Internal heat load=0.6W/m^2.

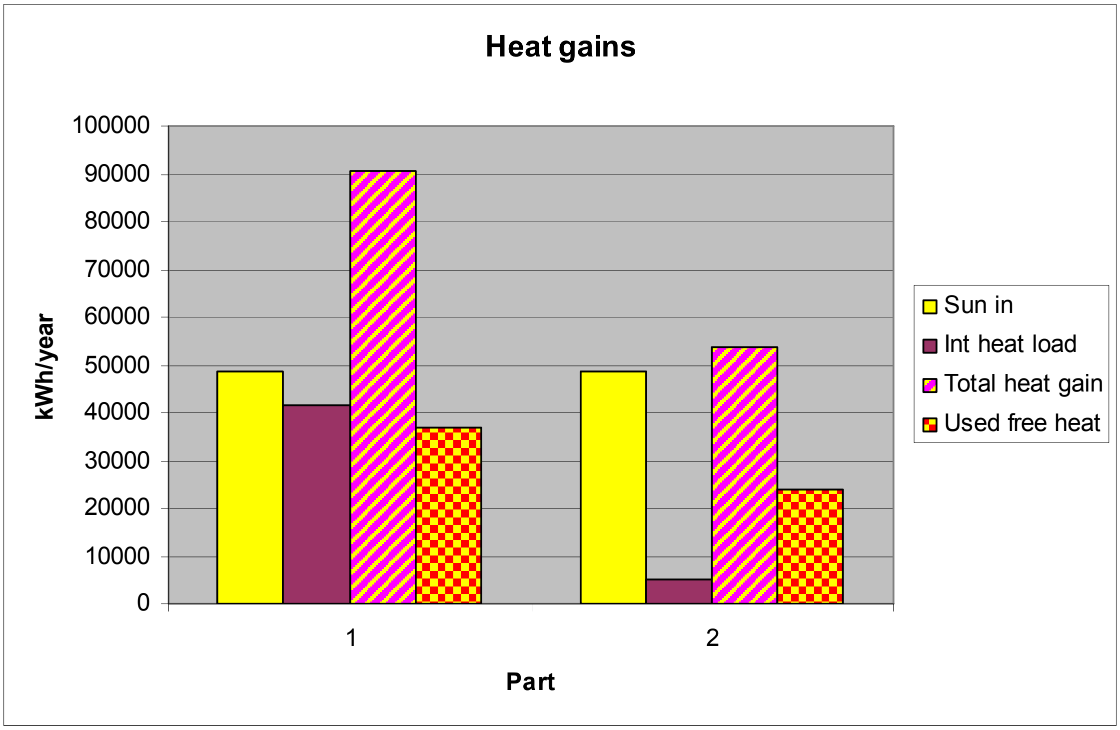


Figure 55: Heat gains comparison.

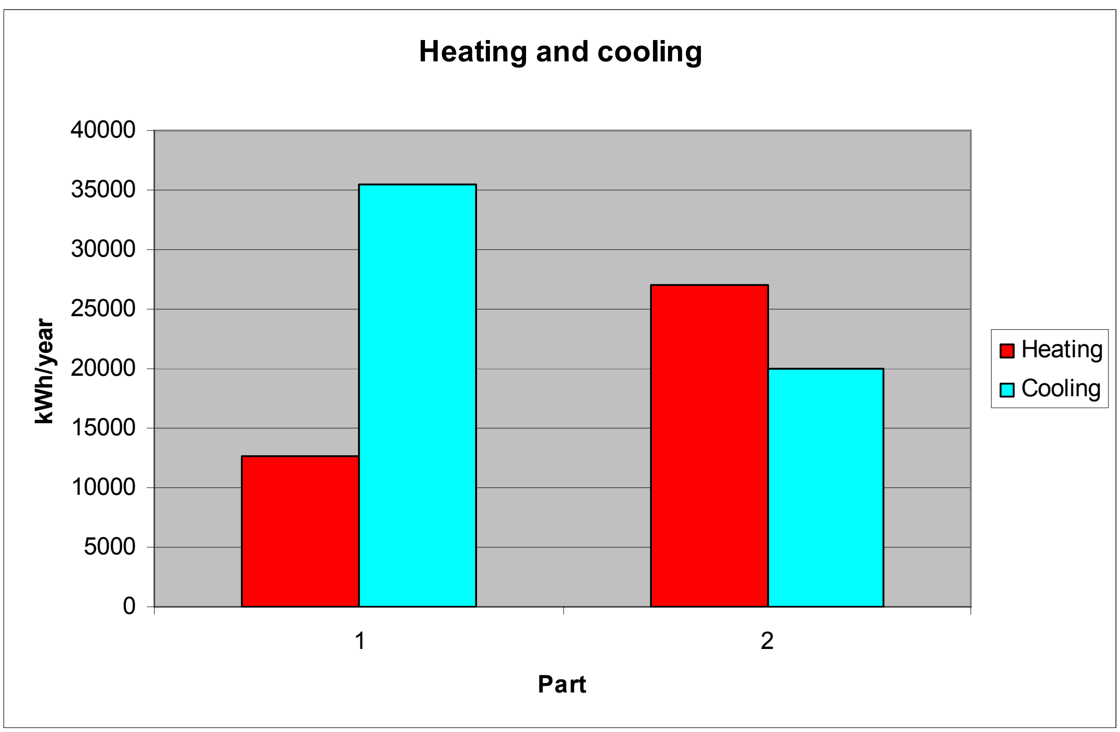


Figure 56: Energy Needs comparison.

Now there is less difference between climate results obtained by Consolis Energy + and CyberMart: the climate needs that have been obtained are the following:

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Average Ext. T	2190,2	2804,9	3988,8	4883,0	5524,3	5973,5	6606,7	5450,6	4005,1	3242,8	2229,0	1912,2	48811 kWh
Sun in	706,8	638,4	706,8	684,0	706,8	684,0	706,8	706,8	684,0	706,8	684,0	706,8	8322 kWh
Internal heat load	2897,0	3443,3	4695,6	5567,0	6231,1	6657,5	7313,5	6157,4	4689,1	3949,6	2913,0	2619,0	57133 kWh
Total heat gain	1,00	0,99	0,95	0,82	0,44	0,00	0,00	0,00	0,00	0,50	0,98	1,00	
Utilization factor	0,98	0,89	0,90	0,80	0,44	0,00	0,00	0,00	0,00	0,50	0,93	0,98	
Ut. Factor Dyn calc	2888,0	3393,3	4444,8	4538,9	2741,1	0,0	0,0	0,0	0,0	1962,1	2854,9	2610,9	25434 kWh
Used free heat	6890,0	4442,6	2916,8	1008,9	43,0	0,0	0,0	0,0	0,0	50,2	3227,9	6231,8	24811 kWh
Heat energy EN13790*	6945,0	4764,0	3136,6	1082,4	42,8	0,0	0,0	0,0	0,0	26,7	3376,5	6281,0	25655 kWh
Do dynamic method	0,0	0,0	0,0	0,0	0,0	3523,5	6930,8	6403,0	2585,2	0,0	0,0	0,0	19443 kWh
Cool energy ut f 1	0,0	0,0	0,0	53,4	769,1	3909,8	7047,8	6454,1	2890,7	107,3	0,0	0,0	21232 kWh
Do dynamic method	17105,2	15449,9	17105,2	16553,4	17105,2	16553,4	17105,2	17105,2	16553,4	17105,2	16553,4	17105,2	201400 kWh
El property household	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0
Hot water consumption	2190,2	2804,9	3988,8	4883,0	5524,3	5973,5	6606,7	5450,6	4005,1	3242,8	2229,0	1912,2	48811 kWh

Table 14: Results with "heat internal load"=0.6W/m^2.

Now there is less difference between climate results obtained by Consolis Energy + and CyberMart. The energy needs obtained are the following:

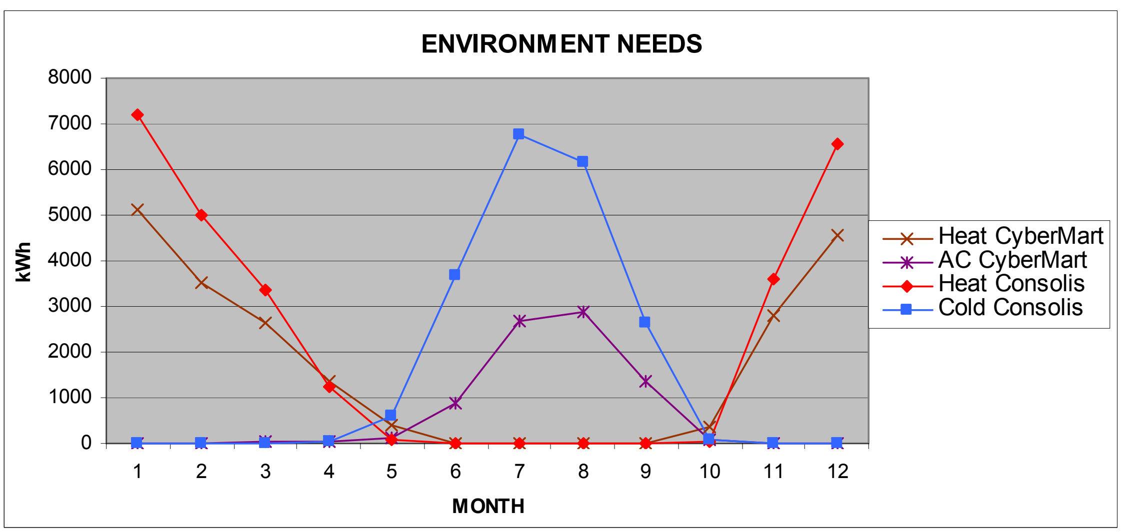


Figure 57: Energy Needs distribution.

Once that the climate needs results have been shown, a recompilation of all processes and their energy needs will be done.

7.2.1. Heat needs

Month	Heat Med (kWh)	Heat Low (kWh)	Heat building (kWh)	AC building (kWh)	Tot. Refrigeration (kWh)
1	28911	10352	7219,5	0	39263
2	26172	9345	4995,6	0	35517
3	29872	10572	3368	0	40444
4	29264	10289	1249,9	27,9	39553
5	32553	11213	61,2	590,7	43766
6	33834	11353	0	3665,4	45187
7	36683	12133	0	6773,8	48815
8	37449	12376	0	6178,2	49825
9	33931	11360	0	2645	45291
10	32463	11213	39,9	68,9	43676
11	29797	10562	3615,9	0	40359
12	28126	10055	6556,5	0	38180

Table 15: Energy needs.

7.2.2. Electricity needs

Month	Light (kWh)	Equipment (kWh)	Others (kWh)	Tot. Elect.(kWh)
1	3282	7152	7925	18359
2	2960	6456	7168	16584
3	3276	7146	7941	18363
4	3168	6912	7686	17766
5	3284	7158	7954	18396
6	3168	6912	7840	17920
7	3276	7146	8444	18866
8	3284	7158	8483	18925
9	3160	6900	7933	17993
10	3284	7158	7954	18396
11	3276	7146	7936	18358
12	3168	6912	7680	17760

Table 16: Electricity needs.

7.3. Exergy

7.3.1. Exergy concept.

Energy conservation concept alone is not able to explain completely the energy processes that take place in buildings. Exergy concept solves this problem, as it shows an understanding method to analyse the energy flows in buildings.
Exergy is based on a combination of the first and second law of the thermodynamics.

A good first explanation of exergy is given in Design of Low Exergy Buildings (Schmidt 2004) "In the theory of thermodynamics, the concept of exergy is stated to be the maximum work that can be obtained from an energy flow or a change of a system". Also exergy is used to compare the quality of energy sources and theirs profits.

Usually calculations of energy, including heating and cooling buildings are based on energy balances, in a clear reference to the first law of thermodynamics which states that the energy is conserved in every device and process and energy can neither be destroyed nor consumed (Moran and Shapiro 1998). Note that the first law has been used to understand a lot of science concepts and introduces terms like energy savings and energy consumption.

The second law of thermodynamics has a great influence in energy flow processes: in every process where energy or matter is dispersed, entropy is generated (Gertis 1995) and therefore there is a portion of energy that is lost in each process. This fact is possible to observe in ideal and non-ideal processes in which there is an increase of entropy as a result the increase in the irreversibility (Moran and Shapiro 1998). This portion of energy that is destroyed is called "exergy". This concept indicates to which extent a certain amount of energy is available to do mechanical work; exergy can also be regarded as the valuable part of energy (Schmidt 2004).

7.3.2. Exergy calculations.

For calculating the exergy needs in the supermarket is used the following formula:

$$Ex = Q\left(1 - \frac{T_0}{T_{source}}\right)$$

In which:

Q: is the heat required in the process
T_0: is the ambient temperature (often set to 15ºC)
T_{source}: is the temperature at which the heat is given.

The exergy units are the same as heat, and the temperature are expressed in Kelvin.

Then processes in the supermarket have been studied: to calculate the climate exergy needs, has been taken the temperatures inside supermarket as 21ºc during cold seasons and 25ºC during warm seasons as T_{source}, while taking the average temperature for each month for T_0 and the Q (heat needs) of each month.

With respect Refrigeration needs the method is the same, but taking T_{source} as evaporator temperature and $T_{0\ as}$ the average temperature of each month. The heat that is given to the system is the evaporator heat.

For the electricity needs it is possible to take the same values of energy as exergy, because electricity is pure exergy.

Month	Heat Med (kWh)	Heat Low (kWh)	T eva medium (ºC)	T eva Low (ºC)	To (ºC)	Ex medium T (kWh)	Ex low T (kWh)
1	28911,06	10352,25	-13	-35	11,50	2724,31	975,50
2	26171,51	9345,46	-13	-35	12,60	2576,89	920,17
3	29872,04	10571,86	-13	-35	13,90	3090,61	1093,78
4	29263,81	10288,82	-13	-35	15,50	3207,76	1127,81
5	32552,88	11212,66	-13	-35	18,40	3931,39	1354,14
6	33833,98	11353,29	-13	-35	22,10	4567,59	1532,69
7	36682,72	12132,66	-13	-35	24,90	5347,21	1768,57
8	37449,05	12375,56	-13	-35	25,50	5545,34	1832,53
9	33931,25	11359,85	-13	-35	23,10	4711,22	1577,27
10	32462,69	11212,97	-13	-35	19,10	4007,89	1384,37
11	29797,39	10561,57	-13	-35	14,90	3197,49	1133,34
12	28125,73	10054,70	-13	-35	12,40	2747,67	982,27
					Sum	45655,37	15682,45

Table 17: Refrigeration exergy needs.

Month	Heat (kWh)	Cold (kWh)	T_0 (ºC)	EX heat (kWh)	EX cold (kWh)
1	7219,50	0,00	21	2062,71	0,00
2	4995,60	0,00	21	1427,31	0,00
3	3368,00	0,00	21	962,29	0,00

4	1249,90	27,90	21	357,11	7,97
5	61,20	590,70	21	17,49	168,77
6	0,00	3665,40	25	0,00	1466,16
7	0,00	6773,80	25	0,00	2709,52
8	0,00	6178,20	25	0,00	2471,28
9	0,00	2645,00	25	0,00	1058,00
10	39,90	68,90	21	11,40	19,69
11	3615,90	0,00	21	1033,11	0,00
12	6556,50	0,00	21	1873,29	0,00
			Sum	7744,71	7901,39

Table 18: Climate exergy needs.

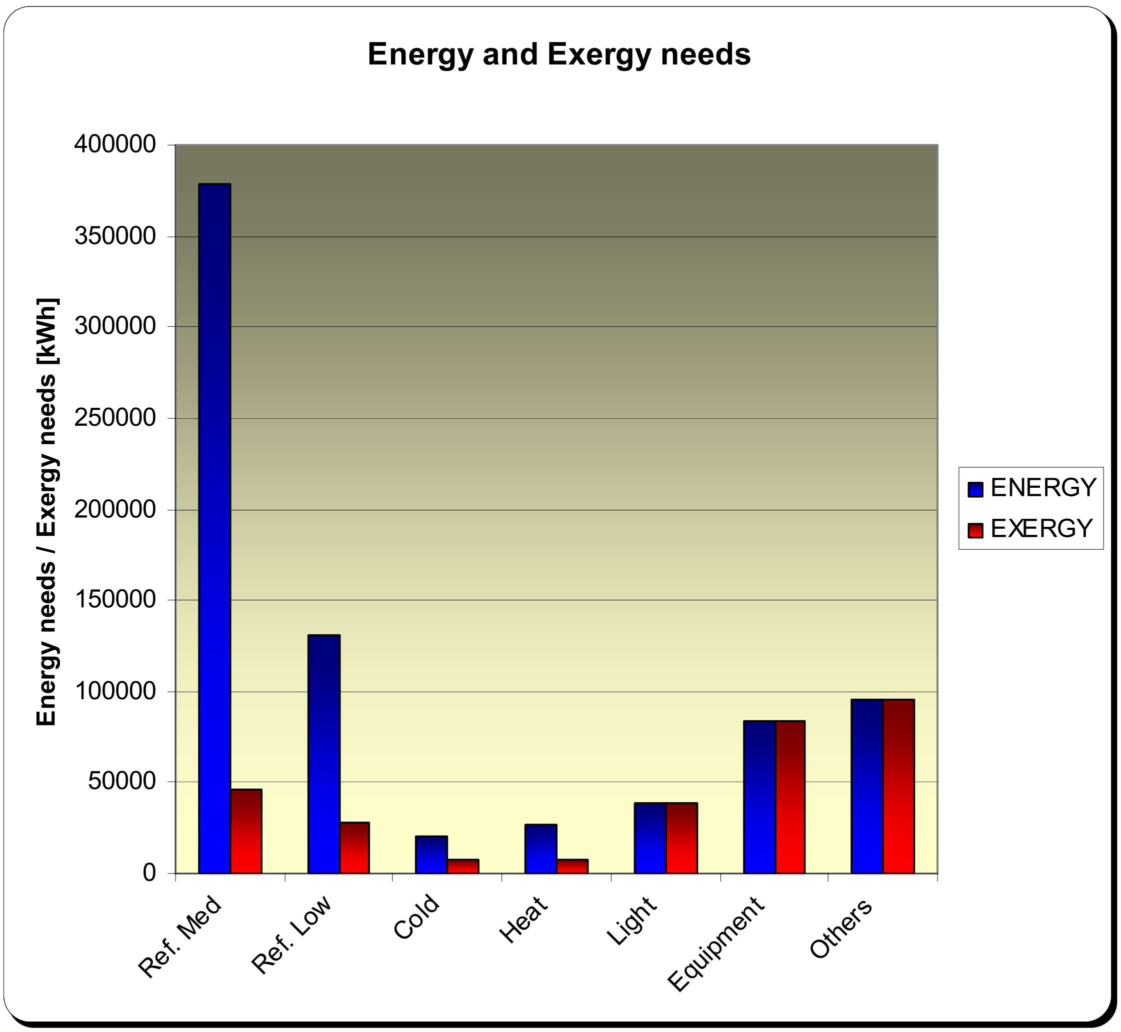


Figure 58: Exergy-Energy needs.

7.3.3. Conclusions.

The figure 58 shows the different exergy needs and its comparison with the energy consumption of the system. This comparison shows on the other hand the quality of the energy that is used in the supermarket.

Note that the most of energy consumption is used by medium refrigeration line, that is normal due to the fact in this line there are the most of cabinets that are placed in the supermarket. On the other hand the relation between energy-exergy that represents the Carnot factor is lower in the low temperature refrigeration.
This reason is in close relation with the COP, and it is explained because of the low temperatures, COP is lower when the system works with low temperatures. Then remembering the COP of both lines, the low temperature line had a COP_{low}=1,42 and medium had COP_{medium}=2,58.

The lighting needs have been reduced with a daylight analysis, but they still represent great consumption. As before said, the electrical needs have the same values of energy and exergy that means that electric energy source is valuable.

The conclusion of this analysis is that refrigeration system has a good potential for improving, as the relation between energy and exergy shows: therefore the study should be focused in this way, for trying to save the biggest among of energy.

8. COLD STORAGE CALCULATION

8.1. Introduction

A new method to save energy has been developed in this study. The main idea is to store cold energy under the ground for later use this cold to supply the supermarket energy/exergy needs.

Since the supermarket under consideration is situated in Valencia (Spain), the main needs are for cooling the ambient and supply freezers needs. As before said at the beginning of the study, supermarkets are very intensive energy/exergy consumers, and therefore a great amount of cold for freezers and cabinets is needed.

This project is following in Jorge Noguera's thesis wake, in which the studied a similar system with the aim of providing heat storage in houses in cold climates like Sweden.: in a symmetrical way, now the goal is to obtain a feasible study of cold collector and cold store in an industrial building.

8.2. System

The system is composed by pipes that begin on the roof, where the exterior air inlet is located, then the air is carried to the floor or a solar airborne, according to the system that is going to be chosen. Afterwards, a vertical pipe carries cold air to the ground, where there is long pipe spirally distributed in a horizontal plane, under an isolation layer and surrounded of a special of material, which makes it easy the heat transfer between cold air that circulates along pipes and the terrain.

The study is focused in how much energy/exergy is possible to save: several simulations with a program that will later be explained have been done.

An important data is exterior temperature: introduced hourly in the software.
The way to calculate hourly temperatures is to make some calculations, due to the fact that there is not an hourly data base of temperatures in meteorological data bases like meteorological institutes and it is also difficult to find in internet.

However in this project it has been necessary to use an hourly temperatures distribution to make some calculations: CyberMart uses Meteonorm program to calculate the hourly temperature distribution.

The approximation with Consolis Energy + is quite good, but it does not take into account the possible frost that takes place usually in Mediterranean climates. Thus

Meteonorm will be used the temperatures calculation; note that Meteonorm takes into account a database of 30 years.

But on the other hand, these temperatures could be estimated 3 degrees less due to the effect that wind has on temperature distribution.
Then if it is estimated as wind temperature, only a fan in the inlet part of pipe that is placed on the roof is needed: this collector system is very simple, and it is only necessary to vary work conditions of fan in order to obtain the necessary flow trough the pipe.

Also there is in the market a new generation of solar airborne collectors that faces the phenomenon of thermal inversion: with these kinds of collectors it is possible an estimated reduction in inlet air of 6ºC, but so far it does not seem a realistic solution for this system.

8.3. Program

The software that has been used to calculate the amount of exergy/energy that is feasible to save in the cold store has been developed by Alberto Lazzarotto in his Master Thesis, still not yet finished, under the supervision of Gudni Jóhannesson, professor in Building Technology at KTH.

The mentioned software studies the heat interaction between a liquid transferred along pipes in the ground: with this interaction is obtained the energy that is possible to store in the ground and later reuse.

The aim of this software is to create a model able to describe the thermal behaviour of the ground.

The program has been written for using in Comsol Script, which uses a similar language to Matlab, and is run in Comsol Multiphysics. There are three main sheets of input data:

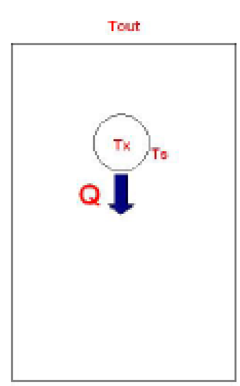


Figure 60: distribution of pipe and ground

Figure 60 shows the area under consideration, in a spiral distribution: the distance between the centre of pipes is the distance estimated not to have heat interaction between the two areas over study.

8.3.1. Input Data

There are three main sheets of input data:

- Definition of parameter data:

  In this sheet is introduced on one hand the outside temperature of considered climate and temperature inside the supermarket. Note that the first one contains a huge amount of data, due to be an hourly distribution along the year. The latter is easy to simulate because it is estimated in 21ºC during cold months and 25ºC during warm months. On the other hand Cybermart has been used for the hourly distribution inside the supermarket, with the purpose to obtain more real results.

  Physical parameters are introduced, length of the pipe, density of the fluid in the pipe, heat transfer coefficient, velocity of the fluid in the pipe, diameter of the pipe (L, r_{h0}, C_p, u, d)

  - L = 80 m
  - r_{h0} = 1.2 kg/m^3
  - cp = 1000 J/kg.ºC
  - u = 1 m/s
  - d = 0, 4 m.

- Geometrical parameters of the Analyzed Module:

  Instead of analysing the whole serpentine system the simulation is done only in a cross section of a single pipe. This is possible because at a certain distance from the pipe the temperature become constant and a boundary insulation condition (no heat transfer in that direction) can be set. We analyse the ground till 6 meter of depth. At this depth it is assumed that temperature is constant during the all year (the value is the average temperature of the year).

  - Thickness of insulation = 0.2 m
  - Depth of the ground = 6 m
  - Depth of the pipe = 2 m

- Diameter = 0.2

- Parameter for the system study:

  Density of the ground (r_{h01}), density of the insulation (r_{h02}), specific heat coefficient (c_p), ground thermal conductivity (λ_{ground}), insulation thermal conductivity ($\lambda_{insulation}$).

  - r_{h01} = 1800 kg/m^3 .
  - r_{h02} = 30. kg/m^3
  - cp = 1000. J/kg.ºC
  - λ_{ground} = -2.8 W/(m.K)
  - $\lambda_{insulation}$ =0.036 W/(m.K)

The aim is to store cold under the ground during cold season and use it during the warm season and for this purpose the velocity at the entrance of the pipe is controlled, varying the velocity according to the optimal flow. Then a reference temperature is set and when the outside temperature is higher, the velocity is zero not to introduce into the system air too warm: when with the temperature is below case 15ºC, the entrance of air is allowed.

This control of velocity is done during the year, but in summer month; May, June, July, August, September, the pipes are always open to allow the air becomes colder than in the entrance, obtaining the cold stored in the ground during the cold seasons.

8.3.2. Results

For the simulations, the following results are obtained:

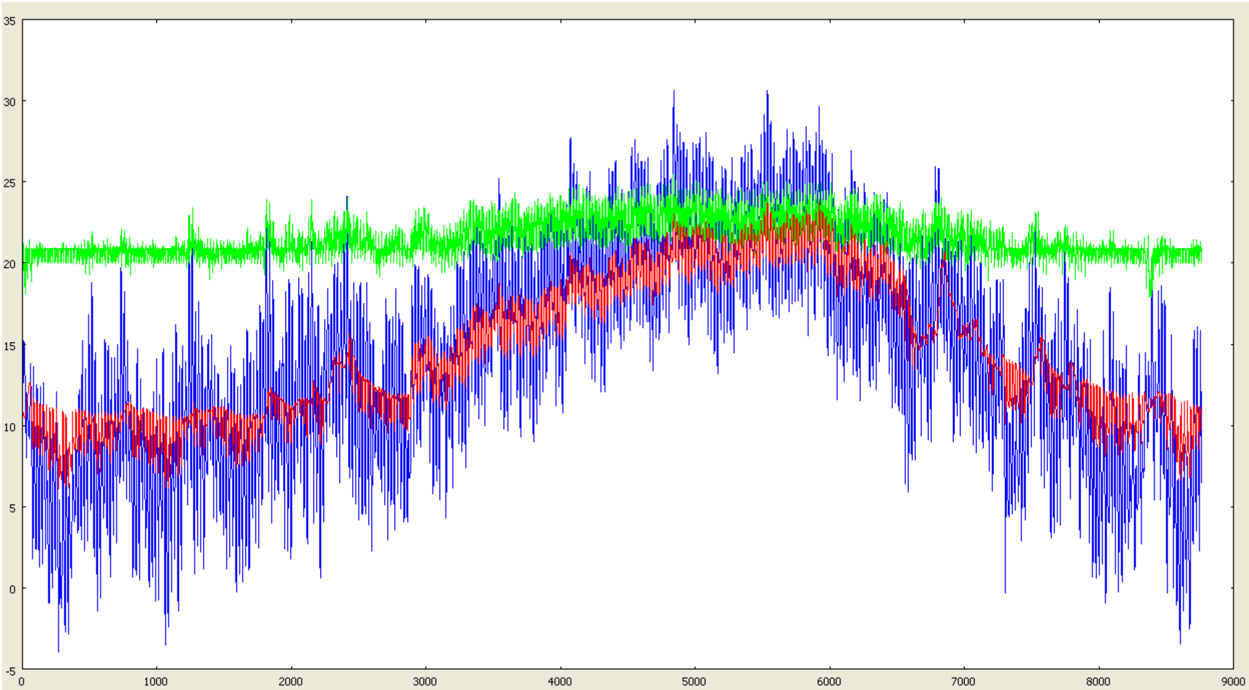


Figure 61: Temperatures distribution

The figure shows the different temperature distributions, in the Y-axis is located the temperatures and in the X-axis the hours along the year. The green curve represents the inside supermarket temperature, the blue one the outside temperature minus three degrees due to the wind effect, and the red one the temperature obtained with the system at the end of the pipe.

Zooming in the curve, the differences between the different curves can be appreciated:

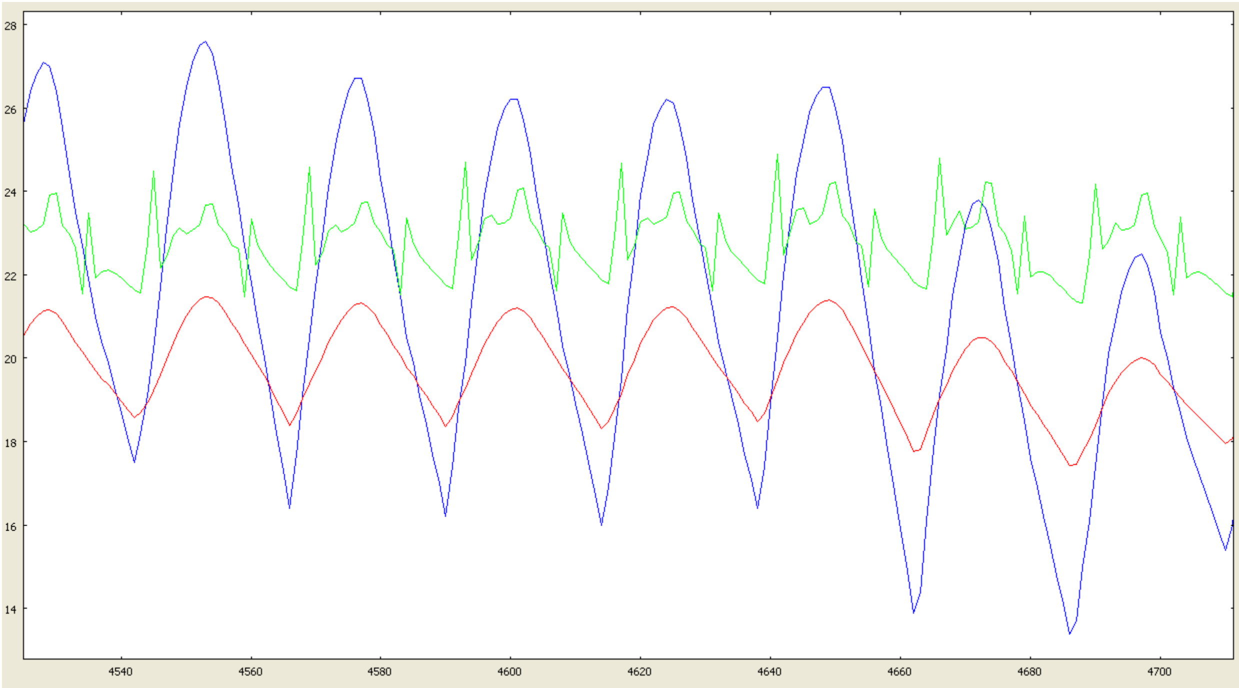


Figure 62: Zoom in Temperatures distribution

The conclusions of these simulations are that it is possible to reduce the outside temperature for warm season in 4 degrees with respect to the temperature that get in the pipe, when the difference between the outside temperature is more or less 7ºC.
Two simulations have been done, varying only the pipe lenght, one with 60m of length and the other one with 80m of length. These results have been obtained as the average of the difference with temperature at the beginning of the pipe and the temperature at the end of the pipe during the warm seasons.

Pipe Longitude (m)	ΔT (ºC)
60	7,2
80	7,4

Table 19: Temperature reduction.

It is then necessary to study the possible benefits of these results. In a first view and looking at the energy-exergy needs in the supermarket, the best way to approach this reduction in the temperature could be getting down the temperature in the condensers of the refrigeration lines, which had the worst energy approach (relation energy-exergy). This will be better explained in the next chapter.

9. SYSTEM IMPROVEMENTS

9.1. Introduction to Heat Pumps

The heat delivered by a heat pump is theoretically the sum of the heat extracted from the heat source and the energy needed to drive the cycle. The steady-state performance of an electric compression heat pump at a given set of temperature conditions is referred to as the coefficient of performance (COP). It is defined as the ratio of heat delivered by the heat pump and the electricity supplied to the compressor.

Figure 63 shows the COP for an ideal heat pump as a function of temperature lifts, when the temperature of the heat source is 0°C. Also shown is the range of actual COPs for various types and sizes of real heat pumps at different temperature lifts. The figure shows also an increase in the COP with a reduction in the condensation temperature. (www.heatpumps.org)

The ratio of the actual COP of a heat pump and the ideal COP is the efficiency: it varies from 0.3 to 0.5 for small electric heat pumps and 0.5 to 0.7 for large, very efficient electric heat pump systems.

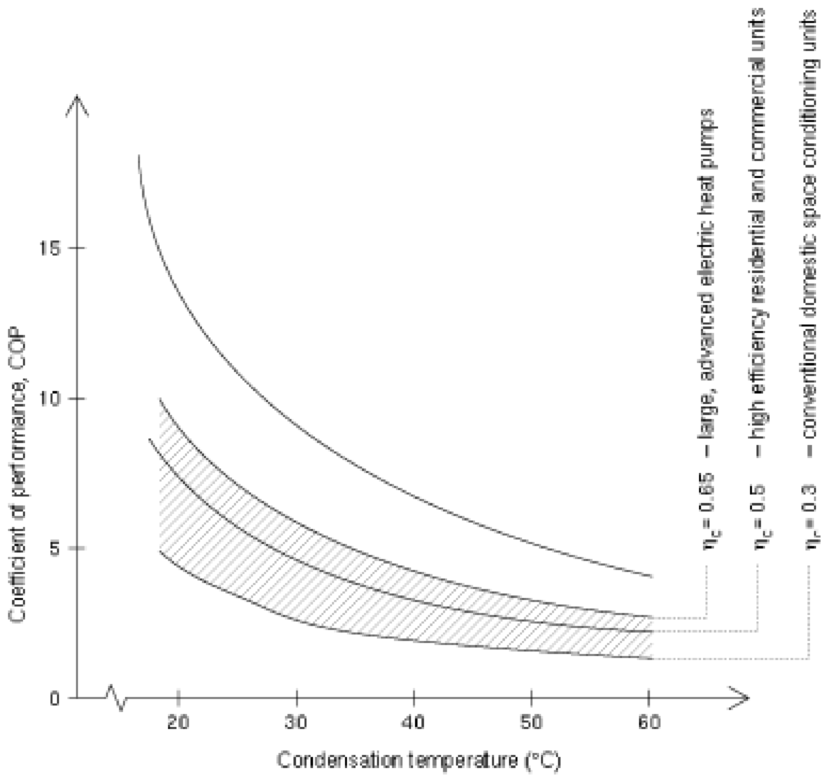


Figure 63: Relation COP-Condensation temperature

The idea is to use the cold system for cooling the air that is used by the condenser, and in this way to improve the COP of the low and medium refrigeration temperature system and reduce energy use in the compressor during the warm seasons.

9.2. Method

The method to evaluate the possible improvement of COP is:

- Calculate the COP over work conditions

$$COP = \frac{Q_{evaporator}}{W}$$

- Calculate ideal COP with temperatures:

$$COP_{ideal} = \frac{T_{evaporator}}{T_{condenser} - T_{evaporator}}$$

- Calculate the total performance of the compressor:

$$\eta = \frac{COP}{COP_{ideal}}$$

- Calculate the new COP ideal with a reduction of temperature in the condenser:

$$COP'_{ideal} = \frac{T_{evaporator}}{T'_{condenser} - T_{evaporator}}$$

- Obtain the new COP:

$$COP' = \eta . COP'_{ideal}$$

- Obtain the work necessary with the new COP

$$W' = COP'.Q_{evaporator}$$

Note that this methodology is an approximation of a real case, due to the fact that the reduction in the outside temperature could be considered as temperature reduction in the condenser. Condensers have a heat transfer with the ambient trough the refrigerant with the exterior air, the performance of heat transfers can be high, but for this case is considered close to the unity. This consideration is because of the impossibility to obtain the refrigerant flows trough the low and medium temperature system pipes.

On the other hand it has been taken into account the air flow that is necessary to extract the condenser heat, that has been calculated with the next formula:

$$Q(J) = q(m^3/s).\rho_{air}(kg/m^3).Cp_{air}(J/kg.^{o}C).\Delta T(^{o}C)$$

Then, is possible to get the flow of medium temperature line condenser and low temperature line condenser, as it is shown in the following table.

Month	Heat.Cond.Med (kWh)	Heat.Cond.Low (kWh)	T cond med (ºC)	T cond low (ºC)	Dif T(ºC) Med	Dif T(ºC) low	q med (m3/s)	q low (m3/s)	Q (m3/s)
1	40123,14	17942,72	37,00	36,00	25,50	24,50	0,0157	0,0073	
2	36321,20	16198,13	37,00	36,00	24,40	23,40	0,0149	0,0069	
3	41456,72	18311,41	37,00	36,00	23,10	22,10	0,0179	0,0083	
4	40612,69	17816,90	37,00	36,00	21,50	20,50	0,0189	0,0087	
5	45127,23	19381,45	37,00	36,00	18,60	17,60	0,0242	0,0110	0,0352
6	46498,77	19610,21	37,00	36,00	14,90	13,90	0,0311	0,0141	0,0452
7	49342,88	21073,24	37,00	36,00	12,10	11,10	0,0407	0,0189	0,0596
8	49719,55	21494,85	37,00	36,00	11,50	10,50	0,0431	0,0204	0,0636
9	46464,99	19667,01	37,00	36,00	13,90	12,90	0,0334	0,0152	0,0486
10	44968,41	19384,96	37,00	36,00	17,90	16,90	0,0251	0,0114	
11	41352,97	18293,45	37,00	36,00	22,10	21,10	0,0187	0,0087	

12	39033,11	17424,38	37,00	36,00	24,60	23,60	0,0158	0,0074	

Table 19: Air flow needs.

Therefore it is necessary a minimum flow of 0,064 m^3/s to exhaust the heat from the condenser on August. The simulation was run with a flow of 0,45 m^3/s because of the system does not work well with low air flows. Therefore there is enough flow to supply to condensers.

9.3. Results

The results are shown in the following tables:

9.3.1. Medium refrigeration temperature

Month	El.Comp.Med (kWh)	Ref.Cab.Med (kWh)	Heat.Cond.Med (kWh)	T med (ºC)	T cond med (ºC)	T evap med (ºC)
1	11192,46	28911,06	40123,14	11,50	37,00	-12,50
2	10131,85	26171,51	36321,20	12,60	37,00	-12,50
3	11564,41	29872,04	41456,72	13,90	37,00	-12,50
4	11329,04	29263,81	40612,69	15,50	37,00	-12,50
5	12589,98	32552,88	45127,23	18,40	37,00	-12,50
6	12992,17	33833,98	46498,77	22,10	37,00	-12,50
7	13950,18	36682,72	49342,88	24,90	37,00	-12,50
8	14066,71	37449,05	49719,55	25,50	37,00	-12,50
9	13031,94	33931,25	46464,99	23,10	37,00	-12,50
10	12549,50	32462,69	44968,41	19,10	37,00	-12,50
11	11535,56	29797,39	41352,97	14,90	37,00	-12,50
12	10888,39	28125,73	39033,11	12,40	37,00	-12,50

Table 20: Medium Temperature Refrigeration.

In table 20 is shown the characteristics of medium refrigeration temperature, the power that is needed in the compressor, the needs in the cabinets, the heat that is exchanged by the condenser,the average temperature in Valencia and the temperatures in the condenser and evaporator.

Following the methodology explained before the columns of table 21 are; COP real is the actual COP, COP_{teo} is the theoretical COP, η the relation between both is the efficiency of the system. COP'real is the COP performance with the improvements in the system,by the temperature decrease.
With the COP'real and the heat needs in the condenser it is possible to obtain W' that is the necessary compressor power taking into consideration the improvements; the next two columns show the compressor needs reduction and the percentage of total compressor needs that is saved.

Month	COP real	COP Teo	COP' teo	η	COP' real	W' (kWh)	Dif W (kWh)	ΔW(%)
1	2,583	5,263	5,854	0,491	3,009	9609,688		
2	2,583	5,263	5,854	0,491	3,009	8699,094		
3	2,583	5,263	5,854	0,491	3,009	9929,106		
4	2,583	5,263	5,854	0,491	3,009	9726,938		
5	2,586	5,263	5,854	0,491	3,011	10820,185	1769,795	7,114
6	2,604	5,263	5,854	0,495	3,033	11246,007	1746,163	7,440
7	2,630	5,263	5,854	0,500	3,063	12192,894	1757,286	7,938
8	2,662	5,263	5,854	0,506	3,101	12447,613	1619,097	8,688
9	2,604	5,263	5,854	0,495	3,033	11278,339	1753,601	7,432
10	2,587	5,263	5,854	0,492	3,013	10790,207		
11	2,583	5,263	5,854	0,491	3,009	9904,293		
12	2,583	5,263	5,854	0,491	3,009	9348,654		

Table 21: Medium Temperature Results.

It is then feasible to save around the 7 until 8,78% of compressors needs in the medium refrigeration line, with a possible save around 1800 kWh during the warm months.

9.3.2. Low refrigeration temperature.

Table 22 is similar to table 21: this shows the characteristics of low refrigeration temperature system and the meaning of each column is the same as medium temperature system that has been explained before.

Month	El.Comp.Low (kWh)	Ref.Cab.Low (kWh)	Heat.Cond.Low (kWh)	Tmed (ºC)	T cond low (ºC)	T evap low (ºC)
1	7303,22	10352,25	17942,72	11,50	36,00	-35,60
2	6593,58	9345,46	16198,13	12,60	36,00	-35,60
3	7449,38	10571,86	18311,41	13,90	36,00	-35,60
4	7246,92	10288,82	17816,90	15,50	36,00	-35,60
5	7871,97	11212,66	19381,45	18,40	36,00	-35,60
6	7964,36	11353,29	19610,21	22,10	36,00	-35,60
7	8633,29	12132,66	21073,24	24,90	36,00	-35,60
8	8808,18	12375,56	21494,85	25,50	36,00	-35,60
9	8012,36	11359,85	19667,01	23,10	36,00	-35,60
10	7875,14	11212,97	19384,96	19,10	36,00	-35,60
11	7442,10	10561,57	18293,45	14,90	36,00	-35,60
12	7091,69	10054,70	17424,38	12,40	36,00	-35,60

Table 22: Low Temperature Refrigeration.

The same procedure of medium temperature refrigeration has been done for low temperature refrigeration.

Month	COP real	COP Teo	COP' teo	η	COP' real	W' (kWh)	Dif W (kWh)	ΔW(%)
1	1,417	3,316	3,565	0,428	1,571	6589,218		
2	1,417	3,316	3,565	0,427	1,571	5948,956		
3	1,419	3,316	3,565	0,428	1,573	6721,089		
4	1,420	3,316	3,565	0,428	1,574	6538,422		
5	1,424	3,316	3,565	0,430	1,579	7102,364	769,606	10,349
6	1,426	3,316	3,565	0,430	1,580	7185,721	778,639	11,088
7	1,405	3,316	3,565	0,424	1,558	7789,253	844,037	10,436
8	1,405	3,316	3,565	0,424	1,557	7947,045	861,135	9,304
9	1,418	3,316	3,565	0,428	1,571	7229,029	783,331	10,053
10	1,424	3,316	3,565	0,429	1,578	7105,224		
11	1,419	3,316	3,565	0,428	1,573	6714,520		
12	1,418	3,316	3,565	0,428	1,571	6398,368		

Table 23: Low Temperature Results.

Then it is feasible to save from 9 to 11 % of compressors needs in the medium refrigeration line,i.e. around 800 kWh during the warmest months.

Note that there is better improvement in the low refrigeration temperature than in the medium: this is because the temperature difference between condenser temperature with evaporator temperature is bigger in Low temperature system.

10. CONCLUSIONS

As a conclusion all chapters can be grouped in two main groups; Building design and Exergy-Energy analysis.

1. Building Design:

Layout of a typical supermarket has been studied and developed with a practical experience. For this purpose a basic knowledge about supermarkets layout, visiting supermarkets and with the information of IEA annex 26 has been necessary: in the layout all the devices that are necessary in a normal supermarket have been taken into account.

The building has an extra insulation called Casa Bona system: the system uses EPS (expanded polystyrene of high density) as insulation material fixed by steel profiles with a Z shape (Z-profiles) .With this system it is possible to save cool, heat, and avoid problems derivated by moisture.

As the building is projected for Spain, the normative that has been necessary to accomplish has been the “Código Técnico de la Edificación”. Loads on the structure have been calculated by this normative. To obtain stresses and displacements in the structure SAP2000 has been used to verify all Ultimate States Limits (ULS) and Serviceability Limit State (SLS) in the obtained model.

The daylight analysis is made with DAYSIM software, making simulations with some possible windows distribution. Obtaining a model with enough Daylight Factor coefficient and getting approximately 60 % of daylight autonomy. Also in this chapter has been studied the influence of the windows in the indoor environment.

2. Energy-Exergy study:

To calculate the energy needs in supermarkets has been necessary to study the different processes that take place. The Doctoral Thesis of Jaime Arias is an excellent book where all processes and interactions between them are explained. The different processes in a medium size supermarket have been studied and calculated with CyberMart (Jaime Arias). Once the results have been obtained, they have been joined in Consolis Energy + with the purpose of taking into account the influences of different processes and also the windows effects, obtaining at the end an accurate result of energy consumption.

The way to improve the performance of processes has been with a cold storage, Alberto Lazzarotto has developed a software that studies the heat transfer between the liquids along the pipes in the floor called “An innovate ground storage” The objective of his study is to obtain a model of ground behaviour; in this case the objective has been to store cold in the ground during cold season and use it during the warm seasons. The energy-exergy analysis has shown that the most of the consumption is located in the low temperature refrigeration line and for this reason it has been tried to improve this process. Note that it has also been possible to use the storage for cool the ambient, but the influence of refrigeration in the indoor environment and its great energy needs had made that the improvements were focused in it. The improvements have been based on heat pumps theory and in concepts like COP performance and have been applied to the refigerations lines. The system has get a temperature fall of approximately 7ºC used to cold the air condenser supply and in this way to improve the COP performance. The result has been a save of compressor needs of 7-9% in medium temperature line and 9-11% in low temperature line during the warm season.

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