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The impact of building orientation on energy usage

Using simulation software IDA ICE 4.7.1

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Abstract

The building sector consumes 32% of global energy used, and it is responsible for 20% of total greenhouse gases emissions. In Europe, more than one third of the buildings are 50 years or older, thus, it is critical that new dwellings are designed in the most efficient way from an energy perspective, since the consequences of the decisions taken today will remain during decades.

The use of Building Information Modeling (BIM) software is promising for the design of a wide range of constructions; from small dwellings to big apartment buildings. These programs allow the architect, designer or civil consultant to perform several simulations of the energy behavior of a building in a timely manner, even before a single brick is put in place. Among them, IDA ICE software utilized in this thesis is a top rated program, situated by some authors within the four main building energy simulation tools. This is an outstanding fact considering that it is estimated in more than 400 the number of available BIM programs.

With the help of IDA ICE it will be demonstrated that for a dwelling object of study, located in Madrid (Spain), it is possible to save up to 4 250€ through the entire life of the building if the proper orientation is chosen. The discussed literature and results will also show that orientation is, by far, the most critical passive design parameter related to a building, from which the efficacy of other related measures depends on.

It will be also proven that the optimal orientation depends on the weather where the dwelling is located, even though a general trend consisting in orienting the houses located in the northern hemisphere to the south, and vice versa, is observed.

Building orientation, BIM programs, building energy consumption, passive design parameters, IDA-ICE simulation tool.

Preface

I would like to thank my supervisor Arman Ameen for his continuous and excellent support during the preparation of this thesis, as well as to express my gratitude to Nawzad Mardan for his guidance during the whole program.

A special dedication note to my parents José and Elisa, and my brother Abel, *me alegra poder dedicaros al menos un par de líneas de este trabajo.*

Nomenclature

Abbreviations and acronyms included within this thesis are detailed in the table shown below.

Letters	Description
IPCC	Intergovernmental Panel on Climate Change
WMO	World Meteorological Organization
UNEP	United Nations Environment Program
CO_2	Carbon Dioxide
IDA ICE	IDA Indoor Climate and Energy
UAE	United Arab Emirates
USA	United States of America
BIM	Building Information Modeling
IFC	Industry Foundation Classes
BEST	Building Energy Software Tools
ASHRAE	American Society of Heating, Refrigerating and Air-conditioning Engineers
PPD	Predicted Percentage of Dissatisfied
PMV	Predicted Mean Vote
N	North
W	West
E	East
S	South
NW	Northwest
NE	Northeast
SW	Southwest
SE	Southeast
NNE	North-northeast

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1. Introduction

1.1 Background

The building sector plays a major role in the world's total energy consumption. According to the last report on climate change issued by the Intergovernmental Panel on Climate Change (IPCC) in 2014, buildings accounted for 32% of global energy use and 19% of energy-related greenhouse gases emissions. This international board, set up in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Program (UNEP) took a step forward and expressed, in the same report, their concerns about the possibility that this energy use and related emissions could be multiplied by 2 or even by 3 in the next decades, due to the increasing access to housing in developing countries, the world population growth and the increasing levels of global wealth.

In Europe, it is estimated that buildings are responsible for 40% of total energy consumption, accounting as well for 36% of CO_2 emissions. The main contributors to this consumption are long-standing buildings, since they need up to 5 times the heating fuel consumed by the most modern buildings. This is a relevant detail taking into consideration that 35% of European buildings are 50 years old or more. The building sector thus offers the largest single potential for energy efficiency in Europe (European Commission, 2017).

Within the building sector, residential dwellings are the most energy-intensive ones, reaching up to 90% of total consumption compared to the non-residential buildings (e.g. offices and public buildings). Most of the energy consumption occurs during the so-called "operational phase" of the building for cooling, heating and lighting purposes (UNEP, 2007). Therefore, it is important to optimize the dwelling design so they make the most of the local weather, decreasing thus the energy consumption during the above mentioned phase.

There are several design parameters that determine the energy requirements of a house, and all of them can be optimized in the design stage of the building: shape factor, transparency ratio, orientation, thermal-physical properties of building materials and distance between buildings (Bektas & Teoman, 2011). Optimizing these parameters entail in a passive solar building design, taking advantage of the sun's energy and local climate characteristics, decreasing the buildings active and energy consuming controls (e.g. heating system).

Among those parameters, building orientation is the most important one, as mentioned in several studies such as the one carried out by Morrissey et al (2011) about affordable passive solar design in temperate climates, Pacheco et al (2012) in their review of energy efficient design of buildings or Friess & Rakhshan (2017) in their research about passive measures to improve energy efficiency in the UAE. This fact makes sense taking into consideration that the effectiveness of other parameters such as the transparency or glazing ratio will be determined by the orientation of the building itself.

However, it has not been found any research discussing the importance of building orientation in a house energy consumption using IDA ICE software, which has signify a strong motivation to develop this thesis. It has not been found either any study analyzing whether the importance of building orientation varies with its location, which is a question answered later in this work.

Finally, on a personal note, energy efficiency in Spain is increasingly becoming relevant. Nowadays it is typical to find notes about a dwelling energy performance in classified advertisements, or to perform refurbishments with the aim of decreasing the energy use. All these actions are being taken with the aim of diminishing the gap that has been present historically between Spain and the European Union in terms of average energy intensity (State Secretariat for Energy, 2014).

Even though a house orientation is only and typically associated with the availability of natural light in its rooms, this thesis will demonstrate that it has an impact as well in the heating and cooling loads, affecting thus the dwelling economy.

1.2 Literature review

There are several publications that show the importance of building orientation as a passive design parameter. These studies, along with many others consulted, have been found on ScienceDirect website database using the following keywords: building orientation, building energy efficiency and building design. References that are not peer-reviewed articles were found in official reports written by governmental agencies such as the IPCC, United Nations or Spanish Government. Finally, the simulation tool user's guide was checked during the building design and simulation, in order to ensure that all the parameters were properly set.

As previously explained in the Background chapter, there are several design parameters that determine building energy requirements, and all of them have been studied by various authors.

Proportion of glazing to the total wall area (transparency) was studied for example by Kontoleon & Zenginis (2017) with the help of a lumped thermal-network model in North Greece. They concluded that glazing area increases heat gain or heat loss depending on the orientation of the wall where windows are installed, being the highest heat losses observed in walls facing North, and the opposite with walls facing South.

The relation between transparency ratio and orientation was noticed as well by Goia (2016) while trying to find the optimal window-to-wall ratio in European office buildings. After carrying out a big amount of integrated thermal-lighting simulations and a sensitivity analysis, it was verified that the optimal transparency ratio could vary from 0.20 to 0.60 depending on the weather and the wall orientation.

The shape factor, which is the ratio between the length and the depth of a building, was studied by Teoman & Inalli (2016) through a numerical method for a cold region of Turkey. Results shown that the optimal ratio was 1:1, even though too many assumptions were adopted since the occupancy, equipment and floor and roof heat losses were neglected. Again, the importance of building orientation was demonstrated, obtaining differences of 7% in heating energy saving rates depending on this design parameter.

The opportunity to design dwellings with a bigger shape factor, more attractive from a design point of view, was analyzed by Premrov et al (2016) with the aim of studying the impact of the building shape factor on the energy performance. This study concluded that buildings with a larger shape factor achieve the best energy performance only if other parameters such as the optimal transparency ratio or external envelope orientation are carefully analyzed.

The importance of insulation thickness and thermal-physical properties of building materials on heat gains and losses was studied again by Kontoleon & Zenginis (2017), demonstrating that their contribution is almost ineligible compared to the influence of zones orientation.

All the above mentioned research had something in common; their results depended on the building, wall or zone orientation. Many studies have been found mentioning the importance of building orientation on its energy use, but only a few analyzed this trend in detail.

Simulation with BIM (building information modeling) software programs was used by Abanda & Byers (2016) to analyze the energy consumption of a dwelling while varying its orientation, following a similar method than the one explained later in this thesis, reaching the conclusion that the orientation determines the internal solar gain, affecting therefore the need for heating and lighting. A properly oriented building could be able to minimize its necessity for heating, cooling and lighting, decreasing thus its energy consumption and improving its efficiency. However, that research had some limitations that have been superseded in this work, such the use of two different software (instead of one integrated program able to design the building and simulate its energy performance, with real-time errors log) or the lack of information about the dwelling object of study, from which only the number of rooms and its orientation was known. Several parameters, including the number of occupants and their schedule and the walls and roof insulation type were unknown.

In other publications, the impact of a dwelling orientation on its energy consumption was studied along with novel design parameters, like in the research performed by Kontoleon & Eumorfopoulou (2010), whose aim was to study the influence of orientation and percentage of plant-covered areas in the energy use of a house. From this research, that used a thermal-network model that simulated the different building zones, it was inferred that the influence of a green layer on the rooms inner temperature depended on each wall orientation, even though it was demonstrated that the use of this kind of plant-covered walls could decrease the cooling load, since they counteracted the solar impact.

To neglect the influence of the occupants of a house on its energy balance is something commonly found in literature, even though it is considered an important limitation, since recent studies have demonstrated the importance of this parameter in the residential energy consumption. For example, behaviors like using a clothes line instead of a drying rack, to optimally adjust the thermostat during Summer and winter nights or to activate the sleep feature on computers and electronic devices would help to save up to 205 $ to some families questioned in the state of Tennessee (USA) (Mardookhy et al, 2014). Not to mention the dwelling income, significantly related to the estimated total energy consumption since it is a parameter that determines, for example, the number of rooms that can be heated (Cheng & Steemers, 2011).

Not to know the insulation materials is another limitation due to it is an important parameter to take into consideration, especially for the roof, as demonstrated by Al-Homoud (2005) in his analysis about the performance of common building insulation materials.

From the research introduced in this chapter, it is inferred that building orientation is a critical parameter, not only affecting its energy consumption but also limiting the importance of other parameters such as the transparency ratio or shape factor.

Although several publications have been found discussing the importance of dwellings orientation, they all have important limitations that are intended to be overcome in this thesis using an integrated design and energy simulation program (IDA ICE), that allows the user to input important parameters normally neglected such as the number and behavior of the occupants (schedules) and the physical properties of the envelope (walls, roof and floor)

1.3 Aims

The main goal of this thesis is to quantify and analyze the importance of a dwelling orientation on its energy consumption. In the pursue of this aim, other objectives will be achieved, as listed below:

- To know the state of the art of BIM programs, introducing and using one of the most important ones (IDA ICE) for the design and energy simulation of the dwelling object of study.
- To study if the impact of building orientation on energy consumption depends on the location of the building, especially when the latitude is different.

- To determine what is the optimal orientation of the dwelling object of study, and to study if this result is true for all the buildings located in the same hemisphere.

1.4 Approach

In order to achieve the aims and goals described before, a simulation tool will be used to design and simulate the energy behavior of a real dwelling, located in Madrid (Spain), when adopting different orientations. Location will be also changed from Madrid to Göteborg (Sweden) to fulfill all the objectives.

2. Method

The dwelling analyzed in this thesis is located in Madrid (Spain), more precisely, in a neighborhood called Barajas (40.48N, 3.58W), located very close to the main airport of the city. Due to this building is located in an urban area, surrounded by big apartment buildings, its 113.1 m^2 floor area makes it a medium size dwelling.

This dwelling was chosen because the author of this thesis has family ties with the owner, which was useful to get information about the design parameters and to verify the obtained results.

2.1 Study object

2.1.1 Technical properties

The case study dwelling comprises eleven rooms in a single floor and a courtyard, and it is inhabited by five people; two adults and three children. It is located on a 15.5 x 9.0 m plot.

Figure 2-1 shown below shows the floor plan of the dwelling, indicating the rooms distribution and the location of the main entrance in the façade.

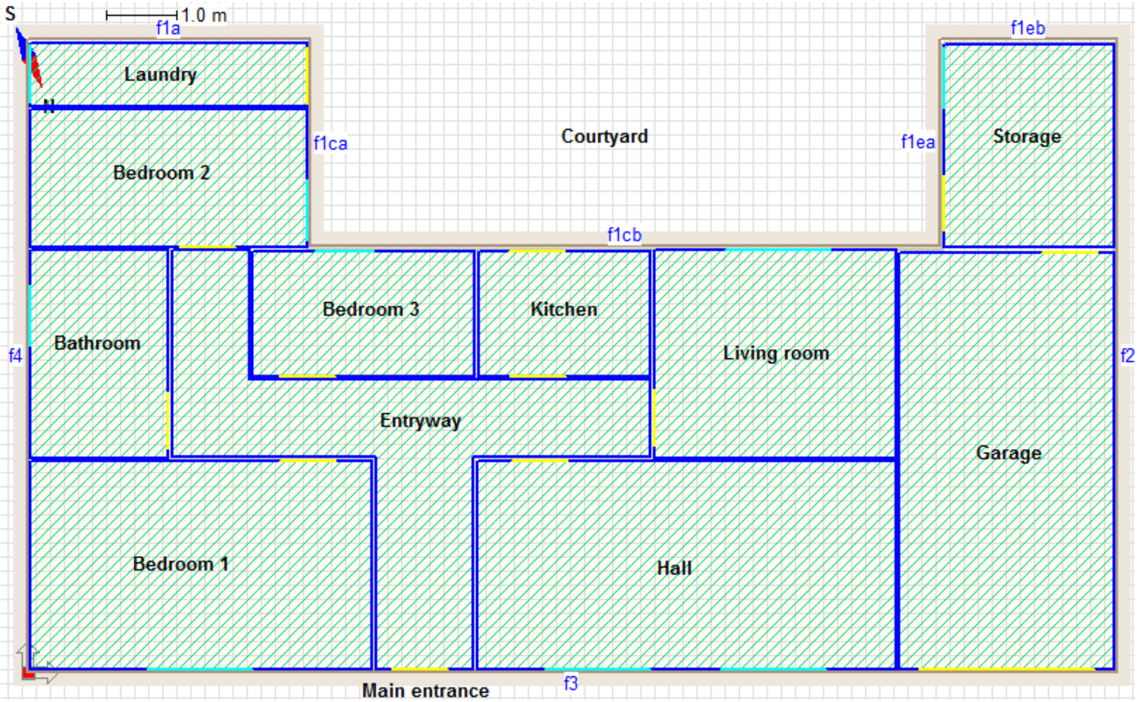


Figure 2-1. Floor plan of the dwelling object of study.

As observed in Figure 2-1, the actual orientation of the dwelling is NNE (North-northeast), with and angle of +24.5º from due North and taking the façade as reference.

Table 2-1, introduced below, shows the technical properties collected for the design of the building. It is important to remark that the use of two pane glazing is mandatory due to the proximity of the dwelling to an international airport. This acoustic insulation system was introduced by the public company AENA, which stands for Spanish Airports and Aerial Navigation, in 2003.

Table 2-1. Summary of the technical properties and design parameters of the dwelling object of study.

Main characteristics	Unit	Properties
Floor area	m^2	113.1
Room height	m	2.8
External walls	-	Concrete (25 mm) + Extruded polystyrene (30 mm) + Brick (130 mm).
Internal walls	-	Gypsum (10 mm) + Extruded polystyrene (7 mm) + Gypsum (10 mm).
External floor	-	Wood (20 mm) + Light insulation (35 mm).
Internal floor	-	Floor coating (5 mm) + L/W concrete (20 mm) + Concrete (150 mm).
Roof	-	Brick (20 mm) + Extruded polystyrene (300 mm).
Windows – quantity	-	10
Windows – construction solution	-	2 pane glazing, clear.
Window/Envelope ratio	%	2.6
Doors – quantity	-	8 inner doors (always open), 5 entrance doors (always closed)
Doors – construction solution	-	Wood (40 mm).
Thermal bridges	-	Typical.
Infiltration	$L\ s^{-1}\ m^{-2}$ ext. surf	0.3
Average hot water use	L per occupant and day	22.2, uniform through the whole year.
Hot water system	-	Fuel heated, 85% efficiency.
Heating system	-	Fuel heaters with a maximum output of 10 000 W and 85% efficiency.
Heating system – location	-	All the rooms but for the laundry, garage and storage.
Heat setpoint	ºC	21
Cooling system	-	4 splits (electrical coolers) with a maximum output of 10 000 W and COP = 3.3
Cooling system – location	-	Bedroom 1, Bedroom 2, Hall and Living room.
Cool setpoint	ºC	24
Air handling unit	$L\ s^{-1}\ m^{-2}$	0.35, return air only.
Internal gains – Equipment	-	100 W equipment in Bedroom 2, Laundry, Hall, Living room and Kitchen.
Internal gains – Occupants	-	5 occupants at Bedrooms 1, 2, 3, Hall and Living room.
Internal gains – Lighting	-	40 W and 60 W light bulbs. 12 units.

As it can be seen in Table 2-1, external doors were always set as closed, while the internal ones were set as always open. This is a simplification done for two main reasons; the first one, was to speed up the simulation, the second one, was to allow the cold air generated in the cooling units (splits) located in four of the eleven rooms to reach the rest of the rooms, achieving thus the thermal comfort in the cooling period.

Another simplification was made with regard to the blinding system, since it was not defined even though the actual dwelling has shutters in all the windows. This was done because the use of these devices is not common in many countries, and this house will be virtually placed in several locations to achieve the aims and goals described before in the Introduction chapter. Thus, the design shall be as suitable as possible for a wide range of countries and climates.

Finally, it is important to mention that the building was assumed to be located in an open area, without near obstacles (natural or artificial) that could cause partial shading to the dwelling. By doing so, the solar irradiation set by the local weather conditions reached the envelope in its totality. Therefore, the building was completely surrounded by the environmental conditions of the chosen location.

2.1.2 Environmental conditions

Since the main parameter that would be measured after the simulations is the total energy consumption, it is important to have knowledge about the environmental conditions where this dwelling is located. In this case, the chosen simulation tool allowed the use of real climate data obtained from a weather station located in Barajas Airport (40.45N, 3.55W, 582 m elevation), located at 4 km distance from the building.

Temperature information obtained from that weather station, shown in Table 2-2, indicates that the climate in the chosen location is known as Continental Mediterranean Climate, typical of Madrid, with hot and dry summers, cold (but not extreme) winters and high average daily oscillations.

Table 2-2. Average dry-bulb temperature per month of the simulation year in the location of the house.

Month	Dry-bulb temperature (ºC)
January	5.0
February	7.0
March	10.0
April	11.6
May	16.7
June	22.3
July	25.7
August	25.2
September	19.9
October	14.9
November	9.2
December	5.6

From the information indicated in Table 2-2, it is expected a short but intense cooling demand in the summer (during June, July and August) and a gentle but long heating demand from October to May.

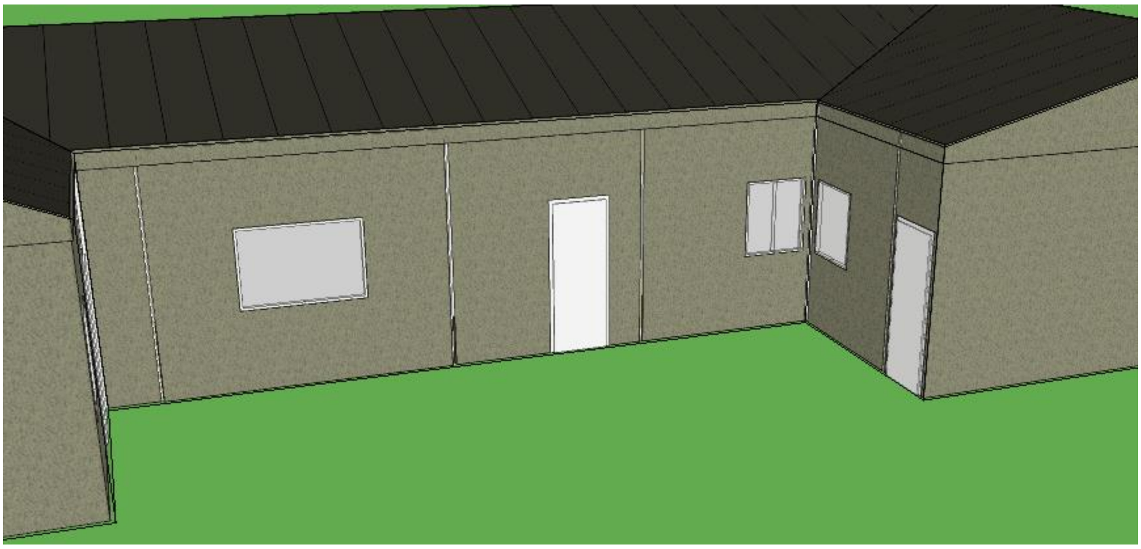
Other parameters obtained from the simulation tool, such as the wind speed or air humidity are not important for the analysis carried out within this thesis.

2.2 Simulation tool

IDA Indoor Climate and Energy (IDA ICE) is a dynamic multi-zone simulation tool that allows the user to analyze thermal indoor climate as well as the energy consumption of a building, or any part thereof (EQUA, 2017). It was developed in Sweden by EQUA Simulation AB and there are free trial versions available on their website. In this case, the installed version was the 4.7.1, released on September 13th, 2016.

As previously mentioned in the Introduction chapter, one advantage of IDA ICE is that it allows the user to both design the building object of study and simulate its energy behavior, without the help of other program or software tool. In fact, this is the main comparative advantage normally associated to this program, along with its flexible architecture, that makes it easy to develop the software continuously to adapt it to local requirements and languages, and to expand it with new modeling possibilities (IBPSA-USA, 2017). However, this program also offers the possibility to import building information modeling (BIM) via IFC format.

The following Figure 2-2 gives an example of the advantage mentioned before, observing the dwelling 3D Model in the first image, and some results of the performed simulation in the image below.



Zones

Expand table

Zone	Group	Zone multiplier	Min temp, °C	Max temp, °C	Min op temp, °C	Max op temp, °C	Max heat supplied, W/m2	Room unit heat, W/m2	Max heat removed, W/m2	R unit W
Bedroom 1		1	21.0	24.0	20.8	24.8	37.23	50.9	51.52	66.
Bathroom		1	21.0	27.3			44.62	56.06	36.86	0.0
Bedroom 2		1	21.0	24.0	20.5	24.8	56.95	66.26	94.83	12:
Laundry		1	13.1	33.4			5.007	0.0	8.608	0.0
Hall		1	21.0	24.0	20.6	25.4	32.96	44.04	70.61	74.
Garage		1	12.4	30.1			4.409	0.0	6.976	0.0
Storage		1	7.8	34.0			5.715	0.0	8.511	0.0
Living room		1	21.0	24.0	20.6	24.6	43.53	54.5	64.69	86.
Kitchen		1	21.0	26.8			46.18	59.63	30.32	0.0
Bedroom 3		1	21.0	26.7	20.9	26.9	35.56	48.03	26.86	0.0

Figure 2-2. Screenshots of IDA ICE interface, showing the 3D model of the dwelling (up) and an extract of the simulation results (down).

Both images shown in Figure 2-2 are directly obtained from IDA ICE without the support of other simulation tool. This feature is the main advantage of IDA ICE with respect to other programs.

The use of this simulation tool is more than justified since it is considered as one of twenty major building energy simulation programs (Crawley et al, 2008), which is relevant taking into consideration that it is estimated in more than 400 the number of building energy software tools available for use (Hilliaho et al, 2008). What is more, IDA ICE is considered in literature as one of the four main building energy simulation tools (Ryan & Sanquist, 2012) and it is a top rated program according to BEST (building energy simulation programs) directory.

The accuracy of IDA ICE simulation tool has been also analyzed in several occasions, resulting in a really accurate program for sunny periods (Loutzenhiser et al, 2009), as it is typical of the location where this dwelling is located. Thus, it is expected that the obtained results will adjust to reality.

However, since one of the main objectives of this thesis is to analyze the differences in energy consumption depending on the different orientations adopted, rather than studying in detail the energy use of the dwelling for a fixed orientation, accuracy is not a critical parameter since the possible error or uncertainty will be the same for all the simulations performed. Therefore, the comparison of the results obtained for each orientation will not be affected by this parameter.

2.3 Procedure

The first step was to choose the dwelling object of study, trying to find a house with a variety of rooms and appliances not always present in all the buildings, such as a garage, air handling units or a laundry. At the same time, the dwelling had to be accessible enough to gather the information needed for the design. This was the moment when the technical properties of the dwelling, introduced in the previously included Table 2-1, were taken.

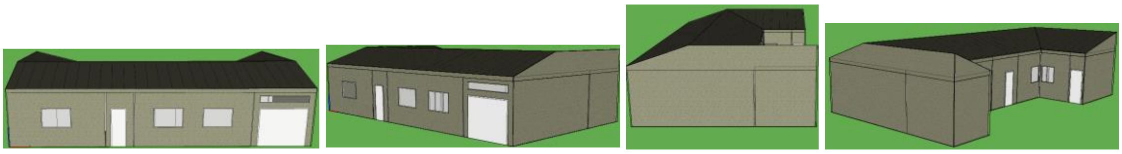
Even though the author of the thesis had access to the building, it was not possible to know all the parameters like for example the thermal bridges or infiltration information. In these cases, typical parameters already utilized in other projects were set. This limitation is normal considering that infiltration, for instance, is one of the most difficult variables to measure, as found in literature (Al-Homoud, 2005).

Second, the plot plan of the dwelling was drawn, maintaining the rooms distribution, geometry and dimensions of the original house. The number of doors and windows was also maintained.

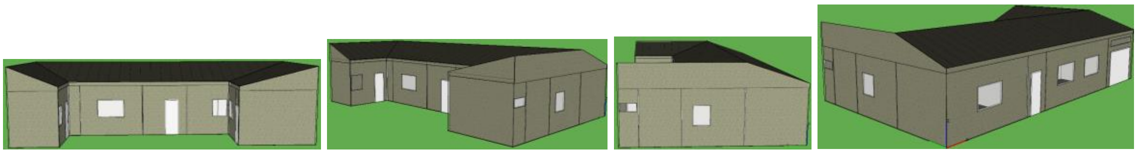
Third, the information gathered in the first step was introduced into the program, running one simulation of one year of duration to check that no mistakes were committed during the design. In this step, it was also analyzed the building thermal comfort with the help of Fanger's comfort indices, and it was decided to put one more cooler (split) in order to meet ASHRAE comfort criterion, that establishes that the predicted percentage of dissatisfied (PPD) should be less than 10% and the predicted mean vote (PMV) should be located between -0.5 and +0.5 (Abel & Elmroth, 2007).

The design resulting at this point was considered as the Base Model.

Finally, eight simulations were carried out varying the orientation 45º among them, taking the initial façade orientation as reference. The followed procedure is shown in Figure 2-3 below.



Façade +0º (due North) Test 1 | Façade + 45º Test 2 | Façade + 90º Test 3 | Façade +135º Test 4



Façade +180º (due South) Test 5 | Façade + 225º Test 6 | Façade + 270º Test 7 | Façade +315º Test 8

Figure 2-3. Building orientation for each simulation, viewed from due North.

As observed in Figure 2-3, the initial orientation of the main entrance was due North, and it was varied 45º clockwise for each test. All the images included above shows the sight of the dwelling from the North.

The eight simulations were performed for two different locations, leading to two scenarios and sixteen simulations in total, eight for each scenario as detailed below:

- Scenario 1: the dwelling is located in Madrid (Spain).
- Scenario 2: the dwelling is located in Göteborg (Sweden).

These two scenarios were introduced to fulfill the aims and objectives explained in the Introduction chapter.

3. Results

The results obtained in the previously mentioned simulations are presented in this chapter, and they will be analyzed in detail in the Discussion chapter included lately. This chapter shows the results obtained from the two scenarios described in the Procedure; when the dwelling is located in Madrid (Scenario 1) and when it is located in Göteborg (Scenario 2).

3.1 Scenario 1

Test 1: Façade +0º

With this configuration, Bedroom 1, Hall and Garage were oriented due North, while the inner Courtyard was oriented due South. The total energy delivered for the complete year was 15 836 kWh, from which 9 185 kWh were fuel-based and 6 651 kWh were electricity-based.

The following Table 3-1 details the delivered energy depending on its final use.

Table 3-1. Results of Test 1 (façade oriented to N).

Use	Delivered Energy (kWh)	Energy Carrier
Heating	6 404.5	Fuel
Domestic hot water	2 780.4	Fuel
Lighting	1 906.4	Electricity
Cooling	1 177.2	Electricity
HVAC aux.	220.8	Electricity
Equipment, Occupants	3 346.7	Electricity
Total	**15 836.0**	Fuel and Electricity

As observed in Table 3-1, the main energy user is the heating system, accounting for 40.4% of the total delivered energy. The second main energy user are the equipment and tennants, composing 21.1% of total energy, even though is expected that this number remains constant in all the simulations since it is a defined parameter set during the building design.

With regard to the variation of fuel and electricity supply during the simulation year, this trend is shown in the following Figure 3-1.

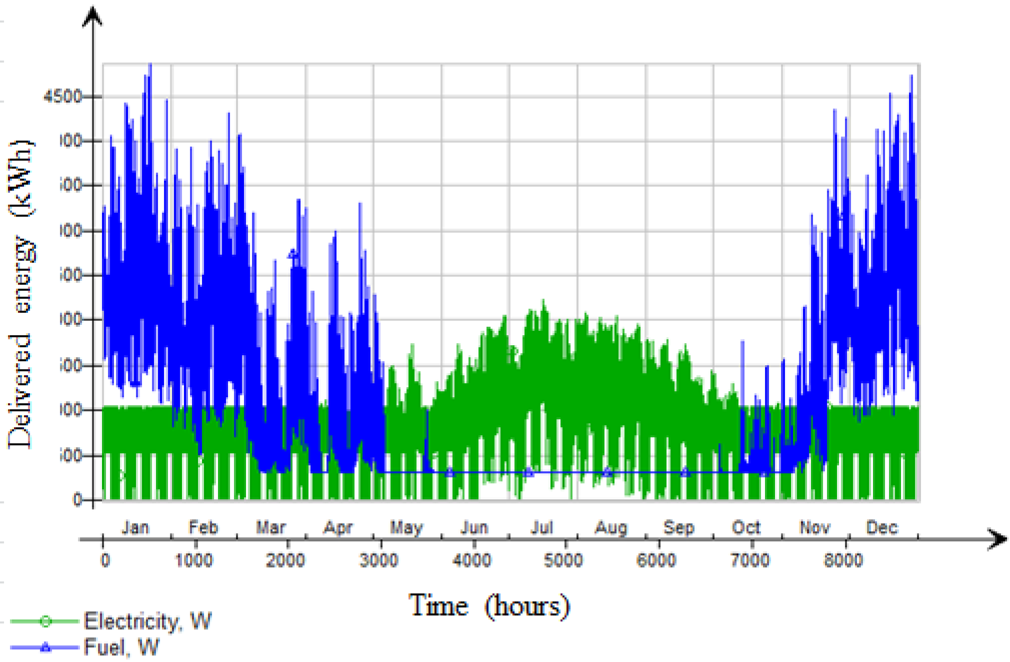


Figure 3-1. Electricity and fuel use during the simulation year.

As presented in the above mentioned Figure 3-1, fuel consumption from June to September is exclusively aimed for domestic hot water, since it is an energy use that remains constant during the whole year. On the other hand, during the same period the highest electricity use is reached, coinciding with the warmer months and therefore with the cooling period.

The opposite trend is observed from October to April, when the electricity consumption remains almost constant and the use of fuel varies depending on the heating demand needed in each moment. In May, both heating and cooling systems are used, which is normal taking into consideration that May is a transition month between winter and summer and weather changes continuously.

Test 2: Façade + 45º

In this case, the main entrance of the dwelling had Northeast (NE) orientation, placing thus the opposite side of the building oriented to southwest (SW). For this configuration, the annual energy consumption was 15 856 kWh, a very similar result to the one obtained when the façade was oriented due North. Fuel consumption accounted for 57% of the total use (9 042 kWh) while electricity consumption accounted for 43% (6 814 kWh)

Table 3-2 shown below introduces the delivered energy in this case, including also the variation observed with respect to the previous building configuracion (when main entrance was oriente due North).

Table 3-2. Results of Test 2 (façade oriented to NE).

Use	Delivered Energy (kWh)	Observed variation from Test 1 (kWh)	Energy Carrier
Heating	6 261.4	-143.1	Fuel
Hot water	2 780.4	0	Fuel
Lighting	1 907.3	+0.9	Electricity
Cooling	1 339	+161.8	Electricity
HVAC aux.	220.8	0	Electricity
Equip/Occup	3 346.6	-0.1	Electricity
Total	**15 855.5**	+20	Fuel and Electricity

As it can be seen in Table 3-2, when the dwelling is oriented NE the energy consumption increases 20 kWh. Heating demand decreases, but cooling demand rises to a greater extent.

The variation of fuel and electricity use during the simulation year was very similar to the trend explained in Figure 3-1, so this graphic representation was not included again.

Test 3: Façade + 90º

When the façade was East (E) oriented, the total delivered energy was 15 514 kWh, with a fuel and electricity consumption of 8 606 kWh and 6 908 kWh, respectively. According to these numbers, fuel consumption accounted for 55% while electricity use accounted for 45%, obtaining thus 2% variation in the energy distribution with respect to the previous orientation.

The delivered energy distributed between the users is shown in the following Table 3-3.

Table 3-3. Results of Test 3 (façade oriented to E).

Use	Delivered Energy (kWh)	Observed variation from Test 2 (kWh)	Energy Carrier
Heating	5 825.5	-435.9	Fuel
Hot water	2 780.4	0	Fuel
Lighting	1 907.9	+0.6	Electricity
Cooling	1 432.3	+93.3	Electricity
HVAC aux.	220.8	0	Electricity
Equip/Occup	3 346.6	0	Electricity
Total	**15 513.5**	-342	Fuel and Electricity

As observed in Table 3-3, there is an important decrease in the energy use when orientation is changed from NE to E. Heating load is reduced by 435.9 kWh, while the cooling load only increases by 93.3 kWh. Thus, the balance is negative from an energy-consumption point of view.

Test 4: Façade + 135º

In this configuration, the main entrance was oriented to Southeast (SE), while the Courtyard was facing Northwest (NW). After running the simulation, it was obtained a consumption of 8 278 kWh (fuel) and 6 873 kWh (electricity), adding up a total energy use of 15 151 kWh for the year object of study. Fuel and electricity weights remained constant (55% and 45% of total energy consumption, respectively).

The following Table 3-4 shows the energy use in this configuration.

Table 3-4. Results of Test 4 (façade oriented to SE).

Use	Delivered Energy (kWh)	Observed variation from Test 3 (kWh)	Energy Carrier
Heating	5 497.1	-328.4	Fuel
Hot water	2 780.4	0	Fuel
Lighting	1 907.4	-0.5	Electricity
Cooling	1 398.5	-33.8	Electricity
HVAC aux.	220.8	0	Electricity
Equip/Occup	3 346.6	0	Electricity
Total	**15 150.9**	-363	Fuel and Electricity

As observed in Table 3-4, this is the first simulation that achieves an energy consumption decrease in all the uses, including a reduction in the heating load, cooling load and lighting use.

Test 5: Façade +180º

This test shows a building orientation totally opposite to the one set in Test 1, since the façade is oriented due South instead of due North (180º rotation).

Energy consumption in this case was 14 902 kWh, with a fuel use of 8 136 kWh and an electricity use of 6 766 kWh. The contribution of each energy carrier remained 55% and 45% for fuel and electricity. Table 3-5 introduced below shows the detailed delivered energy in this case.

Table 3-5. Results of Test 5 (façade oriented to S).

Use	Delivered Energy (kWh)	Observed variation from Test 4 (kWh)	Energy Carrier
Heating	5 355.3	-141.8	Fuel
Hot water	2 780.4	0	Fuel
Lighting	1 908.9	+1.5	Electricity
Cooling	1 289.2	-109.3	Electricity
HVAC aux.	220.8	0	Electricity
Equip/Occup	3 347.1	+0.5	Electricity
Total	**14 901.7**	-249	Fuel and Electricity

As it can be observed in the previous Table 3-5, both heating and cooling loads decrease, obtaining only a small increase in the lighting and equipment/occupants energy use. The progression with respect to the previous test is negative, inferring therefore that this configuration is more efficient from an energy use perspective.

Test 6: Façade +225º

In this case, the main entrance is oriented SW, while the Courtyard is facing NE. Total delivered energy for the simulation year was 15 475 kWh, 8 584 kWh from fuel and 6 891 kWh from electricity. Table 3-6 shows the delivered energy obtained through this simulation.

Table 3-6. Results of Test 6 (façade oriented to SW).

Use	Delivered Energy (kWh)	Observed variation from Test 5 (kWh)	Energy Carrier
Heating	5 803.8	+448.5	Fuel
Hot water	2 780.4	0	Fuel
Lighting	1 909.5	+0.6	Electricity
Cooling	1 413.3	+124.1	Electricity
HVAC aux.	220.8	0	Electricity
Equip/Occup	3 346.9	-0.2	Electricity
Total	**15 474.7**	+573	Fuel and Electricity

As observed in Table 3-6, this orientation is much worse in energy consumption terms than the previous one, since the total energy use increases by 573 kWh. The main contributor to this increase is the heating system which is 448.5 kWh higher than the one obtained in the previous Test 5.

Test 7: Façade +270º

When the façade adopted this orientation, facing West, the annual energy consumption reached 15 892 kWh, from which 9 005 kWh were fuel-based and 6 887 were electricity-based.

The details about the delivery energy in this case can be seen in the following Table 3-7.

Table 3-7. Results of Test 7 (façade oriented to W).

Use	Delivered Energy (kWh)	Observed variation from Test 6 (kWh)	Energy Carrier
Heating	6 224.6	+420.8	Fuel
Hot water	2 780.4	0	Fuel
Lighting	1 908.1	-1.4	Electricity
Cooling	1 411.4	-1.9	Electricity
HVAC aux.	220.8	0	Electricity
Equip/Occup	3 346.6	-0.3	Electricity
Total	**15 891.9**	+417	Fuel and Electricity

As observed before in Test 6, when the dwelling takes this orientation the energy consumption increases due to the rise in the heating demand and the use of fuel, as observed in Table 3-7.

Test 8: Façade +315º

In this last simulation, the main entrance was oriented to Northwest (NW), while the opposite side of the dwelling faced SE. The total delivered energy was 16 093 kWh, from which fuel consumption accounted for 9 323 kWh and electricity use accounted for 6 770 kWh.

Table 3-8 shown below provides more detail about the energy use when this orientation is adopted.

Table 3-8. Results of Test 8 (façade oriented to NW).

Use	Delivered Energy (kWh)	Observed variation from Test 7 (kWh)	Energy Carrier
Heating	6 542.2	+317.6	Fuel
Hot water	2 780.4	0	Fuel
Lighting	1 907.1	-1.0	Electricity
Cooling	1 295.6	-115,8	Electricity
HVAC aux.	220.8	0	Electricity
Equip/Occup	3 346.6	0	Electricity
Total	**16 092.7**	+201	Fuel and Electricity

Following the trend observed during the last two tests, there is an increase in the total energy consumption coming from the rise of heating demand. Previous Table 3-8 shows that the decrease of cooling load cannot compensate the rising heating load.

3.2 Scenario 2

The results of the eight simulations performed when the dwelling is located in Göteborg are presented in Table 3-9

Table 3-9. Delivered energy for the eight orientations when the house is located in Göteborg.

	Delivered Energy (kWh)						
	Heating	**Hot water**	**Lighting**	**Cooling**	**HVAC aux**	**Equip/ Occup**	**Total**
N	16 850.2	2 780.4	1 907.1	75.64	220.8	3 346.4	25 180.5
NE	16 666.7	2 780.4	1 907.9	95.75	220.8	3 346.2	25 017.8
E	16 417.6	2 780.4	1 906.9	114.1	220.8	3 346.6	24 786.4
SE	16 183.1	2 780.4	1 907.7	110.2	220.8	3 346.2	24 548.4
S	16 171.6	2 780.4	1 908.0	96.19	220.8	3 346.4	24 523.4
SW	16 339.0	2 780.4	1 907.4	109.0	220.8	3 346.3	24 762.9
W	16 723.5	2 780.4	1 908.5	107.8	220.8	3 346.4	25 087.4
NW	16 882.6	2 780.4	1 907.0	87.58	220.8	3 346.5	25 224.9

As it can be seen in Table 3-9, the main difference found with respect to the first scenario is the increase of fuel used to meet the heating demand. As expected and due to the different climate conditions, the energy needed to fulfill the cooling demand in this Scenario is drastically reduced.

The rest of results are very similar to the ones obtained in the simulations of the first scenario.

4. Discussion

With the objective of analyzing and finding an explanation for the results obtained in the first scenario, where the different energy uses were shown for each orientation, the following Figure 4-1 is done taking the results as input data.

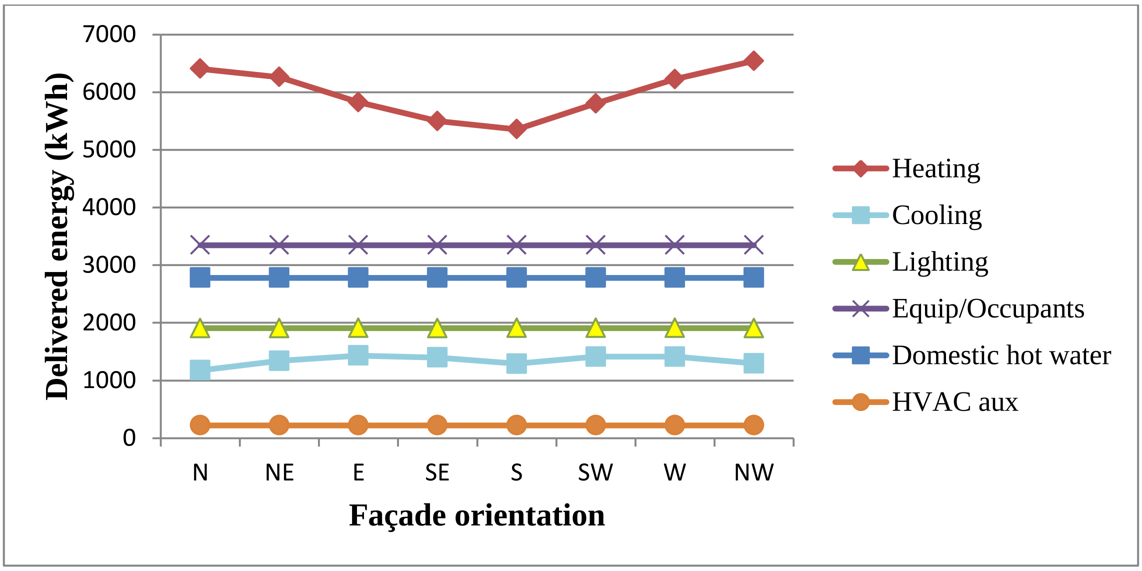


Figure 4-1. Variation of delivered energy with the façade orientation for Scenario 1 (Madrid location).

As observed in Figure 4-1, the delivered energy is plotted for each orientation, in order to know how they vary by changing this parameter.

From the above mentioned Figure several conclusions are drawn. The first one is that from the six types of energy uses, only two of them; heating and cooling, vary depending upon the orientation. The results shown in the previous chapter also indicated small variations in the electricity delivered for lighting and equipment/occupants, however, variations were so small that this consumption is considered as constant throughout all the simulations.

It can be also observed that the energy consumption related to the equipment and occupants is relevant, being the second energy consumer. This result agree with the empirical findings explained before in the literature review when discussing the research of Mardookhy et al (2014) and Cheng & Steemers (2011). These studies demonstrated the importance of the occupants of a dwelling in the way they use the electrical appliances in the total energy consumption.

Finally, it could be possible to jump to conclusions and report that the orientation involving the lesser energy consumption is due South, however, this conclusion cannot be seen with clarity in the previous Figure 4-1, so the orientation-depending energy users (heating and cooling systems) are plotted in the Figure 4-2 shown below.

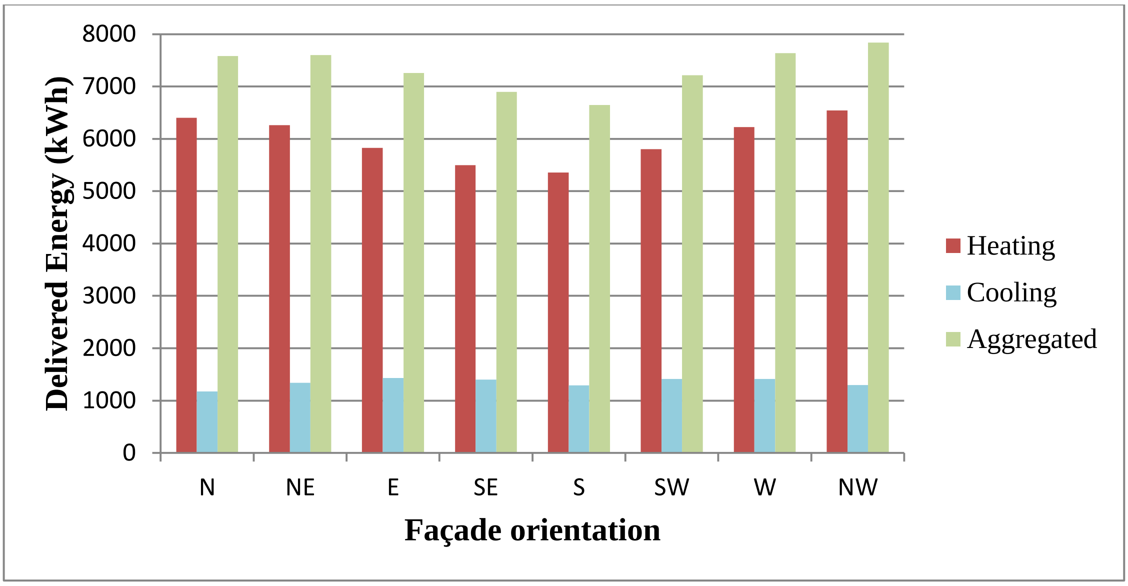


Figure 4-2. Energy delivered for heating, cooling and the combination of both for each orientation in Scenario 1.

As observed in Figure 4-2, when the façade is oriented due South the aggregated (which is the result of adding the energy used for heating and cooling) reaches a minimum, confirming thus that due South is the most optimal orientation for this dwelling in terms of energy consumption, since the rest of energy uses remain constant for all the simulations.

In contrast, orientations that represent a larger energy consumption are those where the façade is oriented to the North. For this dwelling the worst orientation would be Northwest.

The following Table 4-1 shows the differences in energy consumption between the best and worst orientations found for this dwelling.

Table 4-1. Difference in delivered energy between NW (worst) and S (better) location.

Delivered energy	Northwest (worst) (kWh)	South (best), (kWh)	Difference, (kWh)
Heating	6 542.2	5 355.3	-1 186.9
Cooling	1 295.6	1 289.2	-6.4
Lighting	1 907.1	1 908.9	+1.8
Equip/Occupants	3 346.6	3 347.1	+0.5
Hot water	2 780.4	2 780.4	0
HVAC aux.	220.8	220.8	0
Total	16 092.7	14 901.7	-1 191.0

Column “Difference” introduced in Table 4-1 results from the difference between the best and worst orientation, obtaining a difference of 1 191 kWh among them for one year of simulation. As expected from the trend observed in Figure 4-2, almost all the difference in energy use between these two orientations is because of the heating load, for which a difference of 1 186.9 kWh out of 1 191 kWh is found.

With the purpose of calculating the savings that due South orientation represents with respect to the worst orientation, Table 4-2 is introduced.

Table 4-2. Energy consumption (electricity and fuel) and associated costs for the best and worst orientations found.

	Energy carrier		**Total Cost (€)**
	Electricity (kWh)	**Fuel (l)**	
Northwest	6 770	934	2 204
South	6 766	815	2 119

As it can be seen in Table 4-2, the cost difference between the two studied orientations is 85€. This number has been calculated taking into consideration a fuel heating value of 9 981.3 kWh/m^3 and a price of 0.707 €/L, which was the average price for this type of fuel in Spain for the simulation year. In regard to the electricity price, it was set as 0.228 €/kWh (Eurostat, 2017) for the same period.

Taking into consideration an average building life of 50 years, something typical as explained at the beginning of this work, to orientate this dwelling due South instead of Northwest would represent 4 250€ of savings.

The results introduced and discussed before agree with the trends found in diverse literature, like for example the study carried out by Abanda & Byers (2016) where it was proven that the most optimal orientation for a dwelling located in the United Kingdom was due South, or the research performed by Kontoleon & Zenginis (2017) where it was demonstrated that buildings oriented due South had an important heating gain during the heating period, while those oriented due North had several heat losses. These losses were caused by the absence of heat irradiation through the glazing, being this fact the main difference between both orientations.

However, the results cannot be extrapolated to all locations. This can be inferred by looking at the cooling load represented for each orientation in Figure 4-2, where it can be seen that contrary to the heating load, that is minimum when the main entrance of the dwelling is oriented due South, the cooling load is minimum when the façade is oriented due North. This means that in a very warm climate, where the cooling demand is more important that the heating demand, due North would be the most efficient orientation from an energy consumption perspective.

This finding is supported through literature, for example, the research performed by Alghoul et al (2017) where it was proven that for an office building located in Tripoli (Libya), the energy consumption was minimum when orientation was due North. This result was explained by means of local weather, with very hot summer and gentle winter, with a fair number of sunny days.

In relation to the results obtained in Scenario 2, being the dwelling located in Göteborg instead of Madrid with the aim of analyzing whether the orientation remained as an important parameter or not, the following Figure 4-3 is introduced.

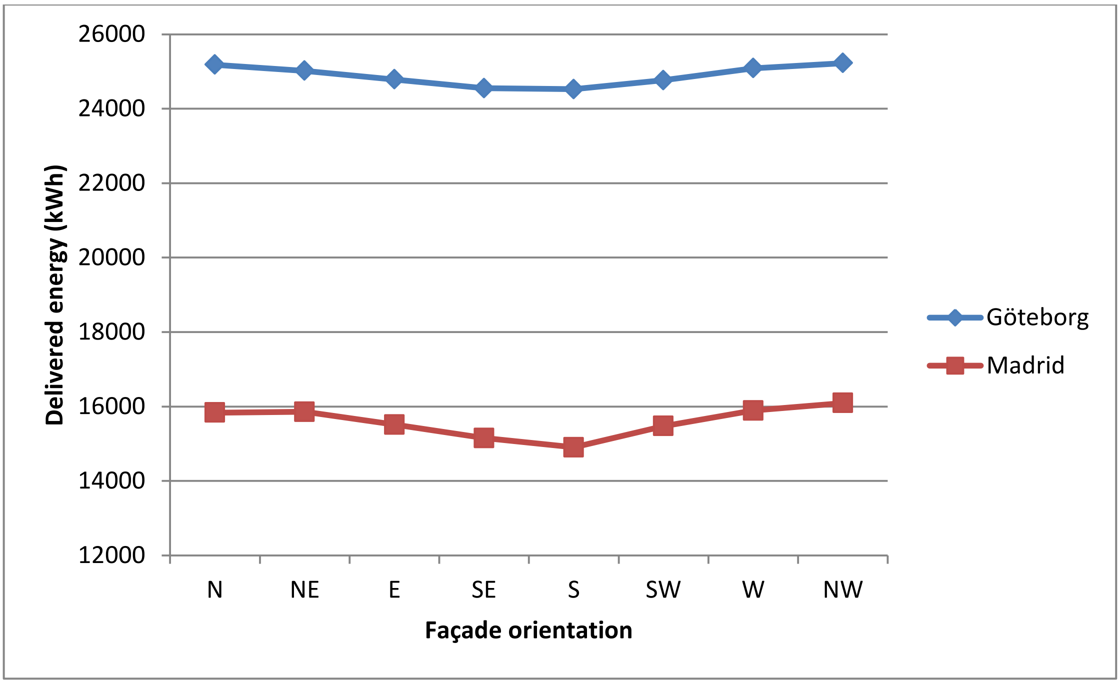


Figure 4-3. Comparison of the total delivered energy.

As observed in Figure 4-3, the trend of delivered energy for both locations is very similar, obtaining that due South is the most efficient orientation in the two scenarios. In addition to that, it was also obtained that the energy consumption was maximum when the façade was oriented to Northwest, regardless of whether the location was Göteborg or Madrid.

Therefore, it can be inferred that in both cases it is critical to orientate the dwelling in an efficient way, obtaining possible savings of 1 191 kWh when the building is located in Madrid, and 702 kWh when it is located in Göteborg.

5. Conclusions

5.1 Study results

Below is a summary of the main conclusions drawn from this thesis:

- IDA-ICE software is a powerful BIM program through which it has been possible to perform up to 16 simulations of one year of duration in a timely manner, being also capable of carrying out the design and simulation of the energy consumption of a dwelling using the same interface and obtaining real-time information about possible mistakes or errors.
- For the dwelling object of study, it is concluded that the most efficient orientation from an energy use perspective is due South, due to the decrease of heating demand.
- If the house was located in another location, as long as it remains in the northern hemisphere and the heating load is higher than the cooling load, due South would remain as the lesser energy intensive orientation. The importance of building orientation remains constant, regardless of the location.
- If the dwelling was located in the northern hemisphere, but due to the local climate the cooling load was higher that the heating load, the most efficient orientation would be due North.

5.2 Outlook

Further research could be performed taking the same dwelling as object of study and using the technical properties described in the Method chapter. For example, it could be interesting to analyze the reason why Northwest is the worst orientation, from an energy consumption perspective, in both locations (Madrid and Göteborg).

A priori, based on the findings studied in related literature, the reason could lie in the geometry (shape factor) of the dwelling and the way glazing areas are distributed, but this fact could be demonstrated with the help of BIM simulation tools for a better understanding.

5.3 Perspectives

As introduced in the Background chapter, building sector is responsible for 32% of global energy use, 40% if the boundary is only set to Europe. This consumption involves greenhouse gases emissions, affecting thus to the environment and all the human beings.

Residential buildings use up to 90% of this energy (when compared to the non-residential buildings), therefore, it is critical that our dwellings are built in the most efficient way and following the best construction practices.

However, the construction sector is reluctant to introduce the use of better material, heating systems or air conditioning units, since this means an extra-cost and a loss of benefit. This is the main reason why passive design parameters, such as the building orientation, become more significant.

Finally, the most developed countries should optimize the design of their dwellings, not only for their own benefit, but also to give example and develop the technology needed. This optimized design could be used by developing countries in their construction projects, especially taking into consideration that the population in these emerging countries is currently rising and the need of new buildings is likely to be increased.

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