Department of Mechanical and Aerospace Engineering

# Impact of different heat gains due to improved appliance efficiency on a building which meets the Passivhaus Standards

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## Copyright Declaration

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Signed: Maria Damaskou Date: 31/08/2016

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Special thanks to my family, without whom I would not have been able to study for this degree. Great thanks also to my friends and classmates for supporting each other during the course and making this year an unforgettable experience.

# ABSTRACT

The Passivhaus standard is the fastest growing energy performance one worldwide. Initially developed in Germany in 1991, it already counts 30,000 buildings meeting it. At the same time, electricity consumption in Europe has increased significantly over the past decades, with the domestic sector consuming almost 30% of electricity demand; hence there is a reasonable trend to improve the equipment efficiency.

This project examines the performance of a model dwelling according to the continuously improved efficiency of domestic appliances and, therefore, the lowered heat gains they offer to its interior. The major objective is to investigate the effectiveness of different heat gains to the heating demands of a Passivhaus building in Scotland during the winter.

In order to understand the concept in depth, an extensive literature research was conducted followed by the development of a dynamic model on the ESP-r design software, to achieve an approach as realistic as possible. Different combinations of building envelope components and air tightness were run for baseline and future internal heat gains in order to compare their results and reach conclusions.

The key finding has been that the more advanced the structure in terms of thermal characteristics of its components and air tightness, the more efficiently the building is able to respond to cold weather conditions and the less its heating demand to maintain the internal temperature within the acceptable levels.

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# 1 INTRODUCTION

## 1.1 Aim of the Project

Nowadays, it has been realised that a transition towards sustainable solutions is much required for the present and future. Given that buildings consume some 30 to 40% of final energy in developed countries and, on top of that, they rely mostly on electricity which has an even worse carbon footprint compared to other fuels, several approaches have been developed to address the buildings' effect on the environment. (Kapsalaki, Leal and Santamouris, 2012). Methodologies, calculation platforms, codes to create toolkits are only a few cases in point of what research has led to in order to achieve this goal.

Policies and Directives related to energy performance of buildings have been applied in several countries around the world; the Energy Performance of Buildings Directive (EPBD) approved in 2002 by the European Union, has been updated in 2010 adapting a "nearly zero" target for new buildings by the end of 2020. Likewise, in the UK where the housing sector is responsible for some 27% of carbon emissions, the Code for Sustainable Homes (CSH) was launched in 2006 to define the criteria for new buildings in accordance with the UK's general aim to reduce carbon emissions by 80% compared to 1990 levels by 2050. (Gupta and Chandiwala, 2009).

The Passivhaus is a construction concept and the leading energy performance standard worldwide, while in numerous European regions it has been implemented as a mandatory minimum standard for the new buildings (iPHA, 2014). It combines a healthy, comfortable and energy efficient living applicable to any climate, based solely on the post-heating or post-cooling of the fresh air mass.

The aim of this dissertation will be to examine how the heat gains from people and equipment affect a dwelling that meets the Passivhaus standards; specifically, since improved appliances reduce the heat gains, it will be tested whether their impact on the space heating demand is considerable or the excellent fabric design alone is able to counteract the internal differentiations caused by variable occupancy and more efficient equipment.

## 1.2 Methodology

In order to approach the aim of the project, a literature review was conducted to understand in depth the Passivhaus standard and define the heat gains in a dwelling according to its equipment and its variable occupancy during the weekdays. The model space was designed with the building simulation software tool ESP-r; key points of the simulation were, firstly, that the design was as close as possible to the limiting values of the Passivhaus standards (a "worst-case scenario") in order to examine whether the building can be certified after the modifications and, secondly, that the focus was on the winter season and on Scotland. Numerous calculations were made on the Microsoft Excel to create Tables of information to be used for the simulation and to present its results. The Passive House Planning Package (PHPP) was finally approached so as to examine whether the increased heat demand of the model would be within the acceptable standards, but the complexity of its calculations and entry data made it difficult to include safe results in the project.

# 2 LITERATURE REVIEW

## 2.1 Key topics

Topics of interest for the project have been:

- Passive House design
- Heat gains by equipment – Experimental results
- Trends in the equipment efficiency
- Heat gains according to the occupant behaviour
- Thermal comfort levels
- Simulation of a dwelling
- ESP-r building simulation software
- Passive House Planning Package (PHPP)

## 2.2 Survey results

A literature survey was conducted in order to assist in the approach of the subject that this project intends to address and understand the reported results of research already carried out in relevant areas. The studies that have been considered present findings after applying modelling techniques, statistical analyses and exploitation of surveys.

The Passivhaus standard, in general, is considered to be a low energy building performance standard; perfectly insulated, airtight envelopes, combined with the use of mechanical ventilation with heat recovery (MVHR) and optimal utilisation of passive solar gains contribute to meet the standards' limitations. At the same time, clearly defined thermal comfort criteria play primary role to the concept and have to be achieved. The functional definition of a Passivhaus, states that:
*"A Passive House is a building in which thermal comfort can be guaranteed solely by heating or cooling of the supply air which is required for sufficient indoor air quality – without using additional recirculated air"* (McLeod, Hopfe and Kwan, 2013).

According to Blight and Coley (2013), several examples of low-energy design failing to result in low measured energy consumption in dwellings have occurred. This failure can be ascribed to occupant behaviour and household variation so it is important that deviations from design can be perceived as reasonable variation instead of a design problem. Generally, it has been found that Passivhaus buildings are less sensitive to behaviour than expected. However, when estimating the energy consumption based on a specific design philosophy, if the final in-use performance deviates from the anticipated one, the design can be seen as failed while it may just be an example of a particular user's consumption being different that the average.

In the same study it is stated that electric use and the subsequent heat gains can diverse up to 30% from the median results causing significant discrepancies among the users. Differences in appliance and lighting use have been observed between different European countries. Using for weighting the "Cost Efficient Passive Houses as a European Standard" (CEPHEUS) data, an average 27% lower use of appliances and lighting is anticipated from a building in the CEPHEUS project to a UK home. This is because the domestic buildings of the CEPHEUS project were fitted with the most efficient 'white' appliances of the time, whereas the UK stock was represented by the notional value. Another point to highlight is that the domestic energy use has changed the previous years, and whilst domestic energy consumption in Europe was at a slightly lower level in 2008 than in 2001, the proportion of electricity going to appliances was 8% higher. Finally, some 80% of the appliance gains happen when there is activity within the home which will be causing other gains, therefore reducing the need for additional heat and rendering the additional contribution from a doubling of appliance gains less useful. Lighting and occupancy gains also are likewise affected by the same phasing effect, to twice the extent; hence only an 11% and 17% increase happen for each doubling in use respectively.

According to Richardson et al (2010), the appliance use within a house is related to the number of people who are inside and awake at a given period of time. This time is referred to as “active occupancy” and it reflects the realistic behaviour of people going about their daily life. The appliances in this study are activated at certain times during the day without details about the appliance usage statistics being necessary.

Firlag and Zawada (2013) mention that, since the energy needed for heating and ventilation in a Passivhaus building is notably less than a standard one’s, heat gains can compensate for some 20% of whole energy loss in the case of a standard building and up to 65% in a passive house. In the same paper it is highlighted that a fluctuation of internal heat gains can result to an important change of the internal air temperature and requires specific control strategies to be handled. Appropriate control is essential to ensure good thermal comfort as well as high energy efficiency. That explains why precise building and system modelling tools have to be exploited in order to predict accurately the internal environment conditions in a very low-energy building such as a Passivhaus or a nearly zero-energy one, and estimate correctly its energy needs.

Wilkins and Hosni (2000) conducted a research about the importance of the heat gain from equipment in determining the overall cooling load of a space. Extensive measurements concluded that the actual heat gain from equipment is often some half of the indicated one on equipment nameplates or even less. In order to analyse these diversity factors of the equipment, measurements were taken at panels that serve large areas of office buildings. In the same area of interest, Duska et al (2007) found that for typical office equipment with nameplate power consumption of less than 1,000 W, the actual total heat gain to nameplate ratio ranged from 25% to 50%. When all tested equipment was taken into consideration, the range was even broader. All research completed by the publication of that paper, suggested that it was not possible to define a standard ratio value which could be applied to all nameplate data to obtain a useful estimation of the actual heat gain.

Hosni, Jones and Xu (1999) had also approached the manufacturers' power ratings - which are usually based on instantaneous measurements while the equipment is working at maximum capacity - and had realized that the equipment nameplate values when used to calculate the cooling load may lead to oversizing of air-conditioning equipment, which afterwards may result in additional cost in both the initial equipment purchase and the operation of the cooling system. In fact, in some cases, the power rating of a component, e.g., a power supply in a personal computer, is used as a nameplate value that is irrelevant to the actual power consumption of the equipment.

As ASHRAE suggests, another significant factor to be taken into account when calculating the cooling load is the split between the radiant and convective heat load from the equipment. On the one hand, the convective portion of the heat gain is an instantaneous load since it is added to the room air by natural or forced convection without time delay; on the other hand, the radiant portion of the heat gain is absorbed by the room surfaces and dissipated over time. 20% to 80% of the heat gain from machinery and appliances may be classified as radiant heat gain. The importance to specify the split with such a wide range limit lies on the estimation of the equipment sizing and design calculations (Hosni, Jones and Xu, 1999).

The initial literature review offered a variety of information about the different areas that the project aims to cover, namely the occupancy and appliances, and the heat gain by them. The interrelation between them was not clearly defined from the search on Google Scholar. According to the survey, a rough conclusion was that reasonable differentiations either in the occupancy levels or in the efficiency of the equipment have no great impact on the heat demands of a Passivhaus building; however, the simulation tool ESP-r was expected to provide us with accurate results.

# 3 INTRODUCTION TO THE PASSIVHAUS CONCEPT

## 3.1 Approach of the concept

As analysed by the Passive House Institute, the Passive House Standard was initially developed and applied in Central Europe where the typical heating systems are centralised hot water heating systems which consist of central oil or gas boilers, radiators, and pipes. The standard buildings in this particular area have an average heating load of approximately 100 W/m² (or approximately 10 kW for a 100 m² apartment). The concept of the Passivhaus Standard is based on the aim to reduce heat losses to an absolute minimum, thus rendering large heating systems such as the typical one just described, unnecessary. A post heating coil is adequate to deliver via the supply air the low heat demand existing in a building whose peak heating loads are up to 10 W per square meter of living area. A building that does not need the installation of any heating system other than post air heating is called a Passivhaus; specifically, no traditional heating or cooling systems are required. The Passivhaus as a concept and physics behind it remains the same for all of the climates around the world. However, although the Passivhaus is defined by the same principles across the world, the details of construction have to be adapted to the specific climate at hand. For instance, a building fulfilling the Passivhaus Standard will look much different in Northern Europe than in Africa.

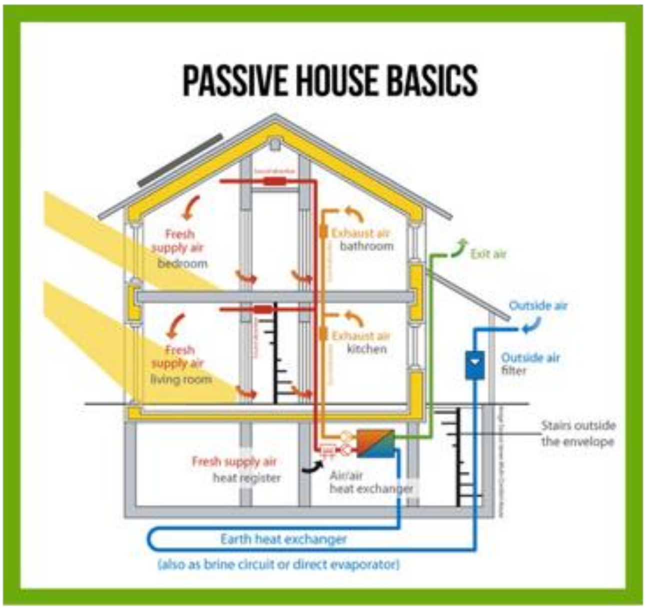


*Figure 1 Passive House basics (Source: http://www.egreengroup.com/passive-house.html)*

## 3.2 Benefits of the Passivhaus standard

Passivhaus Homes LTD (2014) have summarised the following benefits in their "The PH15 kit" to explain the extremely high efficiency of the Passivhaus standard:

- Reduced energy bills and consequently less exposure to differentiations of the fuel prices
- Elimination of drafts and cold spots during the winter which maintain an excellent indoor comfort
- Lower indoor temperatures compared to typical buildings during the summer
- Enhanced indoor air quality which can be potentially beneficial to the residents' health
- Lower noise levels in the indoor space when the windows are not open due to the triple glazing
- More space available since no heating systems such as radiators are installed
- Less equipment and technology installed which leads to reduced costs for maintenance reasons
- Durable fabric since it consists of high quality materials
- Wide variety of designs, layouts and materials can be applied

## 3.3 Passivhaus design principles

The Passivhaus in not a brand name but a combination of construction details to apply the idea anywhere desired. The principles on which the Passivhaus design is based, are presented in the following tables that summarise the BRE guide to designers and local authorities (Passivhaus (passivhaus.org.uk), 2011).

*Table 3-1 Building Energy Performance Criteria*

| Building Energy Performance Criteria | |
|---|---|
| Specific heating demand | ≤ 15 kWh/m$^2$ per year |
| Specific peak heating load | ≤ 10 W/m$^2$ |
| Specific cooling demand | ≤ 15 kWh/m$^2$ per year |
| Primary energy demand | ≤ 120 kWh/m$^2$ per year |

The components of the building should meet the following criteria:

*Table 3-2 Elemental Performance Criteria*

| Elemental Performance Criteria | |
|---|---|
| Air changes per hour | ≤ 0.6 (n50) |
| Walls, roofs and floors U value | ≤ 0.15 W/m$^2$K |
| Doors | ≤ 0.8 W/m$^2$K |
| Glazing area U value | ≤ 0.8 W/m$^2$K |
| Glazing area installed U value | ≤ 0.85 W/m$^2$K |
| Solar transmittance G value | ≥ 0.5 |

Further targets:

*Table 3-3 Services, Thermal and Acoustic Comfort Performance Criteria*

| Services, Thermal and Acoustic comfort Performance Criteria | |
|---|---|
| MVHR heat recovery efficiency | ≥ 75% * |
| MVHR electrical efficiency | ≤ 0.45 Wh/m$^3$ |
| Thermal bridging (linear psi (Ψ) value) | ≤0.01 W/mK |
| Overheating frequency | ≥ 25ºC ≤ 10% of year |
| Maximum sound from MVHR unit | 35 dB (A) |
| Maximum transfer sound in occupied rooms | 25 dB (A) |

* according to Passivhaus standards, not manufacturer's rating

## 3.4 Design details

According to the same as previously BRE guide (Passivhaus (passivhaus.org.uk), 2011), designers should take into account the following design details in order to meet the criteria presented in the precious section for the Passivhaus Standard:

- *Orientation:*
  Where possible a Passivhaus building situated in the Northern hemisphere should be orientated along an east/west principle axis so as to face within 30 degrees of due south. This orientation assists the building to maximise the benefit from the useful solar heat gains, which are predominantly available to south facing facades during the winter. Conversely, north facing facades are the beneficial ones and should be applied in the Southern hemisphere.

- *Building Form:*

  The compactness of a building is indicated by the surface area to volume (A/V) ratio. This ratio, between the external surface area and the internal volume of the building, allows useful comparisons of its efficiency relative to the useful floor area. Practically, small buildings with an identical form have higher A/V ratios than their larger counterparts. As a result, it is advisable to prefer the design of small detached buildings with a very compact form. A favourable compactness ratio is suggested to be one were the A/V ratio does not exceed the $0.7m^2/m^3$ value.

- *Construction materials:*

  Numerous construction methods and combinations can virtually be applied successfully when designing a Passivhaus building. Masonry (cavity wall and monolithic), timber frame, off-site prefabricated elements, insulated concrete formwork; steel, straw bale and many hybrid constructions have been utilised in Passivhaus buildings with positive results. The design however needs attention to be given to the combination of the materials utilised for the wall and roof constructions as, apart from the structural integrity that they have to maintain, they are also expected to meet the required U values and eliminate thermal bridges. Reducing the heat losses through the building fabric and the energy required for space heating, enhances the thermal performance of the construction which is the substantial aim.

- *Glazing Units:*

  In the Northern hemisphere, the exploitation of the useful solar gains when designing a Passivhaus requires the glazing to be optimised on the south facade using approximately 25-35% of this side to install glazed parts, whereas the glazing on the North facade should be as low as possible. In order to both minimise the unwanted heat losses through the windows and increase the surface temperature of the inner pane thereby reducing radiant the sensation of cold "draughts" from the glass and the possibility of mould growth, many European climates can be addresses with double glazing of high quality to achieve the Passivhaus standard; in the UK however, the triple glazed windows are the ones that should be installed.

- *Solar gains and shading:*
  The efficient use of the sun is crucial for the Passivhaus constructions, since solar gains are a most useful component to the free heat gains provided to the building. In order for the sun to be effective, the orientation and quality of the glazing should be the optimal ones. However, it should be taken into account that much glazed areas can have an adverse effect during the summer and increase the overheating risk. For that reason, seasonal and permanent shading devices are recommended to be installed to prevent the high summer sun angle particularly on South, West and East facades. The optimal performance is achieved when the glazing and shading are fine-tuned on each facade of the construction.

- *Thermal Bridges:*
  Geometric junctions and connections between elements typically allow a thermally conductive bypass route for heat loss and must be minimised by designing carefully the features which intersect with the fabric of the building exterior. Certain intersection points which play a pivotal role are the window frames, exterior door frames, roof joists, foundations of the building and the points where MVHR interacts with the building exterior piercing the latter for the supply and extract vents. Strategic placement of external insulation materials used in the construction of these intersections can not only ensure reduced thermal bridges but also sometimes negative psi ($\Psi$) values, which imply that a junction is so well insulated that the two dimensional heat flow through the junction is less than the respective one dimensional heat flows.

- *Airtightness:*
  High airtightness levels are required so as to reduce the heating demand and prevent warm moisture laden air from entering the fabric. They only method to reach them is using air tight membranes or barriers within each of the building elements. In the BRE guide it is highlighted that at least two airtightness tests should be included in the construction schedule.

- *Mechanical Ventilation with Heat Recovery (MVHR):*

  Since ventilation losses affect considerably the heat losses in low energy buildings and the indoor air quality is a significant factor of the Passivhaus structures, a ventilation system imperceptibly supplies constant fresh air, maintaining excellent indoor air quality without unpleasant draughts. A highly efficient MVHR unit allows for the heat contained in the exhaust air to be re-used since the supplying fresh air is filtered and post heated.

- *Primary Energy and efficient appliances*

  Primary Energy is considered to be the Energy that exists in the natural environment before conversion processes; specifically, it is the Energy that can be found in a raw, unprocessed fuel when it is extracted or the one that be harnessed by renewable energy sources. The Passivhaus buildings are limited to use only Primary Energy so as to eliminate the carbon emissions, especially the ones associated with electricity which can be used for example for electric resistance heating. This target can be achieved if appliances with high energy efficiency are installed (A++ rated appliances).

  The BRE guide though, highlights that PHPP is designed not to address the energy generated by Photovoltaics as Primary one, in order to avoid low energy efficiency to be offset by the exploitation of renewable energy resources.

# 4 SOFTWARE – ESP-r

The ESP-r simulation tool has been developed since 1974 by the University of Strathclyde. It is an open source programme which can be exploited to simulate the performance of a building in a most realistic way, exploring the complex interrelationship among the form, fabric, plant, air flow and control of the examined building.

On the one hand, ESP-r in advantageous in terms of providing results for specific advanced technologies such as natural ventilation, heat demand, contaminant distribution and control systems. Furthermore, it facilitates its combination with other programmes and, for instance, the geometry of the building under examination can be input via CAD tools. On the other hand, it requires advanced technical knowledge of the subject and, by its overview, it is advised to be learned with the assistance of a mentor rather than trying self-instruction.

It is used for the needs of the current project to simulate a model Passivhaus dwelling and deliver results about its heat demands for different internal heat gains which are calculated according to the occupancy and the efficiency of the domestic appliances.

Ideally, the Passive House Planning Package (PHPP), initially introduced in 1998 by the Passive House Institute and based on Microsoft Excel, would have been exploited to double check the ESP-r results. The PHPP is a trustworthy software when examining the following:

- Heating and cooling demand per year [kWh/($m^2$a)] and maximum loads [W/$m^2$]
- Comfort during the summer and frequency of overheating [%]
- Annual demand for renewable primary energy (PER) and primary energy (PE) of the total energy services throughout the building [kWh/($m^2$a)]
- Assessment of the renewable energy gains per year [kWh/($m^2$ground a)]

In order to reach the above results, several data are input on the Excel, namely the floor areas, the U values of the construction materials and the glazed parts, the shading, details about the ventilation, the heat gains, the heating demands and loads etc. However, due to lack of information, safe results are impossible so the rough ones obtained are not cited after all.

# 5 HEAT GAINS

## 5.1 Solar heat gains

According to the Passive House Institute, the Passivhaus buildings use in a most efficient way the sun, the internal heat sources and heat recovery; hence, conventional systems for heating are not necessary even if the building is exposed to extremely cold weather conditions during the winter. Passive cooling techniques - strategic shading is a case in point – are exploited during the warm months to maintain the interior comfortably cool.

The Passive solar heating design, also known as passive solar design, when designed appropriately is able to supply the building with both heating and cooling.

“Passive solar systems are used to collect, store and distribute thermal energy by natural radiation, conduction and convection through sophisticated design and wise selection of building materials” (Paul, 1979).

The Active solar uses electrical or mechanical equipment (solar collectors, chillers etc.) to regulate the heat that can be usable of a system; on the contrary, the Passive Solar takes advantage either of solar radiation to trap heat inside a building or airflows that remove the heat and trigger cooling effects. These crucial factors combined with numerous others - the local climate, the season of the year, the orientation of the spaces, the quality of the insulation and of the materials used to construct the building which defines the heat transfer and thermal capacity, the glazed areas, potential shading, the occupancy levels – play pivotal role in determining the amount of heat in the investigated building.

Barber of East Carolina University suggests the separation of the systems which use the solar energy in passive ways to three categories, direct, indirect and isolated gain.

- Direct gain is the prevalent and simplest application of Passive solar energy; in this way, the glazing of the space permits the solar radiation to enter the interior by the direct sunlight. In the Northern Hemisphere, this happens more efficiently through the south-facing side of the building – where the angle of the sun during the winter months offers direct solar radiation to the buildings, whereas the angle during summer months prevents it (Figure 5.1.1). Conversely, in the Southern Hemisphere, the north-facing side is the beneficial one. For best results, the technique should be combined with appropriate materials to distribute and trap the heat in the space.

- Indirect gain, as shown in Figure 5.1.2, is commonly captured by a south-facing wall of high thermal capacity. The solar radiation that enters the glass is trapped as heat in the wall, and afterwards it is transferred in the interior via thermal masses. In order to circulate the air and distribute the heat, ventilation for airflow is implemented at the top and bottoms of that south-facing wall. This practice is regularly assisted by shading to avoid overheating during the warm months.
- Isolated gain is a most advantageous method and applicable both to new constructions and existing buildings. Pivotal role is played by the ventilation and natural or forced convection; they deliver the heat obtained by the solar radiation which is absorbed by a separate collector at the exterior, to the interior of the building. This application has the disadvantage that requires slight changes to be implemented to the external design (Figure 5.1.3).

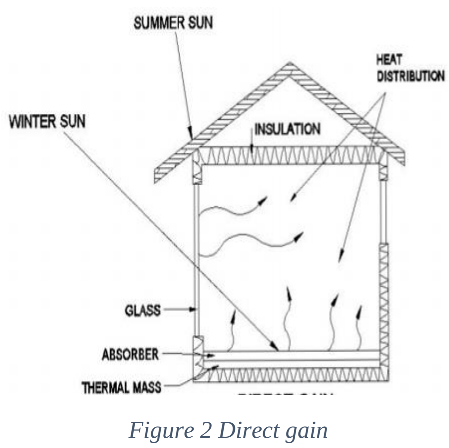

*Figure 2 Direct gain*

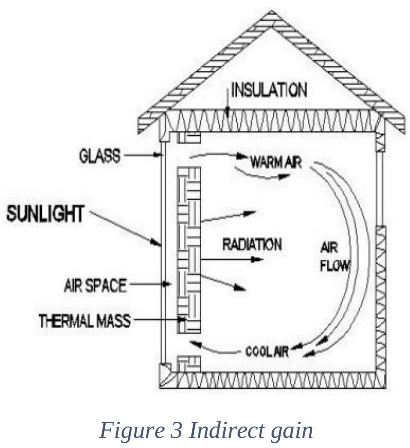

*Figure 3 Indirect gain*

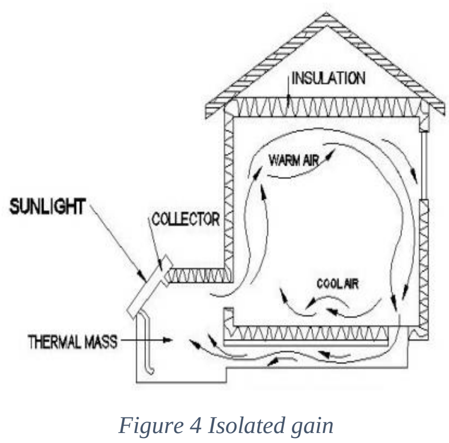

*Figure 4 Isolated gain*

The passive cooling methods are not of particular interest for this project, however, it could be cited that the prevalent ones are the shading above the openings, increased natural ventilation, and use of glazing characterised by low solar and thermal transmission.

## 5.2 Internal heat sources

Badescu and Sicre (2003) follow the German Passivhaus Institute guidelines that resulted from the examined prototype Passivhaus of Kranichstein, and cite eight different categories of both positive and negative internal heat sources. They are the following:

1. Heat released by the residents:
   For an average German family which consists of two adults (husband - wife) and two children, a detailed time schedule was prepared for every working day and the weekends. The heat fluxes for the adults were 92 W by 20 °C and 98 W by 18 °C (reduced by 30% when sleeping) and 60 W for the children with the same reduction during the night.
2. Heat released by electrical appliances:
   The electrical appliances considered were: lighting (14 W), fridge (heat flux: 10 W), freezer (30 W), notebook (25 W), radio/hi-fi (20 W), hoover (900 W), iron (500 W) and hair drier (450 W). Another detailed time schedule was developed for the different electrical appliances, for all the working days and the weekends.
3. Heat released by the cooking stove (heat flux: 26.5 W)
4. Heat loss of the hot water pipes of the residence (heat flux: 3.3 W on average daily).
5. Average washing, bathing and evaporation (heat flux: 10.5 W).
6. Heat transfer to the fresh water pipes of the residence:
   During the colder months (November to March), the average transfer of heat from room to the fresh water (heat flux: −4 W) and bathroom (−3.3 W).
7. During the same cold season, the average transfer of heat from room to the WC flush water tank (heat flux: −4 W), bathroom (−3.3 W).
8. During the same cold months again, heat gain because of the water condensation and evaporation:
   Average heat sink because of the evaporation (enthalpy loss) (heat flux: −115 W).

## 5.3 Appliances

### 5.3.1 Appliance efficiency trends in Europe

As Borg and Kelly (2008) state, domestic electricity consumption is increasing in Europe, accounting for some 21% of final energy demand; it is highlighted that the domestic sector alone is responsible for around 25% of the final energy consumed and almost 30% of the demand for electricity. This increase is addressed by offering initiatives to its residents to replace appliances with high electrical consumption with more efficient ones. As for the effect of this trend to the electrical demand, it is indicated by the results of the above research that energy efficient appliances reduce the electricity demand and benefit the domestic households in terms of reducing their annual average energy consumption, however its peak values are not affected to a considerable extent as instantaneous demands are susceptible to the combination of appliances used simultaneously.

The main reason why electrical demand in the domestic sector is increasing has been the increase in the number of electrical appliances such as computers, televisions and, in Southern Europe of domestic air conditioning. Additionally, social and demographic changes affect the size of the households and consequently the energy demand. Specifically, between 2002 and 2008, the electrical energy consumption in countries bordering the Mediterranean ones rose by some 3.7% annually, whereas in the rest of the Europe around 2% increase was noticed. The European Union has introduced several initiatives to confront the growing demand for electricity such as the energy labelling of popular appliances.

A more detailed analysis of the trend is presents by De Almeida et al. (2006) in the project "Residential Monitoring to Decrease Energy Use and Carbon Emissions in Europe (REMODECE)". The increase by 2% per year stated earlier of the electricity consumption is associated with:

- Need for higher levels of comfort and amenities
- Widespread use of new load types which have become very popular recently
- Increase in the use and size of equipment, as well as the presence of some in multiple numbers in each household

- Need for more traditional appliances had not been saturated
- Increase in the single family homes and the size of the apartments

Based on the International Energy Agency (IEA) it is highlighted in the project that despite the policies to address the increase in electrical energy consumption, the latter will be 25% higher in 2020 compared to the 2000 levels and 13% higher compared to the 2010 ones. Special interest is attracted to the fact that the higher increase in electricity demand is observed in the standby mode power consumption, which is predicted to be responsible for the 15% of the total consumption by appliances by 2030. The average domestic consumption of electrical energy in Europe was estimated to be some 2700 kWh annually, while in the UK it was around 4000 kWh during the previous years (2014, 2015).

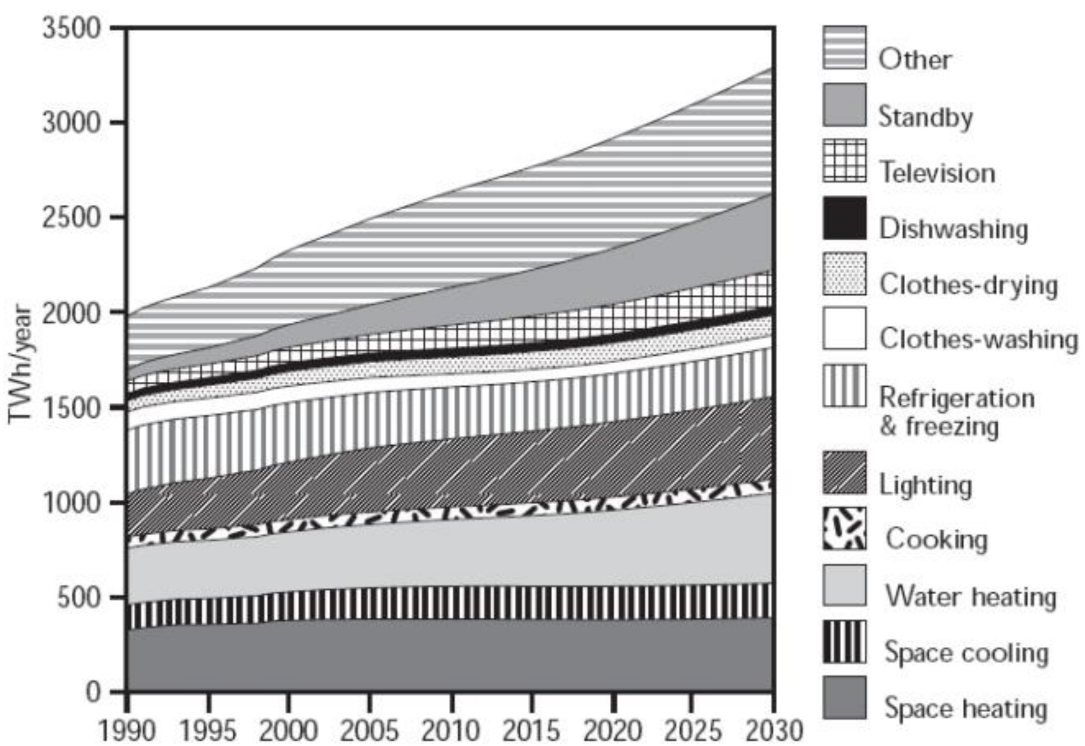


*Figure 5Projected IEA domestic electricity consumption(Source: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.622.4340&rep=rep1&type=pdf)*

REMODECE suggests that a switch to the Best Available Technology and Best Practice behaviour (BAT/BP) can lead to a 48% reduction in the consumption of electricity.

Huge savings by changing to the BAT can be achieved by the cold appliances, computers, televisions, ovens and lamps. Emphasis is given on the change to A+ and A++ energy labelled categories of appliances (which represent only a 10% of the appliances used in the European Union) and compact fluorescent bulbs and LEDs. The annual savings from such a switch are estimated to be around 1300 kWh per European household.

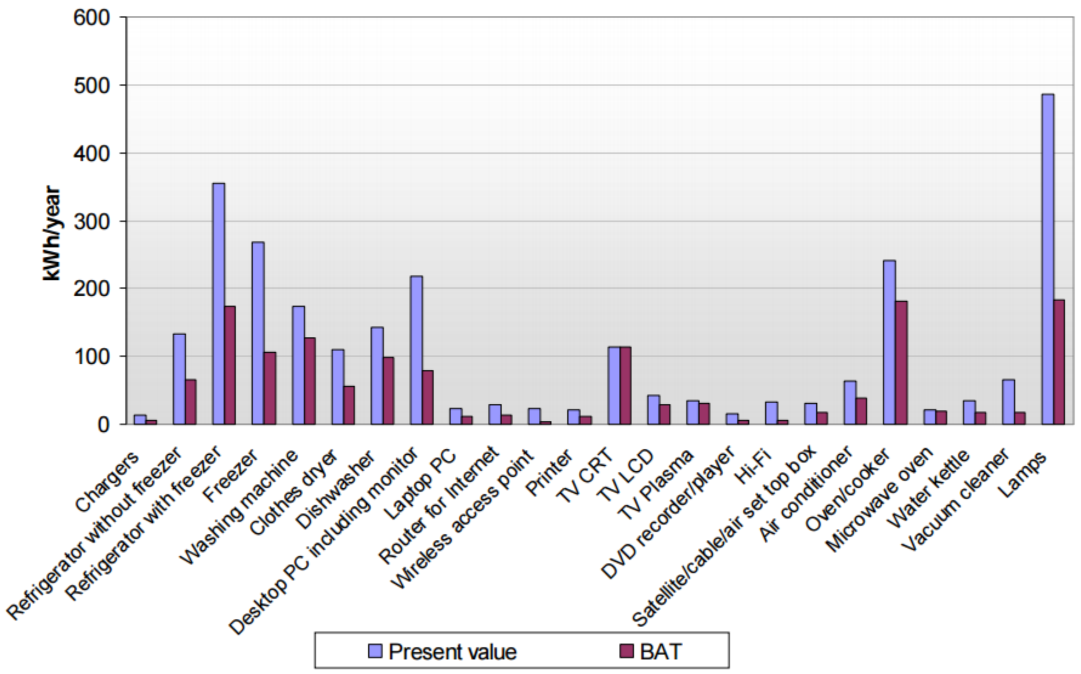


*Figure 6 Potential Electricity savings per appliance per household by switching to the BAT (Source: [http://remodece.isr.uc.pt/downloads/REMODECE_PublishableReport_Nov2008_FINAL.pdf](http://remodece.isr.uc.pt/downloads/REMODECE_PublishableReport_Nov2008_FINAL.pdf)*

The Lighting has conflicting trends, despite the huge benefit in terms of lifespan and running costs of new technologies, the European residents until recently have not been well informed about the CFLs and they did not prefer them when replacing a light bulb. However, the last years their penetration is growing since they reduce consumption even by 75% compared to the conventional light bulbs. the LED lamps offer huge savings as well and are entering gradually the market.

### 5.3.2 Scaling Factors for selected domestic appliances

Borg and Kelly (2008) present a most valuable table with the annual scaling factors by which the change of domestic appliance profiles are reflected. The data were based on the UK's Department for Environment, Food and Rural Affairs (DEFRA) Market Transformation Program (MTP) in combination with the findings of investigating Italian dwellings – the intra-country validity of this combination was ensured by the fact that the MTP is predominantly based on the energy efficiency labelling programme used throughout the European Union.

The "What IF? Tool" database of the MTP programme shows an estimation of the energy consumption of commercial and domestic appliances in the future and, among the scenarios presented the "Earliest Best Practice Scenario" is cited below. The scaling factors for the domestic appliances were calculated by dividing the electricity consumed in 2008 - reference year for that work - by the expected electrical energy consumption in 2020. The resulting factors are predominantly affected by the development of the technology and therefore the device average power draw. However, changes in residents' requirements or behaviour, such as a potential trend from the traditional cooking using electric ovens to ready-cooked meals prepared by the microwave ovens. As a result, the scaling factors also depend on the time the appliance is active and its average steady-state power demand. The figure below shows the trend of the Scaling factors from 2008 to 2020.

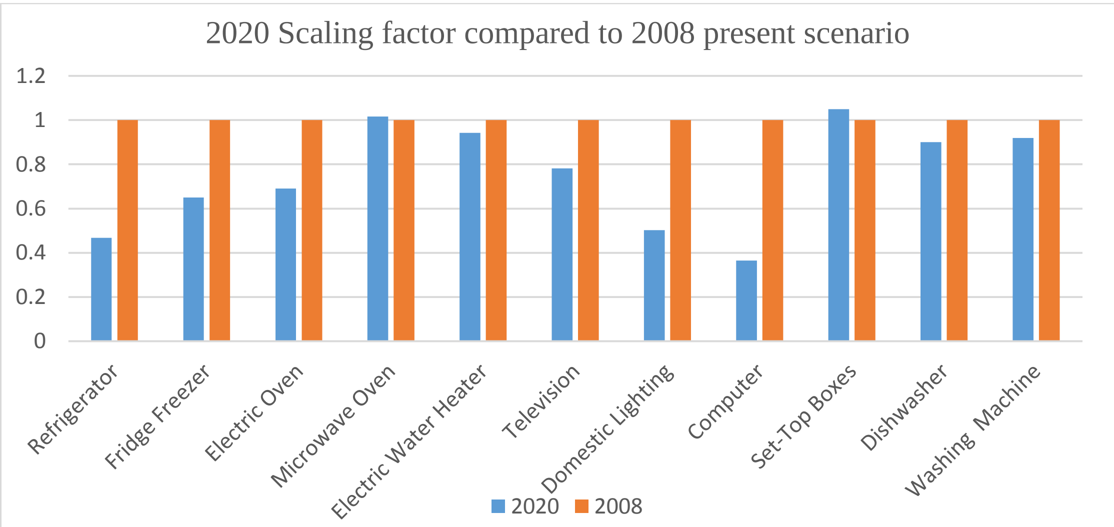


*Figure 7 2020 Scaling factors for selected appliances compared to the 2008 ones*

The following table is the one presented in the paper and its data are used in the next units to define the expected heat gains from the domestic appliances in the future.

*Table 5-1 Scaling factors for selected appliances under the future Earliest Best Practice Scenario*

*(Source: Borg and Kelly (2011)*

| Appliance | 2020 Scaling factor compared to 2008 present scenario | Application of Scaling factor | Rationale behind assumed change |
|---|---|---|---|
| Refrigerator | 0.467 | reduced power demand | Shift towards A++ technology. |
| Fridge Freezer | 0.65 | reduced power demand | |
| Electric Oven | 0.69 | reduced time-in-use | Reduction in cooking time, driven by technology improvements and aptitude towards more ready-made meals. |
| Microwave Oven | 1.016 | increased time-in-use | More frequent use. |
| Electric Water Heater | 0.943 | reduced time-in-use | Slight improvement brought about by better insulation. |
| Television | 0.782 | reduced power demand and standby | Technology evolution leading to OLED. Envisaged that new technologies will be mature and efficient by 2020 with additional energy-efficiency features such as automatic switching off during prolonged stand-by periods or motion sensors. |
| Domestic Lighting | 0.502 | reduced power demand | Increased use of Compact Fluorescent Lamps (CFLs) and LEDs, with direct replacement of tungsten filament lamps [40]. Given that a range of power ratings is equivalent to an incandescent bulb the scaling factor represents a conservative average of the future demand. |
| Computer | 0.364 | reduced power demand | General improvement in energy-efficiency. |
| Set-Top Boxes | 1.05 | increased power demand | Although more elaborate and powerful set-top boxes will be available, efficiency is expected to improve slightly. |
| Dishwasher | | reduced power demand | Improved technology and better detergents. |
| (65 Deg°C cycle) | 0.845 | | |
| (55 Deg°C cycle) | 0.902 | | |
| Washing Machine | | reduced power demand | Improved technology with better laundry load management. |
| (90 Deg°C cycle) | 0.958 | | |
| (60 Deg°C cycle) | 0.895 | | |
| (40 Deg°C cycle) | 0.902 | | |

### 5.3.3 Appliance electricity consumption trends in the UK for different appliance categories

Combining information from the previous unit with data collected from the ECUK Tables for 2016 from the Department for Business, Energy & Industrial Strategy, the tables below show the trend to different appliance categories. 1990 is considered to be the baseline year and the consumption of electricity for the following years as a percentage compared to the 1990 level.

*Table 5-2 Trend in the electricity consumption for Lighting*

| Index (1990=100) | LIGHTING | | | | |
|---|---|---|---|---|---|
| | Halogen | Fluorescent Strip Lighting | Energy Saving Light Bulb | LED[1] | **Total** |
| 1990 | 100.0 | 100.0 | 100.0 | - | 100.0 |
| 2000 | 75.6 | 122.3 | 101.9 | - | 102.6 |
| 2008 | 71.8 | 116.2 | 73.3 | 82.9 | 107.6 |
| 2009 | 72.1 | 115.4 | 51.7 | 72.0 | 102.2 |
| 2010 | 66.6 | 114.6 | 37.8 | 65.7 | 97.3 |
| 2011 | 63.3 | 113.8 | 34.6 | 54.5 | 93.9 |
| 2012 | 56.9 | 112.2 | 35.9 | 44.1 | 69.2 |
| 2013 | 58.0 | 111.1 | 34.8 | 38.8 | 68.1 |
| 2014 | 57.2 | 109.5 | 34.5 | 34.8 | 66.6 |
| 2015 | 56.2 | 107.9 | 34.5 | 31.7 | 65.0 |
| 2020 Scaling factor | - | - | - | - | 0.502 |
| 2020 Estimation | - | - | - | - | 54.0 |

*Table 5-3 Trend in the electricity consumption for Cold Appliances*

| Index (1990=100) | COLD APPLIANCES | | | | |
|---|---|---|---|---|---|
| | Chest Freezer | Fridge-freezer | Refrigerator | Upright Freezer | **Total** |
| 1990 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| 2000 | 67.0 | 76.3 | 72.3 | 74.6 | 73.0 |
| 2008 | 63.1 | 56.0 | 55.1 | 52.9 | 56.8 |
| 2009 | 53.8 | 54.7 | 53.1 | 49.8 | 53.0 |
| 2010 | 38.3 | 52.0 | 50.8 | 47.6 | 47.3 |
| 2011 | 35.0 | 50.9 | 45.3 | 43.2 | 44.1 |
| 2012 | 34.1 | 50.3 | 44.5 | 41.5 | 43.1 |
| 2013 | 32.5 | 48.1 | 43.1 | 39.8 | 41.4 |
| 2014 | 30.7 | 41.5 | 38.8 | 35.3 | 36.8 |
| 2015 | 30.7 | 41.5 | 38.8 | 35.3 | 36.8 |
| 2020 Scaling factor | - | 0.650 | 0.467 | - | - |
| 2020 Estimation | - | 36.4 | 25.7 | - | - |

*Table 5-4 Trend in the electricity consumption for Wet Appliances*

| Index (1990=100) | WET APPLIANCES | | | | |
|---|---|---|---|---|---|
| | Washing Machine | Washer-dryer | Dishwasher | Tumble Dryer | **Total** |
| 1990 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| 2000 | 75.1 | 92.8 | 80.1 | 103.4 | 88.7 |
| 2008 | 72.2 | 84.5 | 63.2 | 116.8 | 83.3 |
| 2009 | 69.7 | 83.9 | 63.1 | 115.7 | 82.5 |
| 2010 | 69.4 | 81.7 | 62.6 | 115.1 | 81.4 |
| 2011 | 68.9 | 81.5 | 62.1 | 113.8 | 80.8 |
| 2012 | 68.4 | 81.2 | 61.3 | 112.9 | 80.2 |
| 2013 | 67.9 | 81.0 | 60.6 | 112.3 | 79.8 |
| 2014 | 67.5 | 80.7 | 59.9 | 111.5 | 79.3 |
| 2015 | 67.0 | 80.5 | 59.5 | 110.7 | 78.8 |
| 2020 Scaling factor | 0.92 | - | 0.9 | - | - |
| 2020 Estimation | 66.4 | - | 56.9 | - | - |

*Table 5-5 Trend in the electricity consumption for Consumer Electronics*

| Index (1990=100) | CONSUMER ELECTRONICS | | | | | |
|---|---|---|---|---|---|---|
| | TV | Set Top Box[1] | DVD/VCR[2] | Games Consoles[3] | Power Supply Units | **Total** |
| 1990 | 100.0 | - | 100.0 | 100.0 | 100.0 | 100.0 |
| 2000 | 102.3 | - | 48.5 | 120.4 | 63.4 | 120.1 |
| 2008 | 137.5 | 100.1 | 96.3 | 965.2 | 57.2 | 144.3 |
| 2009 | 140.1 | 94.2 | 119.0 | 925.6 | 58.3 | 146.4 |
| 2010 | 137.9 | 85.3 | 118.3 | 950.7 | 59.6 | 143.1 |
| 2011 | 135.2 | 78.7 | 106.6 | 780.2 | 60.8 | 138.7 |
| 2012 | 124.2 | 73.3 | 112.6 | 860.0 | 62.3 | 130.0 |
| 2013 | 119.4 | 69.3 | 108.0 | 991.4 | 63.1 | 125.9 |
| 2014 | 115.7 | 43.6 | 104.5 | 1158.3 | 63.9 | 122.9 |
| 2015 | 111.5 | 41.5 | 112.0 | 1215.3 | 64.8 | 119.8 |
| 2020 Scaling factor | 0.782 | 1.050 | - | - | - | - |
| 2020 Estimation | 107.5 | 105.1 | - | - | - | - |

*Table 5-6 Trend in the electricity consumption for Home Computing*

| Index (1990=100) | HOME COMPUTING | | | |
|---|---|---|---|---|
| | Desktops | Laptops | Monitors | **Total** |
| 1990 | 100.0 | 100.0 | 100.0 | 100.0 |
| 2000 | 120.9 | 77.2 | 102.9 | 103.0 |
| 2008 | 227.6 | 60.5 | 163.0 | 152.8 |
| 2009 | 215.0 | 60.3 | 167.0 | 149.8 |
| 2010 | 201.3 | 60.0 | 168.3 | 145.1 |
| 2011 | 186.6 | 59.6 | 166.6 | 138.8 |
| 2012 | 171.0 | 59.1 | 157.6 | 116.1 |
| 2013 | 163.4 | 57.9 | 144.4 | 109.0 |
| 2014 | 155.4 | 56.5 | 130.2 | 101.3 |
| 2015 | 153.3 | 55.3 | 116.4 | 95.6 |
| 2020 Scaling factor | - | - | - | 0.364 |
| 2020 Estimation | - | - | - | 55.6 |

*Table 5-7 Trend in the electricity consumption for Cooking Appliances*

| Index (1990=100) | COOKING APPLIANCES | | | |
|---|---|---|---|---|
| | Electric Oven | Electric Hob | Microwave | **Total** |
| 1990 | 100.0 | 100.0 | 100.0 | 100.0 |
| 2000 | 80.4 | 100.0 | 100.0 | 92.1 |
| 2008 | 79.7 | 100.0 | 100.0 | 91.8 |
| 2009 | 78.9 | 100.0 | 100.0 | 91.5 |
| 2010 | 78.1 | 100.0 | 100.0 | 91.1 |
| 2011 | 77.3 | 100.0 | 100.0 | 90.8 |
| 2012 | 76.5 | 100.0 | 100.0 | 90.5 |
| 2013 | 75.8 | 100.0 | 100.0 | 90.2 |
| 2014 | 75.0 | 100.0 | 100.0 | 89.9 |
| 2015 | 74.3 | 100.0 | 100.0 | 89.6 |
| 2020 Scaling factor | 0.690 | 0.943 | 1.016 | - |
| 2020 Estimation | 55.0 | 94.3 | 101.6 | - |

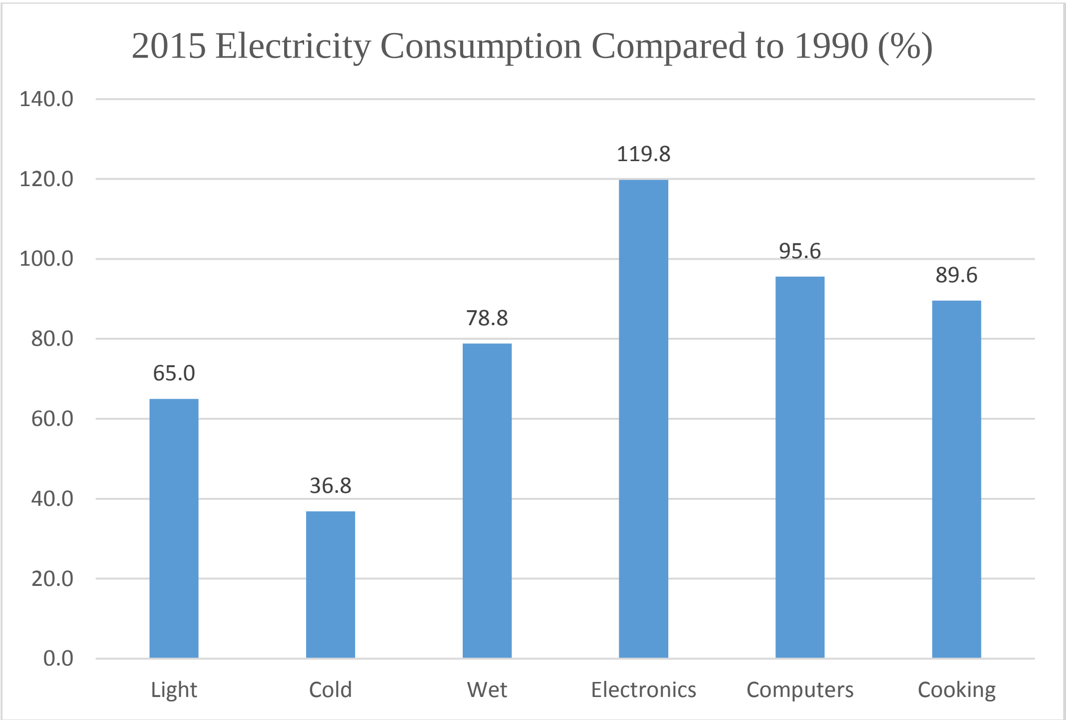


*Figure 8 % Electricity consumption in 2015 compared to the index year 1990 for the appliance categories*

As observed, the use of electronics has risen dramatically, whereas the other categories consume nowadays less electricity that in 1990. Especially the cold appliances and lighting are shown to have improved significantly in terms of consumption.

*Table 5-8 Trend in the electricity consumption for Domestic Appliances in total*

| Index (1990=100) | **TOTAL** |
|---|---|
| 1990 | 100.0 |
| 2000 | 86.6 |
| 2008 | 84.2 |
| 2009 | 82.1 |
| 2010 | 78.9 |
| 2011 | 76.6 |
| 2012 | 73.0 |
| 2013 | 71.3 |
| 2014 | 68.6 |
| 2015 | 67.8 |

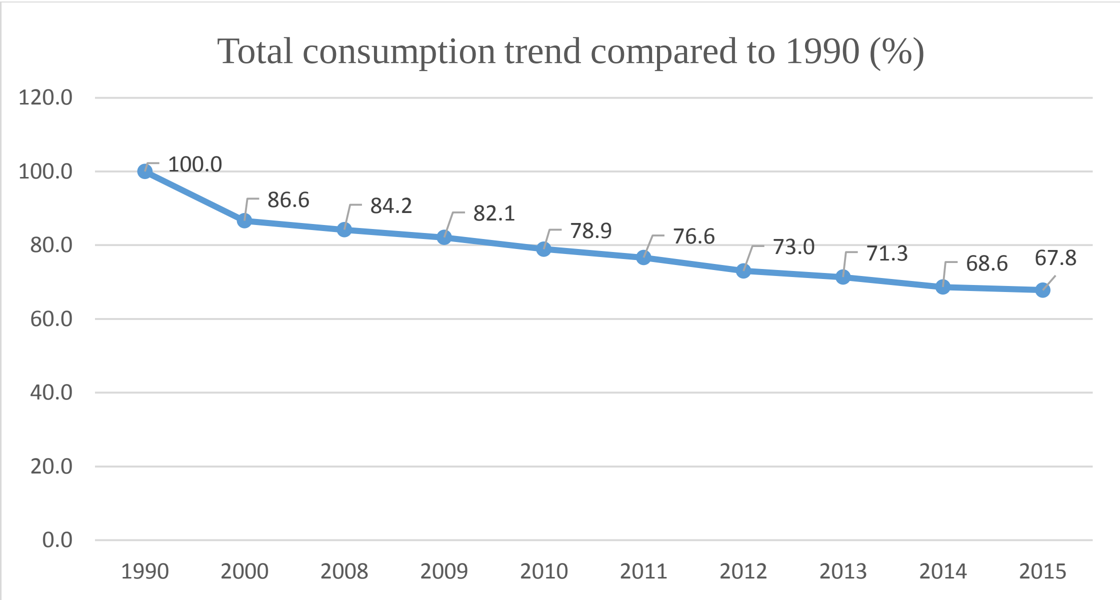


*Figure 9* % Total electricity consumption trend compared to the index year 1990 for the appliance categories

By the last figure, it can be concluded that when the appliance categories are considered as a whole, the trend is every year towards lower levels of consumption.

### 5.3.4 Daily electricity consumption of the appliances in the UK (including Lighting and Heating)

In order to define the heat released by the appliances during the day, the electricity consumption for domestic appliances presented in the ECUK 2016 Data Tables is exploited. Below is cited the Table whose information is processed to be used in the unit 5.3.6.

*Table 5-9 Average daily electricity consumption for domestic appliances in 2010*

*(Source: ECUK 2016 Data Tables)*

| Time | Cold Appliances | Cooking | Lighting | Audio-visual | ICT | Washing/ drying/ dishwasher | Water heating | Heating | Other | Unknown | Showers | Total | % of Daily Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 00:00 | 63.6 | 6.6 | 39.4 | 43.8 | 17.5 | 26.7 | 7.7 | 48.7 | 14.3 | 67.2 | 2.1 | 337.5 | 3.0% |
| 01:00 | 62.2 | 5.8 | 24.0 | 30.9 | 14.9 | 12.6 | 8.7 | 34.3 | 13.2 | 61.7 | 1.9 | 270.0 | 2.0% |
| 02:00 | 61.6 | 5.2 | 18.6 | 25.2 | 13.8 | 8.2 | 14.6 | 26.0 | 12.8 | 57.3 | 1.2 | 244.4 | 2.0% |
| 03:00 | 61.4 | 5.3 | 16.9 | 23.2 | 13.6 | 7.6 | 11.0 | 20.0 | 13.0 | 56.6 | 1.9 | 230.3 | 2.0% |
| 04:00 | 60.9 | 6.6 | 16.2 | 22.0 | 13.5 | 5.2 | 20.2 | 18.9 | 12.6 | 59.5 | 1.3 | 236.9 | 2.0% |
| 05:00 | 59.6 | 11.5 | 17.8 | 22.6 | 13.4 | 4.9 | 7.9 | 18.9 | 12.9 | 61.9 | 5.6 | 236.9 | 2.0% |
| 06:00 | 59.3 | 28.6 | 23.8 | 27.2 | 14.0 | 11.9 | 11.7 | 14.9 | 13.9 | 76.5 | 16.9 | 298.8 | 3.0% |
| 07:00 | 61.3 | 59.6 | 45.7 | 38.1 | 16.2 | 34.7 | 13.8 | 18.0 | 18.3 | 87.0 | 46.0 | 438.6 | 4.0% |
| 08:00 | 62.6 | 65.2 | 48.9 | 48.7 | 19.7 | 65.0 | 9.9 | 20.4 | 21.4 | 99.8 | 36.3 | 498.0 | 4.0% |
| 09:00 | 62.3 | 55.4 | 34.6 | 51.1 | 23.1 | 82.0 | 8.8 | 20.3 | 22.2 | 107.0 | 26.6 | 493.5 | 4.0% |
| 10:00 | 62.6 | 53.2 | 29.3 | 51.3 | 25.1 | 85.0 | 7.1 | 19.5 | 23.1 | 104.5 | 15.4 | 476.0 | 4.0% |
| 11:00 | 63.6 | 62.1 | 26.6 | 50.8 | 26.1 | 81.4 | 5.7 | 15.2 | 26.6 | 99.0 | 16.8 | 474.0 | 4.0% |
| 12:00 | 65.4 | 75.9 | 26.6 | 57.4 | 26.9 | 76.2 | 6.4 | 15.0 | 26.5 | 102.3 | 15.5 | 493.9 | 4.0% |
| 13:00 | 66.1 | 63.8 | 25.4 | 64.2 | 27.5 | 70.9 | 6.7 | 16.3 | 24.2 | 94.9 | 7.9 | 467.9 | 4.0% |
| 14:00 | 66.2 | 48.7 | 26.5 | 66.0 | 28.5 | 66.9 | 6.9 | 17.6 | 23.7 | 92.2 | 5.3 | 448.3 | 4.0% |
| 15:00 | 67.3 | 54.4 | 29.9 | 68.9 | 29.2 | 67.9 | 7.4 | 20.6 | 25.5 | 95.1 | 7.6 | 473.8 | 4.0% |
| 16:00 | 67.8 | 92.1 | 50.6 | 79.2 | 31.2 | 63.5 | 9.4 | 23.9 | 26.6 | 104.6 | 9.1 | 557.9 | 5.0% |
| 17:00 | 70.2 | 135.5 | 82.0 | 90.0 | 32.2 | 59.7 | 9.2 | 25.2 | 24.8 | 130.7 | 16.2 | 675.8 | 6.0% |
| 18:00 | 70.8 | 129.3 | 108.8 | 102.6 | 32.2 | 62.0 | 9.5 | 25.3 | 24.6 | 131.8 | 17.1 | 714.3 | 6.0% |
| 19:00 | 70.3 | 93.7 | 125.3 | 108.3 | 33.2 | 73.7 | 10.2 | 25.9 | 22.3 | 127.7 | 17.0 | 707.5 | 6.0% |
| 20:00 | 68.7 | 63.7 | 127.9 | 114.7 | 32.8 | 69.0 | 11.3 | 25.8 | 19.7 | 127.7 | 15.2 | 676.6 | 6.0% |
| 21:00 | 67.9 | 42.3 | 133.2 | 115.0 | 31.1 | 55.6 | 12.8 | 20.9 | 19.1 | 119.7 | 7.8 | 625.5 | 6.0% |
| 22:00 | 66.7 | 27.9 | 121.1 | 100.0 | 27.9 | 44.1 | 7.2 | 27.7 | 17.5 | 103.6 | 6.0 | 549.8 | 5.0% |
| 23:00 | 65.4 | 14.1 | 74.0 | 68.6 | 22.2 | 37.1 | 4.5 | 50.4 | 15.4 | 88.4 | 6.2 | 446.4 | 4.0% |
| **Total** | **1,554.0** | **1,206.2** | **1,273.2** | **1,469.8** | **565.5** | **1,171.6** | **228.6** | **569.7** | **474.1** | **2,257.0** | **302.8** | **11,072.4** | **100%** |

### 5.3.5 Electricity consumption of the appliances depending on the season

Based on data from the paper of Borg and Kelly (2011) about the demand profile of eight households in Italy, comparisons can be made depending on the different season of the year.

*Table 5-10 Electricity Consumption (kWh) for different seasons (Source: Borg and Kelly (2011)*

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| February | Daily electrical energy consumption (kWh) | Present | 4.33 | 6.08 | 3.53 | 10.3 | 12.66 | 6.92 | 9.28 | 9.84 |
| | | Future | 3.18 | 4.96 | 2.59 | 8.04 | 9.94 | 5.22 | 6.92 | 7.27 |
| | | % Difference | -36 | -23 | -36 | -28 | -27 | -33 | -34 | -35 |
| May | Daily electrical energy consumption (kWh) | Present | 4.05 | 6.03 | 3.28 | 9.75 | 11.84 | 6.19 | 8.6 | 8.78 |
| | | Future | 2.97 | 4.7 | 2.58 | 7.55 | 9.45 | 4.7 | 6.17 | 6.62 |
| | | % Difference | -36 | -28 | -27 | -29 | -25 | -32 | -39 | -33 |
| August | Daily electrical energy consumption (kWh) | Present | 2.96 | 5.12 | 2.29 | 7.28 | 7.18 | 4.45 | 6 | 6.95 |
| | | Future | 2.08 | 3.86 | 1.68 | 5.41 | 5.5 | 3.36 | 4.3 | 5.07 |
| | | % Difference | -42 | -32 | -36 | -35 | -31 | -33 | -40 | -37 |

In order to calculate the difference that possibly occurs during the winter which is the investigated season of this project, the following table has been created and the average difference is used for the ESP-r simulation.

*Table 5-11 Electricity Consumption (kWh) difference during the Winter*

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| February | 4.33 | 6.08 | 3.53 | 10.3 | 12.66 | 6.92 | 9.28 | 9.84 |
| May | 4.05 | 6.03 | 3.28 | 9.75 | 11.84 | 6.19 | 8.6 | 8.78 |
| August | 2.96 | 5.12 | 2.29 | 7.28 | 7.18 | 4.45 | 6 | 6.95 |
| Average | 3.78 | 5.74 | 3.03 | 9.11 | 10.56 | 5.85 | 7.96 | 8.52 |
| Winter difference % | 14.55 | 5.86 | 16.37 | 13.06 | 19.89 | 18.22 | 16.58 | 15.45 |

The average difference of the electricity consumption during the winter compared to the annual one (average of all seasons) is calculated to be 15%.

### 5.3.6 Summary for the electricity consumption of the appliances

- 2010 levels of consumption
- 2010 winter levels increased by 15%
- 2020 winter levels increased by 13%
- A++ appliances decrease consumption by 48%
- Lighting presented in the Table 5.3.4.1 is excluded and calculated separately in the next unit. Heating is also excluded.

*Table 5-12 Summary of the electricity consumption/ heat gains from the appliances (without lighting and heating)*

| Period in the day (h) | 2010 (W) | Winter 2010 (W) | Winter 2020 (W) | A++ Winter 2020 (W) |
|---|---|---|---|---|
| 00:00 | 249.4 | 286.81 | 324.1 | 168.5 |
| 01:00 | 211.7 | 243.455 | 275.1 | 143.1 |
| 02:00 | 199.8 | 229.77 | 259.6 | 135.0 |
| 03:00 | 193.4 | 222.41 | 251.3 | 130.7 |
| 04:00 | 201.8 | 232.07 | 262.2 | 136.4 |
| 05:00 | 200.2 | 230.23 | 260.2 | 135.3 |
| 06:00 | 260.1 | 299.115 | 338.0 | 175.8 |
| 07:00 | 374.9 | 431.135 | 487.2 | 253.3 |
| 08:00 | 428.7 | 493.005 | 557.1 | 289.7 |
| 09:00 | 438.6 | 504.39 | 570.0 | 296.4 |
| 10:00 | 427.2 | 491.28 | 555.1 | 288.7 |
| 11:00 | 432.2 | 497.03 | 561.6 | 292.1 |
| 12:00 | 452.3 | 520.145 | 587.8 | 305.6 |
| 13:00 | 426.2 | 490.13 | 553.8 | 288.0 |
| 14:00 | 404.2 | 464.83 | 525.3 | 273.1 |
| 15:00 | 423.3 | 486.795 | 550.1 | 286.0 |
| 16:00 | 483.4 | 555.91 | 628.2 | 326.7 |
| 17:00 | 568.6 | 653.89 | 738.9 | 384.2 |
| 18:00 | 580.2 | 667.23 | 754.0 | 392.1 |
| 19:00 | 556.3 | 639.745 | 722.9 | 375.9 |
| 20:00 | 522.9 | 601.335 | 679.5 | 353.3 |
| 21:00 | 471.4 | 542.11 | 612.6 | 318.5 |
| 22:00 | 401.0 | 461.15 | 521.1 | 271.0 |
| 23:00 | 322.0 | 370.3 | 418.4 | 217.6 |
| **TOTAL** | **9,229.8** | 10614.27 | **11,994.1** | **6,236.9** |

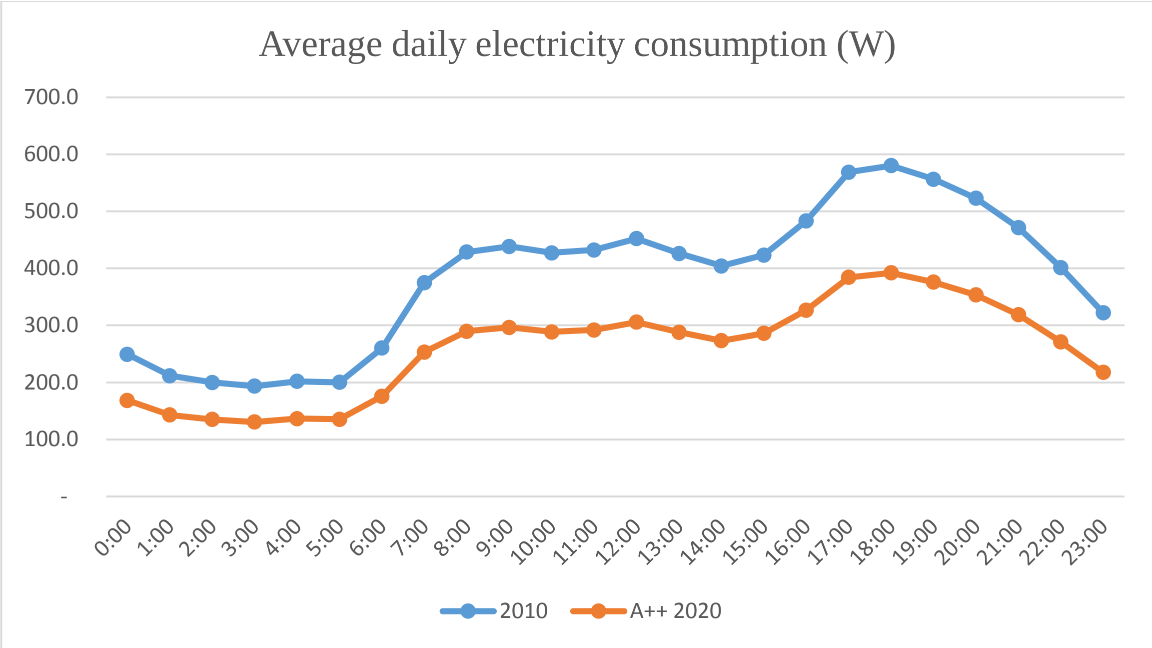


*Figure 10 Average daily electricity consumption for domestic appliances in 2010 and 2020 prediction*

As expected, the peak values of electricity consumption are observed during the evening when the residents are both present and active inside their house.

This detailed information is used for the ESP-r simulation; in order to avoid the complexity that those data would provoke when running the simulations, the following table has the values grouped in a way easier to be applied, still equally accurate.

*Table 5-13 Summary of the heat gains from the appliances in time groups for the ESP-r*

| Period in the day (h) | 2010 (W) | Winter 2010 (W) | Winter 2020 (W) | A++ Winter 2020 (W) |
|---|---|---|---|---|
| 00:00-07:00 | 216.6 | 249.1 | 281.5 | 146.4 |
| 07:00-17:00 | 429.1 | 493.5 | 557.6 | 290 |
| 17:00-24:00 | 488.9 | 562.2 | 635.3 | 330.4 |

## 5.4 Lighting

### 5.4.1 Lighting use during the day

In order to investigate the heat gains from the lighting during December, January and February, it should be identified which periods during the weekdays and the weekends are possibly the lights used. The Scotland Info Guide (2016) provides information considering the Sunrise, Sunset and total Daylight hours in Central Scotland for the start, middle and end of each month. Below are presented the middle days of every month:

*Table 5-14 Daylight hours in Scotland during a year*

| Date | Sunrise | Sunset | Daylight Hours |
|---|---|---|---|
| January 15th | 8:44 am | 16:25 pm | 7 hrs, 41 min |
| February 15th | 7:49 am | 17:30 pm | 9 hrs, 41 min |
| March 15th | 6:40 am | 18:28 pm | 11 hrs, 48 min |
| April 15th | 6:20 am | 20:30 pm | 14 hrs, 10 min |
| May 15th | 5:14 am | 21:30 pm | 16 hrs, 16 min |
| June 15th | 4:40 am | 22:10 pm | 17 hrs, 30 min |
| July 15th | 5:02 am | 21:59 pm | 16 hrs, 57 min |
| August 15th | 5:57 am | 21:01 pm | 15 hrs, 4 min |
| September 15th | 6:56 am | 19:43 pm | 12 hrs, 47 min |
| October 15th | 7:55 am | 18:25 pm | 10 hrs, 30 min |
| November 15th | 7:59 am | 16:19 pm | 8 hrs, 20 min |
| December 15th | 8:47 am | 15:52 pm | 7 hrs, 4 min |

The previous details will be combined with the periods during the weekdays, Saturdays and Sundays when the residents of the dwelling are possibly present and awake so they use the lights. Detailed information about the latter are cited in the following unit.

*Table 5-15 Active presence of the residents*

| Weekdays | Saturday | Sunday |
|---|---|---|
| 07:00–09:00 | 08:00–09:00 | 08:00–09:00 |
| 17:00–23:00 | 14:00–23:00 | 09:00–14:00 |
| - | - | 19:00–23:00 |

Combining the previous two tables, the following presents the average periods and total hours during each day when the lights are required to be on; this information is used for the simulation with the ESP-r.

*Table 5-16 Hours needed for the lights to be used*

| | Weekdays | Total h | Saturday | Total h | Sunday | Total h |
|---|---|---|---|---|---|---|
| December | 07:00–09:00 | 8 | 08:00–09:00 | 8 | 08:00–09:00 | 8 |
| | 17:00–23:00 | | 16:00–23:00 | | 16:00–23:00 | |
| January | 07:00–09:00 | 8 | 08:00–09:00 | 8 | 08:00–09:00 | 5 |
| | 17:00–23:00 | | 16:00–23:00 | | 19:00–23:00 | |
| February | 07:00–08:00 | 7 | 08:00–09:00 | 7 | 08:00–09:00 | 5 |
| | 17:00–23:00 | | 17:00–23:00 | | 19:00–23:00 | |

However, a low amount of heat gains is expected during the rest of the hours as indicated by the ECUK Tables; hence a low value is added to the simulation scenario as shown in the following unit.

### 5.4.2 Heat gains from the Lighting

| **Energy Efficiency & Energy Costs** |  **Light Emitting Diodes (LEDs)** |  **Incandescent Light Bulbs** |  **Compact Fluorescents (CFLs)** |
|---|---|---|---|
| **Life Span (average)** | **50,000 hours** | **1,200 hours** | **8,000 hours** |
| **Watts of electricity used** (equivalent to 60 watt bulb). LEDs use less power (watts) per unit of light generated (lumens). LEDs help reduce greenhouse gas emissions from power plants and lower electric bills | **6 - 8 watts** | **60 watts** | **13-15 watts** |
| **Kilo-watts of Electricity used** (30 Incandescent Bulbs per year equivalent) | **329 KWh/yr.** | **3285 KWh/yr.** | **767 KWh/yr.** |
| **Annual Operating Cost** (30 Incandescent Bulbs per year equivalent) | **$32.85/year** | **$328.59/year** | **$76.65/year** |

*Figure 11 Comparison of Lighting technologies (Source: https://ledhouselighting.wordpress.com/2013/01/10/comparison-chart-for-leds-incandescents-and-cfls/)*

The above figure is helpful to compare the different lighting technologies in terms of power for the same luminance level. Combining this with information from the project REMODECE – which in 2006 predicts a decrease in electricity consumption up to 75% using CFLs or 80% from the use of LEDs in the future – and with the ECUK Tables which present the average domestic electricity consumption for lighting in 2010 without significant difference from the years before, the following Table has been composed. The first column includes the values for the year 2010 from ECUK Tables and the second one shows the expected 75% reduction.

After that Table another two are calculated for the time periods and the wattagethat should be inserted to the ESP-r for the simulations.

*Table 5-17 Daily electricity consumption for Lighting in the UK*

| Time | 2010 (W) | 2020 (W) |
|---|---|---|
| 00:00 | 39.4 | 9.9 |
| 01:00 | 24.0 | 6.0 |
| 02:00 | 18.6 | 4.7 |
| 03:00 | 16.9 | 4.2 |
| 04:00 | 16.2 | 4.1 |
| 05:00 | 17.8 | 4.5 |
| 06:00 | 23.8 | 6.0 |
| 07:00 | 45.7 | 11.4 |
| 08:00 | 48.9 | 12.2 |
| 09:00 | 34.6 | 8.7 |
| 10:00 | 29.3 | 7.3 |
| 11:00 | 26.6 | 6.7 |
| 12:00 | 26.6 | 6.7 |
| 13:00 | 25.4 | 6.4 |
| 14:00 | 26.5 | 6.6 |
| 15:00 | 29.9 | 7.5 |
| 16:00 | 50.6 | 12.7 |
| 17:00 | 82.0 | 20.5 |
| 18:00 | 108.8 | 27.2 |
| 19:00 | 125.3 | 31.3 |
| 20:00 | 127.9 | 32.0 |
| 21:00 | 133.2 | 33.3 |
| 22:00 | 121.1 | 30.3 |
| 23:00 | 74.0 | 18.5 |

*Table 5-18 Daily electricity consumption for Lighting in time groups for the ESP-r (2010)*

| Weekdays | 2010 (W) | Saturday | 2010 (W) | Sunday | 2010 (W) |
|---|---|---|---|---|---|
| 00:00-07:00 | 24 | 00:00-08:00 | 24 | 00:00-08:00 | 24 |
| 07:00–09:00 | 48 | 08:00–09:00 | 48 | 08:00–09:00 | 48 |
| 09:00–17:00 | 32 | 09:00–16:00 | 32 | 09:00–14:00 | 32 |
| 17:00–24:00 | 112 | 16:00–24:00 | 112 | 14:00–19:00 | 24 |
| - | - | - | - | 19:00–24:00 | 112 |

*Table 5-19 Daily electricity consumption for Lighting in time groups for the ESP-r (2020)*

| Weekdays | 2020 (W) | Saturday | 2020 (W) | Sunday | 2020 (W) |
|---|---|---|---|---|---|
| 00:00-07:00 | 6 | 00:00-08:00 | 6 | 00:00-08:00 | 6 |
| 07:00–09:00 | 12 | 08:00–09:00 | 12 | 08:00–09:00 | 12 |
| 09:00–17:00 | 8 | 09:00–16:00 | 8 | 09:00–14:00 | 8 |
| 17:00–24:00 | 28 | 16:00–24:00 | 28 | 14:00–19:00 | 6 |
| - | - | - | - | 19:00–24:00 | 28 |

## 5.5 Occupancy

### 5.5.1 Typical time schedule of residents

Badescu and Sicre (2003) present a detailed time schedule for one resident of a Passivhaus building; its key points to be exploited are the differentiation of the schedule depending on whether it refers to working days or to the weekend and the various activities of the resident which result to different amounts of heat released by their body. The exact table as presented in the paper is the following:

*Table 5-20 Time schedule for a passive house habitant*

| Time schedule for a passive house habitant | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Monday | Tuesday | Wednesday | Thursday | Friday | Saturday | Sunday |
| Absent | 8:30–17:30 | 8:30–17:30 | 8:30–17:30 | 8:30–17:30 | 8:30–17:30 | 9:00–14:00 | 14:00–19:00 |
| Living room | 0:00–7:00 | 0:00–7:00 | 0:00–7:00 | 0:00–7:00 | 0:00–7:00 | 0:00–8:00 | 0:00–8:00 |
| | 23:00–24:00 (sleeping) | 23:00–24:00 (sleeping) | 23:00–24:00 (sleeping) | 23:00–24:00 (sleeping) | 23:00–24:00 (sleeping) | 23:00–24:00 (sleeping) | 23:00–24:00 (sleeping); 9:00–14:00 |
| | 7:30–8:30 | 7:30–8:30 | 7:30–8:30 | 7:30–8:30 | 7:30–8:30 | 14:00–19:00 | 19:00–22:30 (awake) |
| | 17:30–22:30 (awake) | 17:30–22:30 (awake) | 17:30–22:30 (awake) | 17:30–22:30 (awake) | 17:30–22:30 (awake) | 19:30–23:00 (awake) | - |
| Toilet | – | – | – | – | – | – | – |
| Kitchen | 7:15–7:30 | 7:15–7:30 | 7:15–7:30 | 7:15–7:30 | 7:15–7:30 | 8:15–9:00 | 8:15–9:00 |
| Bathroom | 7:00–7:15 | 7:00–7:15 | 7:00–7:15 | 7:00–7:15 | 7:00–7:15 | 8:00–8:15 | 8:00–8:15 |
| | 22:30–23:00 | 22:30–23:00 | 22:30–23:00 | 22:30–23:00 | 22:30–23:00 | 19:00–19:30 | 22:30–23:00 |

### 5.5.2 Heat released by the residents

Based on the data of the previous table and the heat that the adult residents release (92 W by 20 °C reduced by 30% when sleeping) according to the study of Badescu and Sicre (2003) presented in the unit 5.2, the next tables have been created and are used as occupancy levels in the ESP-r simulation. It is assumed that the dwelling hosts two adults.

*Table 5-21 Heat gains according to the occupancy levels during the weekdays*

| Heat gains according to the occupancy levels during the weekdays | | | | | |
|---|---|---|---|---|---|
| | Period in the day (h) | Sensible (W) | Latent (W) | Total Sensible (W) | Total Latent (W) |
| Weekdays | 00:00-07:00 | 64 | 32 | 128 | 64 |
| | 07:00-08:30 | 92 | 46 | 184 | 92 |
| | 08:30-17:30 | 0 | 0 | 0 | 0 |
| | 17:30-23:00 | 92 | 46 | 184 | 92 |
| | 23:00-24:00 | 64 | 32 | 128 | 64 |

*Table 5-22 Heat gains according to the occupancy levels on Saturday*

| Heat gains according to the occupancy levels on Saturday | | | | | |
|---|---|---|---|---|---|
| | Period in the day (h) | Sensible (W) | Latent (W) | Total Sensible (W) | Total Latent (W) |
| Saturday | 00:00-08:00 | 64 | 32 | 128 | 64 |
| | 08:00-09:00 | 92 | 46 | 184 | 92 |
| | 09:00-14:00 | 0 | 0 | 0 | 0 |
| | 14:00-23:00 | 92 | 46 | 184 | 92 |
| | 23:00-24:00 | 64 | 32 | 128 | 64 |

*Table 5-23 Heat gains according to the occupancy levels on Sunday*

| Heat gains according to the occupancy levels on Sunday | | | | | |
|---|---|---|---|---|---|
| | Period in the day (h) | Sensible (W) | Latent (W) | Total Sensible (W) | Total Latent (W) |
| Sunday | 00:00-08:00 | 64 | 32 | 128 | 64 |
| | 08:00-09:00 | 92 | 46 | 184 | 92 |
| | 09:00-14:00 | 64 | 32 | 128 | 64 |
| | 14:00-19:00 | 0 | 0 | 0 | 0 |
| | 19:00-23:00 | 92 | 46 | 184 | 92 |
| | 23:00-24:00 | 64 | 32 | 128 | 64 |

Finally, it should be highlighted that the suggested occupancy levels for certification are 35m$^2$ per person.

## 5.6 Summary of internal heats

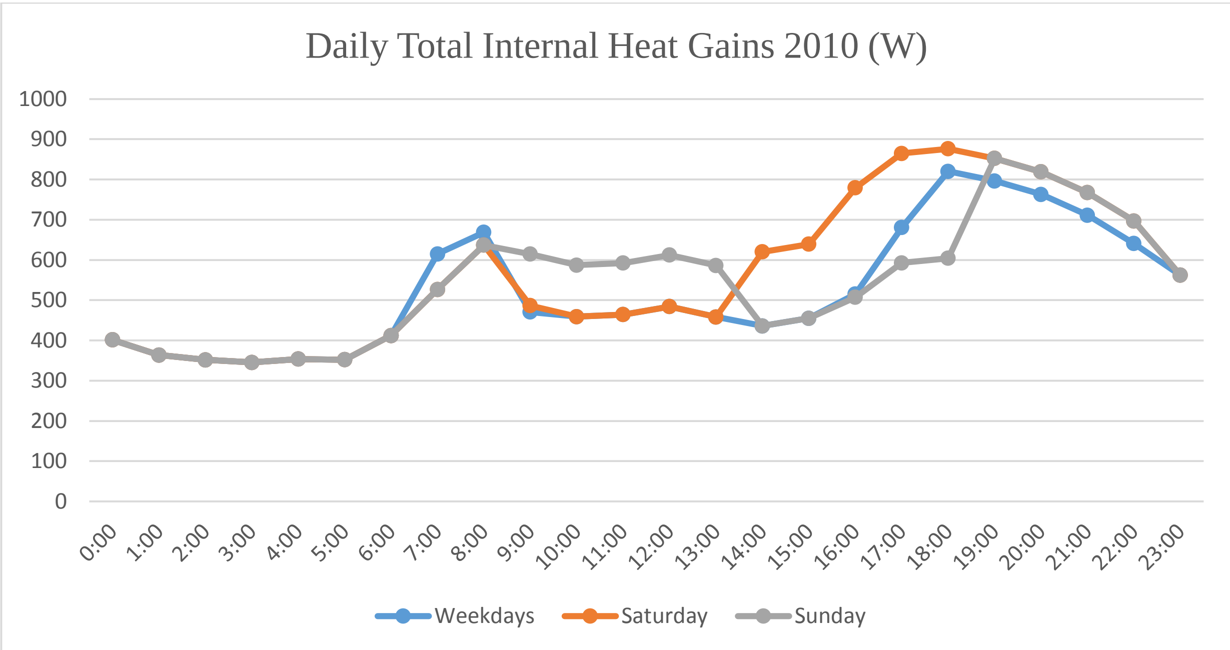


*Figure 12 Daily total internal heat gain*

The previous graph presents the total heat gains from Equipment, Lighting and Occupancy in 2010, and how this aggregation changes during the day.

The following Table consists of the same sum for every day of the week and its comparison to the predicted 2020 levels. Finally, the percentage of the difference is calculated and shown in the last column.

*Table 5-24 Total heat gains on every day of the week in 2010 and 2020*

| Time | Weekday 2010 | Saturday 2010 | Sunday 2010 | Weekday 2020 | Saturday 2020 | Sunday 2020 | % Difference |
|---|---|---|---|---|---|---|---|
| **00:00** | 401.4 | 401.4 | 401.4 | 302.5 | 302.5 | 302.5 | 32.7 |
| **01:00** | 363.7 | 363.7 | 363.7 | 277.1 | 277.1 | 277.1 | 31.3 |
| **02:00** | 351.8 | 351.8 | 351.8 | 269 | 269 | 269 | 30.8 |
| **03:00** | 345.4 | 345.4 | 345.4 | 264.7 | 264.7 | 264.7 | 30.5 |
| **04:00** | 353.8 | 353.8 | 353.8 | 270.4 | 270.4 | 270.4 | 30.8 |
| **05:00** | 352.2 | 352.2 | 352.2 | 269.3 | 269.3 | 269.3 | 30.8 |
| **06:00** | 412.1 | 412.1 | 412.1 | 309.8 | 309.8 | 309.8 | 33.0 |
| **07:00** | 614.9 | 526.9 | 526.9 | 457.3 | 387.3 | 387.3 | 36.0 |
| **08:00** | 668.7 | 636.7 | 636.7 | 493.7 | 479.7 | 479.7 | 32.7 |
| **09:00** | 470.6 | 486.6 | 614.6 | 304.4 | 308.4 | 436.4 | 40.8 |
| **10:00** | 459.2 | 459.2 | 587.2 | 296.7 | 296.7 | 424.7 | 38.3 |
| **11:00** | 464.2 | 464.2 | 592.2 | 300.1 | 300.1 | 428.1 | 38.3 |
| **12:00** | 484.3 | 484.3 | 612.3 | 313.6 | 313.6 | 441.6 | 38.7 |
| **13:00** | 458.2 | 458.2 | 586.2 | 296 | 296 | 424 | 38.3 |
| **14:00** | 436.2 | 620.2 | 436.2 | 281.1 | 465.1 | 281.1 | 55.2 |
| **15:00** | 455.3 | 639.3 | 455.3 | 294 | 478 | 294 | 54.9 |
| **16:00** | 515.4 | 779.4 | 507.4 | 334.7 | 538.7 | 332.7 | 52.5 |
| **17:00** | 680.6 | 864.6 | 592.6 | 412.2 | 596.2 | 390.2 | 51.9 |
| **18:00** | 820.2 | 876.2 | 604.2 | 548.1 | 604.1 | 398.1 | 51.8 |
| **19:00** | 796.3 | 852.3 | 852.3 | 531.9 | 587.9 | 587.9 | 45.0 |
| **20:00** | 762.9 | 818.9 | 818.9 | 509.3 | 565.3 | 565.3 | 44.9 |
| **21:00** | 711.4 | 767.4 | 767.4 | 474.5 | 530.5 | 530.5 | 44.7 |
| **22:00** | 641 | 697 | 697 | 427 | 483 | 483 | 44.3 |
| **23:00** | 562 | 562 | 562 | 373.6 | 373.6 | 373.6 | 50.4 |
| **TOTAL** | **12581.8** | **13573.8** | **13029.8** | **8611** | **9567** | **9221** | **41.3** |

# 6 SIMULATION

## 6.1 ESP-r model basic concept

In order to create a Passivhaus model and run the desirable simulations, the following were considered:

- Geometry and materials of the components
- Internal heat gains as calculated in the previous chapter

In more detail:

- Model choice:

  A simplified model with the option to be heated by underfloor heating was chosen, since according to the BRE Designer's Guide, in case that some supplementary heating is needed during the coldest days, it can be provided either by a post-air heating unit in the MVHR system and/or a small towel radiator or underfloor heating in the bathroom. The setpoint was set at 20$^{o}$C.

  Another available model with shading was initially considered, since seasonal and permanent shading devices are highly recommended to be installed to Passivhaus buildings so as to prevent overheating during the summer. However, the investigated season was the winter so shading was indifferent compared to the option to supply heat if required with the underfloor heating model.

- Geometry:

  The area of the model was designed to be 70m$^2$ in order to meet the suggested occupancy levels - 35m$^2$ per person – for the two adults that were assumed to be the residents. The optimal glazing on the south façade, as mentioned earlier is approximately 25-35%; hence, the one designed occupied 32% of that wall.

- Materials:

  Investigating every available in the ESP-r component, the desirable U-values were not met; hence, modifications to the thickness and conductivity of the individual component parts were made in order to achieve the Passivhaus standard ones.

- Internal Heat gains:

  The operational details in the ESP-r were modified according to the calculation presented in the previous chapter.

- Airflow Network:

  According to the Passivhaus standards, the infiltration must be less than 0.6 changes per hour at 50Pascals. However, as Litvak et al. (2000) state, this pressure is not realistic and in order to reach more reasonable results, according to numerous experimental tests, the changes should be divided by 20 ("$Q_{50}$/20 rule of thumb"). Therefore, the infiltration rate was set to 0.03 changes per hour. The ventilation rate was set to 0 to have more accurate results, independent from the occupants' behaviour and preferences.

## 6.2 Presentation of the model

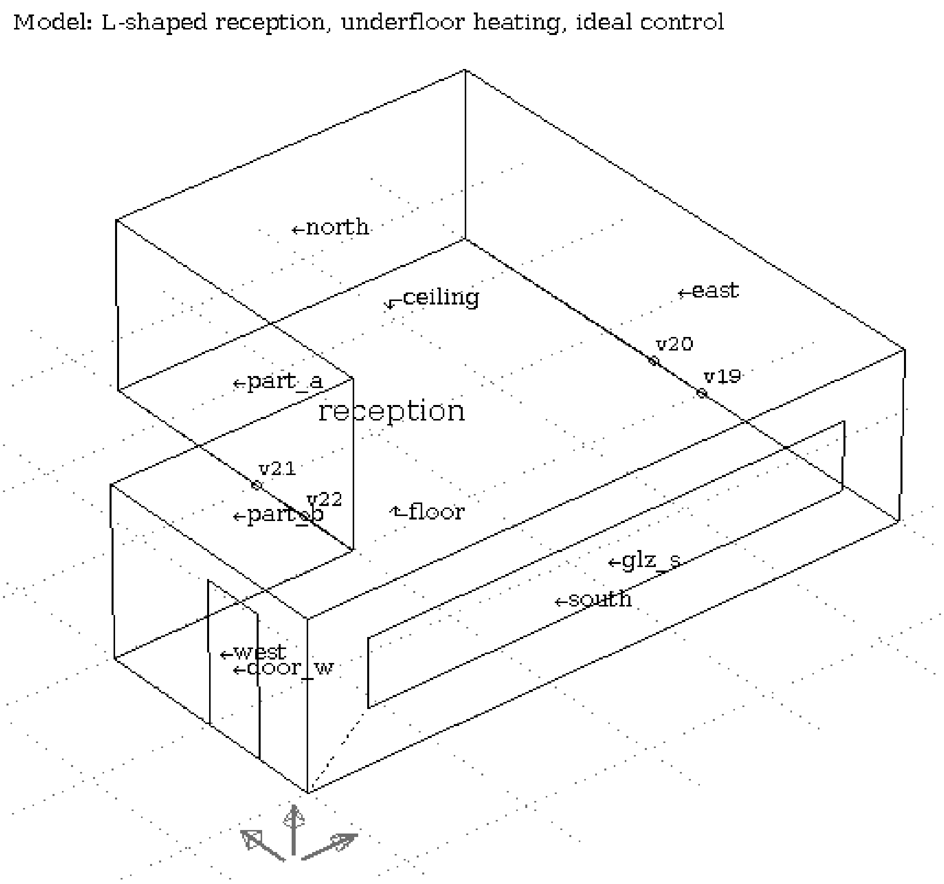


*Figure 13 Model*

Location: Oban, Scotland (56.42N, -5.47W)

*Table 6-1 Geometrical features*

| Feature | Dimensions |
|---|---|
| Floor Area | 70 $m^2$ |
| Volume | 210 $m^3$ |
| Opaque construction | 244 $m^2$ |
| Glazed Area | 9.6 $m^2$ |

The model was initially modified to have components with U values very close to the upper limit of the Passivhaus Standard ones (Worst-case scenario). The results were not completely satisfactory though, so an upgraded combination of materials was created afterwards to compare the results (Upgraded model scenario). The characteristics of both cases, as presented by the ESP-r, are cited in the Appendices A and B, and their U values are summarised in the following table:

*Table 6-2 Synopsis of the componets' U values*

| Component | Passivhaus U Value ($W/m^2K$) | «Worst-case scenario» U Value ($W/m^2K$) | Upgraded model U Value ($W/m^2K$) |
|---|---|---|---|
| Walls | ≤ 0.15 | 0.150 | 0.103 |
| Ceiling | ≤ 0.15 | 0.142 | 0.096 |
| Floor | ≤ 0.15 | 0.143 | 0.100 |
| Glazing | ≤ 0.85 | 0.833 | 0.556 |
| Door | - | 1.026 | 0.794 |

The temperature that should be maintained inside a Passivhaus building during the winter is at least 20$^o$C. Therefore, the setpoints were set at 20$^o$C for the heating and none for the cooling. Along with the minimum limit of 20$^o$C and the hours below it, the maximum one of 25$^o$C was checked as well.

## 6.3 Ambient Temperature

Before presenting the simulation results, it is useful to cite the ambient temperature graph of the examined week.

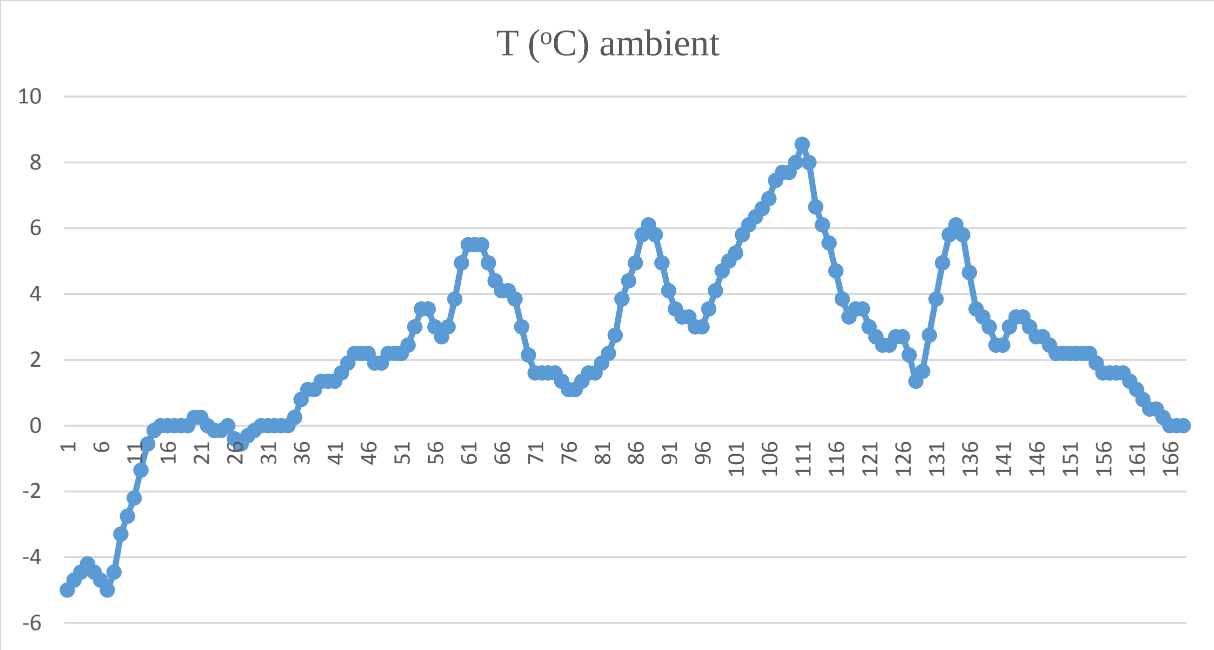


*Figure 14 Ambient Temperature (°C) during the examined week*

From the graph, it is realised that during the first days of the week the ambient temperature is very low, with its starting value at -5°C. However, during the rest of the week it rises and remains very close or above the 0°C. What is expected, therefore, is the investigated model to face the highest difficulty to retain the internal temperature above the 20°C during Monday.

**<u>Note:</u>**

Ideally, the above graph should have been combined in one graph with the temperature results of each simulation but in that case the axis y would have to be of a very big scale to allow the values to be discernible. For that reason, the ambient temperature is presented and commented here separately. The combination of the graphs is presented in Appendix C, as occurred by the ESP-r.

## 6.4 Simulation results

### 6.4.1 Simulation for the "Worst-case scenario"

The initial simulation that was run included:

- The initial components with the U values to the upper limits of the Passivhaus standards,
- The Winter 2010 internal heat gains as presented in the previous chapter.

The following graph shows the results; the time axis consists of an hourly timestep from Monday the 9th of January to Sunday the 15th.

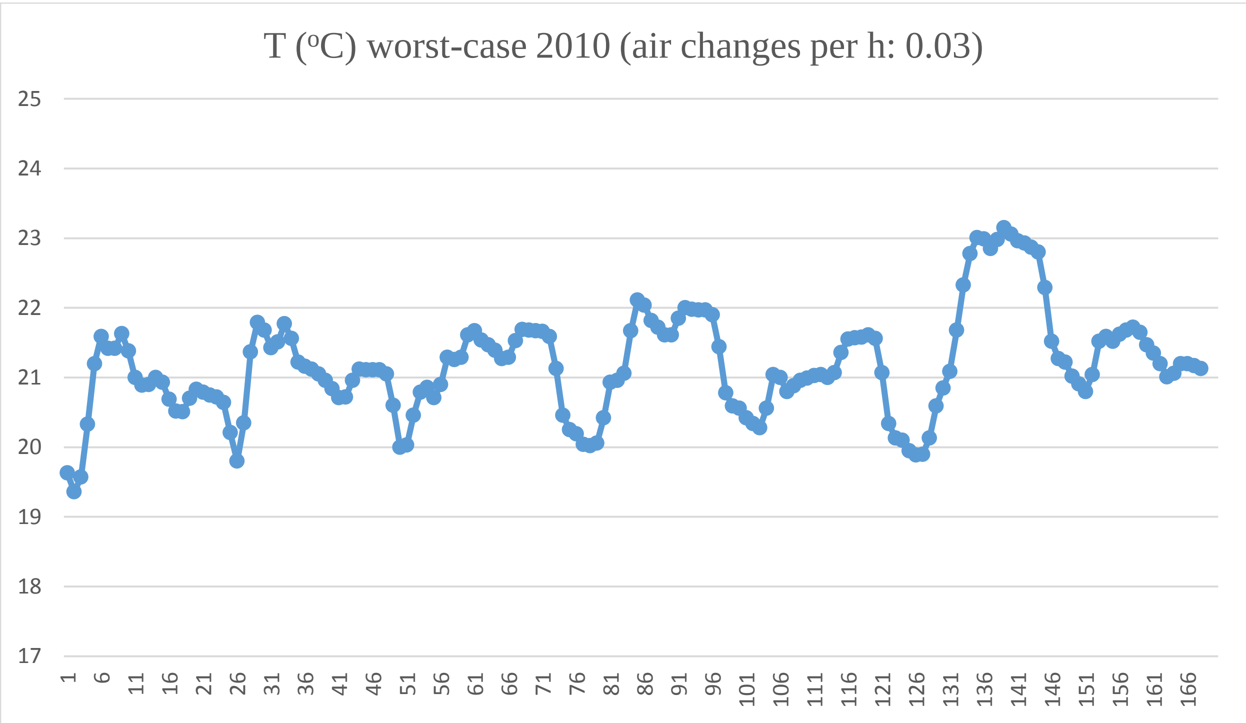


*Figure 15 Temperature hourly results of the "worst-case scenario" in 2010 (air changes per hour: 0.03)*

The Temperature results, as obvious from the relevant graph, show that the temperature of the model space was during the whole week above the 20°C required, and just below that limit at the first hours of Monday.

The annual heat demand was calculated to be 10.7k Wh/m$^2$ (assuming 13 winter weeks). Hence, it was between the acceptable limit (≤ 15 kWh/m$^2$ per year).

The next simulation that was run included:

- The initial components with the U values to the upper limits of the Passivhaus standards,
- The Winter 2020 internal heat gains with the A++ appliances, as presented in the previous chapter.

The following graph shows the results; the time axis consists of an hourly timestep from Monday the 9th of January to Sunday the 15th.

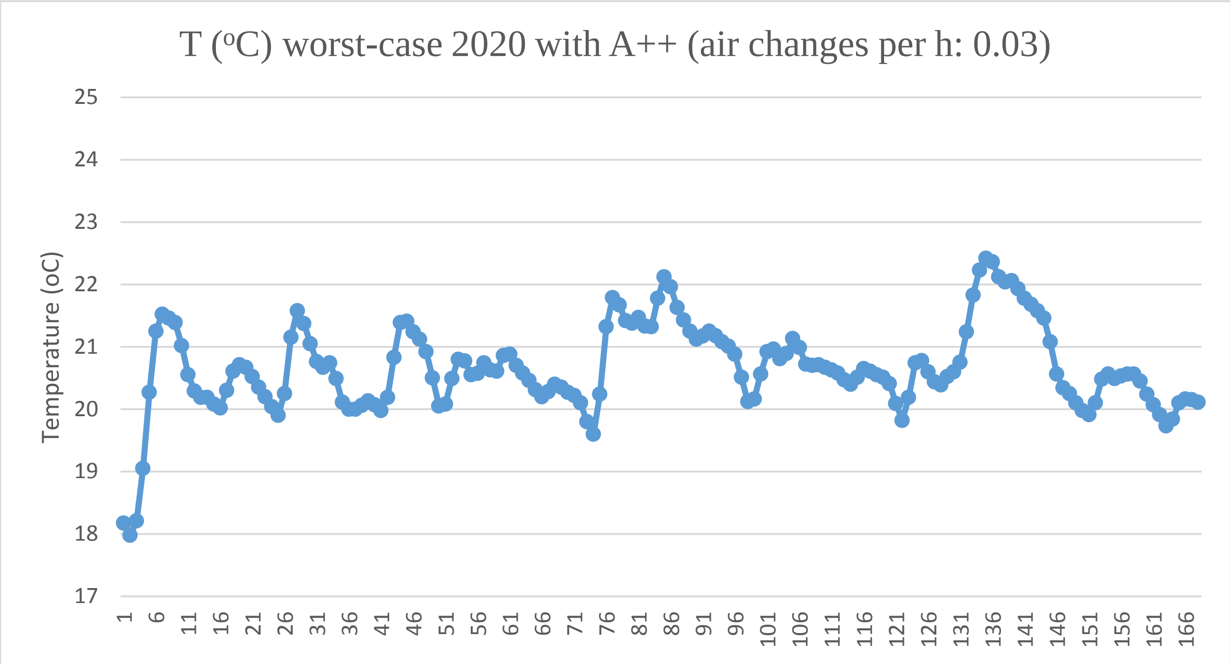


*Figure 16 Temperature hourly results of the "worst-case scenario" in 2020 with A++appliances (air changes per hour: 0.03)*

The Temperature results, as concluded from the above graph, show that the temperature of the model space was mostly above the 20°C required, but in many cases and especially during the first hours of Monday it was below that limit.

The annual heat demand was 24.6 kWh/m$^2$ (assuming 13 winter weeks). Hence, it exceeded by far the acceptable limit (≤ 15 kWh/m$^2$ per year).

**This simulation and its results were the main objective of the project.**

However, an upgraded model with lower U values was created in order to examine whether in that case the lower heat gains in 2020 will be adequate to maintain the internal temperature and heat demand within the acceptable limits.

### 6.4.2 Simulation for the Upgraded model

The next simulation that was run included:

- The upgraded components with U values lowered by 30-35% than the initial model,
- The Winter 2010 internal heat gains, as presented in the previous chapter.

The following graph shows the results; the time axis consists of an hourly timestep from Monday the 9th of January to Sunday the 15th.

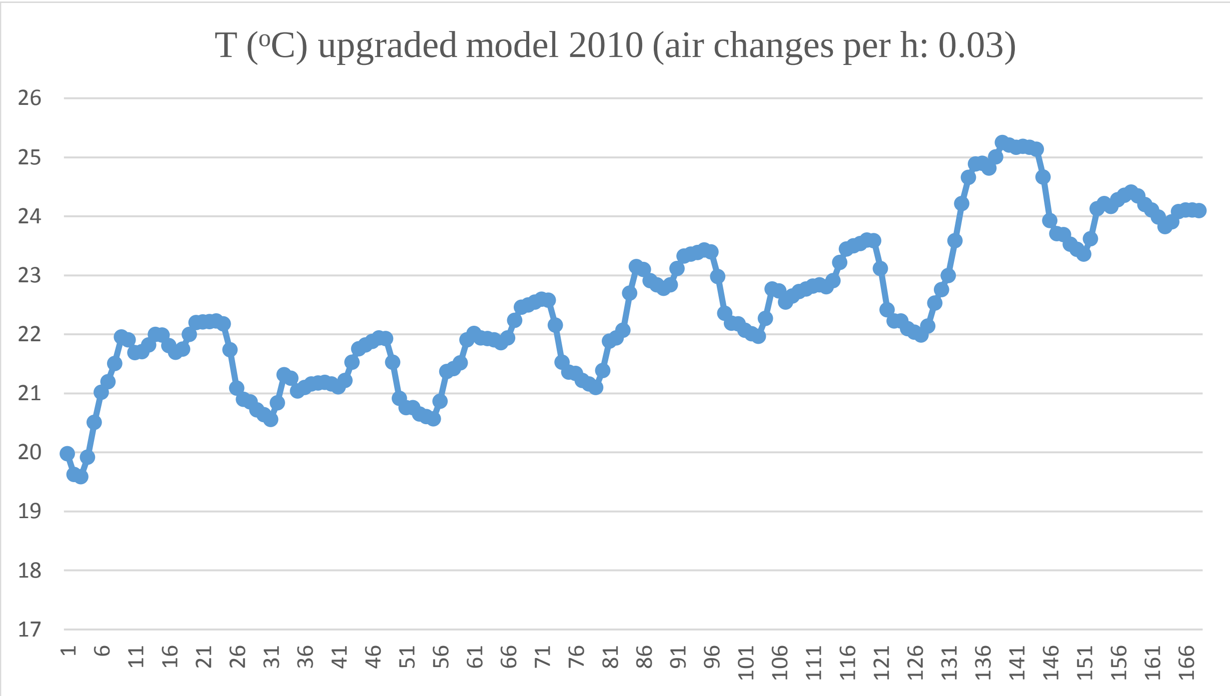


*Figure 17 Temperature hourly results of the upgraded model in 2010 (air changes per hour: 0.03)*

The Temperature results, as obvious from the relevant graph, show that the temperature of the model space was during every day above the 20°C required, and just below that limit at the first hours of Monday. It should be highlighted that during Saturday there were 7 hours with temperature more than 25°C. This practically would not occur given that the occupants would probably open the window (the model assumes no ventilation).

The annual heat demand was calculated to be 3.9 kWh/$m^2$ (assuming 13 winter weeks). Hence, it was between the acceptable limit (≤ 15 kWh/$m^2$ per year).

The simulation that was run afterwards included:

- The upgraded components with U values lowered by 30-35% than initially
- The Winter 2020 internal heat gains with the A++ appliances, as presented in the previous chapter.

The following graph shows the results; the time axis consists of an hourly timestep from Monday the 9th of January to Sunday the 15th.

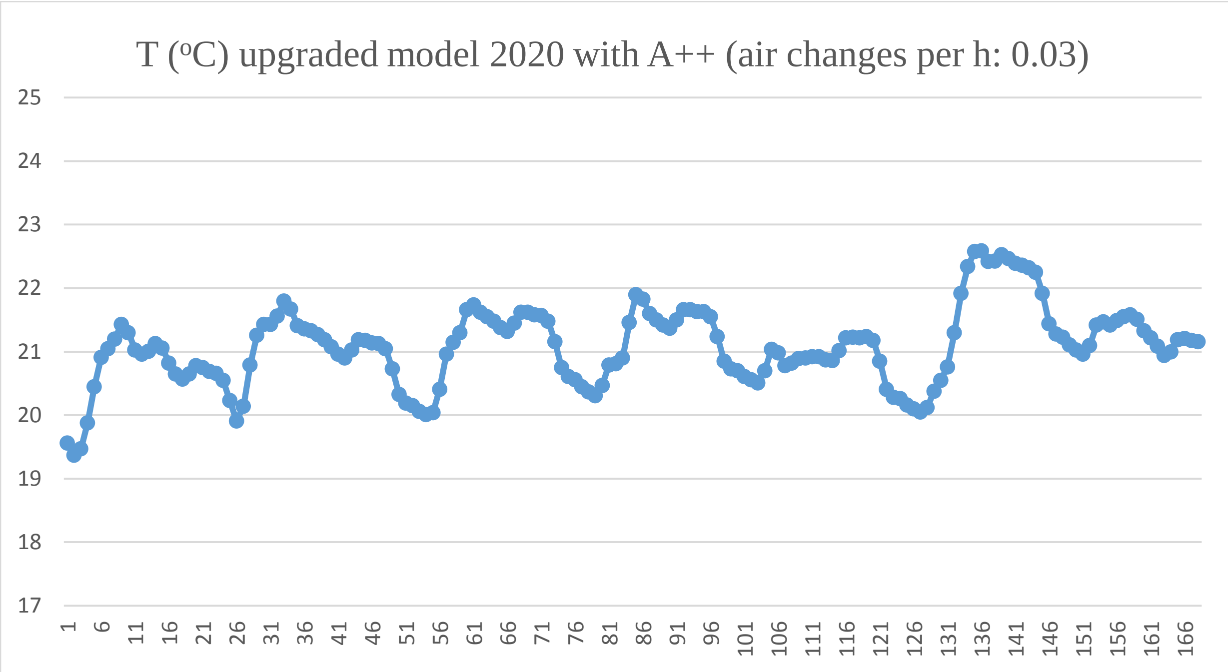


*Figure 18 Temperature hourly results of the upgraded model in 2020 with A++ appliances (air changes per hour: 0.03)*

According to the Temperature results, the model space had more than 20°C almost always, and just below that limit at the first hours of Monday and Tuesday.

The annual heat demand was calculated to be 9.2 kWh/m$^2$ (assuming 13 winter weeks). Hence, it was between the acceptable limit (≤ 15 kWh/m$^2$ per year).

### 6.4.3 Simulation with lower infiltration rate

The final simulations that were run, used the same four models described above but an infiltration rate of 0.01 air changes per hour instead of the 0.03 used before. The graphs were identical with their 0.03 case but 0.1-0.4°C higher at every measurement. For that reason, they are omitted. The new rate though decreased significantly the heat demand so the relevant comparisons are presented in the following unit.

## 6.5 Comparison of the different simulation models

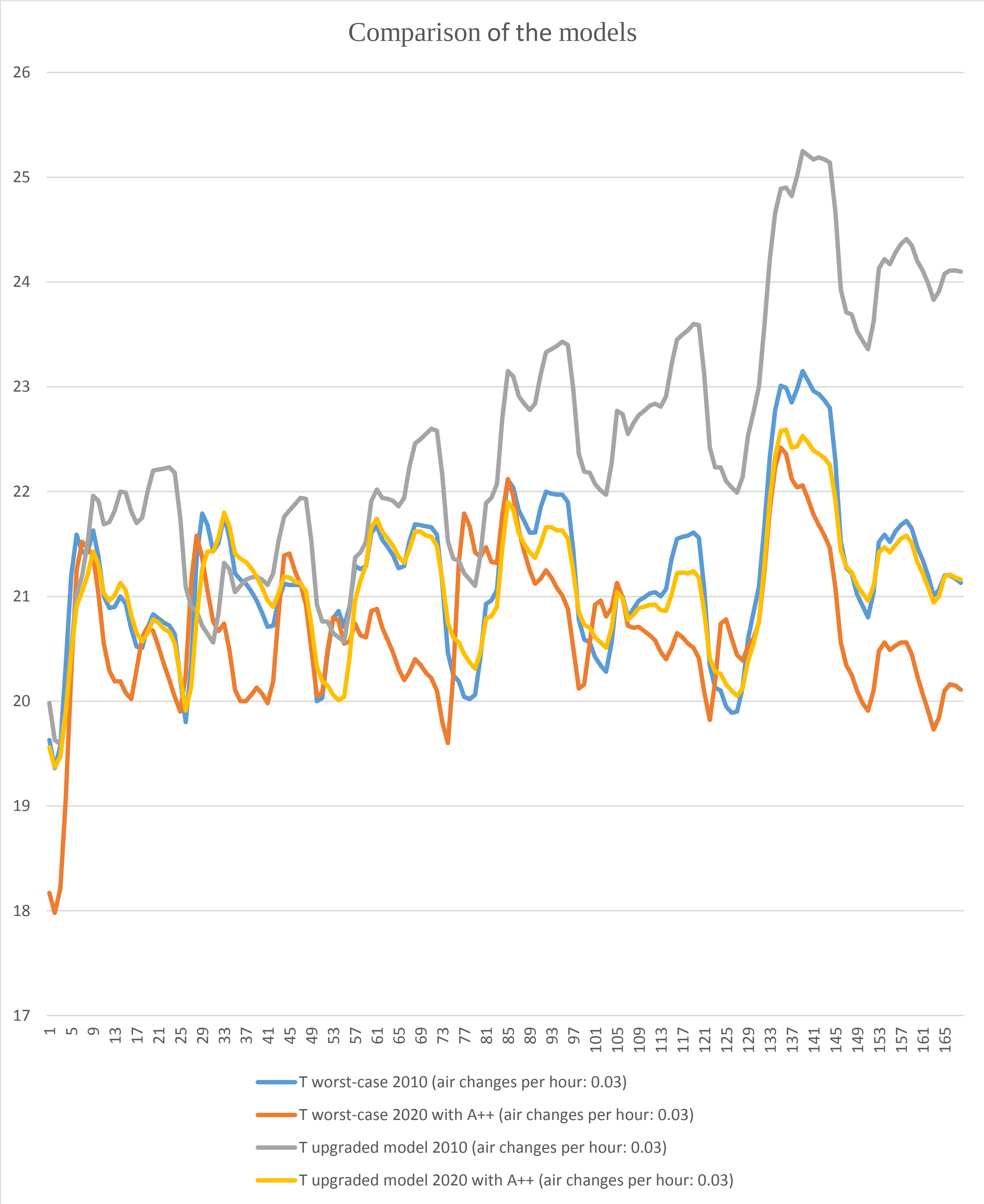


*Figure 19 Comparison of the Temperature results for the different cases run*

As concluded by the above graph, the two cases with the 25% higher gains resulted to a higher temperature than the model with the 30-35% lowered U values during the whole week with only a few exceptions. The Following tables *6-3* and *6-4* present a comparison between the temperature and the time below or above the Passivhaus limits ($20^oC \leq T_{acceptable} \leq 25^oC$) for every model run and for both of the infiltration rates.

*Table 6-3 Comparison of Temperature values and Time below and above the limits between the models (0.03 air changes per h)*

| Model | Lower T ($^oC$) | Higher T ($^oC$) | Average T ($^oC$) | Time below $20^oC$ (h) | Time above $25^oC$ (h) |
|---|---|---|---|---|---|
| Ambient | -5 | 8.6 | 2.3 | 168/168 | 0/168 |
| Worst-case 2010 | 19.4 | 23.2 | 21.2 | 7/168 | 0/168 |
| Worst-case 2020 with A++ | 18 | 22.4 | 20.7 | 15/168 | 0/168 |
| Upgraded 2010 | 19.6 | 25.3 | 22.5 | 4/168 | 7/168 |
| Upgraded 2020 with A++ | 19.4 | 22.6 | 21.1 | 5/168 | 0/168 |

*Table 6-3 Comparison of Temperature values and Time below and above the limits between the models (0.01 air changes per h)*

| Model | Lower T ($^oC$) | Higher T ($^oC$) | Average T ($^oC$) | Time below $20^oC$ (h) | Time above $25^oC$ (h) |
|---|---|---|---|---|---|
| Ambient | -5 | 8.6 | 2.3 | 168/168 | 0/168 |
| Worst-case 2010 | 19.4 | 23.3 | 21.3 | 6/168 | 0/168 |
| Worst-case 2020 with A++ | 18.3 | 22.4 | 20.7 | 14/168 | 0/168 |
| Upgraded 2010 | 19.8 | 25.7 | 22.8 | 2/168 | 12/168 |
| Upgraded 2020 with A++ | 19.6 | 22.7 | 21.1 | 3/168 | 0/168 |

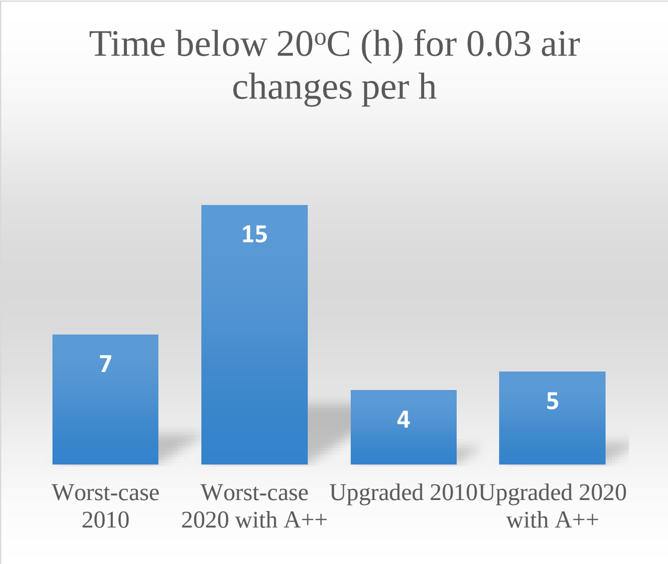


*Figure 20 Time below 20ºC (hours) for 0.03 air changes per hour*

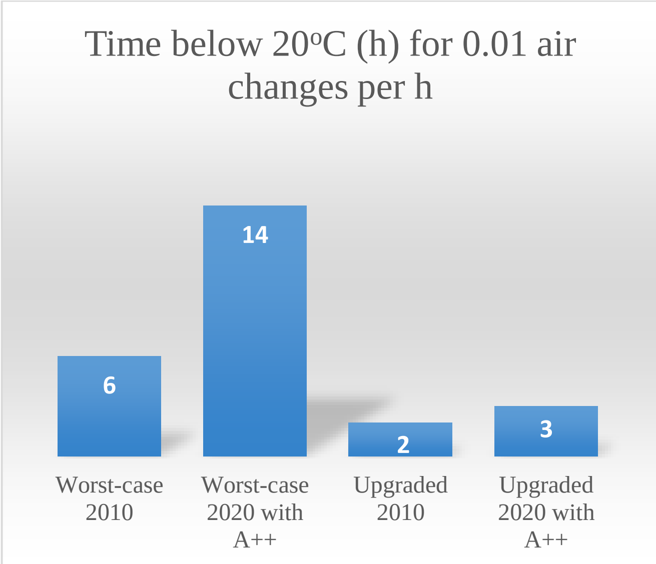


*Figure 21 Time below 20oC (hours) for 0.01 air changes per hour*

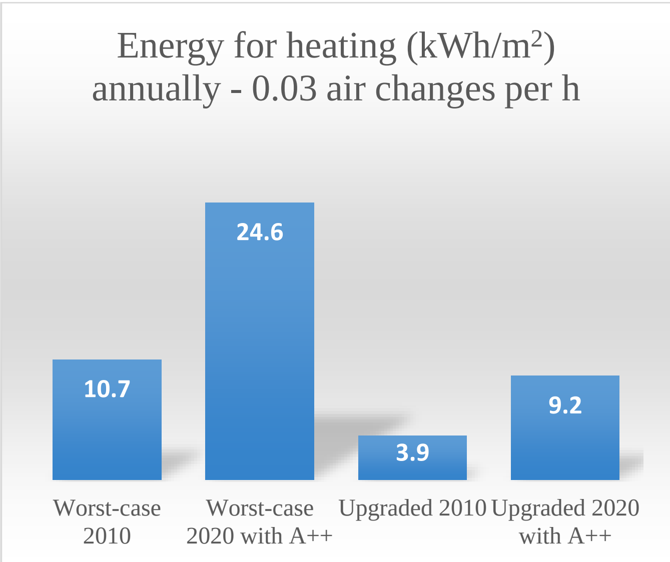


*Figure 22 Energy for heating (kWh/m2) annually for 0.03 air changes per hour*

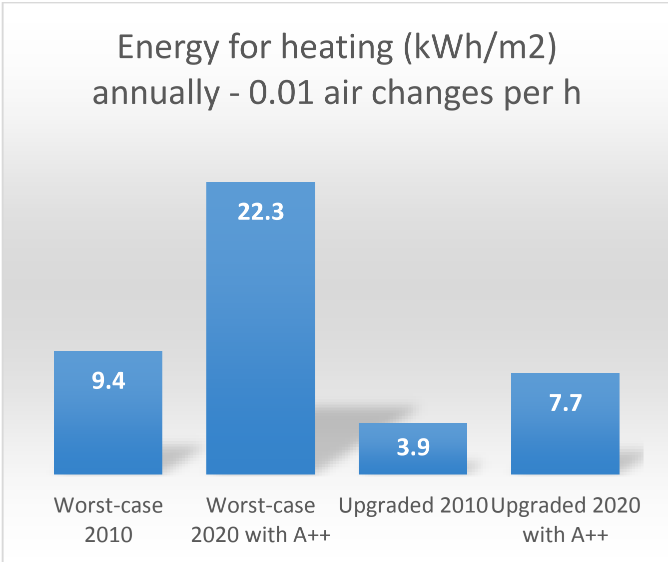


*Figure 23 Energy for heating (kWh/m2) annually for 0.01 air changes per hour*

As shown in the Tables and Figures above, the infiltration rate has an insignificant effect on the temperature increasing it by 0.1 to 0.4ºC. However, the lower rate affects in a positive way both the hours below the limit of the 20ºC decreasing them, and the most important parameter of the heating energy required reducing it as well in three of the four cases (by 14, 10 and 20% accordingly with the order presented in the graphs from left to right), including both of the 2020 ones which are of primary interest for this project. The time above the upper temperature limit of 25ºC is out of scope and unrealistic since the ventilation rate is assumed to be 0.

## 6.6 Discussion of the results

To begin with, the aim of the project was to examine whether a household designed as close as possible to the limiting values of the Passivhaus standards (a "worst-case scenario") would be able to address the winter weather conditions in the future, when the appliances tend to be more efficient and, hence, consume less electricity and release less heat to their surroundings. Although the Temperature results showed that during 151 out of the 168 week hours (90% of the time) the building had at least 20$^{o}$C, the heating demand needed to maintain this percentage, was exceeding by far the upper annual limit. Therefore, the conclusion of the simulations was that a building constructed marginally to the Passivhaus Standards would probably not be able to address a 25% reduction of heat gains even if its air tightness was excellent. What confirms this prediction is the comparison of the above case with the one with higher heat gains; the latter case had 96% of the internal temperature above the 20$^{o}$C and required 57-58% less heating energy to maintain the required temperature level, being within the acceptable annual limits for a Passivhaus.

Further from the above, the investigation of an upgraded structure composed of components with U values lowered by 30-35%, led to the conclusion that such a building would possibly be able to address the lower heat gains, maintaining the internal temperature almost constantly within the limits and requiring significantly less energy to compensate the lower gains. Combined also with a decrease to the infiltration rate from 0.03 to 0.01 air changes per hour, it would require less that 10kWh/m$^2$ of heating energy annually.

At this point, it should be explained that the time above the upper temperature limit of 25$^{o}$C was neither worrying nor realistic since the ventilation rate was assumed to be 0. The infiltration rate is related to the structure so its results are objective; the ventilation rate, though, depends on the occupants' behaviour and preferences to open the window for their desirable time span so, for accuracy, the window was assumed to be always closed. From a realistic perspective though, the occupants would open the window when the space is warm, so the values above 25$^{o}$C would not occur during the winter.

The enhanced air tightness of the building had a crucial positive effect, not easily discernible by the temperature but obvious by the less than 2% of time below the acceptable 20$^{o}$C and, mainly, the decreased even by 20% energy demand for heating.

However, although a building like the one with the upgraded materials would possibly be within the acceptable limits of heat demand even with efficient appliances that release 48% less heat than the conventional ones, it should be pointed out that the domestic hot water is considered to be the major energy consumer in a Passivhaus dwelling (50-80% of heat demand or up to 12kWh/$m^2$ per annum). Therefore, either too low heat gains which would increase the heat demand to maintain the required internal temperature levels, or increased energy demand for hot water, would leave less space to each other to consume energy to satisfy both needs, within the limits. For instance, in the most optimistic scenario where 3.9 kWh/$m^2$ were needed annually to heat the space, if another 12kWh/$m^2$ were required for hot water, the aggregate would exceed the 15kWh/$m^2$ annual limit for heating demand.

Finally, it should be highlighted that several assumptions were made in order to run the model and gather results:

- The winter heat gains were estimated to be 15% higher than the average annual ones, the increase in electricity consumption is predicted to be 13% higher in 2020 compared to the 2010 levels and the A++ appliances provide up to 48% savings when replacing the conventional ones. However, these percentages are subject to change and alter the results.
- The underfloor heating was constantly available to check the heat demand of the building using an efficient system which it originally allowed to be used only in the house’s bathroom.
- The thickness and conductivity of the construction materials used were altered to meet the U values required so they were probably not 100% suitable.
- The infiltration rate of 0.01 air changes per hour is probably too low to maintain the comfort and air quality in acceptable levels for the occupants, it proved though that the air tightness of the building is a most significant factor to its retention of warmth.
- Although the simulation was set to begin 5 days before the examined week to have the internal temperature stabilised, Monday started with considerably low temperature (-5$^o$C) which was not addressed even by the most optimistic scenario. However, a 10% of time annually is allowed to be out of the limits.

# 7 CONCLUSION AND RECOMMENDATIONS

To sum up, the project investigated the effect of different heat gains to several models and combinations which showed that perfectly insulated and air tight buildings as the Passivhaus ones are, are able to address a cold winter week with low demand for energy to heat the interior. However, in order to maintain the acceptable temperature levels if the heat gains are decreased in the future, the construction should be pushed lower than the upper limits and the materials used should be as best as possible. That conclusion agrees with the rough one made by the literature survey that reasonable differentiations in the heat gains in total, as affected by the improved efficiency of the equipment, can be handled by a Passivhaus building with advanced characteristics.

A recommendation that could be made is for the materials to be enhanced in terms of thermal characteristics and reasonably priced in order to make new technologies accessible to the audience. For instance, low-emittance coatings (metallic oxide films) installed on windows or argon gas filling the gap between the glazing parts of the windows are both promising advances, given that they permit the penetration of solar radiation while preventing the internal warmth escape to the outside. Additionally, Philibert (2005), explains an even more innovative development, the electro-chromatic windows, whose transparency can be regulated by small voltages in order to either increase their clarity and allow radiation during the winter or colour them so as to face the summer cooling needs. Installations in New York have proved that their efficiency can be up to 60% in lighting and cooling electricity. Apart from the glazed parts, similar suggestions can be made for the rest of the building envelope.

# 8 FUTURE WORK

Further steps to continue this project and gather more accurate results could be:

- Expand the technical knowledge of ESP-r in order to exploit it to an extent that would allow more realistic inputs and safer outputs,
- Learn in depth the PHPP software, gather the missing data that it requires to calculate heat balances, heating and cooling demands and loads, comfort and renewable energy gains and primary energy demands annually, and compare the findings with the ones form the ESP-r,
- Set the cooling setpoint to the acceptable limit of 25$^{o}$C and some reasonable ventilation value, and examine the behaviour of the building during warm summer conditions and its frequency of overheating,
- Investigate the effect of the heat gains, construction materials and air tightness comparing them, in order to define which one between them is the most crucial and should be a priority in the future (probably run a sensitivity analysis).

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# APPENDIX A – Components (Worst-case scenario)

Detailed figures of the components of the initial model, as presented by the ESP-r:

```
Surface|Mat|Thick  |Conduc-|Density |Specif|IR  |Solr| Description
layer  |db | (mm)  |tivity |        |heat  |emis|abs |
south is composed of Wall_Scot_no and is opaque:
    1  130   20.0    0.570  1300.0  1000.0 0.91 0.70  Render External 20 mm
    2   10  102.0    0.770  1700.0  1000.0            Brick outer leaf
    3    0   50.0    0.000     0.0     0.0          air gap (R= 0.180)
    4  295   90.0    0.020    12.0  1030.0            Min wool quilt 60mm
    5  295   50.0    0.040    12.0  1030.0            Min wool quilt 60mm
    6   40  100.0    1.130  1800.0  1008.0            Concrete med density (1800)
    7    0   25.0    0.000     0.0     0.0          air gap (R= 0.180)
    8  112   13.0    0.210   900.0  1000.0 0.91 0.70  Plasterboard (UK code)
 ISO 6946 U values (hor/up/dn heat flow) for Wall_Scot_no is  0.152  0.152  0.151 (partn)  0.150
```

*Figure 24 Composition of the Initial Walls*

```
ceiling is composed of Fl_roof_noti and is opaque:
    1  323    8.0    0.130   290.0  1300.0 0.90 0.90  virtual_loft_space
    2  281  200.0    0.030    12.0   840.0            glass fibre quilt
    3  156   10.0    1.500  2100.0  1000.0            Tiles Concrete 10 mm
    4  110    9.5    0.210   900.0  1000.0 0.91 0.26  Plasterboard (wallboard)
 ISO 6946 U values (hor/up/dn heat flow) for Fl_roof_noti is  0.144  0.145  0.143 (partn)  0.142
```

*Figure 25 Composition of the Initial Ceiling*

```
floor is composed of Sol_grnd_not and is opaque:
    1  268  150.0    1.500  1500.0  2085.0 0.90 0.70  Clay underfloor 750 mm
    2  268  200.0    1.500  1500.0  2085.0            Clay underfloor 750 mm
    3  268  200.0    1.500  1500.0  2085.0            Clay underfloor 750 mm
    4  268  200.0    1.500  1500.0  2085.0            Clay underfloor 750 mm
    5    9   25.0    0.770  1700.0   940.0          Brick slips 25 mm
    6   39  100.0    1.350  2000.0  1000.0            Cast concrete 100 mm
    7  289  180.0    0.030    15.0  1000.0           EPS 80mm
    8  129   50.0    0.410  1200.0  1000.0 0.91 0.70  Screed 50mm
 ISO 6946 U values (hor/up/dn heat flow) for Sol_grnd_not is  0.145  0.146  0.144 (partn)  0.143
```

*Figure 26 Composition of the Initial Floor*

```
door_w is composed of door and is opaque:
    1   69   50.0    0.070   700.0  2390.0 0.90 0.65  oak
 ISO 6946 U values (hor/up/dn heat flow) for door is  1.131  1.171  1.082 (partn)  1.026
```

*Figure 27 Composition of the Initial Door*

```
glz_s is composed of switched_gl & optics DCF7671_6omb
   1  243   30.0    0.100  2500.0   750.0 0.83 0.05  clear float
   2    0   10.0    0.000    0.0     0.0           air gap (R= 0.170)
   3   45    3.0   40.000  7800.0   502.0           white ptd steel
   4    0   10.0    0.000    0.0     0.0           air gap (R= 0.170)
   5  243   30.0    0.100  2500.0   750.0 0.83 0.05  clear float
 ISO 6946 U values (hor/up/dn heat flow) for switched_gl is  0.901  0.926  0.870 (partn)  0.833

 Clear float 76/71, 6mm open mid blnd: with id of: DCF7671_6omb
 with 5 layers [including air gaps] and visible trn: 0.76
 Direct transmission @ 0, 40, 55, 70, 80 deg
   0.604 0.578 0.521 0.384 0.170
 Layer| absorption @ 0, 40, 55, 70, 80 deg
   1  0.157 0.172 0.185 0.201 0.202
   2  0.001 0.002 0.003 0.004 0.005
   3  0.110 0.108 0.116 0.121 0.097
   4  0.001 0.002 0.003 0.004 0.005
   5  0.117 0.124 0.127 0.112 0.077
```

*Figure 28 Composition of the Initial Glazing Area*

# APPENDIX B – Components (Upgraded model)

Detailed figures of the components of the upgraded model, as presented by the ESP-r:

```
Surface|Mat|Thick  |Conduc-|Density |Specif|IR  |Solr| Description
layer  |db | (mm)  |tivity |        |heat  |emis|abs |
south is composed of Wall_Scot_no and is opaque:
   1  130   20.0    0.570  1300.0  1000.0 0.91 0.70  Render External 20 mm
   2   10  102.0    0.770  1700.0  1000.0           Brick outer leaf
   3    0   50.0    0.000    0.0     0.0           air gap (R= 0.180)
   4  295  150.0    0.020    12.0  1030.0           Min wool quilt 60mm
   5  295   50.0    0.040    12.0  1030.0           Min wool quilt 60mm
   6   40  100.0    1.130  1800.0  1008.0           Concrete med density (1800)
   7    0   25.0    0.000    0.0     0.0           air gap (R= 0.180)
   8  112   13.0    0.210   900.0  1000.0 0.91 0.70  Plasterboard (UK code)
 ISO 6946 U values (hor/up/dn heat flow) for Wall_Scot_no is  0.104  0.105  0.104 (partn)  0.103
```

*Figure 29 Composition of the upgraded Walls*

```
ceiling is composed of Fl_roof_noti and is opaque:
   1  323    8.0    0.130   290.0  1300.0 0.90 0.90  virtual_loft_space
   2  281  200.0    0.020    12.0   840.0           glass fibre quilt
   3  156   10.0    1.500  2100.0  1000.0           Tiles Concrete 10 mm
   4  110    9.5    0.210   900.0  1000.0 0.91 0.26  Plasterboard (wallboard)
 ISO 6946 U values (hor/up/dn heat flow) for Fl_roof_noti is  0.097  0.098  0.097 (partn)  0.096
```

*Figure 30 Composition of the upgraded Ceiling*

```
floor is composed of Sol_grnd_not and is opaque:
   1  268  150.0    1.500  1500.0  2085.0 0.90 0.70  Clay underfloor 750 mm
   2  268  200.0    1.500  1500.0  2085.0            Clay underfloor 750 mm
   3  268  200.0    1.500  1500.0  2085.0            Clay underfloor 750 mm
   4  268  200.0    1.500  1500.0  2085.0            Clay underfloor 750 mm
   5    9   25.0    0.770  1700.0   940.0            Brick slips 25 mm
   6   39  100.0    1.350  2000.0  1000.0            Cast concrete 100 mm
   7  289  180.0    0.020    15.0  1000.0            EPS 80mm
   8  129   50.0    0.410  1200.0  1000.0 0.91 0.70  Screed 50mm
 ISO 6946 U values (hor/up/dn heat flow) for Sol_grnd_not is  0.101  0.101  0.101 (partn)  0.100
```

*Figure 31 Composition of the upgraded Floor*

```
glz_s is composed of switched_gl & optics DCF7671_6omb
   1  243   30.0    0.050  2500.0   750.0 0.83 0.05  clear float
   2    0   10.0    0.000     0.0     0.0            air gap (R= 0.170)
   3   45    3.0   40.000  7800.0   502.0            white ptd steel
   4    0   10.0    0.000     0.0     0.0            air gap (R= 0.170)
   5  243   30.0    0.050  2500.0   750.0 0.83 0.05  clear float
 ISO 6946 U values (hor/up/dn heat flow) for switched_gl is  0.585  0.595  0.571 (partn)  0.556

 Clear float 76/71, 6mm open mid blnd: with id of: DCF7671_6omb
 with 5 layers [including air gaps] and visible trn: 0.76
 Direct transmission @ 0, 40, 55, 70, 80 deg
   0.604 0.578 0.521 0.364 0.170
 Layer| absorption @ 0, 40, 55, 70, 80 deg
   1  0.157 0.172 0.185 0.201 0.202
   2  0.001 0.002 0.003 0.004 0.005
   3  0.110 0.108 0.116 0.121 0.097
   4  0.001 0.002 0.003 0.004 0.005
   5  0.117 0.124 0.127 0.112 0.077
```

*Figure 32 Composition of the upgraded Glazing Area*

```
door_w is composed of door and is opaque:
   1   69   50.0    0.050   700.0  2390.0 0.90 0.65  oak
 ISO 6946 U values (hor/up/dn heat flow) for door is  0.855  0.877  0.826 (partn)  0.794
```

*Figure 33 Composition of the upgraded Door*

# APPENDIX C – Temperature results

Temperature results, as presented by the ESP-r:

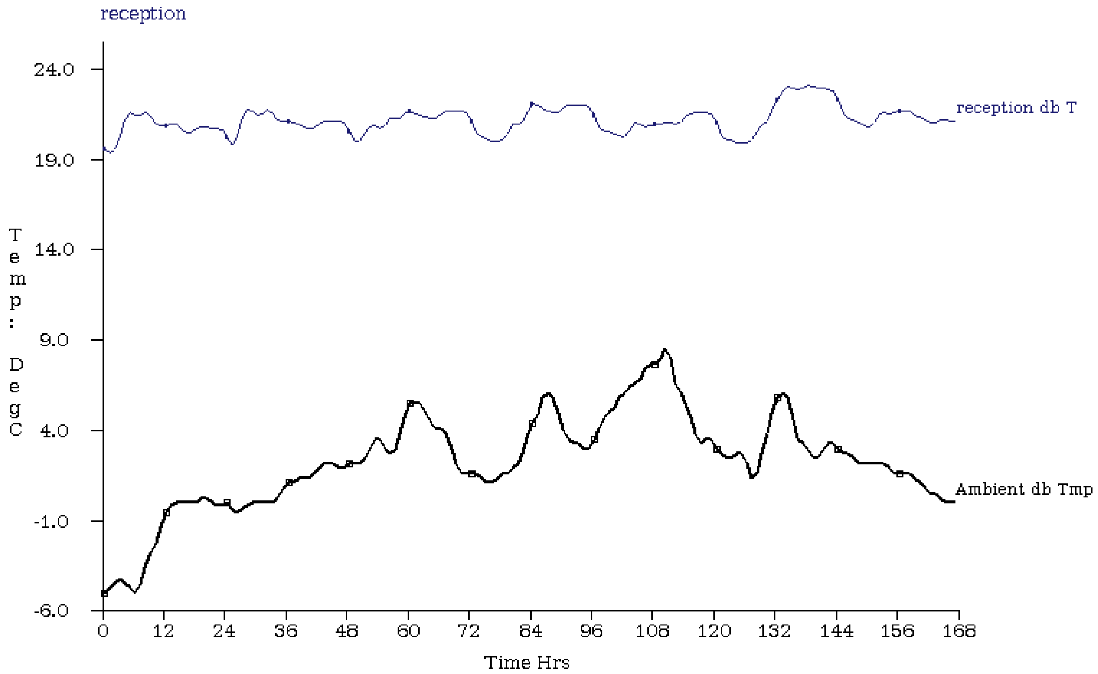


*Figure 34 Temperature hourly results of the "worst-case scenario" in 2010 (air changes per hour: 0.03) combined with the ambient Temperature*

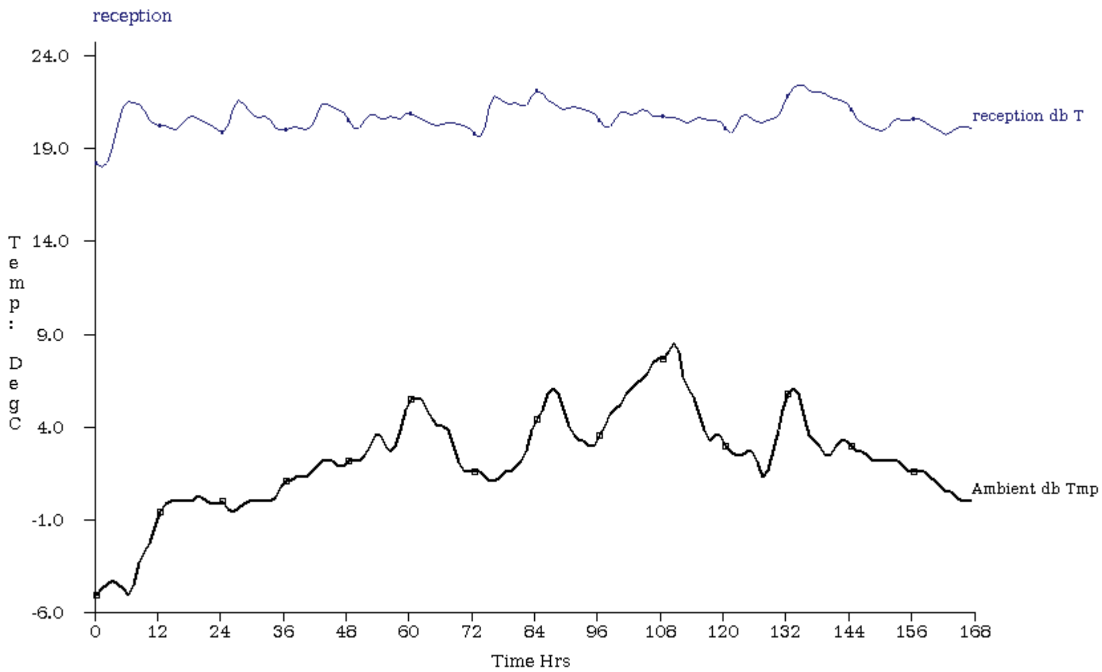


*Figure 35 Temperature hourly results of the "worst-case scenario" in 2020 with the A++ appliances (air changes per hour: 0.03) combined with the ambient Temperature*

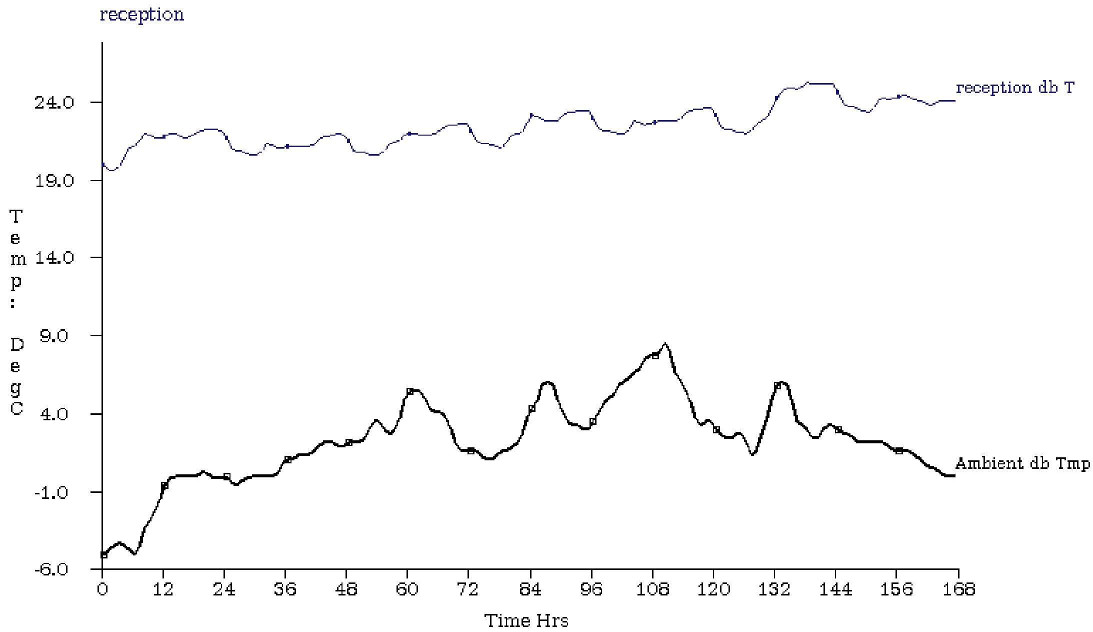


*Figure 36 Temperature hourly results of the upgraded model in 2010 (air changes per hour: 0.03) combined with the ambient Temperature*

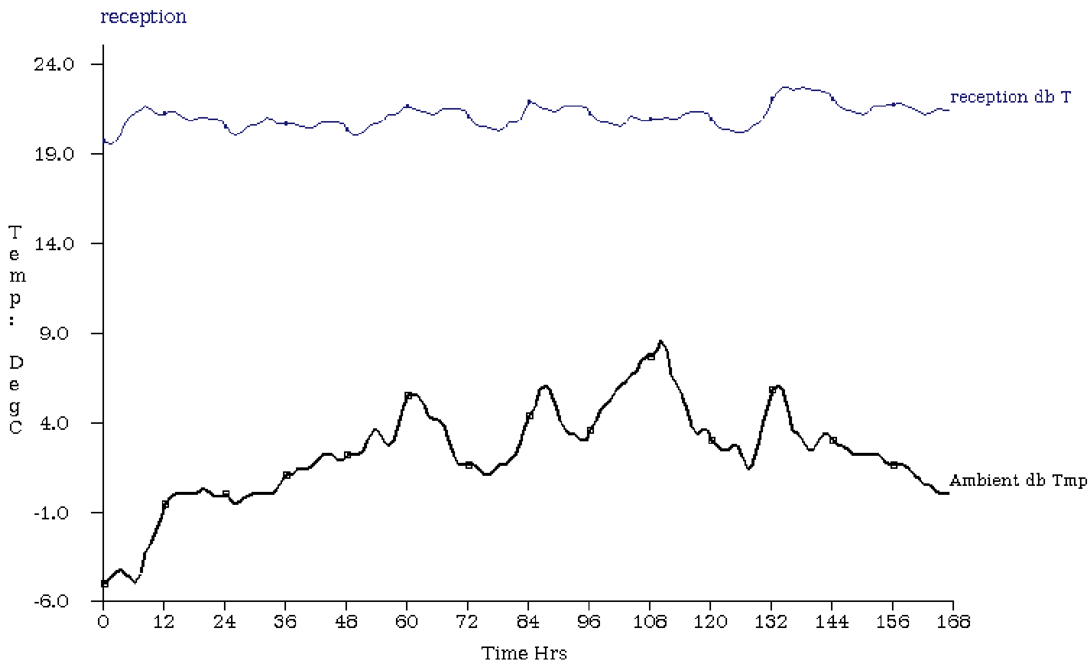


*Figure 37 Temperature hourly results of the upgraded model in 2020 with the A++ appliances (air changes per hour: 0.03) combined with the ambient Temperature*

# APPENDIX D – Energy Delivered

Energy delivered for heating in the “worst-case scenario”, as presented by the ESP-r:

Zone total sensible and latent plant used (kWhrs)

| Zone | Sensible heating | | Sensible cooling | | Humidification | | Dehumidification | |
|---|---|---|---|---|---|---|---|---|
| id name | Energy (kWhrs) | No. of Hr rqd | Energy (kWhrs) | No. of Hr rqd | Energy (kWhrs) | No. of Hr rqd | Energy (kWhrs) | No. of Hr rqd |
| 1 reception | 57.35 | 15.0 | 0.00 | 0.0 | 0.00 | 0.0 | 0.00 | 0.0 |
| All | 57.4 | 15.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

*Figure 38 Energy delivered for heating in the“worst-case scenario” in 2010 (air changes per hour: 0.03)*

Zone total sensible and latent plant used (kWhrs)

| Zone | Sensible heating | | Sensible cooling | | Humidification | | Dehumidification | |
|---|---|---|---|---|---|---|---|---|
| id name | Energy (kWhrs) | No. of Hr rqd | Energy (kWhrs) | No. of Hr rqd | Energy (kWhrs) | No. of Hr rqd | Energy (kWhrs) | No. of Hr rqd |
| 1 reception | 50.61 | 13.0 | 0.00 | 0.0 | 0.00 | 0.0 | 0.00 | 0.0 |
| All | 50.6 | 13.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

*Figure 39 Energy delivered for heating in the“worst-case scenario” in 2010 (air changes per hour: 0.01)*

Zone total sensible and latent plant used (kWhrs)

| Zone | Sensible heating | | Sensible cooling | | Humidification | | Dehumidification | |
|---|---|---|---|---|---|---|---|---|
| id name | Energy (kWhrs) | No. of Hr rqd | Energy (kWhrs) | No. of Hr rqd | Energy (kWhrs) | No. of Hr rqd | Energy (kWhrs) | No. of Hr rqd |
| 1 reception | 132.36 | 33.0 | 0.00 | 0.0 | 0.00 | 0.0 | 0.00 | 0.0 |
| All | 132.4 | 33.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

*Figure 40 Energy delivered for heating in the“worst-case scenario” in 2020 with the A++ appliances (air changes per hour: 0.03)*

Zone total sensible and latent plant used (kWhrs)

| Zone | Sensible heating | | Sensible cooling | | Humidification | | Dehumidification | |
|---|---|---|---|---|---|---|---|---|
| id name | Energy (kWhrs) | No. of Hr rqd | Energy (kWhrs) | No. of Hr rqd | Energy (kWhrs) | No. of Hr rqd | Energy (kWhrs) | No. of Hr rqd |
| 1 reception | 120.07 | 28.0 | 0.00 | 0.0 | 0.00 | 0.0 | 0.00 | 0.0 |
| All | 120.1 | 28.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

*Figure 41 Energy delivered for heating in the“worst-case scenario” in 2020 with the A++ appliances (air changes per hour: 0.01)*

Energy delivered for heating in the upgraded model, as presented by the ESP-r:

Zone total sensible and latent plant used (kWhrs)

| Zone id name | Sensible heating Energy (kWhrs) | Sensible heating No. of Hr rqd | Sensible cooling Energy (kWhrs) | Sensible cooling No. of Hr rqd | Humidification Energy (kWhrs) | Humidification No. of Hr rqd | Dehumidification Energy (kWhrs) | Dehumidification No. of Hr rqd |
|---|---|---|---|---|---|---|---|---|
| 1 reception | 21.00 | 4.0 | 0.00 | 0.0 | 0.00 | 0.0 | 0.00 | 0.0 |
| All | 21.0 | 4.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

*Figure 42 Energy delivered for heating in the upgraded model in 2010 (air changes per hour: 0.03)*

```
Zone total sensible and latent plant used (kWhrs)
  Zone          Sensible heating  Sensible cooling   Humidification    Dehumidification
id name           Energy   No. of   Energy   No. of    Energy   No. of    Energy   No. of
               (kWhrs)  Hr rqd  (kWhrs)  Hr rqd   (kWhrs)  Hr rqd   (kWhrs)  Hr rqd
1,reception,21.00,4.0,0.00,0.0,0.00,0.0,0.00,0.0

All,21.0,4.0,0.0,0.0,0.0,0.0,0.0,0.0
```

*Figure 43 Energy delivered for heating in the upgraded model in 2010 (air changes per hour: 0.01)*

Zone total sensible and latent plant used (kWhrs)

| Zone id name | Sensible heating Energy (kWhrs) | Sensible heating No. of Hr rqd | Sensible cooling Energy (kWhrs) | Sensible cooling No. of Hr rqd | Humidification Energy (kWhrs) | Humidification No. of Hr rqd | Dehumidification Energy (kWhrs) | Dehumidification No. of Hr rqd |
|---|---|---|---|---|---|---|---|---|
| 1 reception | 49.62 | 9.0 | 0.00 | 0.0 | 0.00 | 0.0 | 0.00 | 0.0 |
| All | 49.6 | 9.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

*Figure 44 Energy delivered for heating in the upgraded model in 2020 with the A++ appliances (air changes per hour: 0.03)*

Zone total sensible and latent plant used (kWhrs)

| Zone id name | Sensible heating Energy (kWhrs) | Sensible heating No. of Hr rqd | Sensible cooling Energy (kWhrs) | Sensible cooling No. of Hr rqd | Humidification Energy (kWhrs) | Humidification No. of Hr rqd | Dehumidification Energy (kWhrs) | Dehumidification No. of Hr rqd |
|---|---|---|---|---|---|---|---|---|
| 1 reception | 41.50 | 8.0 | 0.00 | 0.0 | 0.00 | 0.0 | 0.00 | 0.0 |
| All | 41.5 | 8.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

*Figure 45 Energy delivered for heating in the upgraded model in 2020 with the A++ appliances (air changes per hour: 0.01)*