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Energy Performance for a Residential Building: comparison between seasonal method (national) and monthly method (PHPP)

Dissertation presented for the conclusion of the Master degree in Civil Engineering with Specialization in Constructions

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ABSTRACT

Under the pressure of saving energy, the world is seeking different ways to pursue a sustainable development concept. Buildings are a sector which plays one of the most important role in energy consumption. One important step to slow down this uncontrolled energy consumption in this sector is the development of the low energy buildings.

A recently published European norm, the EN ISO 13790:2008, describes four methodologies to simulate the energy demand of a building: seasonal method, monthly method, simple hourly method and detailed hourly method. The simulation of the energy demand of a building requires a set of information about construction materials and solutions in order to assess the performance of a building.

The aim of this thesis is to compare the final energy demand results obtained by the two quasi-steady-state methods presented in EN ISO 13790:2008 (seasonal and monthly method). For the simulation of both methods the data of a residential Passive House built in Portugal was used. The main differences between the two methodologies were identified and the main reasons for those differences between the simulation results were discussed. Moreover, a comparison between the national and the Passive House requirements will be elaborated. Additionally, upon application of the seasonal method, the energy demand of the building for different climate conditions in Portugal was simulated. At the end, it was proved that this Passive House has a great performance in all cities chosen in Portugal. Finally, the impact of different climate zones around Europe have in the Passive House criteria verification were analysed and it was proved, using the monthly method, that cities with a similar climate, like Rome, only need a few or no changes to achieve the Passive House Standard. Nevertheless, in other cities in Europe like Berlin, Dublin, Madrid and Helsinki, the building will need some improvements in order to achieve the Passive House standard.

RESUMO

Sob pressão de poupar energia, o mundo procura diferentes maneiras de alcançar um conceito de desenvolvimento sustentável. Os edifícios constituem o sector que desempenha o papel mais importante no consumo de energia. Um passo importante para reduzir este consumo de energia descontrolado neste sector foi o desenvolvimento dos edifícios de baixo consumo.

Recentemente foi publicada uma norma europeia, EN ISO 13790:2008, que descreve quatro metodologias para simular as necessidades energéticas de um edifício: método sazonal, método mensal, método horário simplificado e método horário. A simulação das necessidades energéticas de um edifício requere um conjunto de informação acerca dos materiais e soluções de construção de maneira a obter o desempenho do edifício.

O objectivo desta tese é comparar os resultados das necessidades energéticas obtidos pelos dois métodos quase-estacionários presentes na EN ISO 13790:2008 (método sazonal e mensal). Para a simulação dos dois métodos foram usados os dados de um edifício residencial com certificação Passive House construída em Portugal. Os resultados da simulação provaram a existência de diferenças entre as duas metodologias. As principais razões para essas diferenças foram explicadas e discutidas. Foi feita igualmente uma comparação entre os requisitos nacionais e os requesitos Passive House. Adicionalmente, aplicando o metódo sazonal foi simulado para diferentes climas em Portugal, as necessidades energéticas do edificio. No final, provou-se que esta Passive House tem um bom desempenho em todas as cidades escolhidas em Portugal. Finalmente, foi analisado, para o metodo mensal, o impacto que diferentes zonas climáticas na Europa têm na verificação dos critérios Passive House. Concluiu-se que cidades com um clima similar ao de Portugal, como por exemplo Roma, só necessitam de poucas ou até mesmo nenhumas alterações para satisfazer os Standards estipulados para a Passive House. No entanto, em outras cidade como por exemplo, Berlin, Dublin, Madrid e Helsinquia, a casa necessitará de alguns melhoramentos a fim de satisfazer os Standards da Passive House.

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SEASONAL METHOD NOMENCLATURE

γ – Dimensionless parameter related to the building thermal balance
η_g – Utilization factor
η_k – System k efficiency, which take the value 1,00 if it is a renewable energy source recovery system
η_{RC} – Heat recovery efficiency
$\eta_{v,ref}$ – Reference gain utilization factor for the cooling season
a – Dimensionless parameter which depends on the building thermal inertia
A_p – Treated floor area
$A_{s,j}$ – Solar collector area of the element *n* with orientation *j*
$b_{ve,i}$ – Temperature correction factor
$E_{ren,p}$ – Energy produced by renewable sources *p*
$f_{a,k}$ –Fraction of domestic hot water energy needs supplied by the system *k*
$f_{i,k}$ – Fraction of heating energy needs supplied by the system *k*
$F_{s,j}$ – Obstruction factor on the element surface *n* with orientation *j*
$f_{v,k}$ –Fraction of cooling energy needs supplied by the system *k*
GD – Heating degree-days
$G_{sol,j}$ – Monthly average of incident solar energy on a surface with orientation *j*
G_{sul} – Average of incident solar energy on a south vertical surface
$H_{tr,i}$ – Heat transmission coefficient
L_v – Length of the cooling season
M – Length of the heating season (month)
N_i - Maximum limit of the heating energy needs
N_{ic} – Annual heating needs
N_{tc} – Primary energy
N_v – Maximum of the cooling energy needs
N_{vc} – Cooling energy needs
P_d – Headroom
Q_a – Domestic hot water energy needs
Q_g – Total solar and internal gains
$Q_{gu,i}$ – Useful heat gains (winter)
$Q_{gu,i\,ref}$ – Useful heat gains during the heating season

$Q_{g,vref}$ – Reference total gains during the cooling season
Q_{int} – Internal gains
q_{int} – Internal gains load
Q_{sol} – Solar gains
$Q_{tr,i}$ – Transmission heat losses through the envelope (winter)
$Q_{tr,i\,ref}$ – Reference transmission heat losses through the building envelope during the heating season
$Q_{ve,i}$ – Heat losses by air renovation
$Q_{ve,i\,ref}$ – Reference ventilation heat losses during the heating season
$R_{ph,i}$ – Air change rate in the heating season
V_{ins} – Inflated air through the heat recovery system
W_{vm} – Electrical energy used by the ventilation system

MONTHLY METHOD NOMENCLATURE

$\Delta\vartheta_i$ – Temperature difference of the building element of the weather condition 1 or 2
η_G – Utilization factor
n_v – Effective energy exchange for heating load
Φ_{HR} – Total heat recovery efficiency of the heat recovery system
A – Treated floor area
A_w – Windows area
c_{air} – Specific heat capacity of air
E_i – Space heating energy, electricity, DHW energy, household and auxiliary energy and cooling energy.
E_p – Specific primary energy demand
f_T – Reduction factor
g – Total solar energy transmittance coefficient for the glazing
G – Glazing solar factor
$G_{1\ or\ 2}$ – Solar radiation depends on the orientation for weather conditions 1or 2
G_t – Time integral of the temperature difference
n_V – Energetically effective air exchange rate
$n_{V,inf}$ – Infiltration air exchange
$n_{V,system}$ – Air exchange rate achieved through the ventilation system
P_C – Maximum cooling load
PEF_i – Primary energy factor for each energy source
P_H – Heating load
p_i – Internal specific heat gains
P_G – Heat gains power
P_L – Heat losses power
Q_C – Annual cooling demand
Q_F – Total solar and internal gains
q_H – Upper limit for the specific heat demand
Q_H – The annual heat demand
q_I – Specific heat load
Q_I – Internal heat gains

Q_L – Transmission losses plus the ventilation losses
Q_S – Solar gains
Q_T – Transmission heat losses
Q_V – Heat losses through ventilation system
$Q_{V,n}$ – Useful cooling demand
r – Reduction factor, considering shading, frame to windows area ratio, dirt on the window and the angle of inclination of the solar radiation
t – Heating period
U – Thermal transmittance coefficient (exterior dimensions of the building elements)
V_V – Reference volume of the ventilation system

LIST OF ACRONYMS

CEN – European Committee for Standardization
CEPHEUS – Cost efficient Passive Houses as European Standard
DGEG – Direção Geral de Energia e Geologia
DHW – Domestic Hot Water
EN – European Norm
EPBD – Energy Performance of Building Directive
EU – European Union
GHG's – Greenhouse Gases
HVAC – Heating, ventilation and Air-Conditioner
ISO –International Organization for Standardization
ITeCons – Instituto de Investigação e Desenvolvimento Tecnológico em Ciências da Construção
LCA – Life-Cycle Assessment
LCC – Life-Cycle Cost
LNEC – Laboratório Nacional de Engenharia Civil
MN – Meteonorm
NUT – Nomenclatura das Unidades Territoriais para Fins Estatísticos
PHI – Passivhaus Institute
PHPP – Passive House Planning Package
RECS – Regulamento de Desempenho Energetico dos Edifícios de Comércio
RCTEE – Regulamento Comportamento Térmico e Energetico de Edifícios
REH – Regulamento de Desempenho Energetico dos Edifícios de Habitação
SCE – Sistema de Certificação Energética de Edifícios
TFA – Treated Floor Area

1 INTRODUCTION

"The best energy is less energy"

Wolfgang Feist

The rapid growth of the World's population, the over-consumption of natural resources and also the inappropriate use of energy led to the energy crisis that we are living in today. Since the 19^{th} century, the energy consumption and the emission of greenhouse gases (GHGs) has increased by 50%. Reversing this uncontrollable energy use has become one of the biggest challenges of the current society.

The building sector (both residential and commercial buildings) is responsible for 40% of the energy consumption and 36% of the CO_2 emissions in Europe (European Comission, 2015). In 2012, the building sector represented 29% of the total primary energy consumption in Portugal. Thereby, 17% was used by residential buildings and 12% by service buildings (Chart 1.1) (DGEG, 2015). Hence, a reduction of energy consumption in buildings can be the key for a substantial reduction of the energy consumption.

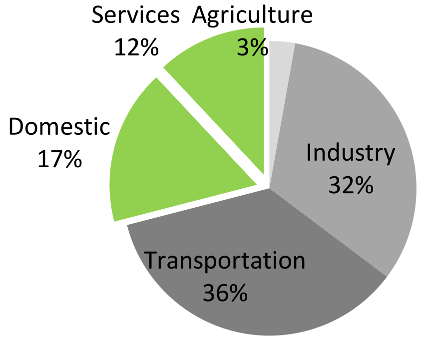

Chart 1.1 - Energy consumption in Portugal in 2012 (DGEG, 2015)

To overcome this situation, European countries, including Portugal, have created standard regulations and laws with the intention to reduce the energy consumption in buildings. In 2002, the European Union (EU) created the Energy Performance of Buildings Directive (EPBD), referenced as Directive 2002/91/EC. It aims increasing the energy performance of buildings, according to the climatic conditions of each State Member (Briga-Sá, Martins, Boaventura-Cunha, Lanzinha, & Paiva, 2014). In 2010, the EPBD was recasted by the Directive 2010/31/EU, setting that each European Member State should adapt their regulations in order to achieve in all building a nearly Zero Energy Building concept by the end of 2020 for residential new buildings and by 2018 for public buildings (Oliveira Panão, Camelo, & Gonçalves, 2012; EPBD, 2010; Michalak, 2014; Salvalai, Masera, & Sesana, 2015). This Directive had three key targets, known as the "20-20-20", which are: reduction of the greenhouse gas emissions by 20%, the increase of renewable energy by 20% and achievement of 20% more energy savings.

Portugal recently recasted the previous building energetic regulation (Law Decree 80/2006), also known as RCTEE, and implemented the Law Decree nº118/2013 on 20 August of 2013. This included three regulations, the "Sistema de Certificação Energética de Edifícios" (SCE), the "Regulamento de Desempenho Energético dos Edifícios de Habitação (REH) and the "Regulamento de Desempenho Energético dos Edifícios de Comércio e Serviços" (RECS). The implementation of these regulations proves that energy saving in buildings has become a global issue and reducing it is one of the aims of society. According to Schnieders and Hermelink (2006), "houses provide an important possibility to build on our way towards sustainable living standard, especially concerning energy". It is well known that significant reductions in energy demand can be achieved by promoting low-energy buildings (Feinst et al., 2005). A particular type of "low energy" building is the Passive House (PH) (Stephan et al., 2013). The Passive House concept, emerged in Germany in the early 1990s. It is an efficient constructive concept not only at an energetic level, but also at a comfort, economical and ecological level. The term "Passive House" is associated with a highly insulated and airtight building. The Passive House Standard assures a comfortable indoor climate in winter and in summer, using solely a mechanical ventilation system for heating delivery (Persson, 2006). The annual space heat demand is so low that the conventional heating system can be omitted (Feist, 2007). The European project "Cost Efficient Passive Houses as European Standard", CEPHEUS, where 221 Passive Houses were tested and it was evaluated the technical, economical and social feasibility of the Passive House concept (Schnieders, 2006). Subsequently, the construction of Passive House buildings started to spread quickly all over the world. Nonetheless, this did not mean an energy consumption reduction in the building sector. There is a long path to go, since most of the existing buildings in the world were built without any concerns about energy saving (Abel&Elmroth, 2007). Retrofiting them with the

Passive House principles is one of the solutions to reduce the total energy consumption. (Utveckling & Wan, 2013).

The national regulation establishes the thermal quality requirements and the buildings energetic performance. The performance evaluation depends on the suggested simulation methodologies. The Passive House certification model also imposes energy requirements. It is possible to verify them using an appropriated calculation model, developed by the Passive House Institute. In Portugal in order to certificate a Passive House, it is also necessary to verify both, the national and the Passive House requirements. In practice, designers need to apply two calculation methodologies and verify different requirements. Both methodologies are quasi-stead methods, one is based in seasonal approach and the other on a monthly approach. They both respect the European Norm EN ISO 13790.

1.1 Scope of the investigation & main research questions

The European Committee for Standartization (CEN) and the International Organization for Standartization (ISO), developed a standard “calculation methodology used for space heating and cooling” (Orosa & Oliveira, 2010). This standard presents two main approaches to calculate heating and cooling energy needs:

- Dynamic methods: to calculate the heat balance with short time steps (usually an hour) – simple hourly dynamic calculation method and detailed dynamic simulation methods;

- Quasi-static methods: to calculate the heat balance over a sufficiently long time (normally a month or a season) – monthly and seasonal quasi-state calculation method.

The approaches used for certification of residential buildings rely on steady-state methods, where a monthly or a seasonal balance is used to estimate the energy demand and to analyse different building designs under a predefined boundary conditions (Fink & Fh, 2014).

In these simulations is important to consider the location of the house as well as some parameters, such as thermal characteristics of the constructive solutions, heating and cooling systems, use of renewable energies sources, shadows devices, obstructions from the surrounding environment, the solar radiation and internal air quality (Jacinto, 2014).

This thesis pointed out the following three main research topics:

- Do the two calculation methods – seasonal method and monthly method, present in EN ISO 13790:2008, give significant differences in the energy demand results? Which are the factors that may influence this discrepancy?

- What is the influence of the climate conditions in Portugal for a Passive House? How much energy will be saved by a Passive House when compared to a standard new building in the same location?

- How significant will be the impact observed in the energy demand of a Portuguese Passive House dwelling if it was placed in a different climate region in Europe?

To obtain responses to these research questions a sequence of work tasks were performed. First, a Passive House building, already built in Portugal, was chosen and its respective data was collected. The input data of the building and construction solutions, was used in the quasi-static simulations (seasonal and monthly method). An analysis of results performed and the parameters that represent different values were identified. This analyse resulted in an answer to the first research topic of this dissertation.

The second research question has motivated a seasonal simulation of the same building, placed in different climate regions in Portugal. Seven cities were chosen and the respective energy demand for each situation was calculated. Moreover, the results of this simulation were compared with the energy demand for new reference building in the same location. Additionally, a brief analysis of the Portuguese law was made, taking into account the evaluation of energy requirements.

Finally, the Passive House was placed in different climate zones around Europe, with the intention of seeing how much the climate can influence the performance of a Passive House. A monthly method was used. For all the cities were the Passive House criteria were not achieved some modifications were suggested.

1.2 Dissertation structure

This dissertation is composed of five chapters. The first one contains an introduction of the topic and the framework of this thesis, where an explanation of the scope of the work & the main research questions, as well as the dissertation structure is included.

The second chapter presents an introduction to the Passive House concept and a description of the Passive House dwelling in Ílhavo, where information about the building elements, location and technical equipment is presented.

The third chapter contains a literature review of the quasi-static methodologies (seasonal and monthly methods).

The fourth chapter is divided into three parts according to the main research topics. The first subchapter will present the results for the energy demand for seasonal and monthly method, respectively, according to the DL nº118/2013 and the EN ISO 13790:2008. The factors that influence the differences in the results, as well as, some limitations founded during the simulation will also be discussed. The second subchapter consists of the study of the Passive House building when placed in eight cities in Portugal. Moreover, a comparison of the energy demand with a reference new building is performed for each location. It is also discussed the changes of the Portuguese requirements. The last subchapter focuses on the influence of the European climate on the performance of the Passive House. The house will be placed in different climate zones in Europe. In the cities where the Passive House Standard was not achieved, some improvements will be suggested in order to fulfill these criteria.

Finally, the fifth chapter presents the final remarks of this dissertation and some future work ideas are proposed.

2 CASE STUDY

2.1 Introduction

The Passive House is a comfortable, affordable, ecological and energy efficient building (Passipedia, 2015). The idea was developed in Germany by Dr. Wolfgang Feist and Professor Bo Adamson. The first passive house was built in 1991 in Darmstadt, Germany (Wall, 2005). The original definition given by Feist (Heier, 2012) was:

"*A passive house is a building in which a comfortable interior climate can be maintained without active heating and cooling systems*"

The passive house concept is reached by two main principles: optimizing the heat gains and minimizing the heat losses. Passive energy sources are the heat from solar radiation and the internal heat gains. The internal heat gains include the body heat from occupants, the heat from the domestic appliances and the recycled heat from the ventilation- and domestic hot water system.

The high insulation and air tightness level of the envelope are conditions that minimize the heat losses. The thermal envelope has also to be thermal bridges free and the house must be provided with a ventilation heat recovery. Moreover, the windows need to have a low U-value as well as good installation definition. These principles constitute the main requirements to consider during the Passive House design. All of the construction systems should be based on natural and environmentally friendly materials (Kuzman, Grošelj, Ayrilmis, & Zbašnik-Senegačnik, 2013).

Due to the well insulated envelope and the good ventilation conditions, the Passive House offers a good indoor comfort, in summer and winter, and at the same time reduces the energy consumption. The quality of the ventilation is one of the most important factors for a high level of comfort in the house (Dimitroulopoulou, 2012). A constant temperature is maintained across all of the rooms, once the building is thermal bridges free and there is no draughts at the windows. Because there is no moist reaching the walls the probability to have mould damage is low. A low level of moist also reduces the probability of development of some respiratory diseases, like asthma.

Passive Houses are more demanding with regards to conception, design and execution than a standard building (Antonova, 2010). Consequently, a Passive House implies an additional cost, however this can be compensated by the lower operating costs. According to Schnieders and Hermelink (2006), the addicional investment costs of a Passive House standard may be expected to decresease significanthly in the future. In 2007, the Passive-On project estimated an additional cost of 57€/m^2 in Portugal, with a payback period of 12 years (Passive-On, 2007). But in 2012, the additional cost was only around 5% more than a standard new house (Marcelino & Homegrid, 2012)

The European Passive House Standard requires an annual specific heating demand lower than 15 kWh/(m^{2}a), which is the same energy as the energy content in 1,5 litres of heating oil (Passive House Institute, 2016). The Passive House concept can be implemented in every part of the world. Until 2011, there are already about 30000 certificated Passive Houses in Europe (Engström, n.d.).

To obtain this certification, it is necessary to apply an energy simulation model and fulfil a set of requirements. The simulation tool is an Excel-based program named "Passive House Planning Package" (PHPP) which allows the calculation of the energy demand of the building. The established limits are presented in the Table 2.1.1:

Annual heating demand [kWh/m^2·year]	15
Annual cooling demand [kWh/m^2·year]	15
Heating/Cooling load [W/m^2]	10
Primary energy [kWh/m^2·year]	120
Air change rate (at 50 Pa) [h^{-1}]	0,60
Thermal bridges losses [W/mK]	0,01
Overheating frequency [%]	10

Table 2.1.1 - Energy demand of European Passive House, according to the European Passive House Standard

2.2 Description of the Passive House dwelling

2.2.1 Overall presentation

The building data was collected from a detached family Passive House (dwelling B), illustrated in Figure 2.2.1.1, located in Ílhavo, near to Aveiro. The implementation site is within the limits of an urban area and 6,8 km from the coast. The climate is in a transition range between Oceanic climate and Mediterranean climate (Marcelino & Homegrid, 2012).

Figure 2.2.1.1 - Left: site map of passive houses. Right: the two Portuguese Passive Houses (only right dwelling will be studied).

The building unit is a residential single-family house with 3 floors, where the ground floor has 2 bedrooms, 2 bathrooms and a living area. The first floor is composed of a kitchen, a living room, a bathroom, a garage and a laundry room. The last floor has 2 bedrooms, a bathroom and an open study space. The total area is 223,7 m^2. The building plans are presented in the Appendix A.

The U-value indicates the amount of heat which flows, per unit of time, through a square meter of wall area at a constant temperature difference of one degree Kelvin. Lower U-value represent better performances. The U-values of some elements are listed in Table 2.2.1.1.

The air change rate (at 50 Pa) measured in the dwelling had a value of n_{50}=0,45 h^{-1}. The windows are double glazing (6/16/4mm) and the façade with the major glazing area is orientated to the West.

The house was not initially defined according to the Passive House concept. The construction started before the adaptation process to the Passive House standards (Marcelino & Homegrid, 2012). For the Portuguese energetic certification this building follows the previous Law Decree 80/2006.

	Total Thickness (m)	Thermal transmittance (W/m$^{2°}$C)
South, East and West Walls	0,32	0,26
North Wall	0,32	0,27
Sloped Roof	0,42	0,23
Flat Roof	0,39	0,51
Partition Wall	0,27	0,39
Garage Wall	0,20	0,22
Garage ceiling	0,48	0,22
Garage floor	0,43	0,45
Floor Slab	0,48	0,42

Table 2.2.1.1 - U-values of building components of the case study

2.2.2 Technical installations and experimental installation

All this equipment needs to have a strict quality control since any uncontrolled air leakage means heat losses. The house has a high thermal inertia and it posses a natural and mechanical ventilation. The ventilation system used in the Passive House has a high efficiency heat recovery with 77% efficiency and the average air flow rate is 190 m^3/h.

In order to produce domestic hot water (DHW), the house uses a solar collector with 4,6 m^2 which is orientated 65° from the north. It is connected to stratified solar storage with 313L of capacity, which will store hot water. When the production or storage of hot water is not sufficient to suppress the DHW needs, there is a compact air pump unit, with a COP greater than 2,0.

3 METHODOLOGIES

The indoor comfort depends on numerous factors, including the heating and cooling system and building construction solutions. Consequently, these parameters are directly related to the total energy cost for a building. In order to obtain the energetic performance of a building, it is necessary to know the energy demand for heating and cooling during a whole year, which can be calculated according to the methodology described in the EN ISO 13790:2008. The EN ISO 13790:2008 describes two calculation methods for heating and cooling energy needs:

- Quasi-steady-state methods to calculate the heat balance during a long period of time, typically one month or a whole season. It allows to take into consideration the dynamic effects by a determined gain or/and loss utilization factor. In this group, the seasonal and monthly methods are included.

- Dynamic methods to calculate the heat balance during a short period of time, normally an hour. It takes into account the heat stored and consequently released from the various elements of the building. In this group, the simple hourly method and the hourly method are included.

For residential buildings, due to the complexity of the dynamic models, it is common to use the quasi-steady-state methods (Figure 3.1).

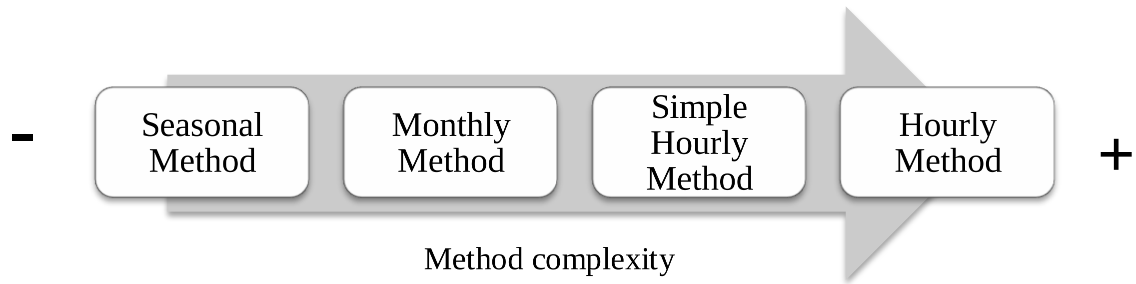

Figure 3.1 - EN ISO 13790:2008 method complexity

In the following chapter the two mathematical quasi-steady-state methodologies, used for the simulations, will be described. At the end, there is a comparison and discussion of results. The factors that justify the value discrepancies will be discussed. It is important to underline that for the comparison of the results in each method (seasonal and monthly), the input data (physical parameters) was as similar as possible.

3.1 Seasonal Method

The directive DL nº118/2013, which is based on EN ISO 13790:2008, regulates the calculation of the energy demand in residential buildings. The REH together with the directive nº15793-I/2013 and the directive nº349-B/2013, approved by the Law-decree nº118/2013 on 20th August, describe the national seasonal method, which determine the annual energy demand for heating (N_{ic}) and cooling (N_{vc}). These parameters must not exceed the require energetic limits – N_i and N_v, for heating and cooling, respectively. The results were obtained using an Excel worksheet provided by IteCons.

3.1.1 Energy calculation

3.1.1.1 Heating demand

The annual heating energy needs are calculated according to the equation (1):

$$N_{ic} = \left(Q_{tr,i} + Q_{ve,i} - Q_{gu,i}\right)/A_p \quad [k\text{Wh}/(\text{m}^2 \cdot \text{a})] \tag{1}$$

A_p - Treated floor area [m^2].

The transmission heat losses through the envelope (winter), $Q_{tr,i}$, and the heat losses by air renovation (for a ventilation with heat recovery), $Q_{ve,i}$, for the heating season can be obtained using the equation (2) and (3):

$$Q_{tr,i} = 0{,}024 \cdot GD \cdot H_{tr,i} \quad [k\text{Wh}] \tag{2}$$

GD – Heating degree-days [$°C \cdot$ days];

$H_{tr,i}$ - Heat transmission coefficient [W/°C].

$$Q_{ve,i} = 0{,}024 \cdot GD \cdot b_{ve,i} \cdot 0{,}34 \cdot R_{ph,i} \cdot A_p \cdot P_d \quad [k\text{Wh}] \tag{3}$$

$R_{ph,i}$ - Air change rate in the heating season [h^{-1}];

P_d – Headroom [m];

$b_{ve,i}$ – Temperature correction factor.

The equation (4) it is only applied for mechanical ventilation:

$$b_{ve,i} = 1 - \eta_{RC} \cdot \frac{\dot{V}_{ins}}{\mathrm{R_{ph,i}} \cdot A_p \cdot P_d} \tag{4}$$

η_{RC} - Heat recovery efficiency;

V_{ins} – Inflated air through the heat recovery system [m^3].

The useful heat gains which occur during the heating season depend on the internal gains (Q_{int}) and the solar gains (Q_{sol}), as well as the utilization factor (η_g):

$$Q_{gu,i} = (Q_{int} + Q_{sol}) \cdot \eta_g \quad [k\mathrm{Wh}] \tag{5}$$

According to Corrado, (V. Corrado, 2007) the utilization factor represents the portion of the gains (during the heating season) which contribute to the heating demand reduction.
The utilization factor for the heating season is calculated according to the equations:

a) If γ ≠ 1 and γ > 1

$$\eta_i = \frac{1 - \gamma^a}{1 - \gamma^{a+1}} \tag{6}$$

b) If γ =1

$$\eta_i = \frac{a}{a + 1} \tag{7}$$

c) If γ < 1

$$\eta_i = \frac{1}{\gamma} \tag{8}$$

Where γ is a dimensionless parameter related to the building thermal balance and a is a dimensionless parameter which depends on the building thermal inertia ($a = 1{,}8$ for low thermal inertia, $a = 2{,}67$ for medium thermal inertia or $a = 4{,}2$ for high thermal inertia).

$$\gamma = \frac{Q_g}{(Q_{tr,i} + Q_{ve,i})} \tag{9}$$

Q_g - Total solar and internal gains [kWh];

(10)

$$Q_{int,v} = 0{,}72 \cdot q_{int} \cdot A_p \cdot M \qquad [k\mathrm{Wh}]$$

q_{int} – Internal gains load. A reference value of 4 $\mathrm{W/m^2}$is considered;

M – Length of the heating season [month].

The solar heat gains is given by the following equation:

$$Q_{sol,v} = G_{sul} \cdot \sum_j \left[X_j \sum_n F_{s,inj} \cdot A_{s,inj} \right] \cdot M \qquad [k\mathrm{Wh}] \qquad (11)$$

G_{sul} – Average of incident solar energy on a south vertical surface, during the heating season $[k\mathrm{Wh/m^2} \cdot \text{mês}]$;

$F_{s,inj}$ - Obstruction factor on the element surface *n* with orientation *j* for the heating season;

$A_{s,inj}$ – Solar collector area of the element *n* with orientation *j* for the heating season $[\mathrm{m^2}]$.

The maximum limit of the heating energy needs is calculated with the equation (12):

$$N_i = \left(Q_{tr,i\,ref} + Q_{ve,i\,ref} - Q_{gu,i\,ref}\right)/A_p \quad [k\mathrm{Wh/(m^2 \cdot a)}] \qquad (12)$$

$Q_{tr,i\,ref}$ – Reference transmission heat losses through the building envelope during the heating season $[k\mathrm{Wh}]$;

$Q_{ve,i\,ref}$ – Reference ventilation heat losses during the heating season $[k\mathrm{Wh}]$;

$Q_{gu,i\,ref}$ – Useful heat gains during the heating season $[k\mathrm{Wh}]$.

3.1.1.2 Cooling demand

The amount of cooling energy needs is given by the following equation:

$$N_{vc} = (1 - \eta_v) Q_{g,v,ref} / A_p \qquad [k\mathrm{Wh/(m^2 \cdot a)}] \qquad (13)$$

where, $\eta_{v,ref}$ is the gains utilization factor for the cooling season, $Q_{g,vref}$ is the reference value for the total gains during the cooling season and A_p is the treated floor area (measured inside the building). The gains utilization factor depends on the heat losses by transmissions and by air exchange, and also on the heat gains.

The total gains include the internal gains, $Q_{int,v}$, and the solar gains, $Q_{sol,v}$:

$$Q_{g,v} = Q_{int,v} + Q_{sol,v} \quad [k\mathrm{Wh}] \tag{14}$$

$$Q_{int,v} = q_{int} \cdot A_p \cdot L_v / 1000 \quad [k\mathrm{Wh}] \tag{15}$$

L_v – Length of the cooling season (2928 hours).

$$Q_{sol,v} = \sum_j \left[G_{sol,j} \sum_n F_{s,vnj} \cdot A_{s,vnj} \right] \quad [k\mathrm{Wh}] \tag{16}$$

$G_{sol,j}$ – Monthly average of incident solar energy on a surface with orientation j during the whole cooling season $[k\mathrm{Wh/m^2}]$;

$F_{s,vnj}$ - Obstruction factor on the element surface n with orientation j;

$A_{s,vnj}$ – Solar collector area of the element n with orientation j $[\mathrm{m^2}]$.

The maximum of the cooling energy needs is calculated:

$$N_v = \left(1 - \eta_{v,ref}\right) Q_{g,vref} / A_p \quad [k\mathrm{Wh/(m^2 \cdot a)}] \tag{17}$$

3.1.1.3 Primary energy

The primary energy includes the energy demand for heating and cooling as well as the energy for DHW production and mechanical ventilation:

$$N_{tc} = \sum_j \left(\sum_k \frac{f_{i,k} \cdot N_{ic}}{\eta_k} \right) \cdot F_{pu,j} + \sum_j \left(\sum_k \frac{f_{v,k} \cdot \delta \cdot N_{vc}}{\eta_k} \right) \cdot F_{pu,j} + \sum_j \left(\sum_k \frac{f_{a,k} \cdot Q_a}{\eta_k} \right) \cdot F_{pu,j} + \sum_j \frac{W_{vm,j}}{A_p} \cdot F_{pu,j} + \sum_j \frac{E_{ren,p}}{A_p} \cdot F_{pu,p} \quad [k\mathrm{Wh_{EP}/(m^2 \cdot a)}] \tag{18}$$

N_{ic} - Heating energy needs $[k\mathrm{Wh/(m^2 \cdot a)}]$;

$f_{i,k}$ – Fraction of heating energy needs supplied by the system k;

N_{vc} - Cooling energy needs $[k\mathrm{Wh/(m^2 \cdot a)}]$;

$f_{v,k}$ – Fraction of cooling energy needs, supplied by the system k;

Q_a – Domestic hot water energy needs $[k\mathrm{Wh/(m^2 \cdot a)}]$;

$f_{a,k}$ – Fraction of domestic hot water energy needs supplied by the system k;

η_k - System k efficiency, which take the value 1,00 if it is a renewable energy system;

$E_{ren,p}$ – Energy produced by renewable sources p, $[k\mathrm{Wh/a}]$, including only the energy used in the building;

W_{vm} - Electrical energy used by the ventilation system $[k\mathrm{Wh/a}]$.

3.1.2 Input data

For the simulations the user will need information about the building location, building geometry, material characteristics, thermal bridges and windows. It will be also required information about the type of ventilation, heat recovery system and heating and cooling equipments. At the end, an energetic balance is obtained: heating energy demand and cooling energy demand and DHW energy needs.

During the simulation, the thermal envelope is considered as a single thermal zone where the temperature is maintained constant. According to Law Decree nº118/2013 the indoor reference temperature for the heating season should be 18°C and for the cooling season at 25 °C. When one of these limits are exceeded, the house should be warmed up or cooled down.

The sum of internal heat gains, including the heat losses from appliances, lighting and body heat release, are considered a standard value of $4 W/m^2$ for residential buildings (Directive nº349-B/2013,2013), which is also the value adopted by the EN ISO 13790:2008 (Jokisalo & Kurnitski, 2007).

The domestic hot water (DHW) has a standard value of 40 litres per person in residential buildings.

Portugal has mild seasons, which is a characteristic of the Mediterranean climate. Nonetheless, there is a visible diversity in the Portuguese climate. Indeed, the Directive nº15793-F/2013 divides Portugal into three climate areas for winter (I1, I2 e I3) and three climate areas for summer (V1, V2 e V3), as it is shown in Figure 3.1.2.1.. The criteria to choose the climate area, where the building is located, is given by Table 3.1.2.1 and Table 3.1.2.2.

Criteria	GD ≤ 1300	1300 < GD ≤ 1800	GD > 1800
Zone	I1	I2	I3

Table 3.1.2.1 - Criteria to determinate the winter climate area (Iii, Pena, Flor, & Vouga, 2013)

Criteria	$\Theta_{ext,v} \leq 20°C$	$20°C < \Theta_{ext,v} \leq 22°C$	$\Theta_{ext,v} > 22°C$
Zone	V1	V2	V3

Table 3.1.2.2 - Criteria to determinate the summer climate area (Iii, Pena, Flor, & Vouga, 2013)

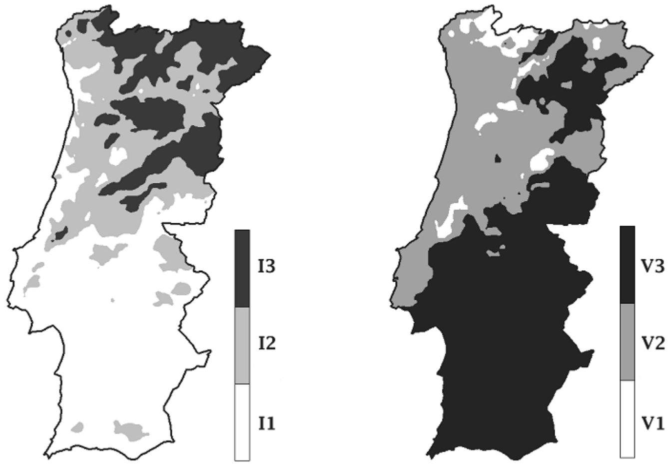

Figure 3.1.2.1 - Climate areas in Portugal. Left: Winter. Right: Summer (Iii et al., 2013)

3.2 Monthly Method

The monthly method was analysed using the simulation tool Passive House Planning Package 2007 (Feist, 2007). PHPP was developed in 1998 by the PassivHaus Institute (PHI) to validate the building design into the requirements of the Passive House Standard. It is a program based on an Excel worksheet that allows the user to obtain the annual heating demand (and monthly – the result will be the higher from both), the heating load, the cooling demand, the cooling load as well as the primary energy (Feist, 2007). The verification requires specific data about the design, components and materials to be entered in these worksheets.

3.2.1 Energy calculations

3.2.1.1 Annual energy demand

The upper limit for the specific heat demand is the coefficient between the annual heat demand (Q_H) and the treated floor area (A):

$$q_H = \frac{Q_H}{A} \leq 15\ kWh/(m^2 a) \tag{19}$$

The annual heat demand is represented by the difference between the losses and gains of a building and it is calculated using the equation (2):

$$Q_H = (Q_T + Q_V) - (Q_I + Q_S) \cdot \eta_G \quad [kWh/a] \tag{20}$$

The transmission heat losses, Q_T, and the heat losses through ventilation, Q_V, can be obtained using the equation (21) and (22):

$$Q_T = \sum A \cdot U \cdot f_T \cdot G_t \quad [kWh/a] \tag{21}$$

A – Building element area $[m^2]$;

U – Thermal transmittance coefficient (external measurements of the building elements) $[\mathrm{W}/(m^2 \cdot \mathrm{K})]$;

f_T - Reduction factor for reduce temperature differences;

G_t – Time integral of the temperature difference (heating degree hours) $[°\mathrm{C} \cdot \mathrm{h}]$.

$$Q_V = n_V \cdot V_V \cdot c_{air} \cdot G_t \quad [kWh/a] \tag{22}$$

n_V – Energetically effective air exchange rate;

V_V - Volume of the ventilated spaces;

c_{air} - Specific heat capacity of air: 0,33 $[\mathrm{Wh}/(\mathrm{m}^3 \cdot \mathrm{K})]$.

$$n_V = n_{V,system} \cdot (1 - \Phi_{\mathrm{HR}}) + n_{V,Res} \tag{23}$$

$n_{V,system}$ - Air exchange rate achieved through the ventilation system. The standard value for residences is 0,4 h^{-1};

$n_{V,inf}$ - Infiltration air exchange rate;

Φ_{HR} – Efficiency of the heat recovery system.

In equation (20) the heat gains are composed by internal heat gains (Q_I) and the solar gains (Q_S):

$$Q_I = t \cdot q_I \cdot A \qquad [kWh/a] \tag{24}$$

where, t is the heating period [h] and q_I is the specific heat load [$\mathrm{W/m^2}$].

$$Q_S = r \cdot g \cdot A_w \cdot G \;\; [kWh/a] \tag{25}$$

r - Reduction factor, considering shading, frame to windows area ratio, dirt on the window and the angle of inclination of the solar radiation;

g – Glazing solar factor;

A_w – Windows area [$\mathrm{m^2}$];

G - Global solar radiation during the heating period [$k\mathrm{Wh/m^2}$].

The heating utilization factor, η_G, is a reduction factor for the heat gains, introduced to compensate additional heat losses likely to occur when heat gains exceed the calculated heat losses (De Lieto Vollaro et al., 2015) and it is calculated by the equation (26):

$$\eta_G = \frac{(1 - (Q_F/Q_L)^5)}{(1 - (Q_F/Q_L)^6)} \tag{26}$$

where, Q_F are the total solar and internal gains and Q_L are the transmission losses plus the ventilation losses.

3.2.1.2 Heating load

The heating load, P_H, is calculated for two situations. First in a cold but sunny winter day (weather condition 1) and the second on a moderate cold, but overcast day with minimum solar radiation (weather condition 2) (Feist,2007). The maximum value of the two cases is given by the difference between the heat losses (P_L) and the heat gains (P_G):

$$P_H = \max(P_L - P_G) \qquad [W] \tag{27}$$

The heat losses power, P_L, and the heat gains power, P_G, are calculated by the equations (28) and (29):

$$P_L = \sum (A_i \cdot U_i \cdot f_T \cdot \Delta\vartheta_i) + V_v \cdot n_v \cdot c_{air} \cdot \Delta\vartheta_i \qquad [W] \tag{28}$$

A_i – Area of the building element, i [m^2];

U_i – Thermal transmittance of the building element, i [W/(m$^2 \cdot$ K)];

f_T - Temperature factor;

$\Delta\vartheta_i$ – Temperature difference of the building element for the weather condition 1 or 2;

V_v - Air volume [m^3];

n_v - Air exchange rate for heating load [h^{-1}];

c_{air} - Heat capacity of air [Wh/(m$^3 \cdot$ K)].

$$P_G = \sum (A_{w,i} \cdot g_i \cdot r_i \cdot G_{1\ or\ 2}) + p_i \cdot A_{TFA} \qquad [W] \tag{29}$$

$G_{1\ or\ 2}$ – Solar radiation depends on the orientation for weather conditions 1or 2;

p_i - Internal heat gains [W/m^2].

3.2.1.3 Annual cooling demand

The annual cooling demand is the difference between the gains (Q_I and Q_S, present in equation 24 and 25) and the useful cooling demand $Q_{V,n}$:

$$Q_C = Q_I + Q_s - Q_{V,n} \quad [kWh/a] \tag{30}$$

The useful cooling demand is calculated according the following equation where η_G is the utilization factor and Q_L, represents the heat losses calculated using the equation (21) and (22):

$$Q_{V,n} = \eta_G \cdot Q_L \quad [kWh/a] \tag{31}$$

3.2.1.4 Cooling load

The maximum cooling load is the sum of the heat losses power and the internal gains power:

$$P_C = P_L + P_G \quad [W] \tag{32}$$

3.2.1.5 Primary energy

The specific primary energy demand includes the energy needs for heating, DHW, auxiliary and household electricity.

$$E_p = \sum E_i \cdot PEF_i \tag{33}$$

E_i – Space heating energy, electricity, DHW energy, household and auxiliary energy and cooling energy;

PEF_i – Primary energy factor for each energy source;

To achieve the passive house requirements the primary energy has to be lower than 120 $[kWh/(m^2a)]$.

3.2.2 Input data

The simulation process is illustrated in the Figure 3.2.2.1. Typically the user starts by introducing building location and geometry, material characteristics and all essential Passive House verification data (Fink & Fh, 2014). The next step is to define the building as residential or non-residential. Finally the user defines the mechanical equipment as well as different systems for heating, domestic hot water production and ventilation. After introducing all data, the heating demand and all the other Passive House verification results are calculated.

During the simulation, the thermal envelope is considered as a single thermal zone where the temperature is maintained. It was assumed six occupants living in the dwelling. By default, the PHPP tool considers a constant specific internal load of 2,1W/m^2 (Feist, 2007), which includes the heat from the occupancy and the heat released by all the equipments and appliances.

The reference temperature is considered as θ_{set} =20°C, nevertheless in summer this temperature can rise to the maximum of 25°C. This limit is stipulated to prevent the overheating of the house and to guarantee a good indoor climate.

The Passive House guidelines recommend a supply flow rate of 30 m^3/h per person. Then, the total supply air flow rate depends on the number of persons assumed to live in the house and on the type of operation. It was considered a basic operation with an air flow rate of 190 m^3/h.

The recommended a air change rate of $0{,}3h^{-1}$. The minimum air supply when there is no occupancy corresponding to an air change rate of $0{,}2h^{-1}$.

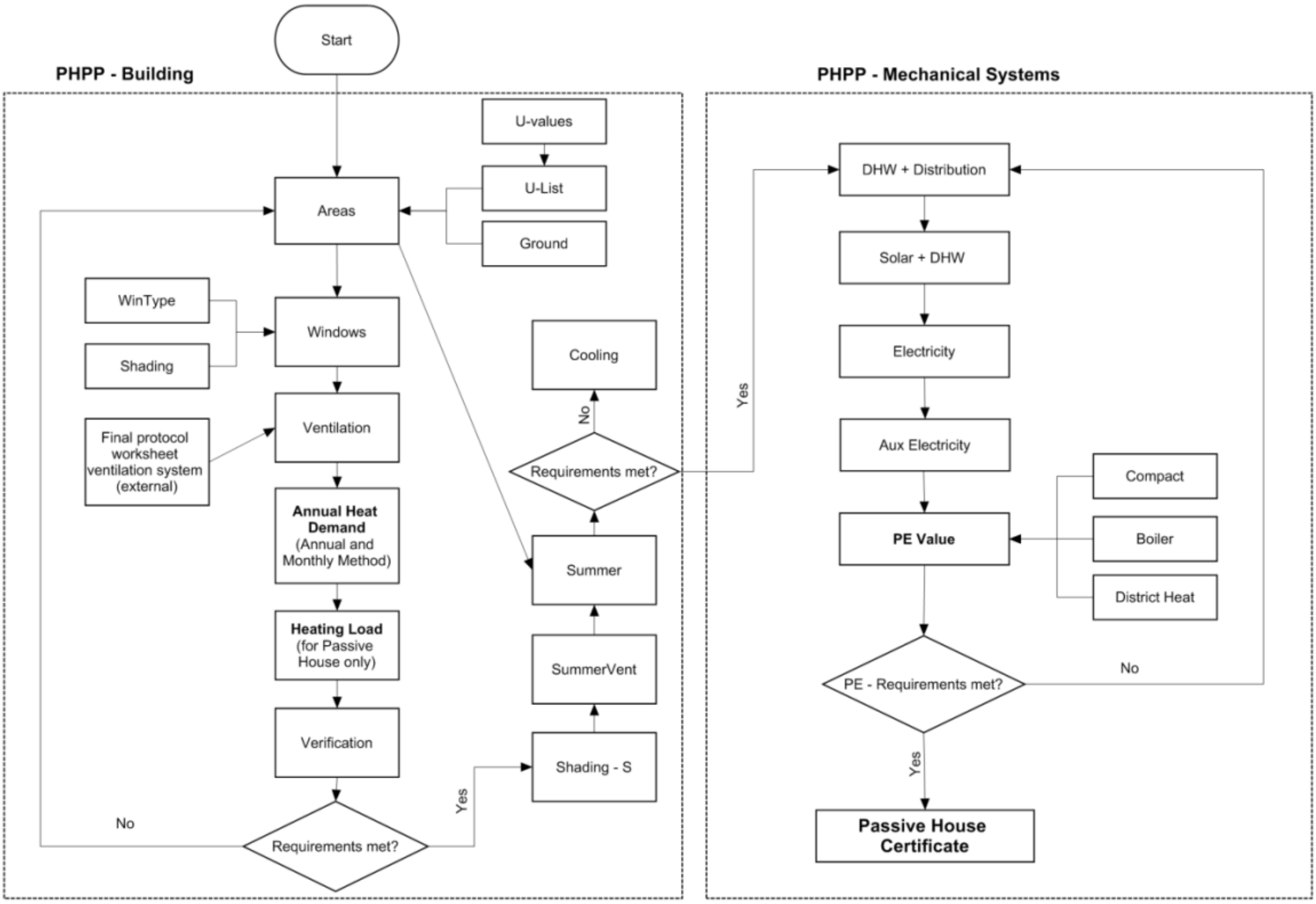

Figure 3.2.2.1 - PHPP simulation process (PHPP Excel Worksheet, 2007)

The domestic hot water (DHW) demand of 25 litres per person is a standard value used for residential building. The hot water for washing machines and dishwashers connected to the hot water distribution system are also considered. According to the PHPP, the DHW demand can be guaranteed with a solar collector area of about $1m^2$/person. Additionally, should be considered a solar storage tank with a volume of 70-100 l/person.

4 SIMULATION AND RESULTS

4.1 Seasonal and monthly simulation results for the Ílhavo climate

Hereafter, the input of all values in the both simulation programs, the results for the transmission losses, ventilation losses, internal gains, solar gains, heat and cooling energy demand and primary energy were obtained. They are summarized in the Table 4.1.1 - Energy balance results using the two approaches when the Passive House is located in Ílhavo
.

		Seasonal Method	Monthly Method
Winter	Transmission losses kWh/a	9845,0	10107,0
	Ventilation losses kWh/a	825,7	874,0
	Solar gains kWh/a	13889,9	9174,0
	Internal gains kWh/a	3997,0	2041,0
Summer	Transmission losses kWh/a	4025,5	6980,0
	Ventilation losses kWh/a	1446,7	11232,0
	Solar gains kWh/a	6745,7	5204,0
	Internal gains kWh/a	2620,0	1725,0
Heating energy demand kWh/(m²a)		2,4	7,0
Cooling energy demand kWh/(m²a)		18,5	0,0
Primary Energy kWh/(m²a)		23,2	24,9 (1)

Table 4.1.1 - Energy balance results using the two approaches when the Passive House is located in Ílhavo

(1) The primary energy result (67 kWh/(m²a)) given by the PHPP includes DWH, heating, cooling, auxiliary (5,9 kWh/(m²a)) and household electricity (36,2 kWh/(m²a)). While in the seasonal method, it is only considered DHW, heating and cooling.

In general, the final results of the models have a difference of 80% in the heating energy demand. In the cooling season, the energy needs are completely suppressed in the monthly method while in the seasonal method it is required 18,5 kWh/(m²·a). Considering that in both simulations the input data was similar, it is important to inquire if the differences are caused mainly by a methodological difference or by a pre-defined value, like the climate data. Therefore, the Table 4.1.2 - Climate parameters of the two approaches for Ílhavo compares the climate parameters for winter and summer between the two methods. Because the two methods use different units, the seasonal method parameters were converted to the units of the monthly method. It was also calculated some climate parameters when both simulations have the same heating and cooling period, assuming the duration of the monthly method Table 4.1.3.

	Seasonal Method	**Monthly Method**
Length Heating period	186 days (1)	181 days
Length Cooling period	122 days (2)	153 days
Degree-days in Winter	30,8 kKh/a (3)	41,0 kKh/a
Degree-days in Summer	11,7 kKh/a (4)	26,0 kKh/a
Solar radiation in winter (south)	868,0 kWh/m^{2}a (5)	572,0 kWh/m^{2}a
Solar radiation in summer (south)	420,0 kWh/m^{2}a	529,0 kWh/m^{2}a
Indoor set temperature (Winter)	18,0 °C	20,0 °C
Indoor set Temperature (Summer)	25,0 °C	25,0 °C
Outdoor temperature (Winter)	9,7 °C	10,5 °C
Outdoor temperature (Summer)	20,7 °C	19,6 °C

Table 4.1.2 - Climate parameters of the two approaches for Ílhavo

(1) The heating season has a duration of 6,2 months and it was considered that each month have 30 days;
(2) To obtain the days of the cooling period, the season length (2928 hours) is divided by the 24 hours;

(3) According to the seasonal method the degree-days in winter are 1284 °C·days. To convert this value in kKh/a was multiplied by 24 hours/day and divided by 1000 (units conversion);
(4) The length of the cooling season in the seasonal method was multiplied by 4°C (difference between the indoor and outdoor space) and divided by 1000;
(5) The solar radiation in winter (140 kWh/month) was multiplied by the heating length (in months) of the seasonal method.

	Seasonal Method	Monthly Method
Length Heating period	181 days	
Length Cooling period	153 days	
Degree-days in Winter	38,7 kKh/a (6)	41,0 kKh/a
Degree-days in Summer	14,7 kKh/a (7)	26,0 kKh/a
Solar radiation in winter (south)	844,7 kWh/m^2a (8)	572,0 kWh/m^2a
Solar radiation in summer (south)	526,72 kWh/m^2a(9)	529,0 kWh/m^2a
Indoor set temperature (Winter)	20 °C	
Indoor set Temperature (Summer)	25 °C	

Table 4.1.3 - Climate parameters with the same heating and cooling period

(6) To obtain the degree-days in winter for the same indoor temperature was added to the value obtained in (3), 2°C multiplied by the length of the heating season and divided by 1000. To adjust the heating period the result before was multiplied by 181 days and divided by 186 days;
(7) To obtain the degree-days in the summer, (2) is multiplied by 153 days and divided by 122 days (cooling period adjustment);
(8) To obtain the solar radiation, (5) is multiplied by 181 days and divided by 186 days (heating period adjustment);
(9) To adjust the cooling period, the solar radiation is calculated multiplying 420 kWh/m^2a (Table 4.1.2) by 153 days and divided by 122 days;

To better understand the differences, between the transmission heat losses parts, they are desegregated considering the different parts of the building envelope. The Table 4.1.4 - Terms of the heat transmission coefficients presents the results obtained from the equations (2) and (21). According to the Table 4.1.4, the major differences in the transmission losses occur in walls and in the thermal bridges points. Once the monthly method makes all the measures by the outside of the wall, it is expected that the heat transmitted by the exterior wall is higher in the monthly method. In order to have a balance in the monthly method, the thermal bridges need to have negative values, which is verified. At the end, the total transmission value should have similar results. In this case, it can be considered that the values are close to each other (10% difference). During the simulation of the seasonal method was consulted the ISO 14683:2007 and an online database from ITeCons, where the transmission values were taken. Therefore, the adopted transmission values can have a slightly different. All the chosen values (in the ITeCons database) are exposed in the Appendix B, with images to illustrate each situation. Additionally, both equations, (2) and (21), are dependent on the degree-days and the indoor set temperature in winter. Assuming that in winter time the both methods have the same duration (181 days) and set indoor temperature (20,0 °C), the total transmission losses will be 25% higher in the seasonal method. In summer, when the length of the cooling period is the same both methods presented only a difference of 9%.

	Seasonal Method	**Monthly Method**
External walls [W/°C]	34,3	49,2
Thermal bridges [W/°C]	68,8	-2,2
Heat losses by windows [W/°C]	130,4	130,4
Exterior door [W/°C]	1,6	2,00
Floor slab [W/°C]	41,4	59,6
Exterior wall - Garage [W/°C]	5,2	7,5
Roof/ceiling [W/°C]	31,5	36,3
Total [W/°C]	**313,1**	**282,7**

Table 4.1.4 - Terms of the heat transmission coefficients

In terms of losses by the ventilation system, the both simulation results present a good agreement between them in winter. Nevertheless, the results present a discrepancy of 6%. One of the main reasons is related again to the degree-days, as observed by the equations (3) and (22). Moreover the specific heat capacity of air presents slightly different values in both simulations, $0{,}33\ [\mathrm{Wh}/(\mathrm{m}^3 \cdot \mathrm{K})]$ for the monthly method and $0{,}34\ [\mathrm{Wh}/(\mathrm{m}^3 \cdot \mathrm{K})]$ for the seasonal method. The calculation of a temperature corrector, equation (4), is equivalent to the equation (23). Both calculations take into account the heat recovery system and the contribution of the infiltrations in the system. Therefore, the differences are not caused by this factor. With the correction of the climatic parameters, in the heating season, it is observed that the seasonal method have a higher value (20% more). In summer, there is a considerable difference between the two simulations. While in monthly simulation, it is considered night ventilation, in the seasonal simulation this option is not possible to consider. The ventilation losses through night ventilations represent almost 50% of the ventilation losses in summer. Nonetheless, the remaining ventilation losses in the monthly method (5251,0 kWh/a) is still higher than the one obtained in seasonal method. As mentioned before, the length of the cooling season isn't the same. Additionally, in the monthly method the general window ventilation has a higher air rate (1,09 h^{-1}) comparing to the 0,6 h^{-1} in the seasonal method. Considering these two factors together and calculate the conductance ventilation in the seasonal method with this new air exchange rate, the obtained value will have a difference of 3% to the one present in the monthly method (202,1 W/°C and 208,6 W/°C, respectively monthly and seasonal method).

The solar gains have higher values in both seasons in the seasonal method. According to the equations (11) and (25), respectively, for the seasonal and monthly method, the solar gains depend on the solar radiation. According to the Table 4.1.2 - Climate parameters of the two approaches for Ílhavo

, the solar radiation in winter is almost 36% higher in the seasonal method than in the monthly method. Assuming the radiation of the monthly method in the calculation of the solar gains of the seasonal method, the result will be 9146,28 kWh/a, which is really close to the one obtained in the monthly method. In summer, the south solar radiation, have similar values, when the duration of the season is the same, however the most glazing area is toward the West and East. The radiation value difference is 9% in the West and 29% in the East, which means an increase of the gains in around 500 kWh/a. Additionally, there are small differences between the two methods like the angle selective factor (0,90 for monthly and 0,85 for the seasonal method) and the consideration of a dirt factor (monthly method).

The internal gains have big differences between them. The main reason for this discrepancy is due to the fact that the specific heat load in seasonal simulation is considered 4 W/m^2 and in monthly simulation is assumed 2,1 W/m^2. Consequently, the internal gains will be almost doubled. According to the monthly simulation, the internal gains for domestic use are 1,27

W/m^2, where is included the appliances, such as dishwashing, clothes washing, cooking, freezing, refrigerating, amount other household appliances, lighting, occupants body heat, cold water and evaporation. However, the non-domestic used internal gains reach a value of 3,7 W/m^2, which includes computers, printer, telephone, among other electronic equipments. If the both values are added the internal gains are much higher that the one considered in the seasonal method. Nevertheless, the 2,1 W/m^2 is a pre-defined value that does not change, even if the total internal gains (domestic and non-domestic) are higher. In the Table 4.1.5 are described, how much heat is released by the five main groups that contribute to the internal gains (domestic use) in the monthly simulation.

	Monthly Method
Appliances [W]	143
Lighting [W]	46
People [W]	281
Cold Water [W]	-32
Evaporation [W]	-160
Total [W/°C]	283
Total [W/m^2]	1,27

Table 4.1.5 - Internal gains, according to the monthly simulation

All the clauses above mentioned influence the heating and cooling demand. Thus, the values obtained in both simulations have a considerable difference, in the winter season due to the high value of the solar gains and internal gains which will decrease the heating demand in the seasonal method, and in summer due to the night ventilation as well as higher air flow during the day, which decrease significantly the cooling needs in the monthly method.

The primary energy in the monthly method presented a higher value, mostly because it takes into account some domestic electronic devices (like cooking, electrical home appliances, etc.) instead what happen to seasonal method. The consideration of these heat resources together with an average of the utilization frequency makes the simulation more similar to the real use of the building. Nevertheless, when the auxiliary and household electricity are not considered in the primary energy given by the monthly method, the both models present similar values.

In, 2015, the Passive House Institute developed a new evaluation system based on renewable primary energy (PER, Primary Energy Renewable). This new evaluation system consists of three Passive House classes (Passipedia, 2015), which are represented in the Figure 4.1.1:

- The Passive House Classic, which is the traditional Passive House;

- The Passive House Plus, in which additional energy is generated by photovoltaics for example. Such buildings should produce about as much energy as residents consume;
- The Passive House Premium, which produced more energy than needed.

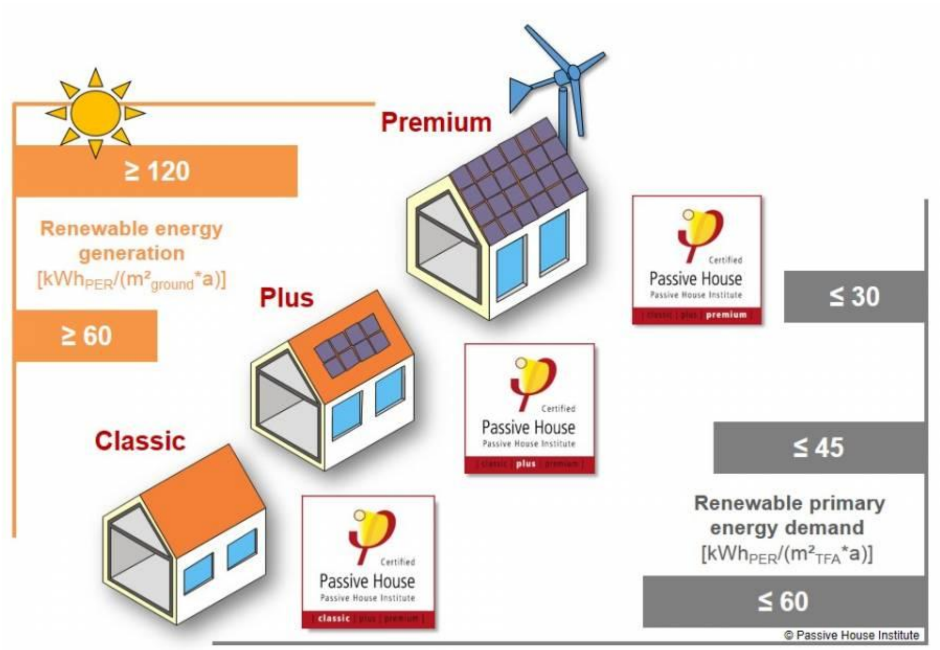

Figure 4.1.1 - The new Passive House classes of Classic, Plus, and Premium Requirements for PER demand and renewable energy generation (Passipedia, 2015).

During this dissertation was not made an analyse of this new evaluation system for the study case. Future works of this building should have this new evaluation in consideration.

Concluding, both methodologies proved that the dwelling has an excellent performance, reducing up 80% the heating energy demand and suppressing the cooling energy demand. Nevertheless, the results obtained present differences in both seasons. In the winter season (Chart 4.1.1), the ventilation losses and transmission losses present a good agreement between the two simulations, while the internal and solar gains present a different up to 50%. When these parameters are deeply analysed, it was observed that the climate data (greatest influence), together with some input/standard values, like internal gains value, are the main reasons for these differences.

On the other hand, in summer (Chart 4.1.2), all parameters have a significant difference, especially the ventilation losses. It was concluded that the input data options, like night ventilation, together with the climate data produce considerable differences in the two simulations.

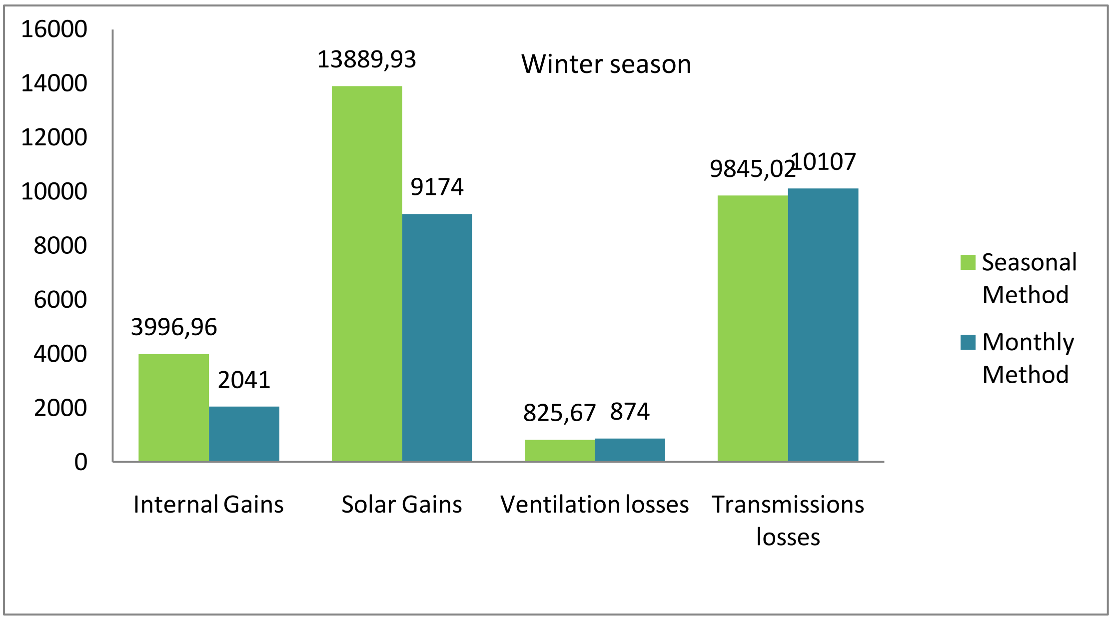

Chart 4.1.1 – Comparison of solar gains and heat losses in the heating season, using both methods [kWh/a]

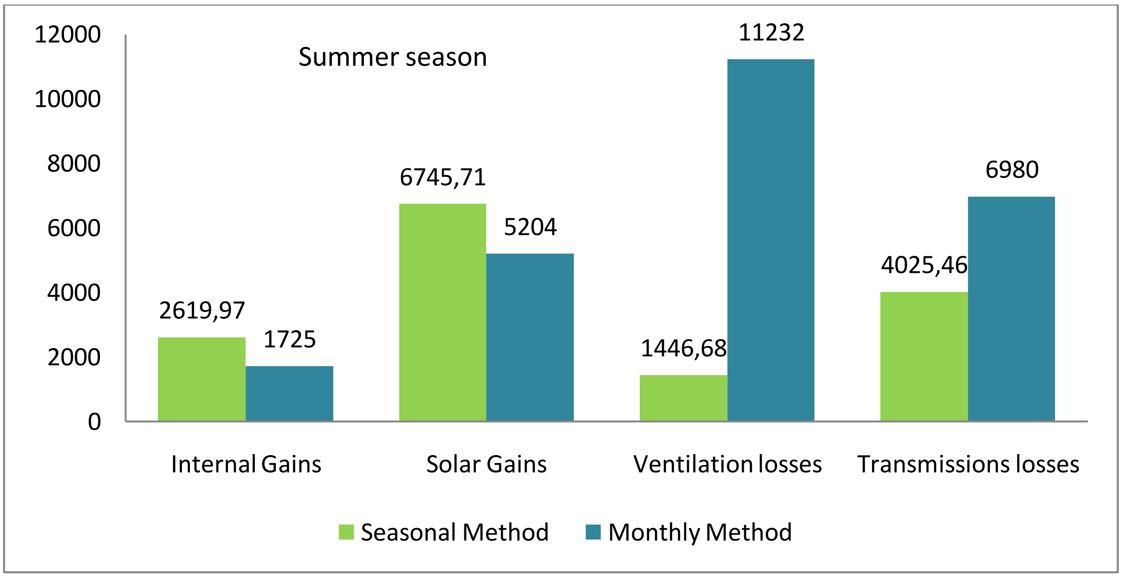

Chart 4.1.2 - Comparison of solar gains and heat losses in the heating season, using both methods [kWh/a]

4.1.1 Limitations

Some limitations found during the simulation were related to pre-defined values. Once the seasonal method is based on Portuguese directives and in the European Norm, some parameters, may present some differences, like climate data or specific heat load, when compared with a seasonal method from other country. Therefore the conclusions made about the results differences can be slightly different for other European country.

Although not analysed in this thesis, the heating demand in warm climates should be considered so important as the cooling demand. The hot temperatures can influence the performance of the building and create indoor discomfort. The seasonal method stipulated a reference value for the cooling energy demand. After the simulation, the results shows a difference of 50% between the actual cooling energy needs and the reference value.

The first limitation and the most influence one was the climate data. While, the Portuguese model uses climate data observed in Portugal, the monthly simulation sometimes makes interpolations to find a climate data. Some of the PHPP climate data are obtained using Meteonorm (MN) interpolation. McLeod (McLeod, Hopfe, & Rezgui, 2012) analyses the limitations of the current system and presents a new method to obtain a better resolution climatic data for current and future probabilistic scenario modelling generated using the UKCP09 weather generator (mainly use in United Kindgom). Recently, Meteonorm 6 allows to generate a complete climate data set for virtually any geographic location in the world. However, according to Schneiders (J. Schneiders, 2009) the results may not be so precise, once the algorithms used to derive daily climate date aren’t well defined.

Another limitation was in seasonal method, where it is not defined the number of occupants or electronic devices. On the other hand, the monthly method, consider some appliances. It also allows the user to input more devices as well as the number of building occupants. However, it isn’t possible to specify how many occupants are children. It is important to mention that an adult person release the double of the energy than a child. Nevertheless, the energy released by a human body also depends on the body activity as well as the appliances that the occupant is using. Additional, the monthly method takes into account that the residents will be at home 365 days a year. This is an unrealistic situation, which should be overcome with schedule occupation profiles, as it is considered in the simple hourly method.

From other studies it is well known that the energy consumption in a house depends on the occupants and their individual behaviour. Consequently, the discrepancy between the expected and actual performance of a low energy building can be explained by the occupant behaviour (Haas, Auer, & Biermayr, 1998; Lindén, Carlsson-Kanyama, & Eriksson, 2006;

Rekstad, Meir, Murtnes, & Dursun, 2015). Even though the passive house fix a maximum primary energy demand value which includes the operation of domestic equipments like lighting, cooking, domestic hot water and other appliances, this value allow the installation of inefficient appliances (Stephan, Crawford, & de Myttenaere, 2013). Of course that energy demand is a powerful factor to take into consideration. However, there are other factors that are not being considered which may cause an increase of the building energy demand during the life-cycle. This is called the "embodied energy" and it includes the energy used during the production process of the products, such as raw material extraction, manufacture and deconstruction. This aspect was already mentioned in numerous articles (Stephan, Crawford, & de Myttenaere, 2012);(Kuzman et al., 2013) as a relevant part of the energy consumption. Stephan et al.(Stephan et al., 2012) developed a method in which the embodied energy of the infraestruturs (such as roads, sewage, power lines, water and gas distribution) that surround the building site are taken into account. This aspects are really important, because most of the Passive Houses are single family houses detached located in the suburbs which implies the use of a car, resulting in a transport related energy (Stephan et al., 2013). Toward this, it is logical to question until when these predicted energy will meet with the real energy consumption of the dwelling.

4.2 Comparation between reference building and Passive House in Portugal

Even though Portugal is considered a warm climate, it is possible to see some differences in the climate data between the North and the South of the country. These differences can have a significant impact on the energy demand of a building. Therefore, a study to evaluate the influence changes should be taken to keep the Passive House requirements.

Although, Portugal presents high temperatures and good values of solar radiation, the poor construction made in the early's 80's and 90's, provide to their occupants a bad indoor climate. There wasn't any concern with insulation or with other factors that today are a must in the planning phase. Hence, there are indoor discomfort situations throughout the year, during the hot summers (can reach 40°C) and cold winters (can reach temperatures below zero) (Ferreira & Pinheiro, 2011). Consequently, Portugal has one of the highest rate of mortality associated to the bad house conditions (Expresso,2010).

In the last couple of years, the building construction in Portugal had a significant improvement. The implementation of the energetic certificates (SCE), which are calculated according to the seasonal method, was one of the first small steps to inform and aware the

Portuguese population for a sustainable construction. But how good were that improvements? How much energy can be saved with a Passive House?

Jacinto (Jacinto, 2014) determined the annual energy needed for a reference new building, during various periods of construction in Portugal according to the three methodologies present in EN ISO 13790 and divided the country on seven regions. This comparison gives a picture of the improvements made during the last 30 years in construction.

The Table 4.2.1 compares the heating energy demand, obtained by the seasonal method, between a Passive House and a reference new building in different locations in Portugal. Due to the diversity of the Portuguese climate, seven different regions were considered (Table 4.2.2). It was considered that the dwelling was placed without any changes in its characteristics.

		Heating energy demand kWh/(m²a)	Max N_i value kWh/(m²a)	Max N_i value (from 1st January 2016) kWh/(m²a)
Beja	Passive House	1,7	47,7	33,0
	Reference Building	14,0	45,0	-
Bragança	Passive House	10,5	82,0	62,2
	Reference Building	56,0	82,0	-
Coimbra	Passive House	2,4	53,1	35,2
	Reference Building	20,0	59,0	-
Faro	Passive House	1,4	43,5	29,5
	Reference Building	10,0	41,0	-
Íllhavo	Passive House	2,4	58,1	40,7
	Reference Building	28,0	61,0	-
Lisboa	Passive House	1,5	47,5	32,2
	Reference Building	14,0	45,0	-
Porto	Passive House	2,5	56,4	40,2
	Reference Building	28,0	61,0	-
Viana do Castelo	Passive House	4,6	68,5	48,8
	Reference Building	31,0	66,0	-

Table 4.2.1 - Heating energy demand for a Passive House and a Reference Building on eight different cities in Portugal and the reference values for the heating demand.

	Degree days for heating (°C·days)	Heating season duration (months)	External medium temperature in winter (°C)	External medium temperature in summer (°C)
Beja	892	5,0	11,1	24,7
Bragança	1066	7,3	8,2	26,2
Coimbra	1239	6,3	10,0	20,9
Ílhavo	1284	6,2	9,7	20,7
Faro	730	4,8	12,2	23,1
Lisbon	889	5,0	11,2	22,8
Porto	1103	6,0	10,5	20,9
Viana do Castelo	1230	6,9	9,5	21,6

Table 4.2.2 - Climate description of the Portuguese cities (analysed from REH)

The results show that a Passive House can reduce the energy demand up to 91 %. Nevertheless, it is noteworthy to say that the values considered for the new reference building were adopted from a standard house which means that some aspects in proportion with the study dwelling may be different and may influence the conclusions.

Portugal stipulates limits for the heating and cooling energy demand of a building. From 1st January of 2016, the reference values of building components were altered. Consequently, the maximum N_i and N_v of the building was also altered.

Looking at the reference values before 2016 and after 2016, it is possible to see a decrease of almost 35% of the maximal heating energy requirements for the same building. These new limits were introduced along with new limits for transparent and opaque elements. A comparison between the Passive House U-values requirements and the new directive are presented in the Table 4.2.3.

According to the Table 4.2.3 the value for external walls or non-heated spaces have lower values than the one proposed by the Passive House. This means that the requirements in the Portuguese construction and components has increased a lot. This will be a great challenge in the next few years, that may have some barriers during the embodied time. These improvements require sometimes high efficient material and most of the products on the market do not achieve this standard, which will imply an increase of the building costs.

	U-value of the exterior building component [W/(m²K)]	**U- value of the installed window (U-value glazing)**
Passive House Standard for Warm climates	0,50	1,25 (1,10)
Portuguese Regulation (2016)	0,50 – 0,30 (external wall $b_{tr}\geq 0,7$)	2,20 – 2,80
Portuguese Regulation (before 2016)	0,90 – 1,75 (external wall $b_{tr}\geq 0,7$)	2,40 – 2,90

Table 4.2.3 – U-values limits, according to the Passive House Standard and Portuguese regulation (before and after 1st January 2016).

The **Erro! A origem da referência não foi encontrada.** shows that in five cities, the heating nergy demand of a Passive House is significant smaller than the limit values imposed by the Portuguese regulations. Additionally, regions with extreme conditions, present the most significant decrease in the energy demand between a new building and a Passive House. Knowing that until 2020, significant reductions in the greenhouse gas emissions (GHG's) need to be made together with improvements in the energy efficiency and renewable energies, the implementation of new building with Passive House Standard can help Portugal to achieve these goals. Another way to accomplish these goals is to retroffit the existing buildings, according to the Passive House concept.

To sum up the comparison with a new reference building provides an overview about how much energy is spent in a standard house in Portugal and how much could be saved if the buildings were built according to the Passive House concept. It was proved that the Passive House can reduce up to 91% of the energy consumption, in all the cities investigated. Cities like Lisbon, Faro and Beja, where the annual heating energy demand is less than 2 kWh/($m^2\cdot a$)], can easily suppress the heating energy demand by considering carefully some aspects, like orientation. Like Ferreira (Ferreira & Pinheiro, 2011), this study also proved that Portugal have conditions to design a low energy building using almost solely passive measures. Nevertheless, a previous study, considering the building characteristics as well as the place where it would be built, should be made in order to find out the most efficient solutions (window's orientation, insulation thickness, glass, etc.) and to attract more buyers and investors. The alteration made in the Portuguese law will impulse an improvement of the construction technics and consequently these new building will provide a better thermal comfort.

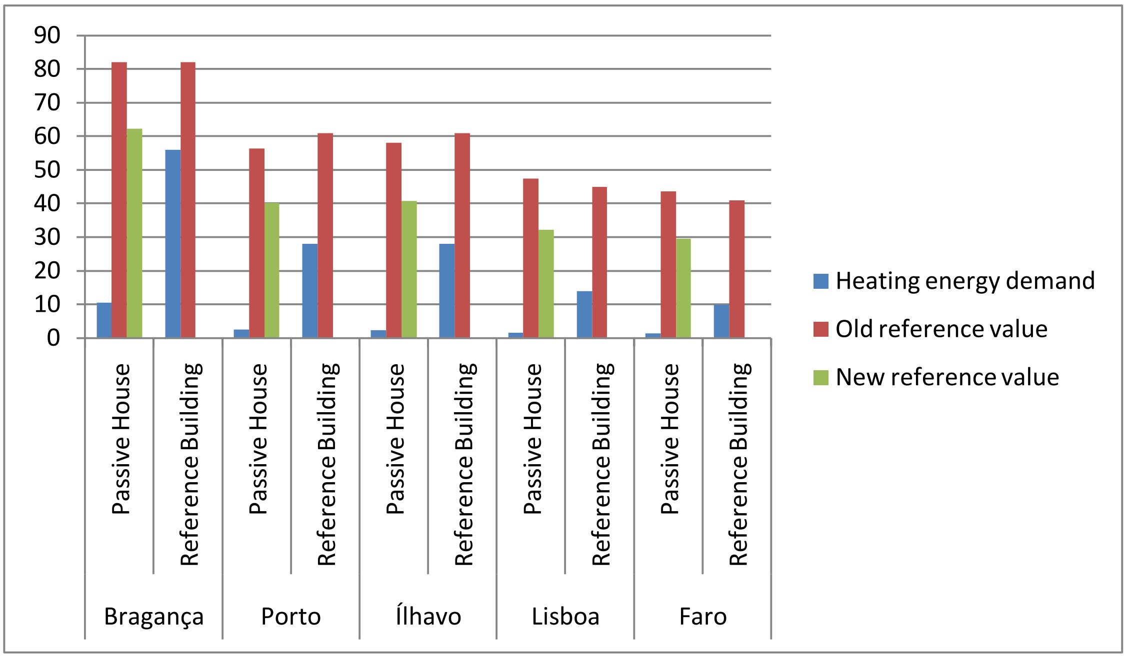

Chart 4.2.1 - Results of the limit heating energy demand for the case study: heating energy limits with the new and old reference values. Comparison with the PHPP results

4.3 The Passive house in different European climate regions

Energy consumption depends on the climate and weather conditions of a specific place. Initially, the Passive House was projected to a typical central European climate. For other regions, the Passive House standard need to be adapted in a particular way, such as in Northern and Eastern Europen where the insulation should be better (Feist, 2007). Therefore, it is important to find out how to make the whole building energy smart, improving not only the energy efficiency of some systems and equipments, but also improving the building`s energy efficiency in general (Ian, 2012). The consideration of aspects such as geometry, construction elements or building orientation can help to reduce the energy consumption. Hence, it was investigated if the dwelling presented in this work will achieve the Passive House requirements in different regions around Europe, without any changes of orientation or construction elements. Using the PHPP 7, five building locations in Europe were simulated: Postdam (Berlin), Dublin, Helsinki, Madrid and Rome. These locations cover a wide range of climate zones: Warm climate, warm temperate climate, cold temperate and cold climate, as can be seen in the Figure 4.3.1.

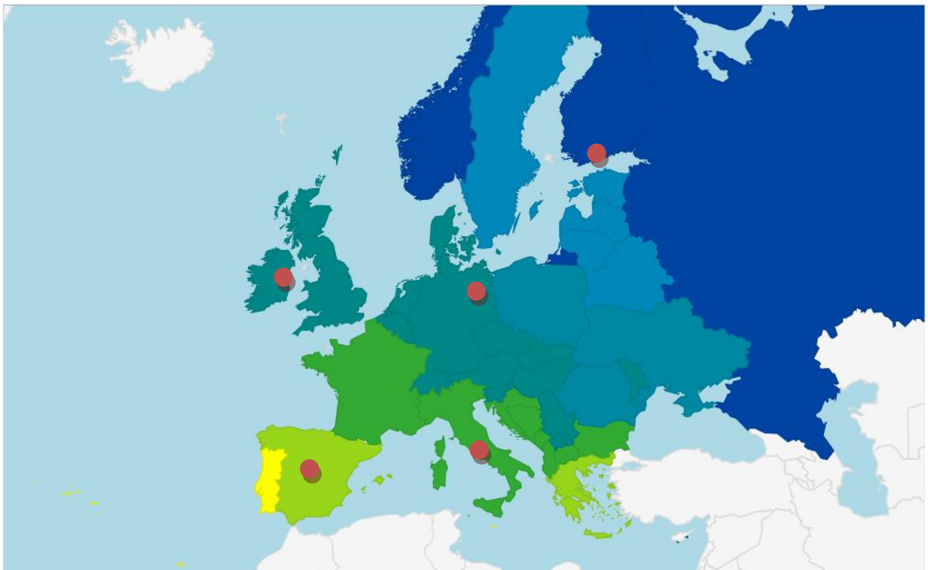

Figure 4.3.1 - Climate zone map according to the Passive House Institute, with the five locations used in this section (Passive House Institute)

The Table 4.3.1 presents some characteristics about the climate in each city where the building was placed as well as the results for three cities in Portugal. The Table 4.3.2 will expose the results obtained for the energy demand in each city. It is also exposed the energy demand obtained in three cities in Portugal in order to compare them with similar climates, like in Madrid or in Rome.

The simulation shows that in Portugal the building have a great performance. However, when it is placed in other cities around Europe the Passive House criteria are not achieved in most of them. Since the requirements for the European Passive House standard allow either the annual cooling demand or the cooling load to exceed the limit, Rome achieved the Passive House Standard. Rome has a Mediterranean climate which is similar as the one in Portugal. The high temperatures in the summer lead to a high cooling demand near to the stipulated limits.

Nevertheless, some results are not so far away to achieve the limits stipulated. This is the case of Madrid were the heating demand are within the limits, but the cooling demand present a slightly higher value. Because the cooling demand and loading demand presents superior values of what is accepted, the house has a high risk of overheating in summer (29% of probability of overheating). The overheating is defined as the frequency that the indoor temperature exceeds a given set point (in the case of PHPP that set point is defined as 25°C). The PHPP recommends that additional measures for cooling should be taken when the overheating rate exceeds 10% (PHPP manual, 2007). Cities in Mediterranean climate zones have both cooling and heating requirements, which requires a more complex solution to deal with energy consumption (Bahrami, 2008). However, simple modifications can reduce the cooling energy demand, like the rotation of the building, placing the façade with the majority of the windows more to northeast, northwest or north, installation of proper solar shading devices, like overhangs, awnings and blinds, which allows the solar radiation to reach the building in winter and block it out in summer, or even opening the windows at night in the cooling season to pre-cool the indoor air. If these measures do not solve the problem, the solution may be the installation of an active cooling system. Previous studies (Badescu, Laaser, & Crutescu, 2010) showed that in warm southeastern climates may be necessary an installation of an active cooling system.

	Type of climate	**Radiation average (south) kWh/(m²·a)**	**Daylight length hours**	**External medium temperature in winter (°C)**	**External medium temperature in summer (°C)**
Berlin	Cold temperate	338	8 - 17	0,4	18,4
Dublin	Cold temperate	391	7,5 - 17	6,7	15,2
Ílhavo	Warm	528	10 - 15	9,5	19,6
Lisbon	Warm	344	10 - 15	12,1	22,4
Madrid	Warm temperate	468	9 - 15	9,6	29
Porto	Warm	380	10 - 15	10,2	19,6
Rome	Warm temperate	574	9 - 15	8,9	26,4
Helsinki	Cold	339	6 - 19	-6,6	16,9

Table 4.3.1 - Climate description of the five European cities (PHPP)

	Berlin	Dublin	Helsinki	Ílhavo	Lisbon	Madrid	Porto	Rome
Annual heating demand kWh/(m²a)	64	41	104	7	1	5	4	8
Heating load W/m²	30	21	41	10	9	11	9	14
Space cooling demand kWh/(m²a)	0	0	0	0	1	24	0	14
Cooling load W/m²	4	0	0	4	9	29	5	12
Primary Energy kWh/(m²a)	219	152	335	67	53	62	59	70
Passive House Standard	No	No	No	Yes	Yes	No	Yes	Yes

Table 4.3.2 - Required energy demand for the building when it is placed in Berlin, Dublin, Helsinki, Madrid and Rome

In Berlin and Dublin, the cooling demand is within the limits while the annual heating demand, the heating load and also the primary energy demand fail. To overcome this problem, energy efficiency measures, such as an installation of better heat recovery, put a thicker insulation layer and installation of windows with a better U-value, should be considered in the project design. This high value of the heating demand can be explained by the fact that in these regions the solar radiation presents low values and the winter temperatures are lower than in the south countries. With this, the heat gains of the building will be lower and once the building is not prepared for big indoor/outdoor temperature differences, the heat transference will be higher.

In the case of Helsinki, the requirements of a Passive House do not follow the exact same regulation as the Passive House Standard. These new criterias were defined by VTT Technical Rearch Center of Finland during the European Projet “Promotion of European Passive House (Ian, 2012). The criteria imposed in Finland are presented in the Table 4.3.3. Nevertheless, even with the increase of the upper limits, the building does not achieve the Passive House Standard. Therefore, the same modifications exposed before for Dublin and Berlin can be implemented also in this case, once the problem is the high heating demand.

Especial attention should be taken to the possibility of the heat recovery unit freezing and the soil freezing due to the lower temperatures in winter.

Annual heating demand [kWh/m²·year]	20 – 30 (depending on the location)
Annual cooling demand [kWh/m²·year]	20 – 30 (depending on the location)
Leakage air rate n_{50} [h^{-1}]	0,6
Primary energy [kWh/m²·year]	130 - 140

Table 4.3.3 - Energy demand limits for Helsinki, according to the VTT

This study proves that *a building which wasn't designed with the concern of the climate conditions where it is placed, probably won't be considered an efficient building in term of energy use and provide for their occupant comfort* (Gonçalves & Graça, 2004). For that reason a detailed study about the proper orientation/location, shading, insulation, air tightness, thermal mass, natural ventilation and daylight should be made (Bahrami, 2008). Additionally, a correct local or regional climate data, including air temperature, humidity and solar radiation are important factors to adopt a proper strategy in the outline phase.

According to the Passive House Institute, each climate requires different criteria in the building envelope and in the building services. The Table 4.3.4 presents the component's characteristics which the building, in the chosen cities should have. According to the data available in this table, the building will not achieve the Passive House certification, once the building components used in Ílhavo do not have the right properties to achieve the requirements. Therefore, some modifications were introduced in the monthly simulation, taking into account the Table 4.3.4 requirements, in order to fulfil the criteria for the new location. For example, the façade with more glazing area was orientated to the south, in the case of cold regions and it was orientated to the north, for warmer regions. Nevertheless, a simple orientation of the building wasn't enough to reduce the values of the heating or cooling demand. Hence, a group of new measures was applied and the obtained results are resumed in the Table 4.3.5.

Since the requirements for the European Passive House standard allow either the annual cooling demand or the cooling load to exceed the limit and still can be certified as a Passive House, the building will be considered as a Passive House in every location. The changes made in the building to achieve the Passive House Standard were dependent on the location.

Building Envelope Criteria							
		Exterior wall insulation (λ=0,035 W/(m·K)	**U-value of the exterior building component [W/(m^{2}K)]**	**Glazing**	**Window frame**	**Shading**	**U- value of the installed window (U-value glazing)**
Warm	Portugal	7 cm	0,50	Double insulated glazing	Conventional window frame	Roof overhang, exterior shading devices	1,25 (1,10)
Warm temperate	Madrid (Spain)	14 cm	0,30	Triple or rarely double insulated glazing	Possible insulated, phC classe or better	Roof overhang, exterior shading devices	1,05 (0,90)
	Rome (Italy)	14 cm	0,30	Triple or rarely double insulated glazing	Possible insulated, phC classe or better	Roof overhang, exterior shading devices	1,05 (0,90)
Cold temperate	Ireland	23 cm	0,15	Triple insulated glazing	Insulated, phB classe or better	Roof overhang, exterior shading devices	0,85 (0,70)
	Germany	23 cm	0,15	Triple insulated glazing	Insulated, phB classe or better	Roof overhang, exterior shading devices	0,85 (0,70)
Cold	Helsinki (Finland)	29 cm	0,12	High performance triple or quadruple insulated glazing	High insulated narrow face with, phA class	Roof overhang, interior shading devices	0,65 (0,52)

Table 4.3.4 - Components guideline (Passive House Institute)

	Berlin	Dublin	Helsinki	Madrid
Annual heating demand kWh/(m²a)	15	12	27	11
Heating load W/m²	12	13	17	10
Space cooling demand kWh/(m²a)	0	0	0	15
Cooling load W/m²	1	0	0	25
Primary Energy kWh/(m²a)	96	83	132	62
Passive House Standard	Yes	Yes	Yes (According to VTT standards)	Yes

Table 4.3.5 - Energy demand for the building after the improvement measures

For example, for Madrid the building was orientated to the north (rotated 70º in the clockwise) and a thicker insulation (200 mm of insulation in the external walls) as well as better windows (U_g=0,75 W/m^2) were installed. In addition was considered that one more window would be open at night during the cooling season and the shading reduction factor will decrease 5%.

In Dublin, the building was rotated 65º in the anticlockwise and was imposed that all the external walls needed to have an insulation layer of 270 mm. Also, a new heat recovery with 88% efficiency was installed.

In Berlin, the building was also rotated 65º in the anticlockwise and was also installed a better heat recovery (91% efficiency). It was imposed that the U-value of the external walls should have a value below 0,12 W/m^2, with a minimum of 230 mm of insulation material. Also the frames from the external door and windows were upgraded (U_g=0,49 W/m^2 and U_f=0,8 W/m^2).

Unfortunately, for Helsinki the simple improvements made in the other cities weren’t enough to reduce the heat demand to new limits stipulated by VTT. Therefore, additionally changes were made, such as an improvement in the walls (it was considered a U-value equal or lower than 0,10 W/m^2) and the in windows (U_g=0,40 W/m^2 and U_f=0,64 W/m^2). In this case, the building should be again careful designed and high efficient materials should be, from the very begin, implemented. One solution could pass by changing the shape and typology of the house, once these two parameters have a significant impact on absorption, storage and consequent release of the heating during the day and night, being a key factor for heating and cooling demands (Bahrami, 2008). Also, a rotation of the building with the maximum glazing area towards the south usually is a good solution, because it will increase the solar gains. A proper insulation of the walls and roofs also decreases the heat losses in winter and in summer reduce the heat transference between the outside and the inside of the building. If these measures were not enough, the implementation of renewable energy sources can compensate part of the heating energy demand.

To summarize, the changes implemented in each city are listed in the Table 4.3.6 to better understanding which measures were applied in each case, a qualitative scale of the level for each measure is given.

	Heat recovery system	**Insulation layer**	**Orientation (Majority of glazing area)**	**Windows**	**Night ventilation**
Berlin	++	++	South	+++	NA
Dublin	+	++	South	++	NA
Helsinki	++	+++	South	+++	NA
Madrid	NA	+	North	+	+

Table 4.3.6 - Summary of the improvement measures according to each city. The symbol "+"means an improvement of that parameter. The symbol "-" means a reduction of the parameter and "NA" means not applied in this case.

Passive House shows that when the climate do not differ much from the original climate for which a building was planned, it will probably achieve the Passive House Standard without any alteration or with some simple changes. Furthermore, due to the different climates that exist in Europe the standard of the Passive House should vary depending on the climate of each country (Utveckling & Wan, 2013). It is noteworthy to say that even with great performances, the Passive House will only accomplish high levels of performance when all the parameters and conditions are analysed since the beginning of the project.

5 CONCLUSION

5.1 Main findings

The main aim of this dissertation was to compare the energy demand results in residential Passive House dwelling, using the two quasi-stead methods described in EN ISO 13790:2008. For the seasonal method was adopted the Portuguese regulation, REH, which is based on EN ISO 13790. On the other hand, the monthly method follows the EN ISO 13790 (Badescu et al., 2011).

The simulation models required data from the building such as: building elements, windows, ventilation system proprieties, amoung others. After the data input in the two simulation programs, were obtained the energy demand for heating and cooling, heating and cooling load as well as primary energy. For the case study, the building proved to have a great performance in the two simulations. Nevertheless, the results presented significant differences in some parameters. In the seasonal method not only the minimum temperature inside the building in winter is 2°C lower, but also the solar radiation has higher values. Hence, the heating energy needs calculated was lower than in the monthly simulation. In other hand, in summer the high values of the radiation, lead to a difficult control of the temperature in the seasonal simulation. Therefore, during the cooling season this model predicts a demand of 18,54 kWh/(m^2·a), while in the monthly simulation the building does not need to be cooled down. The reason why the cooling demand is suppressed in the monthly simulation is because it is possible to increase the day ventilation and considered a night ventilation by opening the windows. Once, there are no cooling demand in the dwelling during the summer, this means that the body heat released from the occupants plus the electronic equipments, a correct window shading and ventilation operation are enough to maintain a comfortable indoor climate. Moreover, if the building was initially designed according to the Passive House standard the heating demand could also be suppressed.

When the building was placed in different cities in Portugal, the Passive House dwelling shows good performance in all cities. Comparing the heating demand of a Passive House and a reference new building in the same city, it was possible to conclude that the Passive House can reduce the energy consumption up to 91%. Nonetheless, the new standard building, in proportion, has a small window's area. Therefore, the values used in this analyse may not give a true comparison, once a bigger glazing area implies more solar gains which result in a reduction of the heating demand.

The next goal of this thesis was to place the Passive House in various climates around Europe. The results demonstrate that cities with a similar climate as Portugal, like Rome can easily achieve the Passive House Standards, however, in places with hotter or colder climates the dwelling does not achieve so easily the requirements. In Madrid, which has a sightly different climate as Portugal, the cooling demand was higher. Thus, was tested if simple improvements on the building would reduce the cooling demand within the limits stipulate by the Passive House. The first modification was rotating the building 70° in the clockwise to minimize the solar gains. Also, it was placed better windows, a thicker insulation layer and it was considered ventilation during the cooling season. In colder climates, the achievement of the requirements needs more improvements. Berlin, Dublin and Helsinki required better windows, a thicker insulation layer and better heat recovery systems. Additionally, the building was rotated in order to place the façade with more glazing area toward the south, increasing the solar gains. With these modifications, the building presented in the all cities values equal or below the limits. To sum up, the Passive House proved to have a great performance in almost all climates around the world, nevertheless a previous study should to be made to determinate the best construction solutions to apply in each case.

The existing energy crises led to a continuous search for new solutions to reduce the uncontrollable energy consume. From the 1st of January of 2021 all new buildings in the European Union will be built according to the nearly-zero building concepts (Langer, Bekö, Bloom, Widheden, & Ekberg, 2015; Directive of the European Parliament and of the Council, 2012). A particular type of "low energy" buildings is the Passive House. Around Europe, there are already some cities and administrative districts that have already stipulated the Passive House standard in their building regulations. In Portugal, Águeda was the first Passive House Municipal, giving funding schemes to motivate the investors and owners to retroffit(Passive House Institute, 2015). To embed it, the Portuguese government and municipalities must become leading actors for implementing sustainable energy policies, creating regulations, fiscal and financial incentives to overcome the existing barriers. Also the labour force need to be educate to know how to implement the new construction technics (Elswijk, 2008). Additional, it is important to inform the end users, who were not involved in the design or building process, about the heating and ventilation system and how to operate correctly with them and thereby achieve a better building energy performance (Mlecnik et al., 2012).

As Winston Churchill said: “We shape our buildings, thereafter they shape us”. This expression may seem a cliché but the truth is that our actions inside a house will influence the indoor conditions. For that reason, living in a house which already provide a high level of comfort will require less effort by the occupant to maintain a good indoor climate. Because energy means money and also less pollution, this concept can presently be the key for a new approach to the current energy consume. So, the final question still remains: when will society starts to be conscious about the world that we live in and act not only to save the planet but also to save money?

5.2 Main limitations and suggestions for future works

The simulations were based on Portuguese regulations for the seasonal method and in the monthly method, according to the Passive House approach. Therefore, in other countries the comparison between the two simulations may lead to a slightly different conclusions. Additionally, the climate data used in the simulations was not similar, once the institution which provide that information was not the same.

The current energetic building certification using in Portugal (seasonal method), it is not adequate to a low energy building like a Passive House, once there is not any modification in the building class from the A+ solution (non-passive design) to the Passive House solution. Therefore, a revision of this new labeling should be made in order to recognize their high performance compared with the standard houses.

During this thesis were found some limitation. Once, the concept is based on a sustainable development principle, a comprehensive analyse should have been made, including the life cycle, where aspects like economic impact, ecologically impacted and environment effects were covered. However, this dissertation does not include an LCA (Life Cycle Assessment) or LCC (Life Cycle Cost). Many studies have been made to prove their importance in the calculation of the energy consumption of a building (Lahais, Henrik, & Blyt, 2012).

In future works, a comparison between the real life scenario data and the two models results is recomended in order to be more conscious about the impact of the occupant behaviour.

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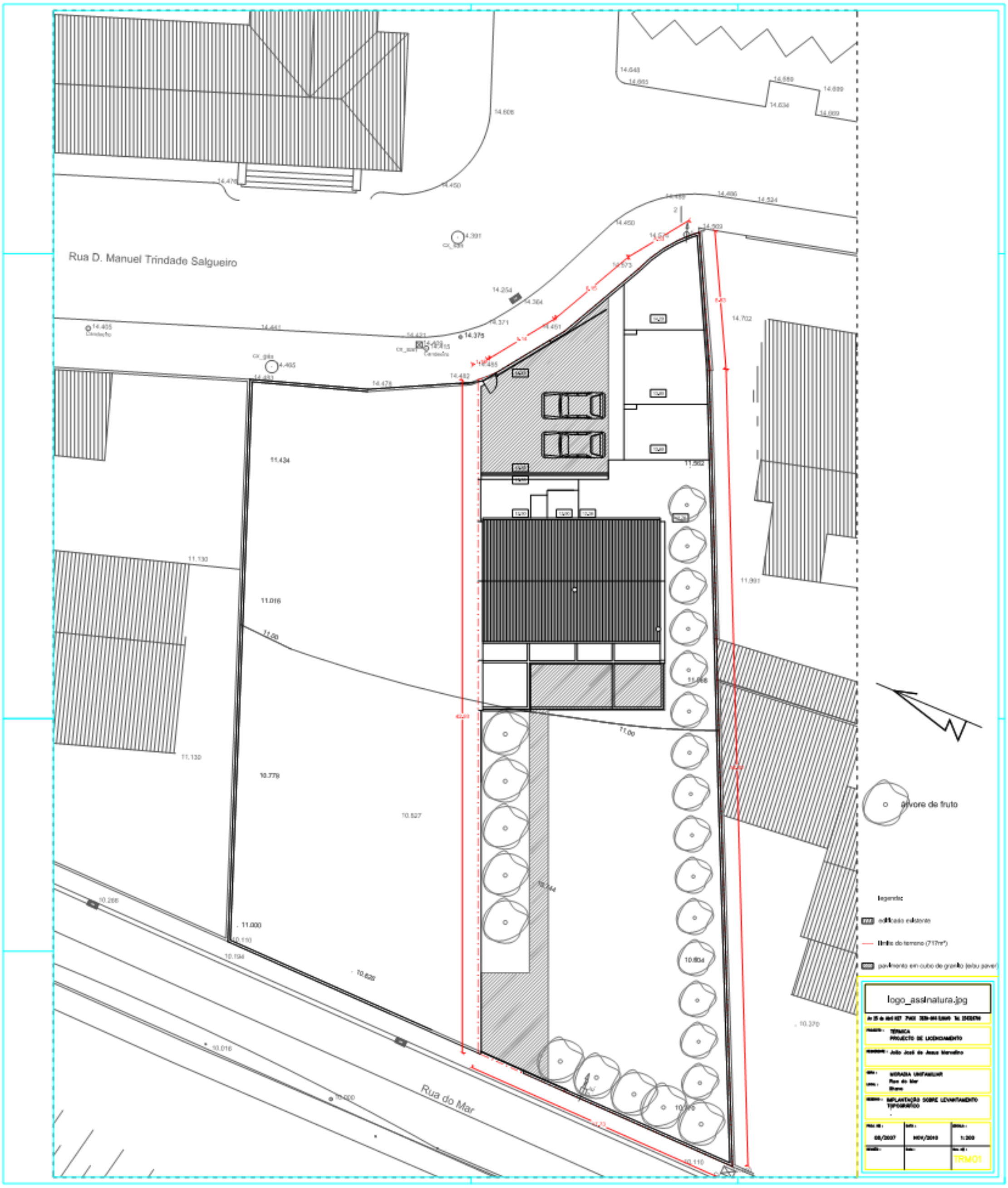
APPENDIX A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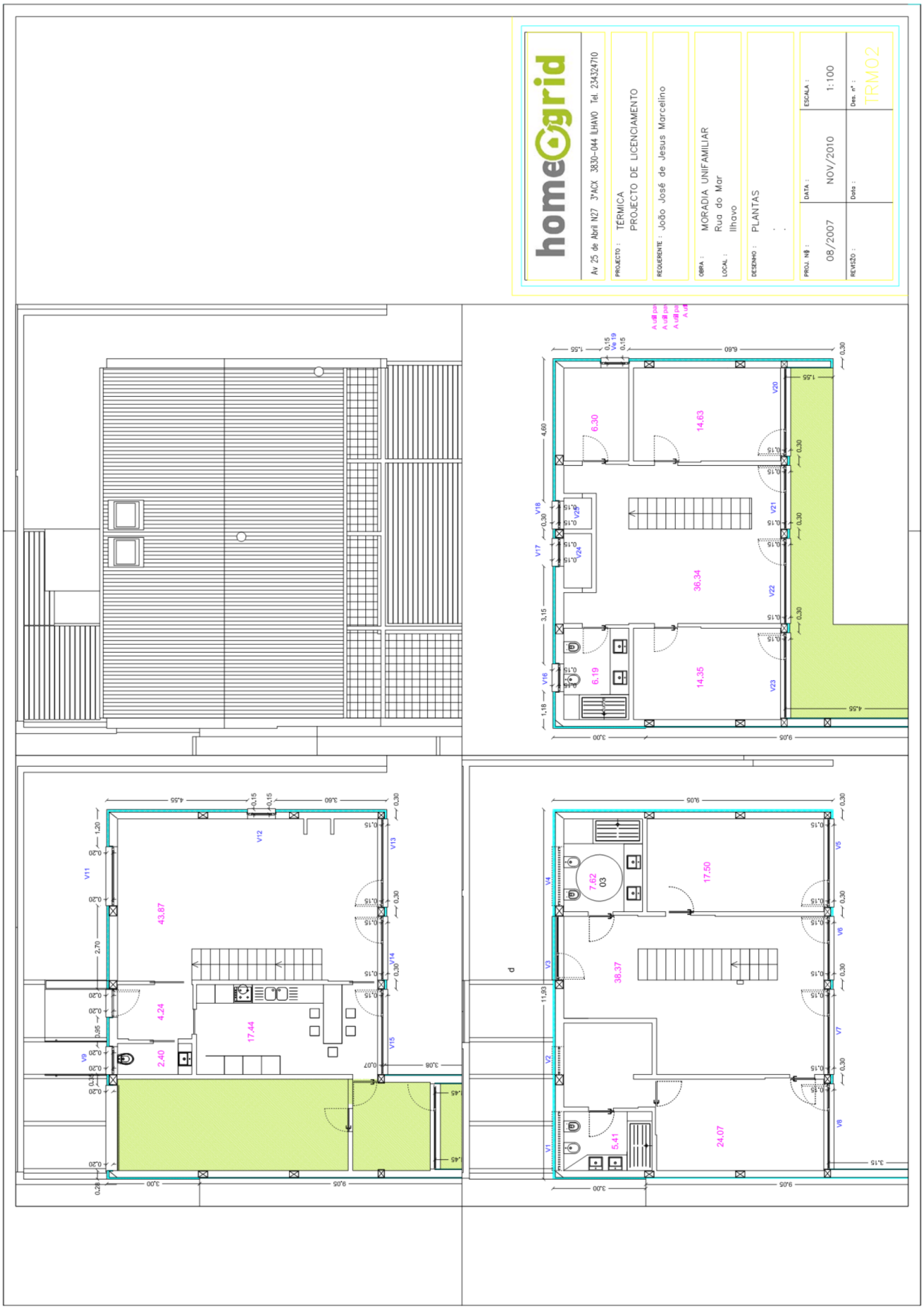
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PROJECTO DE LICENCIAMENTO
João José de Jesus Marcelino
MORADIA UNIFAMILIAR
Rua do Mar
Ilhavo
PLANTAS
08/2007
NOV/2010
1:100
TRM02


homegrid
Av 25 de Abril N27 3ºACX 3830-044 ILHAVO Tel. 234324710
PROJECTO : TÉRMICA
PROJECTO DE LICENCIAMENTO
REQUERENTE : João José de Jesus Marcelino
OBRA : MORADIA UNIFAMILIAR
LOCAL : Rua do Mar
Ilhavo
DESENHO : ALÇADOS
PROJ. Nº : 08/2007
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APPENDIX B

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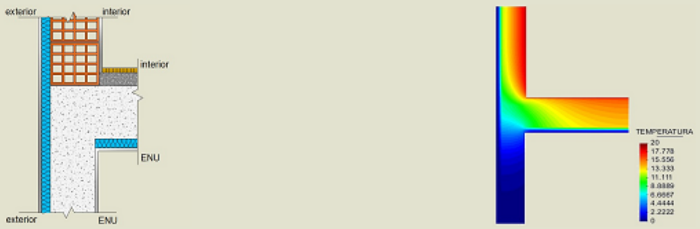
SITUAÇÃO DE PONTE TÉRMICA LINEAR

DESCRIÇÃO

Ligação entre fachada e pavimento sobre espaço não útil. Parede simples em alvenaria de tijolo com isolamento térmico colocado de forma contínua pelo exterior da fachada. Laje de pavimento maciça com isolamento pelo exterior.

Caminho em www.itecons.uc.pt/catalogoptl: Pavimentos > Ligação entre fachada e pavimento sobre espaço não útil > Parede simples com isolamento contínuo pelo exterior > Laje de pavimento isolada pelo exterior > Parede em alvenaria de tijolo



Pormenor construtivo

Perfil de temperaturas

REFERÊNCIA

P.3.3.2.AT

PARÂMETROS

Espessura da laje de pavimento sobre ENU (m): 0,30

Espessura do isolamento na laje de pavimento (m): 0,06

Valor de ψ [W/(m.ºC)]: 0,54

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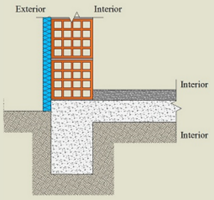
SITUAÇÃO DE PONTE TÉRMICA LINEAR

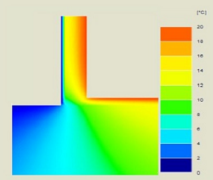
DESCRIÇÃO

Ligação entre fachada e pavimento em contacto com o solo. Parede simples em alvenaria de tijolo com isolamento térmico aplicado pelo exterior. Pavimento não isolado com camada de enchimento em betão de inertes de poliestireno expandido.

Caminho em www.itecons.uc.pt/catalogoptl: Pavimentos > Ligação entre fachada e pavimento em contacto com o solo > Parede simples com isolamento pelo exterior > Laje de pavimento não isolada com camada de forma leve > Parede em alvenaria de tijolo



Pormenor construtivo



Perfil de temperaturas

REFERÊNCIA

P.7.1.1.AT

PARÂMETROS

Espessura da camada de isolamento (m): 0,06

Valor de ψ [W/(m.ºC)]: 0,58

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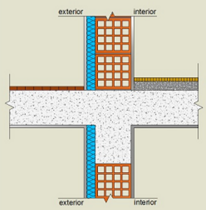
SITUAÇÃO DE PONTE TÉRMICA LINEAR

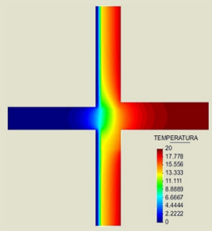
DESCRIÇÃO

Ligação entre fachada e varanda. Paredes simples em alvenaria de tijolo e PTP isoladas pelo exterior.

Caminho em www.itecons.uc.pt/catalogoptl: Pavimentos > Ligação entre fachada e varanda > Parede simples com isolamento pelo exterior > Com ponte térmica plana e sem tecto falso > Paredes em alvenaria de tijolo



Pormenor construtivo



Perfil de temperaturas

REFERÊNCIA

P.5.2.2.AT

PARÂMETROS

Espessura do pano de alvenaria de tijolo (m): 0,22

Espessura da laje de pavimento intermédio (m): 0,22

Valor de ψ [W/(m.ºC)]: 0,95

OBSERVAÇÕES

O valor de ψ apresentado diz respeito à perda total de calor que ocorre pela ligação ψ = ψ(sup) + ψ(inf)

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