DTU Civil Engineering

Department of Civil

FLEXIBLE ELECTRICAL HEATING OF NEW LOW ENERGY BUILDINGS

Master Thesis

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APPROVAL

This thesis has been prepared for over five months together with the Department of Civil Engineering at the Technical University of Denmark (DTU) in partial fulfilment for the master's degree in Energy Technologies for Sustainable Development.

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ABSTRACT

The heat loss in nearly zero-energy buildings may be reduced to such a low level that is similar to the internal heat gain shallow. Therefore, the internal heat gain significantly influences the heating demand of new buildings. It is relevant to investigate the magnitude and distribution in time and rooms of the internal heat gain.

The project focuses on heat from appliances and occupants on indoor conditions and heating demand. Furthermore, the project investigates the possibilities of heating the house with direct electrical heating, especially off-peak electricity during nighttime.

Different simulations were performed in which the thermal loads vary along with their distribution in time and space. As mentioned, two types of distribution are compared. The first one has constant values and distribution, determined by Danish standards. In contrast, the second has variability in time and space. This is based on the typical consumption patterns and behaviour in a Danish one-family house with four members. In addition, different orientation angles and door opening and closing times are also studied. These two measures aim to analyse how they influence indoor conditions and thermal demand.

The analysis of the results shows that, due to the excellent insulation of this type of building and the large amount of thermal energy released by the internal heat gains, a flexible direct electric heating system is feasible from an energy point of view.

Keywords: internal heat gains; body heat; electrical appliances; façade orientation; thermal energy demand, electric panels; hours of non-comfort; behaviour patterns; heat losses; direct and flexible heating system.

ACKNOWLEDGMENTS

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With this dedication, I would first like to thank my two tutors, Svend Svendsen and Kevin Michael Smith, for all the help they have given me during these five months of work. They have always done a great job supervising and advising me, without which this master's thesis would not have been possible.

Secondly, I would like to thank my family for all their support. Moreover, they have allowed me to do my master's thesis in Denmark.

Finally, my friends, both from Spain and Denmark, have always been there to encourage me in the most challenging moments. Also, all the help they gave me, together with my English teacher, solved the language problems.

CONTENTS

ABBREVIATIONS

UPV - Universitat Politècnica de València
DTU - Danmarks Tekniske Universitet
IHG - Internal Heat Gains
BH - Body Heat
EA - Electrical appliances
EP - Electric panels
BR18 - Danish Building Regulations, 2018
DS - Danish Standards
SH - Space Heating
EC - Electricity Consumption

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1 Introduction

This chapter includes a brief introduction of the project background and aim.

1.1 Background

Based on the literature, internal heat gain from electrical equipment can cover part of the thermal energy demand for heating the rooms. For nearly Zero Energy Buildings in Denmark, the heat loss may be so small that most of it can be covered by the internal heat gain resulting in a minimal demand for heating of rooms. For this reason, the resulting heating demand may be so small that a direct electrical resistance heating system may cover it. This means that electric panels and electrical heating cables in the bathroom floors substitute a conventional air-water heat pump and a hydronic heating system in most rooms. Furthermore, the electrical heating system may be operated flexibly, especially during nighttime, to make use of lower electricity prices during nighttime. It is essential to have a realistic model of where and when the internal heat gain from electrical equipment and people occurs in the building. This is the first problem to be investigated in the project.

The possibility of using direct electrical space heating flexibly requires an investigation of the options of switching off heating during the daytime and still maintaining the rooms' comfort temperatures. This is the second problem to be investigated in the project.

1.2 Aim of the project

The project main aim is to investigate the influence of internal heat gain produced by all the electrical appliances and people on energy demand for heating and indoor thermal comfort of a building. Considering that it is impossible to achieve the indoor requirements by only using this internal heat gain, a heating system is also deemed based on a direct electrical flexible heating system. In accordance with this, the direct and flexible electrical resistance heating system is the second study, which will be implemented as a flexible heating system instead of the traditional water-based floor heating system.

They are maintaining the indoor dwelling conditions most cheaply based on the total cost of the installation, and the heating system operation is expected to be achieved. This flexible heating system will provide all the thermal energy demand that internal heat gains cannot cover. Several scenarios will be analyzed in the software IDA ICE for a single-family house, which will calculate the energy balance and the indoor environment of the individual rooms in the house.

1.3 Potential Hurdles

The following list has been established to solve all the expected challenges throughout the project.

- How much internal heat gain from electrical appliances can reduce heating demand? See comments below *Table 22*.
- Could it happen to overheat due to internal heat gains in one room and heating demand in another? See comments *Table 20.* However, in the flexible one? See comments *Table 32.* What could be done to solve this hurdle? See comments *Table 25.*
- Is it relevant to take internal heat gain into account combined with direct and flexible electric resistance heating at the new generation of low energy consumption buildings in a massive way? See the last paragraph of the *Discussion.*

2 State of the art

In this chapter a state of the art review is done for internal heat gains from electric appliances and flexible operation of an electric resistance heating system. Research on thermal power emitted by all the most common devices in Denmark regarding internal heat gain. Based on this, the thermal power emitted is based on actual measurements and not assumptions.

2.1 Internal heat gain.

The most common EA in a Danish dwelling and their use patterns must be studied to perform a realistic model. Non-uniform energy consumption is observed in a typical Danish home, having the following timetable distribution.

- **Morning-time, before working:** Energy demand increases because many EA are switched on.
- **Working time:** Reduction of consumption since people commonly do not work at home. Only essential appliances are used, such as the fridge.
- **Back from work:** An increase in energy demand is experienced, as dinner cooking.
- **Night-time:** Reduction is also experienced; occupants are sleeping.

As shown in the previous four bullet points, internal heat gains differ depending on the day [7]. For that reason, it is experienced a higher thermal power emitted in the morning due to the kitchen equipment in use: kettle, stoves, fume extractor and a less internal heat contribution during the work-time and night-time. The most common daily life timetable is performed in user patterns based on the information found in [10] and [11],. In this way, there is more precise information about daily consumption patterns.

An internal heat gain of each device is studied to know how it can affect indoor thermal comfort conditions. A distribution on time and EA per room [7] and typical electric consumptions need to be studied to reach it [6]. [9]. All data is presented on a methodology based on the studied reports.

2.2 Temperature requirements in the building.

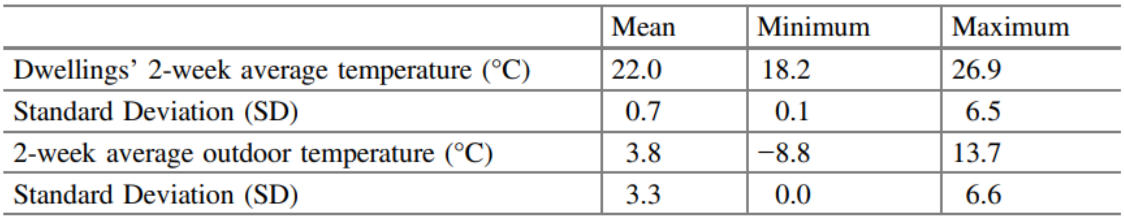
A temperature range is established for winter and summer, accomplishing all the comfortable conditions.

Two regulations establish these ranges. The first is a standard, [8], which each country establishes based on its external environmental conditions and occupant patterns. The second is the building code, [4]., which is mandatory to be implemented in dwellings and fixes the temperature ranges that must be reached to accomplish the required energy qualifications.

However, occupants can modify these ranges depending on the activity life, age, and user’s preferences. Based on the research carried out in 2018 in a dynamic situation in Sweden, a variation of 8ºC in the indoor temperature is acceptable by both young and adults and the elderly. Researchers tested different temperatures for two weeks; a range of almost 8ºC in average temperature was acceptable to occupants, from 18.2ºC to 26.9ºC. [1].

The table below represents the indoor temperatures that occupants accepted as comfortable.

Table 1.Temperature results obtained in the experiment, (Dennis Johansson, Hans Bagge, & Åsa Wahlström, 2018) , [1]



	Mean	Minimum	Maximum
Dwellings’ 2-week average temperature (°C)	22.0	18.2	26.9
Standard Deviation (SD)	0.7	0.1	6.5
2-week average outdoor temperature (°C)	3.8	−8.8	13.7
Standard Deviation (SD)	3.3	0.0	6.6

Another research study is based on how flexibility in indoor temperatures can affect occupants. Researchers set the temperature at 21ºC and experienced three simulations [2].

Case one: 21 ± 0.5ºC

Case two: 21 ± (1ºC or 1.5ºC on standard days depending on time of the day, ± 3ºC on exceptionally winter days)

Case three: 21 ± (from 0.5ºC to 3ºC, depending on occupant's choice)

Summarising the results, most respondents would accept 19ºC as the minimum temperature since lower temperatures require wearing warm clothes, which they were unwilling to do. The highest temperature most respondents would accept was 22.5ºC; higher temperatures made them feel uncomfortable.

However, applied to this project, Danish people prefer 20ºC instead of 19ºC, so the minimum accepted temperature during some periods is 20ºC, except for the Master bedroom since it is preferable to be colder than the rest of the house. During possible sporadic spans at 20ºC, occupants would continue being comfortable. However, to always set up the average temperature in *Table 1* and be sure nobody is uncomfortable with the temperature, all the rooms will be set up at 22ºC, except the Master bedroom, which is at 18ºC.

2.3 Electric resistance heating systems

Based on the literature, two electric heating system types in application in buildings are the most used. Both present high performances. For that reason, it is not required to investigate new heating technologies.

- Electric heating panels mounted on the wall
- Electric resistance floor heating system

Regarding energy performance, direct electrical resistance heating has an efficiency of 100% in transforming electrical power to heating power. In comparison, a heat pump may have an efficiency of 300% but comes with a higher investment cost.

Electric heating panels are mounted on the walls. All the electric energy is converted to heat energy. The electric heating panels may be controlled with smart controllers that can be programmed.

Electrical cables are typically cast in concrete slabs. They may be a simple resistance wire or have self-controlling functions.

3 Methodology and input data

The project first step is to collect typical information on the occupants' patterns and EA consumptions. This data acquisition consists of gathering user patterns, human body heat influence, and EA consumption and distribution on time and room. IDA-ICE Software will run several scenarios to simulate accurate energy models. Following this, some strategies reduce energy consumption and economic costs.

3.1 Body heat influence and user patterns

As an accurate model, variations in human internal loads are considered in daily consumption patterns. The following questions are answered in this subchapter.

- How many people are in the room, and for how long?
- Heat input of the people input to room, activity level.
- Total thermal energy from people in a typical day, in kWh.
- Which are the most common device use patterns in a single-family house?

This chapter presents the most common Danish daily patterns based on reports [10] and [11]. The figure at the bottom, see *Figure 1,* shows the most common occupant's habits during the week, differentiating between weekdays and weekends.

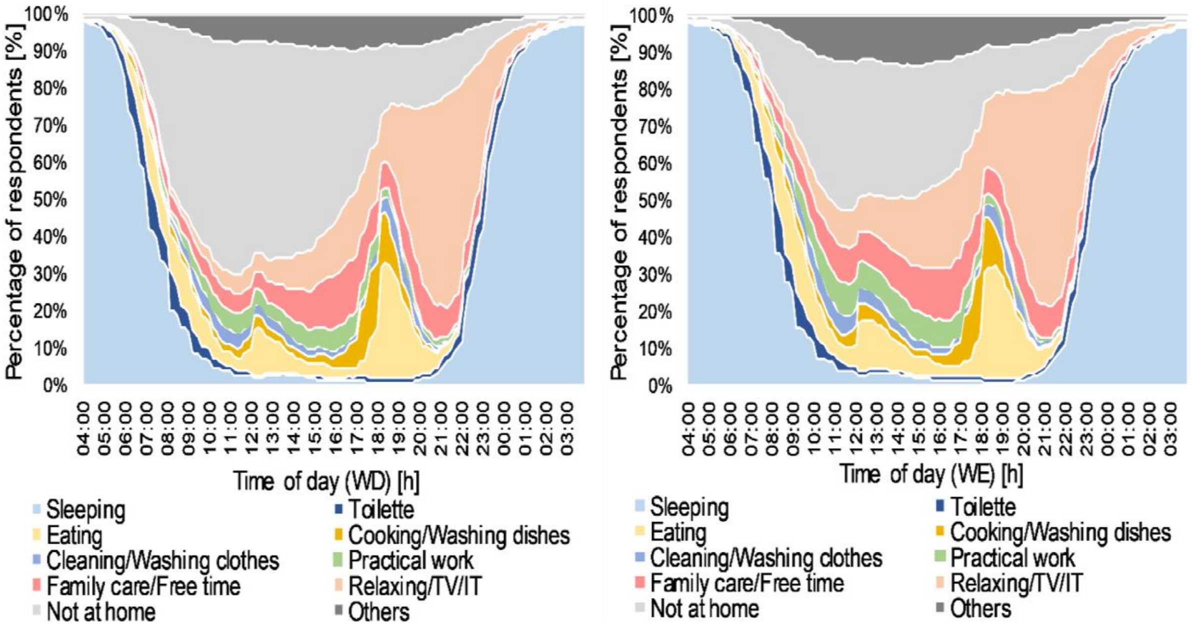


Figure 1. Occupant activities profile during weekdays (left) and weekends (right) (Barthelmes, V.M., y otros, 2018).

This information, detailed in *Figure 1,* together with the actual indoor layout of the dwelling shown in the figure below, see *Figure 2*, will perform the most typical patterns followed in a four-member Danish family during weekdays and weekends. That will be carried out by situating each activity of the figure above in each room presented in the indoor layout below.

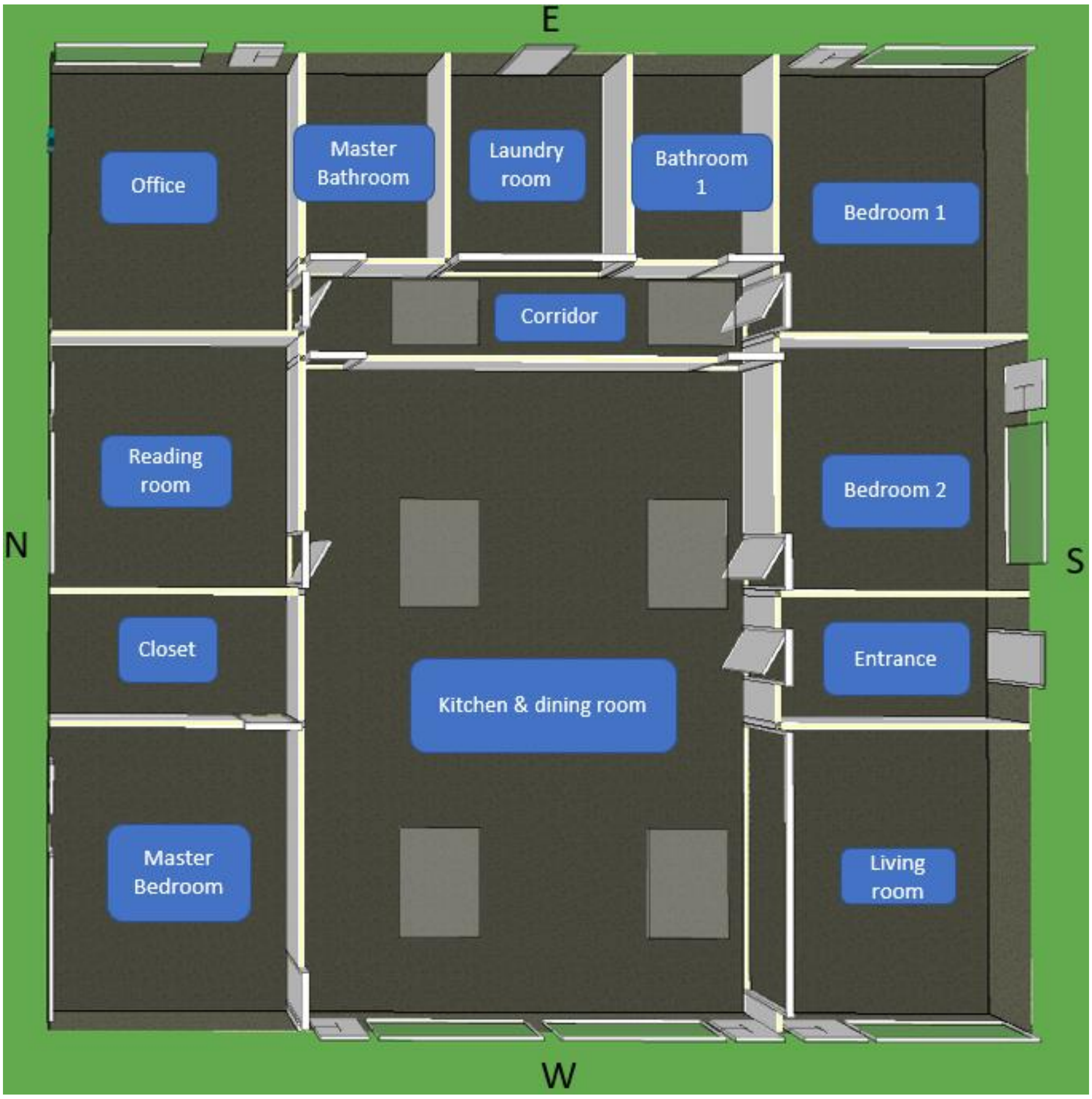


Figure 2. The actual indoor layout of the study building.

As explained before, *Figure 1* together with *Figure 2,* will organize the typical daily life patterns in Danish dwellings depending on each room. This is put together in *Table 4,* which summarizes both figures information in the left column called *"Room and use".* Moreover, *Table 4* implements the heat from the occupant bodies, which calculation procedure is commented following this.

In *Table 2.*, see below, the MET information used to calculate the BH (IDA ICE input), depending on the number of occupants and their activities, is summarized in the table below. See *Table 2.*

Table 2. MET values.

Activity	MET	Standard metabolic rate (W/m2)	Occupants	S (m2)
Sleep	0.7	58.15	Male (M)	1.8
Standing, relaxed, rest	1.2		Female (F)	1.6
Reading, seated	1.0		Children (C1 and C2)	1.3
Cooking	1.8			
Housecleaning	3.0			
Use of toilette and eating	1.4			
Washing clothes	2.5			

As shown in the table above, see *Table 2,* 1 MET equals 58.15 W/m^2, m^2 the whole-body area. Universitat Politècnica de València (UPV), [12], considers 1.80m^2 of average area of the body for an adult. All the MET values presented in the table are based on the IDA-ICE "help" document excepting the use of *toilette/eating* and *washing clothes* activities; both are assumed by taking similarities with other activities. Regarding *Washing clothes*, it has been considered as a part of housecleaning. Nevertheless, the effort is considered to be lower; for that reason, its MET is lower too. Each MET from the table above, see *Table 2,* is multiplied by the standard metabolic rate and the occupant's surface bodies. This is how each occupant's thermal body power is calculated in the table below; see *Table 3*. Heat thermal power depending on the occupant and the activity is set out in *Table 3.*

Table 3. Thermal power is emitted per occupant depending on activity.

Activity	Male (M) W	Female (F) W	Children (C1 and C2) W
Sleep	73.3	65.1	52.9
Standing, relaxed, rest	125.6	111.6	90.7
Reading, seated	104.7	93.0	75.6
Cooking	188.4	167.5	136.1
Housecleaning	314.0	279.1	226.8
Use of toilette and eating	146.5	130.3	105.8
Washing clothes	261.7	232.6	189.0

Based on the thermal power emitted per person in the table above, see *Table 3*, and users' patterns presented in *Table 4,* the total internal heat gain emitted per occupant is presented in the following table, which represents a typical day in a four-Danish-family. The elaborated schedule, see *Table 4,* as commented before, considers the most common distribution of occupants on time and rooms depending on weekdays and weekends.

Table 4. Occupants pattern schedule. Distribution of internal heat gain from human bodies per day and per room based on the typical Danish dwelling behaviours for a four-family-member.

Weekdays						
Room and use	**Range of time**	**Time (h)**	**Nº of people**	**Occupants**	**Power (W)**	**Energy (Wh/day)**
Master bathroom	06:30-06:35	0.08	1.0	F	130.26	10.42
Master bathroom	06:35-06:40	0.08	1.0	M	146.54	11.72
Children's bathroom (Bathroom 1)	06:30-06:45	0.25	1.0	C1	105.83	26.46
Children's bathroom (Bathroom 1)	06:45-07:00	0.25	1.0	C2	105.83	26.46
Kitchen/dining/living room (Cooking/Washing dishes)	06:40-07:00	0.33	2.0	F,M	355.88	117.44
Kitchen/dining and living room (breakfast)	07:00-07:30	0.50	4.0	F,M,C1,C2	488.46	244.23
Practical and garden work	08:00-15:00	7.00	0.0	-	0.00	0.00
Kitchen/dining and living room (Relax/TV/IT)	15:00-17:00	2.00	3.0	F,M,C2	327.97	655.93
Bedroom 1 (relax)	15:00-17:00	2.00	1.0	C1	90.71	181.43
Reading room (Reading)	17:00-19:00	2.00	4.0	F,M,C1,C2	348.90	697.80
Kitchen/dining/living room (Cooking/washing dishes)	19:00-19:30	0.50	2.0	F,M	355.88	177.94
Laundry room (washing clothes)	19:00-19:30	0.50	2.0	F,M	494.28	247.14
Kitchen/dining and living room (Relax/TV/IT)	19:00-19:30	0.50	2.0	C1,C2	181.43	90.71
Kitchen/dining and living room (Dinner)	19:30-20:00	0.50	4.0	F,M,C1,C2	488.46	244.23
Kitchen/dining and living room (Relax/TV/IT)	20:00-22:50	2.83	4.0	F,M, C1,C2	418.68	1184.86
Master bathroom	22:50-22:55	0.08	1.0	F	130.26	10.42
Master bathroom	22:55-23:00	0.08	1.0	M	146.54	11.72
Children's bathroom (Bathroom 1)	22:50-22:55	0.08	1.0	C1	105.83	8.47
Children's bathroom (Bathroom 1)	22:55-23:00	0.08	1.0	C2	105.83	8.47
Bedroom 1 (sleeping)	23:00-06:30	7.50	1.0	C1	52.92	396.87
Bedroom 2 (sleeping)	23:00-06:30	7.50	1.0	C2	52.92	396.87
Master bedroom (sleeping)	23:00-06:30	7.50	2.0	F,M	138.40	1037.98
TOTAL						**5787.58**
Weekends						
Room and use	**Range of time**	**Time (h)**	**Nº of people**	**Occupants**	**Power (W)**	**Energy (Wh/day)**
Master bathroom	08:30-08:45	0.25	1.0	F	130.26	32.56
Master bathroom	08:45-09:00	0.25	1.0	M	146.54	36.63
Children's bathroom (Bathroom 1)	08:30-08:55	0.25	1.0	C1	105.83	26.46
Children's bathroom (Bathroom 1)	08:55-09:20	0.42	1.0	C2	105.83	44.03
Kitchen/dining/living room (Cooking/washing dishes)	09:00-09:20	0.33	2.0	F,M	355.88	117.44
Kitchen/dining and living room (breakfast)	09:20-10:00	0.60	4.0	F,M,C1,C2	488.46	293.08
Not at home	10:00-11:30	1.50	0.00	-	0.00	0.00
Kitchen/dining and living room (Relax/TV/IT)	11:30-12:00	0.50	2.0	C1,C2	181.43	90.71
Kitchen/dining and living room (Cooking)	11:30-12:00	0.50	2.0	F,M	355.88	177.94
Kitchen/dining and living room (Lunch)	12:00-12:30	0.50	4.0	F,M,C1,C2	488.46	244.23
Kitchen/dining and living room (Relax/TV/IT)	12:30-17:00	4.50	3.0	F,M,C2	327.97	1475.85
Bedroom 1 (relax)	12:30-17:00	4.50	1.0	C1	90.71	408.21
Reading room (Reading)	17:00-19:30	2.50	2.0	C1,C2	151.19	377.98
House cleaning	17:00-19:00	2.00	2.0	F,M	593.13	1186.26
Kitchen/dining/living room (Cooking/washing dishes)	19:00-19:30	0.50	2.0	F,M	355.88	177.94
Laundry room (washing clothes)	19:00-19:30	0.50	2.0	F,M	494.28	247.14
Kitchen/dining and living room (Dinner)	19:30-20:00	0.50	4.0	F,M,C1,C2	488.46	244.23
Kitchen/dining and living room (Relax/TV/IT)	20:00-23:50	3.83	4.0	F,M,C1,C2	418.68	1603.54
Master bathroom	23:50-23:55	0.80	1.0	F	130.26	104.20
Master bathroom	23:55-00:00	0.80	1.0	M	146.54	117.23
Children's bathroom (Bathroom 1)	23:50-23:55	0.80	1.0	C1	105.83	84.67
Children's bathroom (Bathroom 1)	23:55-00:00	0.80	1.0	C2	105.83	84.67
Bedroom 1 (sleeping)	00:00-08:30	8.50	1.0	C1	52.92	449.79
Bedroom 2 (sleeping)	00:00-08:30	8.50	1.0	C2	52.92	449.79
Master bedroom (sleeping)	00:00-08:30	8.50	2.0	F,M	138.40	1176.37
TOTAL						**9250.95**

Table 4 considers a four-occupant family with two children. One is a teenager (C1), the other is a kid (C2), both have the same body surface and MET, and there is a father and mother. Because there is a teenager (C1), who sleeps in Bedroom 1, considering the layout shown in *Table 4*, Bedroom 1 has a broader span because it is assumed teenagers prefer to spend more time in their rooms. Because of the difficulty and the scarce information, the corridor, and other zones that occupants do not usually occupy are not considered BH. These rooms are the following: corridor, entrance, office, and closet. The column on the right-hand side of the table

shows the total BH power emitted during each activity, which is the body heat, internal heat gain input to IDA ICE.

The table below, see *Table 5*, compares the heat human standard value, 1.5 W/m^2, together with the most typical Danish four-family-member daily life patterns, i.e. the schedule in *Table 4*, 1.34 W/m^2 on weekdays 1.79 W/m^2 at weekends.

Table 5. Comparison of body heat contribution between the occupant patterns simulation and the standard values.

Human Body Heat		
Occupant patterns simulation W/m^2		**Standard value W/m^2**
Weekdays	**Weekends**	
1.28	1.98	1.50

Both week values have been calculated by dividing the total amount of energy per day, shown in *Table 4* in the *TOTAL* row, by 24h and the entire floor surface of the building, 188.07m^2. This procedure is applied to both week periods; it means weekdays and weekends. The standard values are constant over time, and they do not differ depending on the activity and its time spent in each room. The standard value comes from the Danish building standards, which suggests 5W/m^2 in total for IHG, 1.5 W/m^2 for body heat and 3.5 W/m^2 for electrical appliances.

To compare both body heat values and see how much they differ, it is necessary to only use one value for the occupant patterns during a week. It is impossible to calculate the average because it would not make sense since weekdays are five days, and weekends are only two; therefore, each week is multiplied by its corresponding value. It is the weighted average:

$$Occupant\ patterfives\ heat\ bodies\ simumlation\ = 1.28 * \frac{5}{7} + 1.98 * \frac{2}{7}$$

$$Occupant\ patterns\ heat\ bodies\ simumltion\ = 1.48\ W/m2$$

Comparing both values for the same span, which is a week, the table at the bottom shows that both results are similar. The difference is not noticeable.

Table 6. Human heat bodies contribution during a week.

Human Body Heat	
Occupant patterns simulation W/m^2	**Standard value W/m^2**
1.48	1.50

3.2 Use of electrical energy in households

Internal heat gain of domestic appliances is commonly implemented in Software as a fixed variable, corresponding to 3.5 W/m^2 for the Danish standard value, without considering that each EA has its heat gain. Given this, an accurate model is elaborated using their real thermal power. As a result, an accurate model of the thermal loads contribution per room is done. The following questions need to be resolved.

- What is the purpose of the room?
- How is the regular use of the rooms by a typical family?
- List of electrical equipment per room.
- How is the distribution of the heat gain on an hourly basis and at room level?
- How much energy consumption does a dwelling usually requires?
- Are there always the same consumption patterns, or there are variations?
- How is the thermal power from internal heat gain distributed per room?

However, as there is no information about how much thermal power emits each EA, the procedure to follow consists of:

- Typical annual electricity consumption
- Distribution on time: electricity consumption is distributed on time per day.
- Distribution per room and device: electricity consumption is distributed per room depending on EA.
- Distribution on time and per room: electricity consumption is distributed on time in each room depending on their electric device schedules.

Example of electric consumption in low energy buildings and their electrical appliances heat gains affect heating demand.

This subchapter approximates how much thermal energy can be saved by using IHG from EA. As this is an orientation, the results are demonstrative and are not used in any simulation. There have been nine dwellings considered as population samples. See *Table 7*.

Table 7. Typical energy and DWH consumption in Danish dwelling per year, (Lars Lund Michaelsen & Louise Sabrina Svendsen, 2011) [5]

Basic information	House 1	House 2	House 3	House 4	House 5	House 6	House 7	House 8	House 9
Vital space (m^2)	167	171	143.5	154.8	147.5	167	172	172	149.7
Residents number	4	4	2	4	4	4	4	6	2
Adults number	4	2	2	2	2	2	2	-	2
Children number	0	2	0	1	2	2	2	-	0
Teenagers number	0	0	0	1	0	0	0	-	0
Electric consumption [kWh/year]	5638	3859	5773	4920	4791	2974	2939	9868	1966
Heat consumption [kWh/year]	8279	9920	5395	5291	10345	6367	13555	3288	7561
Water consumption [L/person*day]	68	90.6	180	98.9	73.3	97	124.6	39	75.1
DHW [L/person*day]	14.9	44	39	36.8	26.4	33.3	30.2	4.6	14.5
DHW, percentage of the total amount of DHW [%]	22	49	22	37	36	34	24	12	19

The electricity consumption of houses eight and nine could not have been included because of the following reasons: house eight does not specify the type of residents, and the electric consumption is also exceptionally high; on the contrary, house nine consumption has the lowest electricity consumption. So, both cases are not in the average as the rest of the houses. However, they vary the average, representing a more realistic scenario since only nine dwellings have a few population samples. This variation in the average makes the information more realistic since it is more variable.

The table below, see *Table 8*, shows the average electricity consumption used in a half year instead of the whole year since the amount of useful electricity consumption, IHG, is only profitable during heating consumption. For the rest of the year, they do not reduce the heating demand. Considering all the electric consumption is converted to heat energy, the consumptions in the table below represent the EA heat gains for the heating season in each house.

Table 8. Average electricity consumption for a building per area and half a year.

Eletric consumption	House 1	House 2	House 3	House 4	House 5	House 6	House 7	House 8	House 9
(kWh/m2/halfyear)	16.88	11.28	20.11	15.89	16.24	8.90	8.54	28.69	6.57

The average consumption in *Table 8* results in 14.79 kWh/m^2*half year. Therefore, as all the electric consumption is converted to heat energy, 14.79kW/m^2 is the total thermal energy from internal heat gain that a Danish house could benefit from EA.

From then on, the following subchapters: *3.2.1 Distribution on time, 3.2.2 Distribution per room and device, and 3.2.3 Distribution on time and per room*; will be used to perform the EA consumption IDA ICE input along with the investigation of this project.

3.2.1 Distribution on time

It is also essential to consider the influence of not always having the actual consumptions since there are variations in electricity uses. Consequently, the figure below, see *Figure 3,* represents a possible variation in daily electricity consumption in a Danish family of four members.

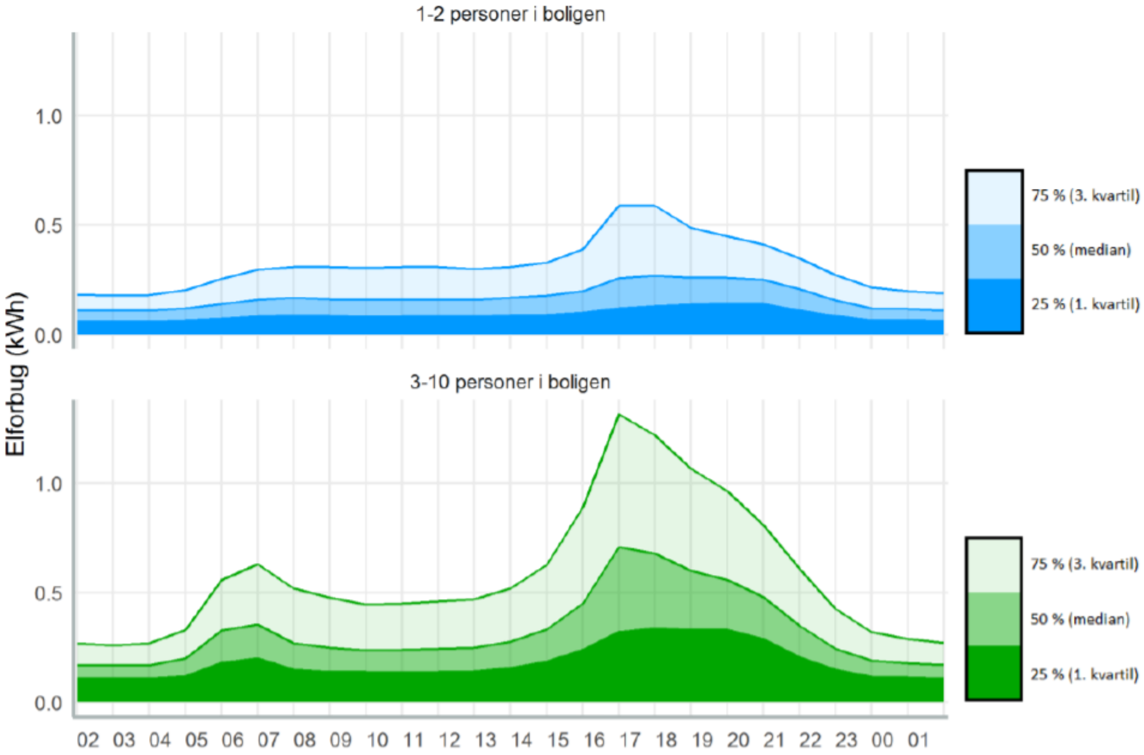


Figure 3. Typical electricity consumption per day for a Danish dwelling, 1-2 persons (top), 3-10 persons (above) (Maria Rønde Holm, Pernille Yde Nielsen, & Laust Hvas Mortensen, 2019)]. [6]

It is experienced an increase during the morning, followed by a reduction during working time, a considerable increment in the afternoon, and finally a decrease during the night. The most substantial consumption is reached in the latest hour of the afternoon. Nevertheless, until getting the peak at the latest afternoon, there is an increment produced by people coming back from work. This is the moment when occupants usually switch on most electric devices. The previous figure, see *Figure 3*, represents a random electric consumption day in Denmark. Given this, the variation in time can be observed depending on daytime or night-time.

3.2.2 Distribution per room and device

Electricity consumption distributed per room is the last point. The following pie chart of different final consumptions in Danish dwellings, see *Figure 4*, shows the percentage of electricity used depending on the room. Electric devices distribution on percentages is so functional because it lets to sense the layout where the consumptions in the dwelling are.

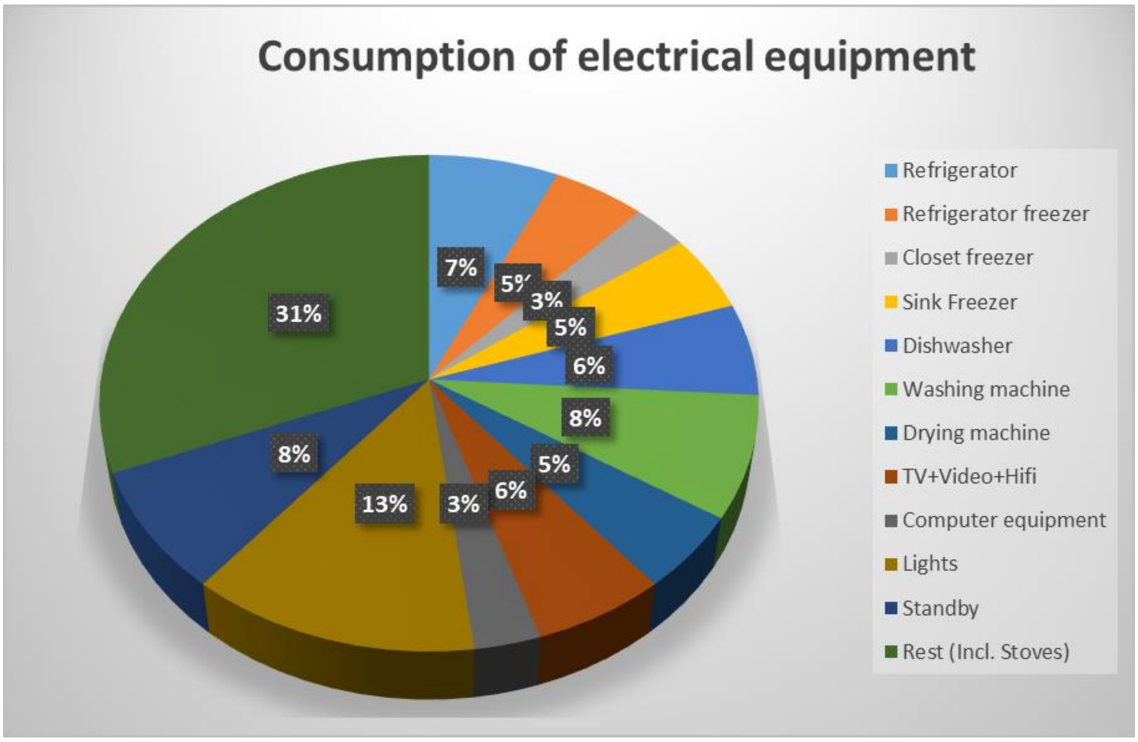


Figure 4. Percentage distribution of household electricity consumption in eight final uses. (Gram-Hanssen, 2005) [7].

Based on *Figure 4,* the following table, see *Table 9*, distributes the percentages of EA consumption per room based on the house layout presented in *Figure 2*, which is typical in Danish houses. In this way, every electric device and its consumption are placed in different rooms depending on where they are.

Table 9. Percentages of electric consumption per room depend on different EA.

	Kitchen & dining, living room	**Laundry room**	**Master bedroom**	**Master bathroom**	**Bedroom 1**	**Bedroom 2**	**Reading room**	**Bathroom 1**	**Walk-in closet**	**Entrance**	**Corridor**	**Office**	**TOTAL**
Appliances	%												
Refrigerator	7.00	-	-	-	-	-	-	-	-	-	-	-	**7.00**
Refrigerate/Freezer	5.00	-	-	-	-	-	-	-	-	-	-	-	**5.00**
Closet freezer	3.00	-	-	-	-	-	-	-	-	-	-	-	**3.00**
Sink freezer	5.00	-	-	-	-	-	-	-	-	-	-	-	**5.00**
Dishwasher	6.00	-	-	-	-	-	-	-	-	-	-	-	**6.00**
Washing machine	-	8.00	-	-	-	-	-	-	-	-	-	-	**8.00**
Drying machine	-	5.00	-	-	-	-	-	-	-	-	-	-	**5.00**
TV+Video+Hifi (see 1 below)	3.00	-	1.00	-	1.00	1.00	-	-	-	-	-	-	**6.00**
PC equipment (see 2 below)	0.60	-	0.60	-	0.60	0.60	-	-	-	-	-	0.60	**3.00**
Lights (see 3 below)	5.45	0.51	1.05	0.40	0.97	0.97	0.88	0.40	0.44	0.44	0.60	0.88	**13.00**
Standby (see 4 below)	8.00	2.00	3.00	1.00	2.00	2.00	1.00	1.00	1.00	0.50	0.50	6.00	**28.00**
Rest (see 5 below)	11.00	-	-	-	-	-	-	-	-	-	-	-	**11.00**
Total (%)	**54.05**	**15.51**	**5.65**	**1.40**	**4.57**	**4.57**	**1.88**	**1.40**	**1.44**	**0.94**	**1.10**	**7.48**	**100.00**

The table above, *Table 9*, represents the typical electricity consumption distribution in a Danish dwelling differentiating by rooms. All data has been distributed depending on where appliances are usually placed, such as dishwashers in kitchens or washer-dryers in laundry rooms. The rest of the devices in the list are generally distributed around the whole house, divided up depending on where they are. Below is an explanation of the five groupings of percentages in the table that do not belong to specific rooms.

- **TV+Video+Hifi:** Most electronic devices are in a joined kitchen, dining and living room. For that reason, half of the entire electric use per group occurs in this area. Supposing all the three bedrooms have a TV, Video and Hifi, the rest of the consumption is distributed among them in the same quantity, (1% per bedroom).
- **PC equipment:** It is assumed there is PC equipment in all rooms where the family can spend time enjoying themselves or working. These rooms are the kitchen & dining and living room, the bedrooms, and the office. The use of devices is considered the same in each room.
- **Lights:** A different procedure has been followed for lights. A distribution based on floor surface (m^2) is done for this case. To do this, a ratio between the whole building surface and the total percentage consumption of lights has been carried out. A simple proportion between the total surface consumption and the rest of the spaces is done. The more lighting surface is required, the higher the light is needed.

- **Standby and Rest:** the same procedure in Lights is applied to the Standby and Remaining EA.

3.2.3 Distribution on time and per room

The electric consumption distribution in time and per room is shown in the table below. See *Figure 5.* The graph results from multiplying the total percentage of electricity consumption obtained in *Table 9* for each room; by the average hourly energy consumed on a lucky day; this hourly consumption is shown in *Figure 3,* being the *50% (median) for 3-10 personer I boligen* representation the one to use. Summarizing this, *Figure 5* illustrates the hourly average electricity consumption in each room in a four-Danish-family day.

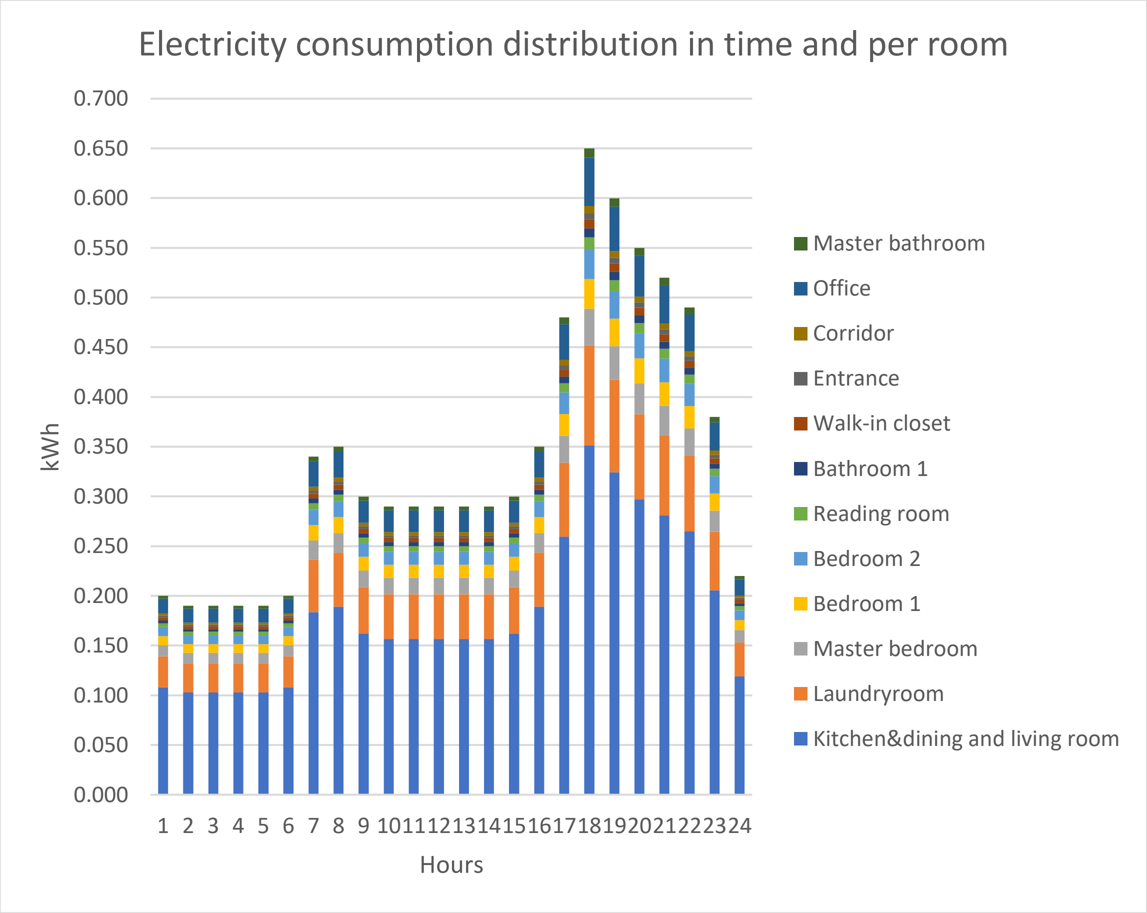


Figure 5. Energy consumption distribution on time and per room.

A comparison between the standard electric consumption of 3.5W/m^2 and the total electricity consumption per day and floor surface of the dwelling is performed in the table below, see *Table 10.* The no-standard result, which is the data analyzed in the reports and plotted in the graph above, has been obtained by dividing the total electric power consumption on the analyzed day, that is, by summing all the hourly energy consumption in the graph above (8,02kWh/day) and dividing the result by 24h. The whole floor surface area of the dwelling, 188.07m^2, and multiplying per 1,000 to obtain W. Given this, looking at *Table 10*, the standard value is compared with the distribution on time and per room one (W/m^2).

Table 10. Comparison of energy consumption between the reports analysed data and the standard case.

Electrical appliances consumption		
Standard 5W/m^2	**Distribution on time and per room W/m^2**	**Distribution on time and per room kWh/day**
3.5	1.78	8.02

As table above illustrates, the expected value is almost half the Standard one, see *Table 10*. The distribution on time, *Figure 3,* used to perform *Figure 5,* is not the most reliable source since it is only considered a lucky day and only few hundreds of houses. Hence, the distribution on time and per room result is not absolute. The following formula has been developed based on a study of the electricity consumption of approximately 8,500 households and for a more extended period[7]. Therefore, the result obtained has higher reliability and can be considered the typical and absolute annual electricity consumption value in Danish households with four occupants.

$$1{,}780kWh + whole\ floor\ surface * 17kWh$$

$$1{,}780kWh + 188.07 * 17kWh$$

$$Typical\ electricity\ consumption = 4{,}977\text{k}Wh/year$$

To compare this value with the total daily consumption shown in *Table 10*, the annual energy is divided by 365 days. The following table, *Table 11*, compares both values.

Table 11. Comparison of the daily electric consumption between the Distribution on time and room, and the typical electricity consumption.

Electric consumption kWh/day	
Distribution on time and room	**Typical electricity consumption**
8.02	13.64

Despite having the typical annual electricity consumption, there may be variations in consumption based on the size of the house, number of appliances etc. Therefore, it is worthy of studying modifications in the consumption, such as when the highest and lowest consumption are reached. For that reason, both cases are evaluated. In this way, it is studied how it would affect the daily consumption. For this purpose, the following figure, *Figure 6*, establishes both the lowest and the highest consumption that can be reached in Danish dwellings; both are the two extremist possible variations in the Danish typical electricity consumption. The dark green color represents the lowest consumption, while the red color illustrates the highest consumption. The information obtained is based on a population sample of more than 50,000 households [7].

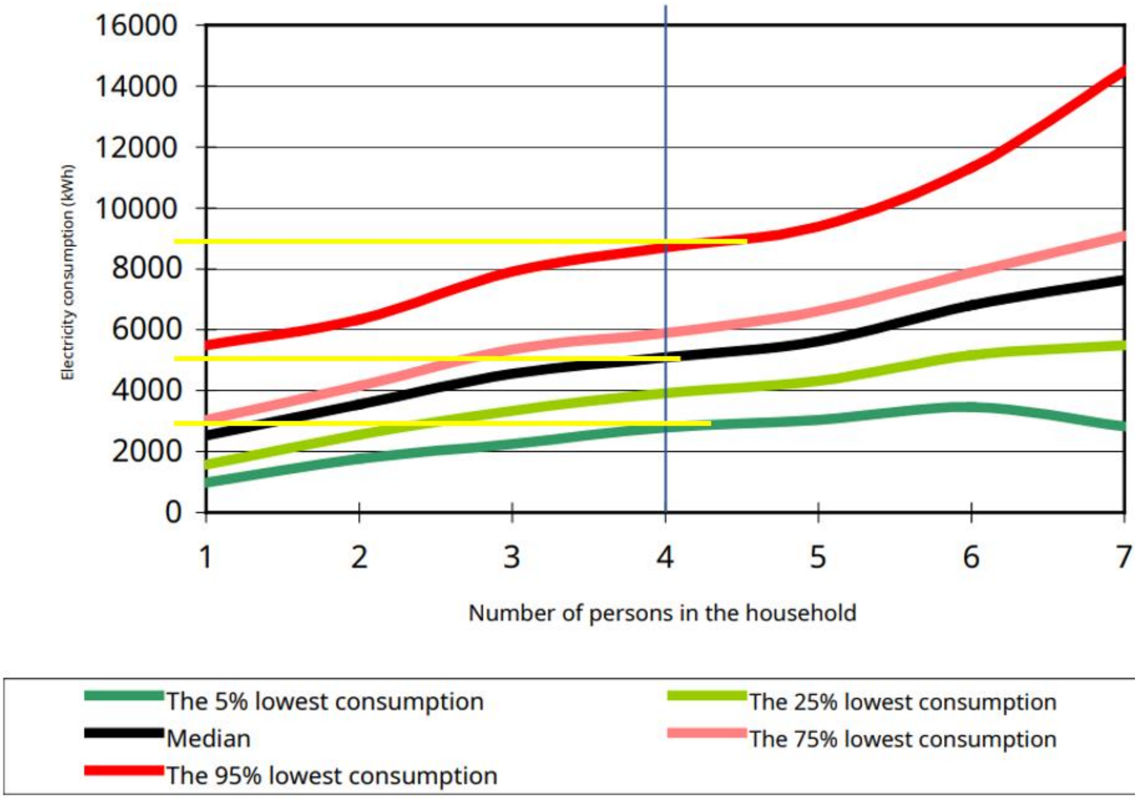


Figure 6. Typical Danish electricity consumption is based on several persons in the household (Gram-Hanssen, 2005).

The graph above, see *Figure 6*, shows that the average annual consumption for a single-family house consisting of four individuals is around 5,000kWh/year. If converted to average daily consumption, this value corresponds to the typical daily electricity consumption shown in *Table 11* (13.64kWh/m^2). The highest and lowest consumptions are around 9,000kWh/year and 3,000kWh/year, respectively. If the lowest, average, and highest typical consumption in the graph above is calculated for a single day, i.e., by dividing the total by 365 days, it is observed that the lowest consumption matches that obtained from the time and room distribution (8.02kWh/year).

To see the effect of having lower or higher typical consumption on the distribution in time and per room, shown in *Figure 5,* it is necessary to make an hourly correction to adapt the current consumption, the lowest typical electricity consumption, to the typical and highest typical electricity consumptions by using adjustment factors. This is obtained by dividing the daily value obtained from the distribution in time and per room (8.02kWh/year) by the daily electricity consumption of the two possible variations in typical consumption. The adjustment factor is multiplied by each hourly electricity consumption on *Figure 5*, the electricity consumption distribution in time and per room graph. In the following table, see *Table 12*, the adjustment factors are shown. The three annual electricity consumptions are converted to daily values and compared with the daily obtained from the time and room distribution on *Figure 5.*

Table 12. Daily electric consumption, adjustment factor and internal heat gain from EA for each typical electricity consumption.

Electric consumption kWh/day			
Distribution in time and room	**Lowest typical electricity consumption**	**Typical electricity consumption**	**Highest typical electricity consumption**
8.02	8.22	13.64	24.66
Adjustment factor			
-	≈1	1.70	3.07
Internal heat gain from electric consumption (electric appliances)			
1.78	1.82	3.02	5.46

Each electricity consumption influences the heating consumption, as detailed in *Table 12*. Their contribution to heat gain is calculated by dividing each daily consumption by 24h, the whole floor surface of the dwelling (188.07m^2), and finally multiplied by 1,000 to transform kW to W. In the table below, see *Table 13*, internal heat gain from EA and human body heat used to perform the *Realistic 4.50W/m^2* is shown. Given this, all the following scenarios will implement the typical electricity consumption, as shown in the table below. See *Table 13*. This is because it is more realistic than the typical low electricity consumption.

Table 13. IHG of the Realistic 4.50 W/m^2.

Realistic 4.50W/m^2		
	BH W/m^2	**EA W/m^2**
	1.48	3.02
TOTAL W/m^2	**4.50**	

3.3 Building measures to reduce energy consumption

In this subchapter, the following three techniques are studied:

- **Orientation of the room façades:** The influence of solar heat gain on heating demand and indoor temperatures is studied. For this reason, four scenarios with different orientations of room façades are run. This is a passive measure.
- **Heat transfer among rooms:** The influence of isolating or connecting the rooms by using doors on heating demand and indoor temperatures is studied. This is a passive measure.
- **Electricity prices in Denmark:** To reduce the economic costs, based on the Danish electricity price during an actual day, to see when is more profitable to use electricity from the grid will be studied.

Extra information will be obtained from the following courses:

- **Sustainable Buildings, course 11116 (DTU):**
    - Variable electricity prices in Denmark, to know when it is more economical to cover the energy demand by the heating system.
    - IDA-ICE instructions to learn how to do the model.
- **New energy technologies applied for buildings, course 34009 (UPV):**
    - Orientation of the room facades to achieve better indoor conditions. Counting with this information, it is possible to perform the two different scenarios based

on the various orientations, knowing which ones are the best and how this variable affects the energy demand and indoor requirements.

  - Building indoor distribution to get the most profitable indoor distribution reduces energy demand and improves heat transfer in rooms that require it.
  - Heat transfer among rooms. The influence of isolating or connecting the rooms by using doors on heating demand and indoor temperatures knowledge is provided by this course.

3.4 Summary of the procedure followed to perform the project

The project procedure is divided into two parts.

The first part of the project's procedure-implementing a continuous heating system

This first part of the project has a continuous heating system that provides heat when required, i.e. the 24h. Most of this first part consists of gathering all the information regarding the inputs to the Software, which are IHG from EA and occupants. Each internal heat gain pattern is studied. The most typical occupants behaviors research considers the following bullet points. Finally, all the answers are put together and summarised in *Table 4*.

- Where are the occupants at any moment?
- What type of activities do they do depending on the weekday?
- When and for how long do they do each activity?
- How much thermal energy do they emit depending on the activity?
- *Table 4* summarises all the questions and shows a schedule for weekdays and weekends. This is the internal heat gains from occupants input to IDA-ICE.

Regarding EA, the most common use of electrical energy in households, the following points are considered.

- What is the typical distribution on time of the electricity consumption?
- What type of electric devices are in each room, and what percentage of the total consumption represent?

Based on the two previous points, a bar chart, *Figure 5,* shows the distribution on time and per room. This is the internal heat gain from EA input to IDA-ICE. This summarises the two previous bullet points. Putting both IHG together, they create the *Realistic 4.50W/m²*. After implementing both IHG into the Software, with a given orientation of 270º from the previous thesis [3], the two following points are discussed.

- Energy study
- Number of no-comfort hours

Additionally, the *Realistic 4.50W/m²* results are also compared and analysed with the results of the following cases.

- ***Realistic lowest 3.30W/m²:*** This is the lowest typical electricity consumption in Danish dwellings and follows the same distribution in time and per room of EA and occupants patterns as the *Realistic 4.50W/m²*. This scenario results from the lowest curve in *Figure 6,* and its electric EA heat gains and BH are 1.82 W/m² and 1.48W/m², respectively.
- ***Realistic highest 6.94W/m²:*** This is the highest typical electricity consumption in Danish dwellings and follows the same distribution in time and per room of EA and occupants' patterns as the *Realistic 4.50W/m²*. This scenario results from the lowest curve in *Figure 6,* and its EA heat gains and BH are 5.46W/m² and 1.48W/m², respectively.
- ***Standard 5W/m²:*** Using Danish's standard values, 1.5W/m² and 3.5W/m² for human BH and EA, respectively. The total IHG result from multiplying each value by the whole floor surface of the building.
- ***Base 4W/m²:*** Using the thesis values, [3], 1.5W/m² and 2.5W/m² for BH and EA, respectively. The procedure is the same as in the *Standard 5W/m²*. Once all the scenarios are run, all the results are compared, explaining differences.

Following this, the effect of implementing two passive measures is evaluated. The first measure is changing the orientation of the façades by using a parametric studio, where four cases will be run and analysed. A comparison and explanation of the four cases are made to see how the orientation of the façades can influence the energy demand in each case. Finally, heat transfer through doors among rooms is researched. Three different door schedules will be implemented to the *Realistic 4.50W/m²* to study the effect on the heating demand. Each case is explained below.

- **The first** schedule proposes isolating all the rooms, so all doors remain closed.
- **The second** is the same used in the thesis [5], where there are three possibilities: some doors remain opened/closed throughout the time, and others only from 23h to 7h; the details are illustrated in *Table* 27.
- **The third** is based on the occupants schedule patterns. This one refers to when the doors are open and for how long, based on the activity detailed in the occupant patterns; see *Table 4* for more details.

All rooms that are connected by doors to the Master Bedroom are permanently closed, these are the closet and kitchen & dining room. That is because the master bedroom temperature is set at 18ºC, whereas the rest is permanently closed. The rest of the doors remain open or closed during the time that the occupants perform the activity detailed in both *Table 4* (human patterns). All doors schedule details are illustrated in *Table 28* and *Table 29.* The explanation of the entire schedule is in *8.3 Realistic- 4.50W/m2-Occupants door patterns*

The second part of the project procedure-with a flexible heating system

This part of the project is focused on implementing a dynamic measure based on the first part of the project procedure conclusions. The study results of using a flexible electric resistance heating system to the *Realistic lowest 3.30W/m*, *Realistic 4.50W/m^2,* and *Realistic highest 6.94W/m^2*. All three scenarios include the second door schedule. The flexible heating system is only used at night, from 9 pm. to 6 am., when the electricity price is lower. The energy assessment will be carried out to compare the results with the continuous electric resistance heating system analyzed in the first part of the project. In this case, to decide if this type of system is feasible, the number of no-comfort hours, that is, below the limit temperatures, are studied.

4 Case building description

Case building is based on a previous study focused on modular buildings [3]. This means that energy demand is low since building techniques are much better and more accurate than traditional methods. Several ways of reducing energy consumption are studied. Some lay in changing room façades to improve heat, solar gain, and light. Indoor distribution is also considered and replacing the common hydronic heat pumps for the heating system using electric heating systems, such a DHW or radiant floor. Many combinations of both systems were researched for different scopes regarding the heating system.

Based on the obtained heating system results, low energy buildings shows that an electric heating system economic cost is much lower than a hydronic floor heating based on a heat pump system, considering a life period of 20 years. A heat pump is three times more expensive than electric heating precisely. Nevertheless, the energy demand of the heat pump is around 3.5 less than with the other systems.

This project's research studies the influence of using IHG on heating demand. The study mentioned does not include only using an electric heating system as a unique system. There is always a combination of a heat pump with an electric heating resistance system. A direct and flexible electrical heating resistance system will provide the rest of the heating demand to maintain indoor comfort. For that reason, this document could be considered as a further investigation. The previous project will be the base scenario for this master's thesis. It consists of the following points.

1. **Insulation**

The insulation thickness is based on the maximum acceptable standards:

- Walls: 0.5m
- Floors and roof: 0.7m

Optimizing the insulation was a vital point of the investigation. For that reason, many thermal conductivity materials were tested.

2. Facade orientation and indoor layout

The master bedroom façade is changed from West to North. Additionally, the kitchen & dining and living room are now placed where the master bedroom used to be. A reduction in overheating hours is reached. On the opposite, lower temperatures were experienced for more extended periods. However, having fewer temperatures does not result in a problem. It is preferable to achieve slightly colder temperatures in the master bedroom than in the other rooms. Even without a cooling system, the results revealed that for the second orientation, the indoor temperature for the whole building was acceptable and even better than in the previous orientation. For that reason, North orientation is the base case for this master's thesis. The indoor layout, see *Figure 7*, shows the distribution of the rooms and the orientation of the facades for the case building [3]. A slight modification in the layout for this project is done. From then on, Bedroom 3 will be replaced by an office.

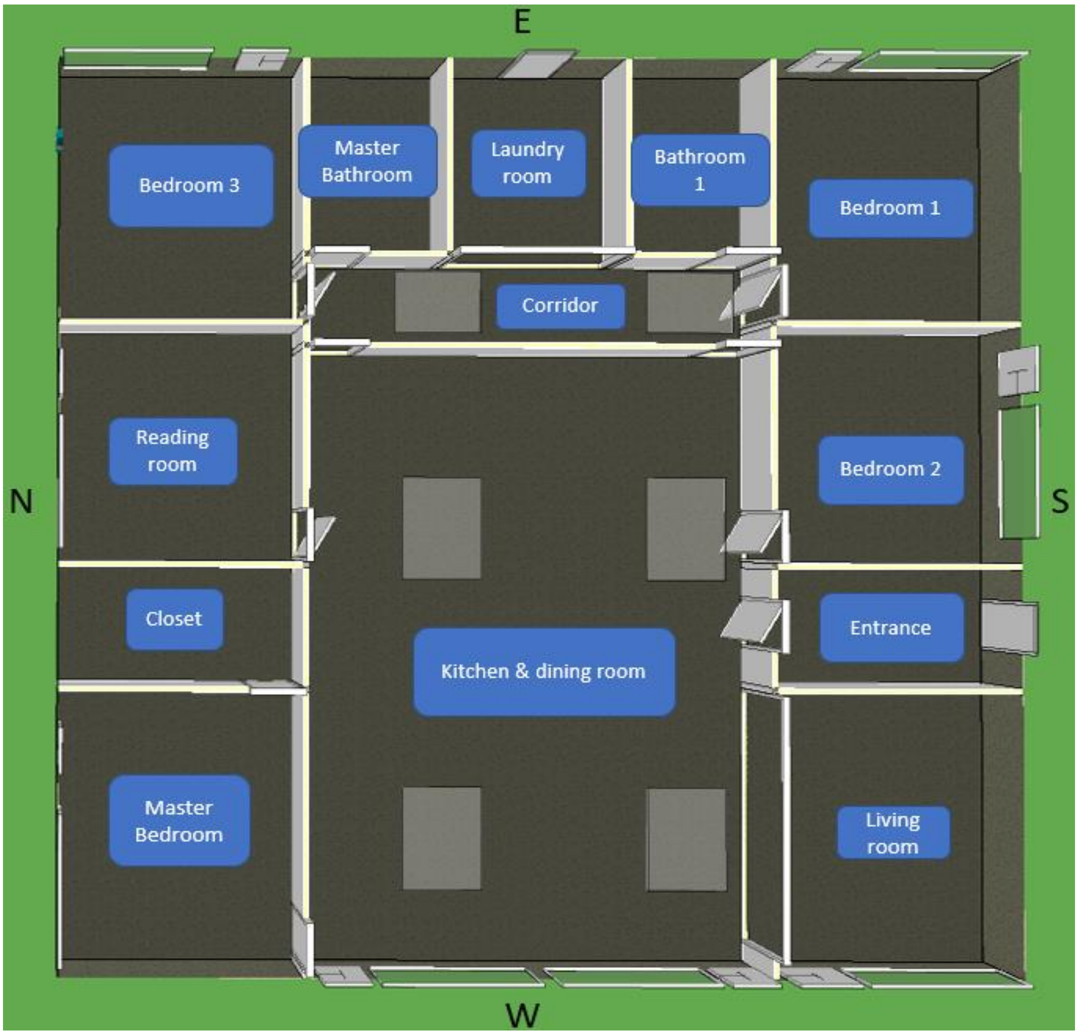


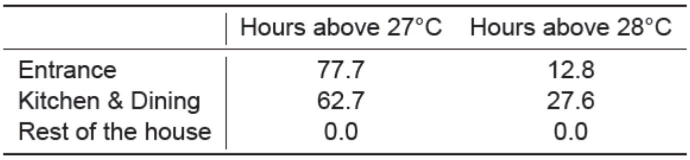
Figure 7. House indoor layout.

3. Zone setpoints, indoor temperatures, and AHU systems

All indoor temperatures are set up at 22ºC except the master bedroom, where the temperature is monitored constantly to set at 18ºC with an AHU system independent of the other AHU that manages the rest of the house. Occupants prefer lower temperatures in the master bedroom. That is also the reason why the master bedroom has no heaters. To maintain 18ºC without a heating system in the master bedroom, heat recovery is separated from the rest of the house ventilation equipment, setting the temperature at 18ºC.

In most Danish dwellings, there is not a cooling system, so that there are rooms that can reach overheating temperatures. This is also the case; the project building does not have a cooling system. The table below, see *Table 14*, summarises the number of hours indoor temperatures exceed the limits.

Table 14. Overheating hours without electrical cooling units, (Moschou, 2021), [3.



	Hours above 27°C	Hours above 28°C
Entrance	77.7	12.8
Kitchen & Dining	62.7	27.6
Rest of the house	0.0	0.0

4. Heating systems and energy use

The most feasible economic proposal chosen is an HP for DHW and electric heaters for indoor space heating. Moreover, a plastic floor with electrical heaters is used for the bathroom instead of a ceramic tile with an electric heating underfloor. The lowest cost and the better maintenance for the all-year-round thermal environment make the plastic floor more feasible. The following figure compares the first proposed scenario with the optimised case. See *Figure 8.* All the presented information in this chapter references the optimised case.

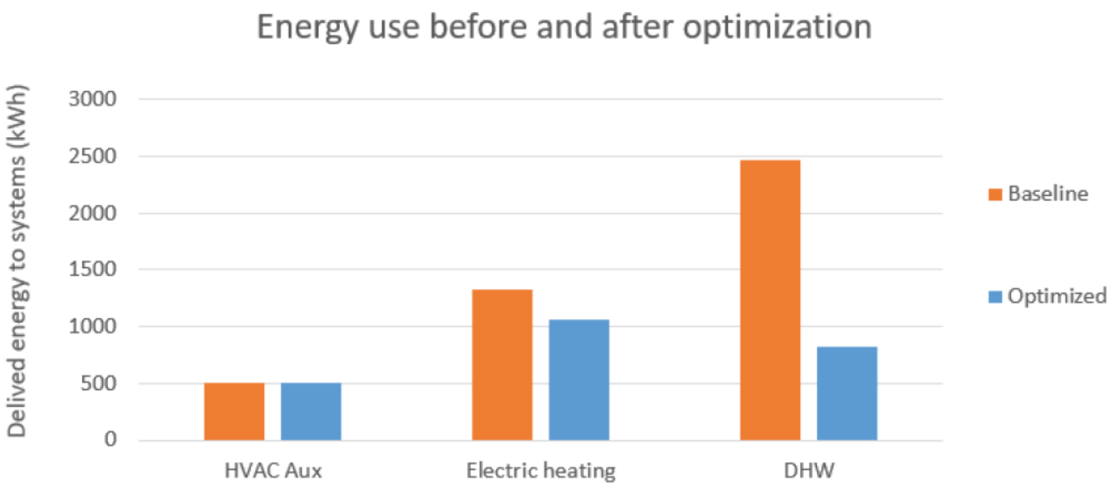


Figure 8. Energy use per system, for baseline and optimized case, (Moschou, 2021), [3].

5 Regulations and standards

The internal environment conditions must be adapted to these minimum requirements based on European and Danish regulations. This chapter will also study a fluctuation range in comfortable conditions once the minimum requirements are achieved.

5.1 Indoor requirements for buildings with flexible heating

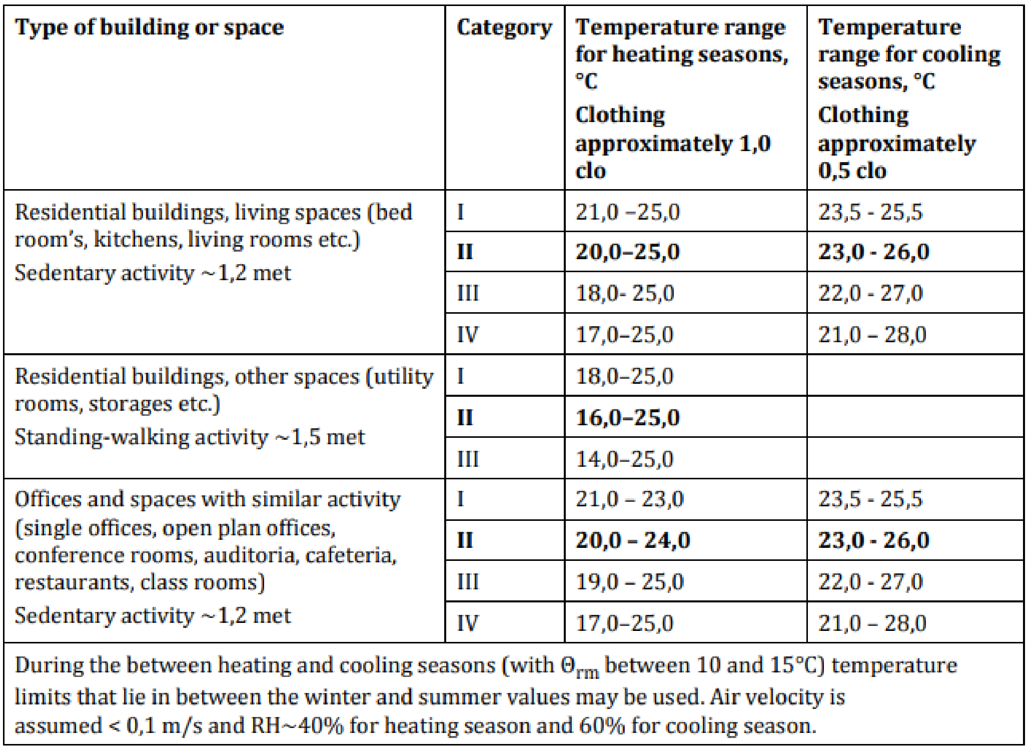
5.1.1 Thermal comfort

As was already introduced in chapter *State of the art*, there are established standards and mandatory regulations of temperature ranges. The following points are presented for Denmark.

Danish Standards [8]

The Danish Standards establish the following table values depending on the type of building and space and category.

Table 15. Design values for indoor operative temperature in buildings with active heating systems in operation during winter seasons and dynamic cooling systems during summer seasons, (16798:2019, 2019-05-07), [8].



Type of building or space	**Category**	**Temperature range for heating seasons, °C** **Clothing approximately 1,0 clo**	**Temperature range for cooling seasons, °C** **Clothing approximately 0,5 clo**
Residential buildings, living spaces (bed room's, kitchens, living rooms etc.) Sedentary activity ~1,2 met	I	21,0 –25,0	23,5 - 25,5
	II	**20,0–25,0**	**23,0 - 26,0**
	III	18,0- 25,0	22,0 - 27,0
	IV	17,0–25,0	21,0 – 28,0
Residential buildings, other spaces (utility rooms, storages etc.) Standing-walking activity ~1,5 met	I	18,0–25,0	
	II	**16,0–25,0**	
	III	14,0–25,0	
Offices and spaces with similar activity (single offices, open plan offices, conference rooms, auditoria, cafeteria, restaurants, class rooms) Sedentary activity ~1,2 met	I	21,0 – 23,0	23,5 - 25,5
	II	**20,0 – 24,0**	**23,0 - 26,0**
	III	19,0 – 25,0	22,0 - 27,0
	IV	17,0–25,0	21,0 – 28,0
During the between heating and cooling seasons (with Θ_{rm} between 10 and 15°C) temperature limits that lie in between the winter and summer values may be used. Air velocity is assumed < 0,1 m/s and RH~40% for heating season and 60% for cooling season.			

Key: The category indicates the predicted percentage of dissatisfaction, being "I" and "IV" the least and the most disappointed, respectively.

Danish Building Code [4]

Following the BR18, the room temperature in a residential building should not exceed 27ºC for more than 100 hours of the annual operating hours and 28ºC for more than 25 hours.

Setpoint temperature for each room

Considering the table above, see *Table 15,* and state of the art, the following temperatures are set up. There is no cooling system in the study building, so all temperatures are for the heating season.

- Master Bedroom: set up at 18ºC.
- The rest of the rooms: set up at 22ºC; the temperature could fluctuate until reaching 20ºC in some periods, where occupants would not be uncomforted, as explained in the State of the Art.

5.2 Energy performance

Two different scenarios are studied in this subchapter. The first one presents the standard values of energy/electric and other consumptions that BR18 establishes as the minimum requirements that low energy class buildings must accomplish.

5.2.1 Standard energy use

In accordance with the "BR18 – Low energy class", the total demanded energy supply is the energy needed to provide heating, ventilation, and domestic hot water per m^2 of heated floor per year and is 27kWh/m^2/year. The energy factors are 0.85 for district heating, 1.9 for electricity, and 1.0 for other heating sources. Ventilation systems, here the unit and duct system only serve one dwelling, must be equipped with heat recovery with a dry efficiency of at least 85%. Finally, the maximum energy for producing DHW will be assumed to be 13kWh/m^2. The following bullet points summarize all requirements for Low energy building class.

Total demanded energy supply: The maximum value is 27kWh/m^2/year, shown in paragraph 474 of the BR18.

- Energy factor for electricity: 1.9 (-)
- Energy factor (district heating): 0.85 (-)
- Energy factor (other heating resources): 1.0 (-)
- Energy balance through windows: It must be ≥0.0 kWh/m^2year, shown in paragraph 478 of the BR18.
- Energy balance through building envelope flaws: It must be ≤0.5 (l/sm^2 heated floor area at 50 Pa), shown in paragraph 478 of BR18.
- Transmission loss for one-storey: It must be ≤3.7 (W/m^2 building envelope), shown in paragraph 476 of the BR.
- Dry heat recovery efficiency: It must be ≥85%, shown in paragraph 483 of the BR18.

This project does not investigate the use of direct electrical heating concerning the energy frame in the building code. It is assumed that it may be updated when flexible use of electrical energy may become a standard solution.

6 Comparison of heating demand for the different scenarios.

In this subchapter, the obtained results of the three simulated scenarios are compared. The scenarios that will be studied are presented below.

- **Standard 5 W/m^2:** This is the 5W/m^2 IHG scenario, where 1.5W/m^2 corresponds to heat from occupants's bodies and 3.5W/m^2 to electrical appliances. The data input into IDA-ICE is each heat gains power (W). Each value is multiplied by each room floor surface to perform it. Both values are constant over time, and they do not differ depending on the room or the individuals behaviours.
- **Base 4 W/m^2:** This is the 4W/m^2 IHG scenario, where 1.5W/m^2 corresponds to heat occupant's bodies and 2.5W/m^2 to electrical appliances. This is used in the previous master's thesis. The input data and the procedure are the same as the *Standard 5W/m^2* except for the internal heat gain values. A lower value for EA is because better performances are considered, making the simulation more realistic.
- **Realistic 4.50 W/m^2:** This is the 4.50W/m^2 IHG scenario, where 1.48W/m^2 corresponds to the occupants BH and 3.02W/m^2 to electrical appliances. The total 4.50 W/m^2 comes from summing bot thermal loads. 1.48W/m^2 is the obtained value in chapter *3.1,* where the most common Danish life patterns during a week were studied and summarised in *Table 4.* This schedule, *Table 4,* is implemented into IDA-ICE to perform the thermal power emitted due to occupants for both spans, weekdays, and weekends. As shown in *Table 17*, there are four rooms where this internal heat gain is not considered. That was explained as the use time of those rooms is so low since they all are transit rooms. Hence, the spent time is not relevant. Additionally, the office is not typical to have a specific space at home; it is only proposed to be used on a few occasions. As a result, it is not considered.

  On the other hand, 3.02W/m^2 for EA comes from chapter 3.2.4, after having summed the energy consumption of the whole dwelling and dividing it by 24h and the entire floor surface. To input the EA heat gains, the excel data used to draft *Figure 5* was implemented into the Software hour to hour. It is essential to clarify that this *Realistic 4.50W/m^2* does not represent a general model applied to any dwelling. This is only an example based on the study of several data. This data comes from a wide variety of population samples distributed in time and per room in different ways. That is why both extreme typical electric consumption scenarios are also considered: Lowest (*Realistic lowest 3.30W/m*^{2}) and Highest (*Realistic highest 6.94W/m*^{2}) typical electricity consumptions in Denmark, as presented in *Table 12.*

The table below, see *Table 16*, summarises how much power the IHG emit per square meter depending on the scenario.

Table 16. IHG for the different scenarios.

	Standard 5 W/m^2	**Realistic lowest 3.30 W/m^2**	**Realistic 4.50 W/m^2**	**Realistic highest 6.94W/m^2**	**Base 4 W/m^2**
Human Heat Body W/m^2	1.5	1.48			1.5
The electric consumption of appliances W/m^2	3.5	1.82	3.02	5.46	2.5
TOTAL W/m^2	**5**	**3.30**	**4.50**	**6.94**	**4**

To compare the heating demand for the five scenarios, data has been shown for two periods:

- One winter month to see how the different IHG may reduce the heating demand in a period with the highest heat loss where the internal heat gain may be most helpful.
- The total annual electricity and heating consumption to see how different electricity consumption can affect yearly heating demand. It is needed to have the same span for all the scenarios to compare the results. Having longer heating seasons presence to the amount of the IHG. Therefore, it would not be realistic to compare the electricity and heating consumption for different periods. Given this, those cases with longer heating seasons have higher electric consumptions, so the effect of the IHG over the heating demand for each case would not be comparable.

The table below, see *Table 17,* shows the different internal gains for each room and the other cases for the same period: January.

Table 17. Thermal demand of each room in each case for January.

January-kWh				
Standard Case- 5W/m2				
	EA	**BH**	**Total IHG**	**EP**
Bathroom 1	15.36	6.58	21.94	1.02
Bedroom 1	36.98	15.85	52.83	40.17
Bedroom 2	33.28	14.26	47.54	19.19
Closet	16.64	7.14	23.78	10.49
Corridor	22.71	9.73	32.44	0.00
Entrance	16.64	7.14	23.78	1.71
Kitchen & Dining	167.00	71.60	238.60	15.30
Laundry room	19.36	8.30	27.66	4.40
Living room	39.89	17.10	56.99	41.11
Master bedroom	39.89	17.10	56.99	0.00
Master Bathroom	15.36	6.58	21.94	1.04
Office	33.28	14.26	47.54	44.75
Reading room	33.28	14.26	47.54	24.71
Base Case- 4W/m2				
	EA	**BH**	**Total IHG**	**EP**
Bathroom 1	10.97	6.58	17.55	4.75
Bedroom 1	26.41	15.85	42.26	52.97
Bedroom 2	23.77	14.26	38.03	28.73
Closet	11.88	7.14	19.02	18.17
Corridor	16.22	9.73	25.95	0.00
Entrance	11.88	7.14	19.02	5.80
Kitchen & Dining	119.30	71.60	190.90	56.94
Laundry room	13.82	8.30	22.12	12.76
Living room	28.50	17.10	45.60	55.54
Master bedroom	28.50	17.10	45.60	0.00
Master Bathroom	10.97	6.58	17.55	4.83
Office	26.41	14.26	40.67	56.55
Reading room	23.77	14.26	38.03	35.72
Realistic lowest case- 3.30W/m2				
	EA	**BH**	**Total IHG**	**EP**
Bathroom 1	4.10	2.56	6.66	15.40
Bedroom 1	13.94	20.13	34.07	61.22
Bedroom 2	13.20	12.28	25.48	37.14
Closet	4.46	0.00	4.46	31.90
Corridor	6.09	0.00	6.09	0.00
Entrance	4.46	0.00	4.46	18.41
Kitchen & Dining	65.13	49.17	114.30	116.50
Laundry room	38.05	7.68	45.73	5.14
Living room	65.13	49.17	114.30	16.20
Master bedroom	14.73	33.22	47.95	0.00
Master Bathroom	4.10	1.91	6.01	15.88
Office	10.44	0.00	10.44	83.69
Reading room	8.92	19.03	27.95	50.34
Realistic Case- 4.50W/m2				
	EA	**BH**	**Total IHG**	**EP**
Bathroom 1	6.98	2.54	9.52	8.88
Bedroom 1	23.70	20.19	43.89	45.13
Bedroom 2	22.44	12.29	34.73	24.14
Closet	7.59	0.00	7.59	25.17
Corridor	10.35	0.00	10.35	0.00
Entrance	7.59	0.00	7.59	10.90
Kitchen & Dining	110.70	47.89	158.59	61.33
Laundry room	64.69	7.67	72.36	1.04
Living room	110.70	47.89	158.59	1.04
Master bedroom	25.04	33.24	58.28	0.00
Master Bathroom	6.98	1.88	8.86	8.83
Office	17.75	0.00	17.75	68.70
Reading room	15.17	25.33	40.50	38.62
Realistic highest case- 6.94W/m2				
	EA	**BH**	**Total IHG**	**EP**
Bathroom 1	12.57	2.56	15.13	0.00
Bedroom 1	42.69	20.16	62.85	1.93
Bedroom 2	40.41	12.30	52.71	0.34
Closet	13.66	0.00	13.66	9.64
Corridor	18.65	0.00	18.65	0.00
Entrance	13.66	0.00	13.66	0.00
Kitchen & Dining	199.40	49.16	248.56	0.00
Laundry room	116.50	7.80	124.30	0.00
Living room	199.40	49.16	248.56	0.00
Master bedroom	45.11	33.30	78.41	0.00
Master Bathroom	12.57	1.89	14.46	0.00
Office	31.97	0.00	31.97	13.01
Reading room	27.32	19.05	46.37	3.07

Comparing the IHG and consumptions of the EP in the same room for the different scenarios, they are inversely proportional. For example, taking the Kitchen & dining room from the table above, where the consumption of the EP is the highest for the *Realistic lowest 3.30W/m*^{2}, resulting in 116.50kWh. Here, considering the sum of the heat from the appliances and that of the occupants, the total is 114.30kWh. In contrast, in the *Realistic highest 6.94W/m*^{2} scenario, where both internal gains total is 248.56kWh, the thermal consumption decreases to 0kWh.

It is expected that, in all cases shown above, see *Table 17,* Bedroom 1 has a much higher thermal demand from the EP than Bedroom 2. The EP provide the energy to supply all the heat losses and maintain the set temperature in the room, 22ºC. Bedroom 1 is located in a corner, so the thermal envelope, i.e. the façade, is much larger than for Bedroom 2; more energy is lost to the outside.

Regarding the *Realistic 4.50W/m*^{2}, the human BH in Bedroom 1 and Bedroom 2 is different since in Bedroom 1, where the adolescent resides, he is considered to spend his Relax hours there, so at the end of the day, the occupants thermal contribution is slightly higher than in Bedroom 2. It is based on the schedule shown in *Table 4, i.e.* the occupants pattern schedule.

The table below, see *Table 18*, summarises the results of the thermal demand for each room shown in *Table 17* for each case.

Table 18. IHG, electric panels, DHW, and AHU consumption in each case for January.

January					
Standard 5W/m^2					
	EA	**BH**	**EP**	**DHW**	**AHU**
kWh	490	210			
TOTAL kWh	**700**		**204**	**232**	3.05
Base 4W/m^2					
	EA	**BH**	**EP**	**DHW**	**AHU**
kWh	352	210			
TOTAL kWh	**562**		**333**	**232**	3.18
Realistic Lowest 3.30W/m^2					
	EA	**BH**	**EP**	**DHW**	**AHU**
kWh	253	195			
TOTAL kWh	**448**		**452**	**232**	3.11
Realistic 4.50W/m^2					
	EA	**BH**	**EP**	**DHW**	**AHU**
kWh	430	195			
TOTAL kWh	**628**		**293**	**232**	2.88
Realistic Highest 6.94W/m^2					
	EA	**BH**	**EP**	**DHW**	**AHU**
kWh	774	195			
TOTAL kWh	**969**		**28**	**232**	1.14

Table 18 illustrates the same effect explained for the previous example of the Kitchen & dining room, but the whole building. The electricity consumption is the only variable that changes considerably from one case to another since occupants BH is 1.50W/m^2 and 1.48W/m^2 for the first and second cases, respectively. It is essential to highlight that the AHU energy is used in the post-heating unit of the AHU to secure a comfortable inlet air temperature even when the heat recovery of the AHU is not working due to the risk of ice when the outside air is below 0ºC. Additionally, *Table 18* shows that the most effective of IHG is because of EA since its contribution is much higher than the BH. Moreover, this parameter can vary much easier than the occupants BH and is constant throughout the time. That is because electricity for equipment may differ from family to family and over time of the day/week and the rooms. Hence, the table above, see *Table 18*, shows that having fewer IHG increases the EP consumption. This is also illustrated in the table below for the whole dwelling but only comparing the total electricity and heat consumption. See *Table 19.*

It is necessary to explain that the electricity consumption takes into consideration the following categories:

- Electrical appliances consumption
- Electric panels consumption
- Domestic Hot Water (DHW) consumption
- Air handling unit (AHU) consumption

Likewise, heat consumption considers:

- Electric panels consumption
- Domestic Hot Water (DHW) consumption
- Air handling unit (AHU) consumption

Table 19. Electricity and heat consumption for each case, January.

January				
	Electricity consumption		Heat consumption	
	kWh	kWh/m^2	kWh	kWh/m^2
Standard 5W/m^2	929	4.94	439	2.34
Base 4W/m^2	921	4.90	568	3.02
Realistic Lowest 3.30W/m^2	940	5.00	687	3.65
Realistic 4.50W/m^2	959	5.10	529	2.81
Realistic Highest 6.94W/m^2	1,035	5.51	262	1.39

Returning to the above, the energy consumption of the EP increases as the internal loads decrease. However, this is only strictly valid when comparing *Standard 5W/m^2* and *Base 4W/m^2*. All values entered are always constant over time and do not depend on the room, its use, or the occupants activities.

A non-permanent distribution in time and per room may not be as strict as the *Standard 5W/m^2* and *Base 4W/m^2*. Those non-permanent distribution in time and per room are the three *Realistic cases*. Examples are the Kitchen & Dining room, where the internal loads in the *Realistic 4.50W/m^2* are significantly reduced compared to the *Standard case 5W/m^2* and the heating consumption; the Bathroom 1, the Bedroom 1 and Bedroom 2, the Closet, the Entrance, the Master Bathroom, and the Office as well but with a fewer influence. The following graph, see *Figure 9*, compares how the energy in each room varies as a function of the internal loads between the *Standard 5W/m^2* and the *Realistic 4.50W/m^2* scenarios. Only these two scenarios are contrasted, and the *Base 4W/m^2* is excluded because, in the *Base 4W/m^2*, it is the same as in the *Standard 4W/m^2* but reduces the appliances heat gain. The *Realistic Lowest 3.30W/m^2* and the *Realistic Highest Case- 6.94W/m^2* are also not considered. The following study only focuses on analysing the effect of having permanent (*Standard 5W/m^2*) and variable (*Realistic 4.50W/m^2*) IHG distributions over time.

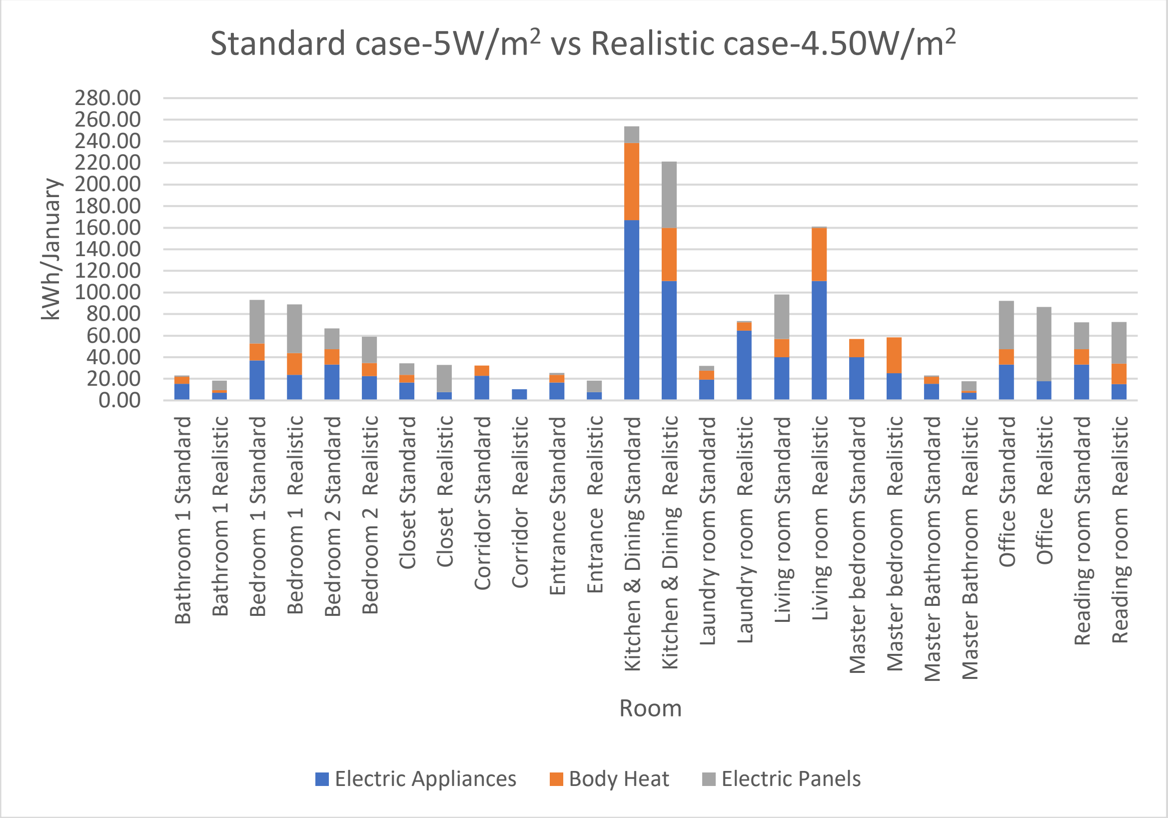


Figure 9. Comparison between the Standard 5W/m² and the Realistic 4.50W/m² IHG and energy consumption for January.

It is noteworthy that the total thermal energy in the Kitchen & dining room has been reduced in the *Realistic 4.50W/m²*. In the *Standard 5W/m² scenario*, despite having more contribution from the IHG, they are not as well utilised as in the *Realistic 4.50W/m²*, so it is still necessary to use heat from the EP. Not well utilised IHG means that, as an example, during specific and brief periods, the Kitchen & dining room reaches temperatures above the set up at 22ºC, but during the rest of the time, the room still demand thermal energy. To better the IHG, they should deliver more heat when demand is higher instead of always the same. In the *Realistic 4.50W/m²*, the contribution of the IHG gains is minor, and the EP as well since the 4.50W/m² is better distributed on time. They highlight that both heat gains in the *Realistic 4.50W/m²* are not constant over time.

Continuing to *Realistic 4.50W/m²* results, in the case of the laundry room, though the contribution of the electric heat gains could already ensure that it would not be necessary to switch on the radiators when comparing with the total thermal in the room (looking at the laundry bar chart for the *Standard 5W/m²*); this is not the case. Its contribution is so low that it is not appreciable in the table above. However, *Table 17* shows 1.04kWh of EP consumption. In this case, they still have to provide energy to the room for two reasons.

First, the internal heat gain is emitted during a short period, in which the temperature is observed to be above the 22°C setpoints for winter. During the rest of the time, its presence is practically negligible. Therefore, although there is a significant contribution from the appliances, it is only helpful during a single period when the room is utilised, as detailed in *Table 4* (from 19:00 to 19:30). That is also the case in the Living and Reading rooms for both IHG. In the case of the Reading room, the essential variable for the heater load is the human factor, as the temperature rises above 22ºC during the short periods when there are people in the room.

Second, there is no door separating the laundry from the Corridor, so the laundry heating system must, in turn, cover the demand from the Corridor too. That said, as detailed in *Table 17*, the contribution of IHG in the Corridor has decreased significantly. So, the laundry room EP must provide more energy to establish the setpoint temperature of 22ºC in both spaces. The software shows this by observing airflows from the Laundry to the Corridor. Based on the thermodynamic laws, heat flows from the hotter to the colder body, so the Corridor acquires energy from the Laundry. In the figure below, see *Figure 10*, "Heat balance" in the Corridor for the *Standard case-5W/m^2* is presented.

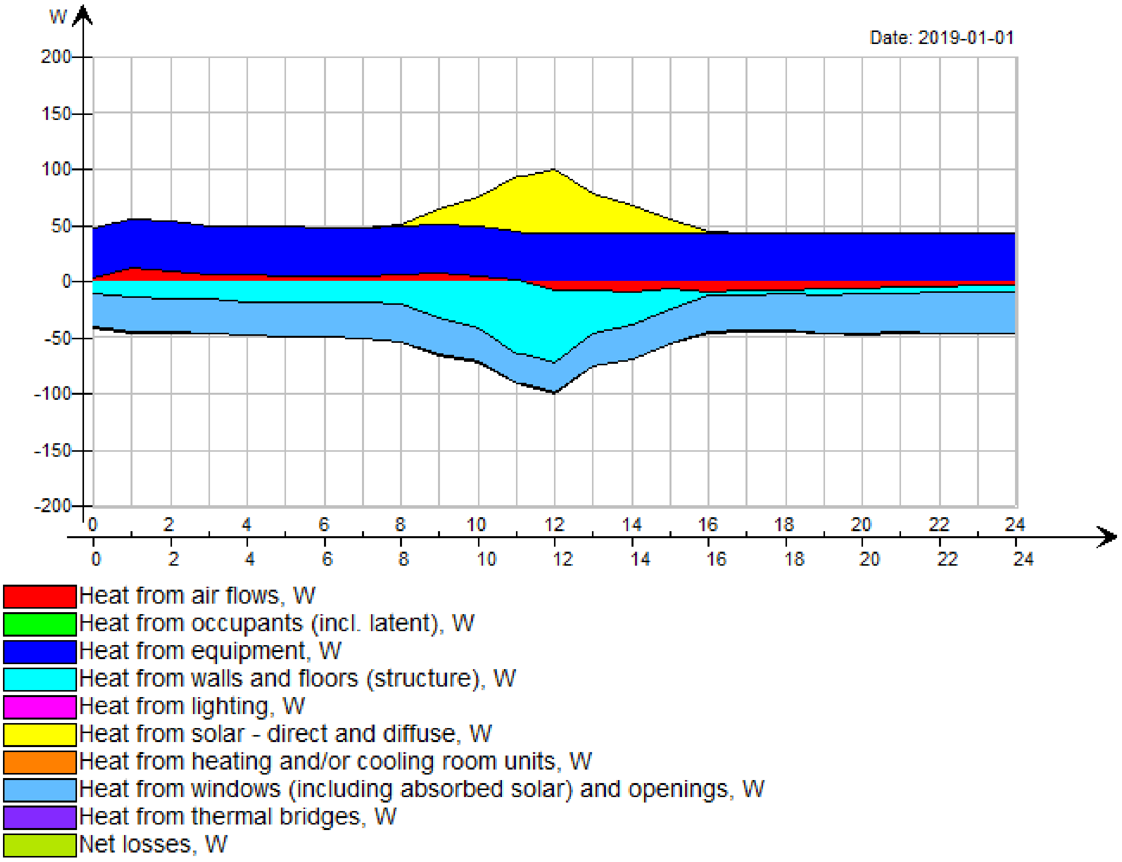


Figure 10. The heat from the air flows in the corridor for the Standard case-5W/m2.

Figure 10 shows there is not almost heat transfer from the air flows coming into the Corridor for the *Standard case-5W/m*^{2}. All the heat that comes into the rooms is defined as a positive value.

On the other hand, the *Realistic 4.50W/m*^{2}, whose IHG in the corridor have noticeable decreased, experience a vast quantity of heat from air flows that go into the corridor. See *Figure 11*.

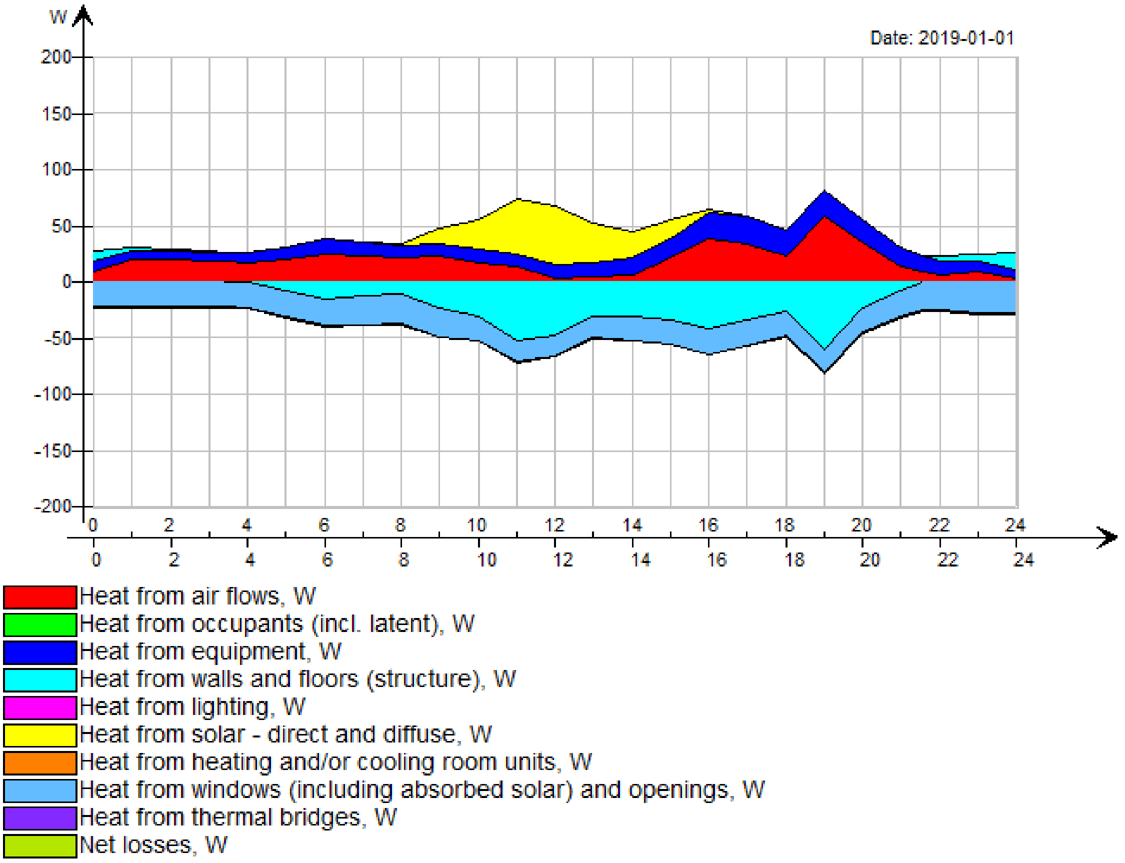


Figure 11. The heat from the air flows in the corridor for the Realistic-4.50W/m^2*.*

In this figure, see *Figure 11; the* positive red area illustrates a huge heat gain. Moreover, the maximum peak is reached at 19:00, which coincides with the Laundry (EA heat gain) and Human patterns activities (body heat). Having more heat in the Laundry room creates air flows from the hotter room (the laundry) to the colder one (the corridor).

To see which of the IHG has the most impact on each thermal demand, the following graph has been made. See *Figure 12*. It compares the *Standard 5W/m*^{2} with the *Realistic 4.50W/m*^{2}, but the latter uses the same value as the *Standard 5W/m*^{2} for the EA, i.e. 3.5 W/m^2. The heat emitted by people remains in 1.48 W/m^2. When comparing the results, the influence of each internal heat gain is understood better.

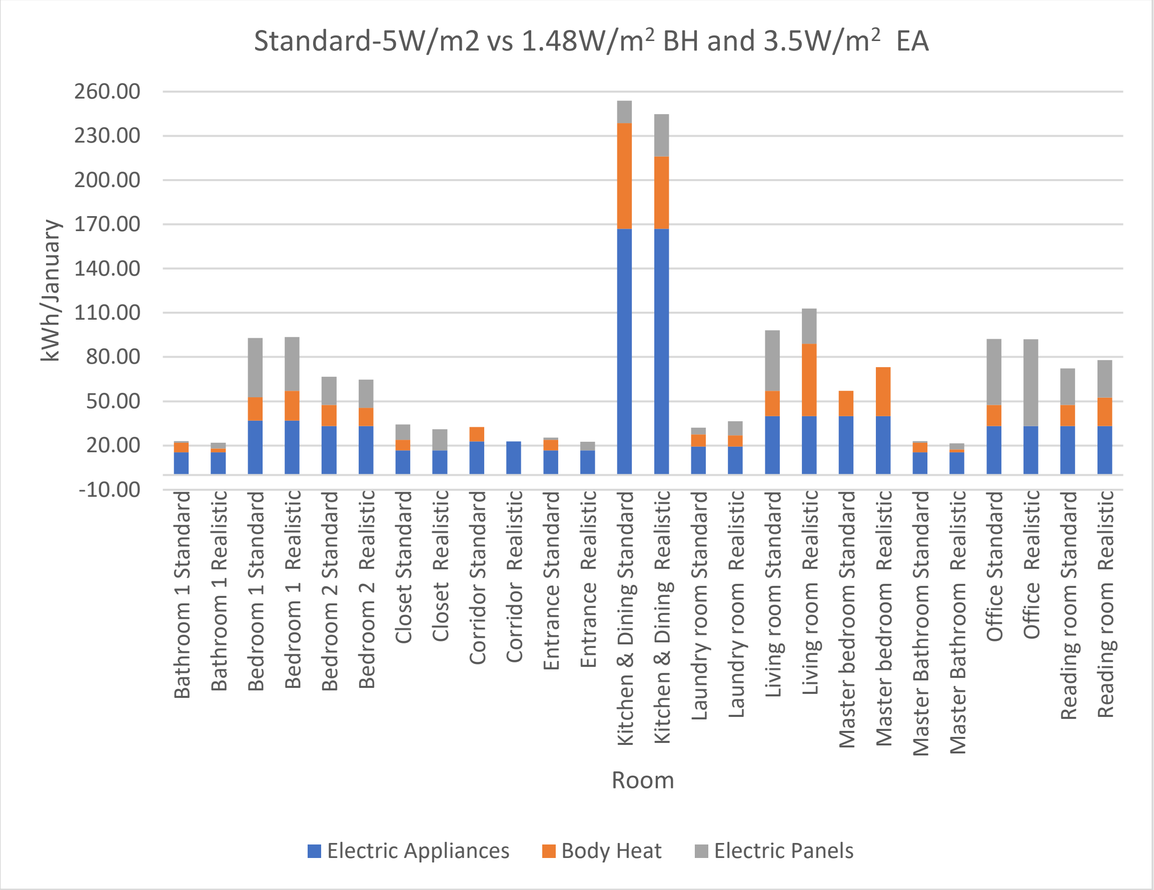


Figure 12. Comparison between the IHG and energy consumption in the Standard 5W/m and the Realistic case but with 2.5 W/m² of EA instead of 3.02W/m² for January.

As shown in the graph above, see *Figure 12*; the more heat the electrical appliances are, the fewer the demand the EP must cover; compared to the previous bar chart, see *Figure 9*. However, even if the no-*Standard 5W/m²* has already covered all the required thermal energy for the same room as in *Standard 5W/m²*, the EP must continue providing power. That is due to the occupant factor. The occupants have an irregular effect, i.e. the heat input over time is not constant and depends on how long they are in each room and how active they are. Therefore, any peak is mainly related to the occupants. In the laundry case, the room is influenced by both IHG. These peaks cause short periods when temperatures are higher than the setpoint temperature, which is 22ºC. If it were a constant heat input over time, as in domestic appliances, it could happen that the EP would not be necessary. The figure presented below, see *Figure 13,* refers to the laundry room for the *Realistic 4.50W/m²*.

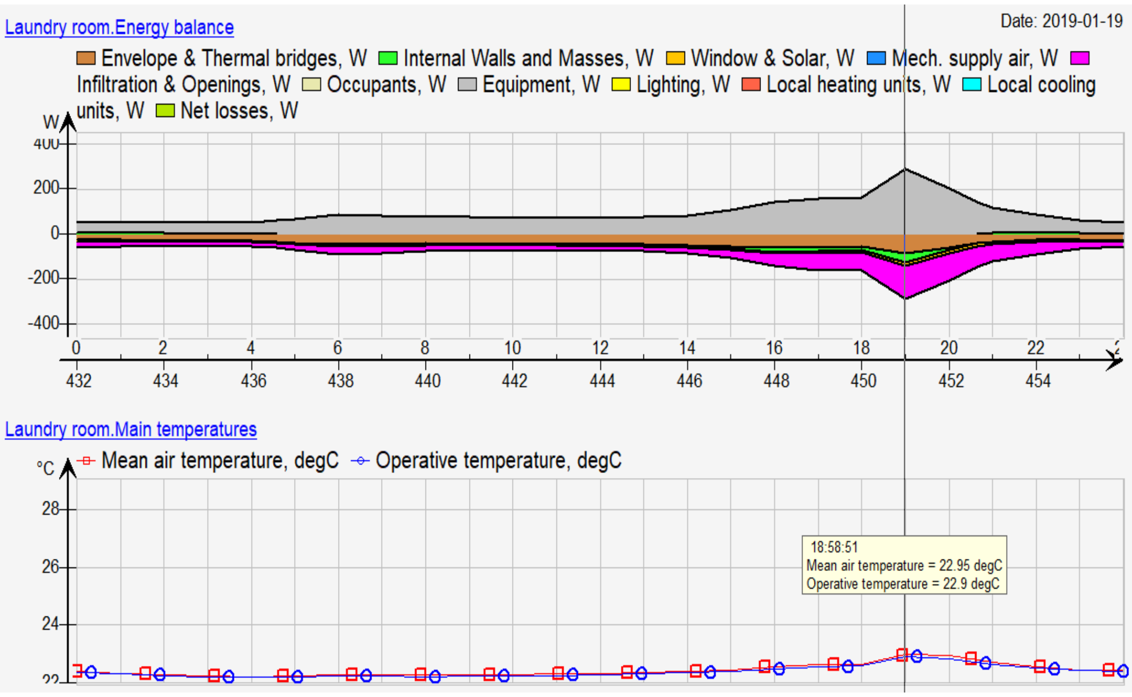


Figure 13. Laundry room energy peak, at 19:00, as an example of a misuse of the IHG, studied in the Realistic 4.50W/m^2.

See *Figure 13*; there is a considerable consumption peak at 19:00. This is due to the occupants patterns and the electricity consumption (from 19:00-19:30, the laundry activity is done every day). Based on that, during the short time of the activity, the air temperature reaches 22.95ºC, but during the rest of the day, IHG presence is negligible. Therefore, they are not well used.

On the other hand, in the *Standard 5W/m^2*, doing the study under the same conditions, see figure below *Figure 14*, there is no peak, and the equipment consumption, including the occupants, remains constant over time. This remains constant over time as the EP are always programmed to keep the room air at this temperature.

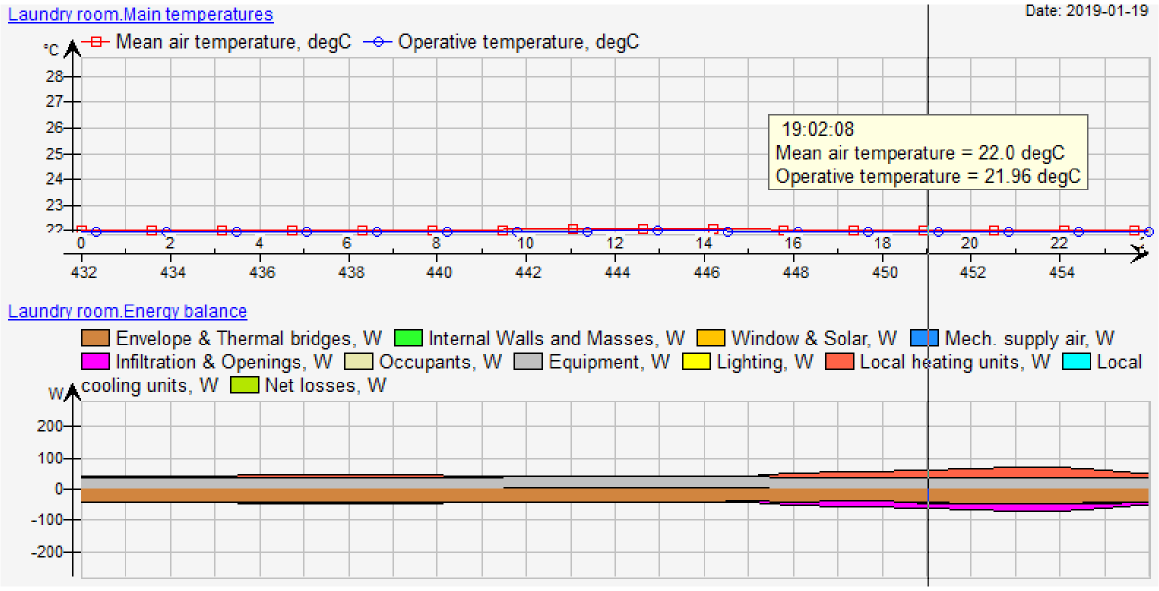


Figure 14. No-laundry room thermal energy peak at 19:00, studied in the Standard 5W/m².

As explained before, IHG are directly related to the heating season. The fewer IHG, the longer the heating season is. For that reason, each scenario has its heating period. All of them are shown in the following graphs.

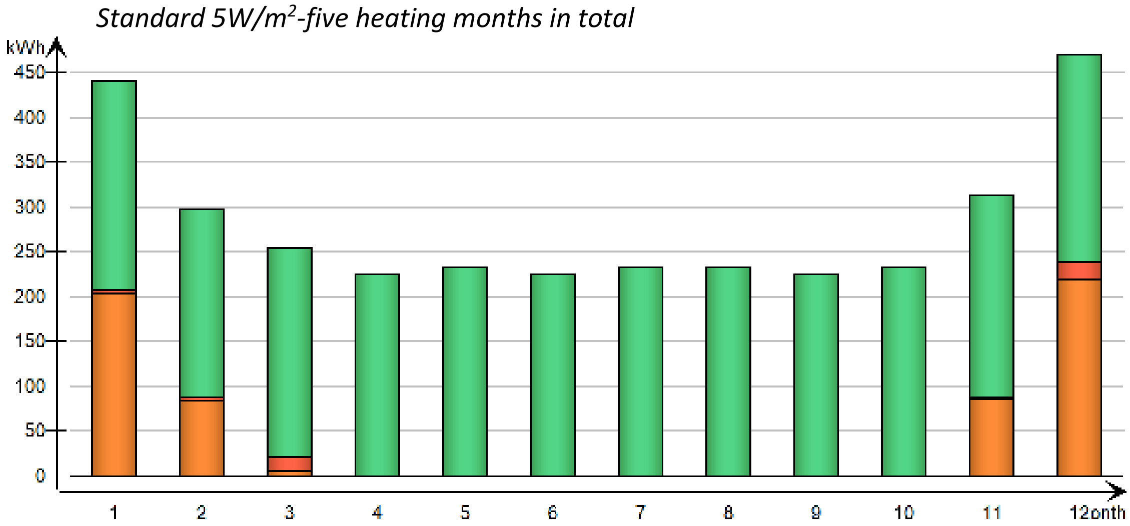


Figure 15. The heating season for the Standard 5W/m²

Base 4.00W/m^2-five heating months in total

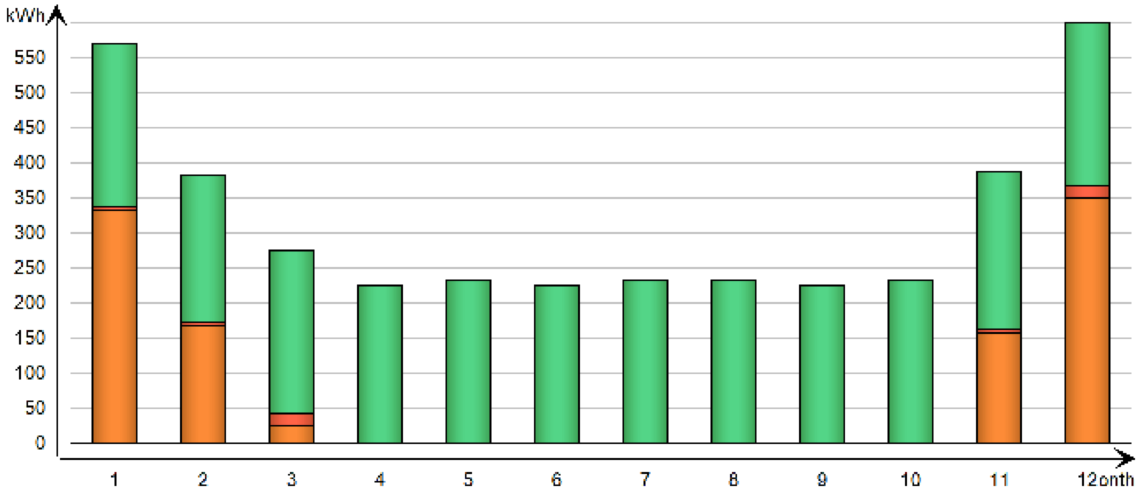


Figure 16. The heating season for the Base 4.00W/m^2

Realistic 4.50W/m^2-seven heating months in total

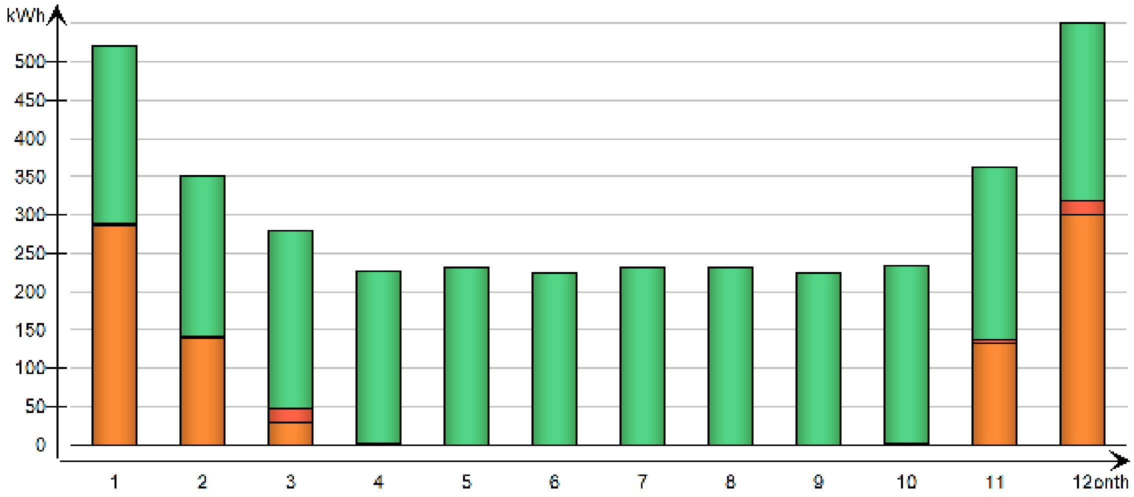


Figure 17. The heating season for the Realistic 4.50W/m^2

Realistic lowest 3.30W/m^2-seven heating months in total

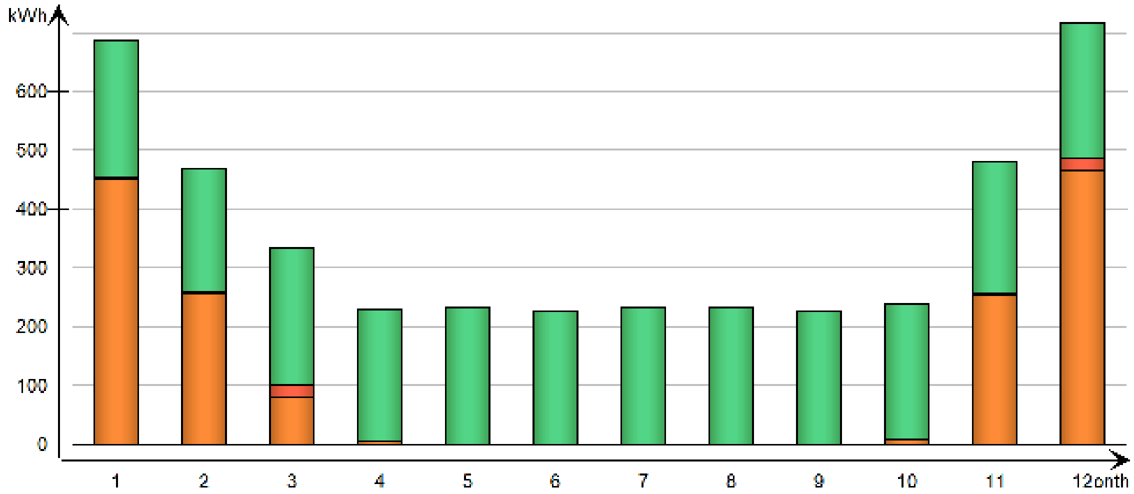


Figure 18. The heating season for the Realistic lowest 3.30W/m^2

Realistic highest 6.94W/m^2-five heating months in total

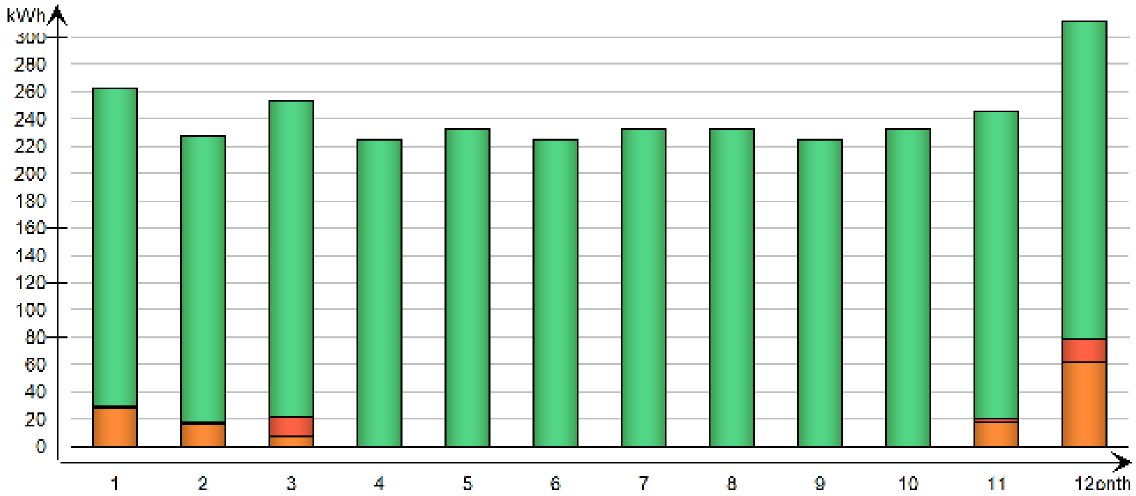


Figure 19. The heating season for the Realistic highest 6.94W/m^2

The table below, see *Table 20*, shows the heating consumption, EP, in each room depending on the number of IHG. Each scenario has its heating period. For that reason, the annual results are analysed to compare the consumption for each case, as shown in the table below. Additionally, thanks to the yearly consumption, the user can use the result of the scenario concerning energy use for equipment fit his family to get realistic information on the total energy bill.

Table 20. IHG and electric panels consumption in each case, considering the whole year for each case.

Annual values-kWh				
Standard case-5W/m2				
	EA	BH	Total IHG	EP
Bathroom 1	180.90	77.52	258.42	5.31
Bedroom 1	435.40	186.60	622.00	118.60
Bedroom 2	391.90	167.90	559.80	49.91
Closet	195.90	84.01	279.91	34.48
Corridor	267.40	114.60	382.00	0.00
Entrance	195.90	84.01	279.91	3.90
Kitchen & Dining	1966.30	843.00	2809.30	42.03
Laundry room	227.90	97.68	325.58	15.31
Living room	469.70	201.30	671.00	107.60
Master bedroom	469.70	201.30	671.00	0.00
Master Bathroom	180.90	77.52	258.42	5.32
Office	391.90	167.90	559.80	140.00
Reading room	391.90	167.90	559.80	76.36
Base case-4W/m2				
	EA	BH	Total IHG	EP
Bathroom 1	129.20	77.52	206.72	16.20
Bedroom 1	311.00	186.60	497.60	168.00
Bedroom 2	279.90	167.90	447.80	82.07
Closet	139.90	84.01	223.91	67.25
Corridor	191.00	114.60	305.60	0.00
Entrance	139.90	84.01	223.91	14.64
Kitchen & Dining	1404.90	843.00	2247.90	154.40
Laundry room	162.70	97.68	260.38	40.15
Living room	335.60	201.30	536.90	164.60
Master bedroom	335.60	201.30	536.90	0.00
Master Bathroom	129.20	77.52	206.72	16.34
Office	279.90	167.90	447.80	189.70
Reading room	279.90	167.90	447.80	117.40
Realistic lowest case- 3.30W/m2				
	EA	BH	Total IHG	EP
Bathroom 1	48.30	30.28	78.58	50.26
Bedroom 1	164.10	239.90	404.00	204.10
Bedroom 2	155.30	144.60	299.90	110.50
Closet	52.51	0.00	52.51	144.10
Corridor	71.68	0.00	71.68	0.00
Entrance	52.51	0.00	52.51	54.47
Kitchen & Dining	766.60	587.80	1354.40	348.50
Laundry room	447.80	90.59	538.39	17.26
Living room	766.60	587.80	1354.40	44.90
Master bedroom	173.40	392.70	566.10	0.00
Master Bathroom	48.30	22.66	70.96	51.91
Office	122.90	0.00	122.90	312.60
Reading room	105.00	221.20	326.20	181.10
Realistic case-4.50W/m2				
	EA	BH	Total IHG	EP
Bathroom 1	82.14	30.28	112.42	24.22
Bedroom 1	279.00	239.90	518.90	134.90
Bedroom 2	264.20	144.60	408.80	64.10
Closet	89.30	0.00	89.30	104.70
Corridor	121.90	0.00	121.90	0.00
Entrance	89.30	0.00	89.30	28.37
Kitchen & Dining	1303.60	587.80	1891.40	150.50
Laundry room	761.60	90.59	852.19	0.20
Living room	1303.60	587.80	1891.40	3.57
Master bedroom	294.90	392.70	687.60	0.00
Master Bathroom	82.14	22.66	104.80	25.38
Office	209.00	0.00	209.00	229.60
Reading room	178.60	221.20	399.80	125.80
Realistic highest case- 6.94W/m2				
	EA	BH	Total IHG	EP
Bathroom 1	147.80	30.30	178.10	0.42
Bedroom 1	502.30	239.90	742.20	16.00
Bedroom 2	475.50	144.60	620.10	3.17
Closet	160.70	0.00	160.70	35.08
Corridor	219.40	0.00	219.40	0.00
Entrance	160.70	0.00	160.70	0.53
Kitchen & Dining	2346.60	587.90	2934.50	1.96
Laundry room	1370.90	90.98	1461.88	0.00
Living room	2346.60	587.90	2934.50	0.00
Master bedroom	530.70	392.80	923.50	0.00
Master Bathroom	147.80	22.62	170.42	0.46
Office	376.10	0.00	376.10	56.67
Reading room	321.50	221.30	542.80	17.15

Looking at the *Realistic highest* $6.94W/m^2$ in the table above, see *Table 20*, the importance of domestic appliances heat on the dwellings thermal demand is evident. This is reflected when comparing this case with all the others. In all the scenarios, the occupants heat is similar but not domestic appliances. The demand for heating panels has decreased satisfactorily. However, while some rooms do not need heat, others do. This is one of the potential hurdles stated in Potential Hurdles, that is, *"Could it happen to have to overheat owing to internal heat gains in one room and heating demand in another?"*

Therefore, it can be concluded that of the two IHG, the one with the most significant thermal impact is domestic appliances. This can occur with only an increase in the electricity consumption of the house. It should be remembered that the consumption data used for the *Realistic highest* $6.94W/m^2$ comes from the analysis of a large population sample whose standard consumption can increase. The annual values for IHG, EP, DHW and AHU consumptions are shown below; see *Table 21*.

Table 21. Influence of varying IHG on heaters consumption for each winter case period.

Annual values					
Standard 5W/m^2					
	EA	**BH**	**EP**	**DHW**	
kWh	5,766	2,,471			**AHU**
TOTAL kWh	**8237**		**599**	**2,736**	**43.06**
Base 4W/m^2					
	EA	**BH**	**EP**	**DHW**	
kWh	4,119	2,471			**AHU**
TOTAL kWh	**6,590**		**1,031**	**2,736**	**46.46**
Realistic Lowest 3.30W/m^2					
	EA	**BH**	**EP**	**DHW**	
kWh	2,975	2,318			**AHU**
TOTAL kWh	**5,293**		**1,520**	**2,736**	**48.56**
Realistic 4.50W/m^2					
	EA	**BH**	**EP**	**DHW**	
kWh	5,059	2,318			**AHU**
TOTAL kWh	**7,377**		**891**	**2,736**	**44.45**
Realistic Highest 6.94W/m^2					
	EA	**BH**	**EP**	**DHW**	
kWh	9,107	2,318			**AHU**
TOTAL kWh	**11,425**		**131**	**2,736**	**34.93**

There can be observed that when comparing both *Standard 5W/m^2* and *Realistic 4.50W/m^2*, the EP consumption is much higher in the second case. This would be unexpected since only a difference of 0.50W/m^2. However, it is strongly related to having not well used in the internal heat when having a variable distribution in time and per room.

The most influential factor is EA since in the *Realistic highest 6.94W/m^2*, its consumption is around 3.8 times the *Standard 5W/m^2*, i.e. around 3,340kWh/year more. However, that is not reflected in the EP consumption, which is only 467kWh/year lower in the *Realistic highest 6.94W/m^2*.

The total electricity and heat annual consumptions are shown in the following table. In there, the electricity consumption includes:

- Electrical appliances consumption
- Electric panels consumption
- Domestic Hot Water (DHW) consumption
- Air handling unit (AHU) consumption

Likewise, heat consumption considers:

- Electric panels consumption
- Domestic Hot Water (DHW) consumption
- Air handling unit (AHU) consumption

Going back to the above, the *Realistic highest 6.94W/m^2* has an inferior performance of IHG. Such a high electricity consumption is barely reflected in heat consumption because of the not useful heat. See *Table 22*.

Table 22. Annual electricity and heat consumption for each case, the whole year.

Annual values				
	Electricity consumption		Heat consumption	
	kWh	kWh/m^2	kWh	kWh/m^2
Standard 5W/m^2	9,144	48.62	3,378	17.96
Base 4W/m^2	7,932	42.18	3,814	20.28
Realistic Lowest 3.30W/m^2	7,280	38.71	4,305	22.89
Realistic 4.50W/m^2	8,731	46.43	3,672	19.53
Realistic Highest 6.94W/m^2	12,009	63.86	2,903	15.43

Regarding the first potential hurdles stated in Potential Hurdles, *"How much internal heat gain from electrical appliances can be beneficial to reduce heating demand"*, as seen in the table above, see *Table 22*, the influence of electric consumption on electric panels demand is so significant. A difference on 1,402kWh/year of thermal energy results when comparing the *Realistic lowest 3.30W/m^2* and *Realistic Highest 6.94W/m^2* consumptions.

In the table below, see *Table 23,* all the annual values of the total thermal energy in the building are compared with a case where there are not IHG. Because of this, only the actual thermal energy consumption in the building is provided by IDA-ICE. The total thermal energy considers DHW, IHG, EP consumption, and AHU.

Table 23. Comparison of the total thermal energy inside the building for all cases, together with the case without IHG.

Annual values		
	Total Thermal Energy	
	kWh	kWh/m^2
Standard 5W/m^2	11,615	61.76
Base 4W/m^2	10,403	55.32
Realistic Lowest 3.30W/m^2	9,597	51.03
Realistic 4.50W/m^2	11,049	58.75
Realistic Highest 6.94W/m^2	14,328	76.18
Only using electric panels	6,442	34.26

This last table, see *Table 23,* clearly shows how the heating demand is affected by having a distribution of internal gains uniformly in the time and space of one variable. The first two cases correspond to fixed values, and as far as can be seen, are the ones that most closely resemble the thermal consumption that a dwelling need. Of all the variable cases, the only one that resembles the total energy requirement, i.e. the last case in *Table 23*, is the *Realistic lowest 3.30W/m*^{2}. Therefore, in the other two realistic cases, although IHG has experienced an increase, it is not constant over time, playing a worse use of internal loads. If the performance were adequate, neither the *Realistic 4.50W/m*^{2} nor the *Realistic highest 6.94W/m*^{2} would require heating demand. Note that in *Table 23*, only the total IHG could provide almost all the thermal energy of the *Only using electric panels case*. It should also be noted that the DHW consumption (2,736 kWh/year) is already included in the count.

7 Influence of the orientation of the facades

The orientation of the facades is studied using the software to know how it can affect dwelling energy demand by increasing or decreasing the external heat gain. Four simulations with IDA ICE will be run, and in all of them, and energy study will be carried out. The four cases are compared to the reference orientation, which is 0º. The four orientations are 20º,40º,60º and 270º. However, these orientations are not realistic since the main facade of the building, that is, the living room would be facing North and East. The scenario where the azimuth angle is zero has the laundry facade facing north. Therefore, the Kitchen & dining, the living rooms, and the Master bedroom are facing south, as shown in the figure below. See *Figure 20*.

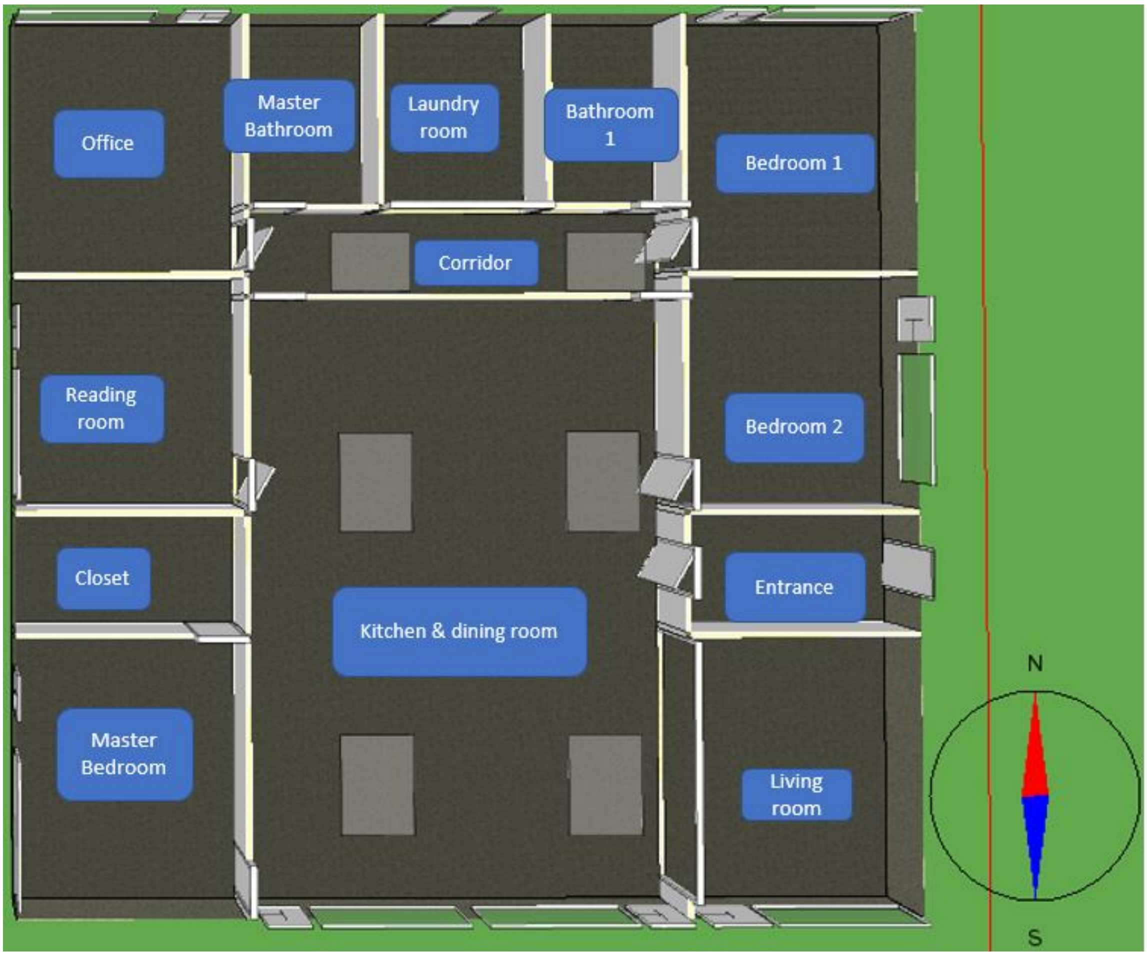


Figure 20. Reference orientation, 0º.

The figure below illustrates the variation of the building orientation. In the upper left corner is the orientation of 20°, and in the upper right corner, the orientation is 40°. At the bottom part of the building layout, from left to right, it is 60º and 270º.

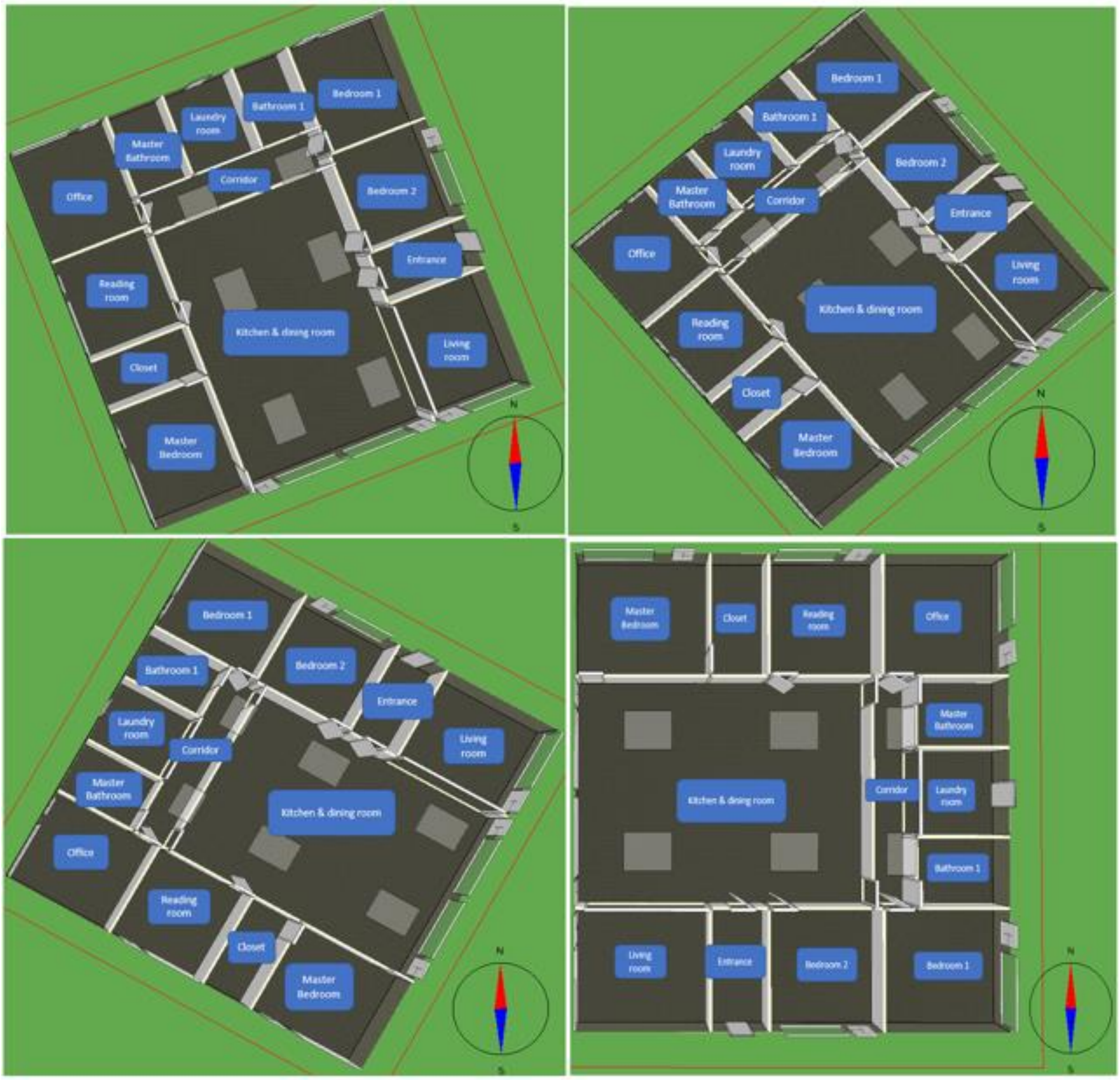


Figure 21. 20º,40º in the upper part from left to right side; 60º and 270º in the lower part from left to the right side.

To understand better the influence of changing the orientation on the indoor environment or room temperatures, the following chart, see *Figure 22*, has been carried out to illustrate how the number of hours in each room varies depending on orientation. This graph is only used to see the effect on overheating hours. It only shows when the temperature is above 27ºC and does not account for T>28ºC because uncomfortable temperatures are already reached when 27ºC is exceeded.

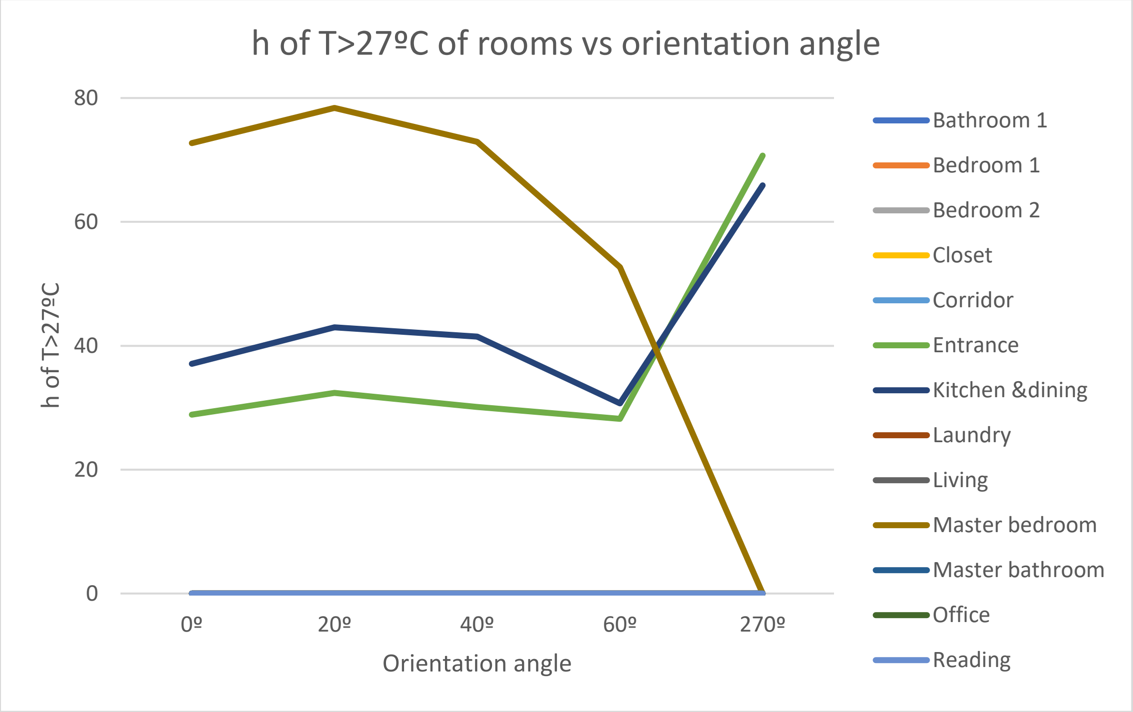


Figure 22. Effect of changing the orientation on overheating in rooms.

Based on the results obtained in the graph above, see *Figure 22*, the number of hours above 27°C in the master bedroom decreases as it is oriented more towards the north. It is also shown in the table below. See *Table 24*. The solar gain is much lower, as the study focuses on Denmark, i.e. in the northern hemisphere. That is reflected in the master bedroom, wherefrom 20º to 270º (both facades facing north and west), the number of hours of overheating is reduced to zero. Emphasis is placed on the master bedroom and overheating hours because it is one of the main selection requirements for orientation. That is because the temperature of the master bedroom is the lowest, being 18ºC. That said, it should remain on the colder side of the house. The second focuses on the living room, commonly facing South and West. This is the connection to the Kitchen & dining room and the terrace. The terrace is typically placed on the south and west to get more sunlight, which happens in the living room. That only happens when the orientation is 270º, as the corner facades face both south and west. For those reasons, the orientation of the building will remain at 270ºC for all future project simulations.

Table 24. Depending on the orientation, the number of hours T depends on 28ºC for each room.

	T>27ºC					T>28ºC				
	0º	**20º**	**40º**	**60º**	**270º**	**0º**	**20º**	**40º**	**60º**	**270º**
Bathroom 1	0	0	0	0	0	0	0	0	0	0
Bedroom 1	0	0	0	0	0	0	0	0	0	0
Bedroom 2	0	0	0	0	0	0	0	0	0	0
Closet	0	**0**	**0**	**0**	**0**	0	0	0	0	0
Corridor	0	32	0	0	0	0	0	0	0	0
Entrance	29	32	30	28	71	2	2	2	2	14
Kitchen &dining	37	43	42	31	66	7	7	6	5	32
Laundry	0	0	0	0	0	0	0	0	0	0
Living	0	0	0	0	0	3	3	3	4	4
Master bedroom	73	78	73	53	0	39	46	42	30	0
Master bathroom	0	0	0	0	0	0	0	0	0	0
Office	0	0	0	0	0	0	0	0	0	0
Reading	0	0	0	0	0	0	0	0	0	0

Table 25, see below, shows the EP consumption for each room depending on the orientation. Moreover, the total number of hours when T>27ºC and T>28ºC for each orientation angle is detailed.

Table 25. Most relevant results when changing the orientation of the building for the whole winter season.

Annual consumption					
Electric panels consumption kWh/year					
Room	**Orientation angle**				
	0º	**20º**	**40º**	**60º**	**270º**
Bathroom 1	14.7	13.9	14.9	16.7	24.2
Bedroom 1	128.1	129.0	132.5	136.9	134.9
Bedroom 2	65.2	68.4	72.5	78.0	64.1
Closet	81.0	75.4	70.9	68.9	1.4
Corridor	0.0	0.0	0.0	0.0	0.0
Entrance	21.9	22.4	23.1	24.7	28.4
Kitchen & dining	104.0	106.6	114.3	130.9	150.5
Laundry	0.0	0.0	0.0	0.0	0.2
Living	2.6	2.9	3.2	4.0	3.7
Master bedroom	0.0	0.0	0.0	0.0	0.0
Master bathroom	15.4	14.6	15.7	17.5	25.4
Office	208.8	209.2	214.5	220.0	229.6
Reading	95.9	94.9	95.2	97.5	125.8
TOTAL	**737.6**	**737.3**	**756.7**	**795.1**	**788.1**
T>27ºC					
TOTAL	**138.7**	**186.2**	**144.5**	**111.6**	**136.6**
T>28ºC					
TOTAL	**50.6**	**57.1**	**53.4**	**41.7**	**49.8**

Considering Table 24 and *Table 25*, despite having reduced the number of overheating hours in the master bedroom to zero when 270º case, the thermal demand of several rooms has increased, causing the total thermal consumption of the dwelling to grow, mainly when the angle of orientation also increases.

Considering the potential hurdles stated in Potential Hurdles, *"What could be done to solve overheating and heating demand in some rooms simultaneously?"*, this table above illustrates that the laundry and closet h T>27ºC could be solved by changing the orientation of the dwelling.

In *Figure 23*, see the figure below, the consumption of radiators in all rooms is represented.

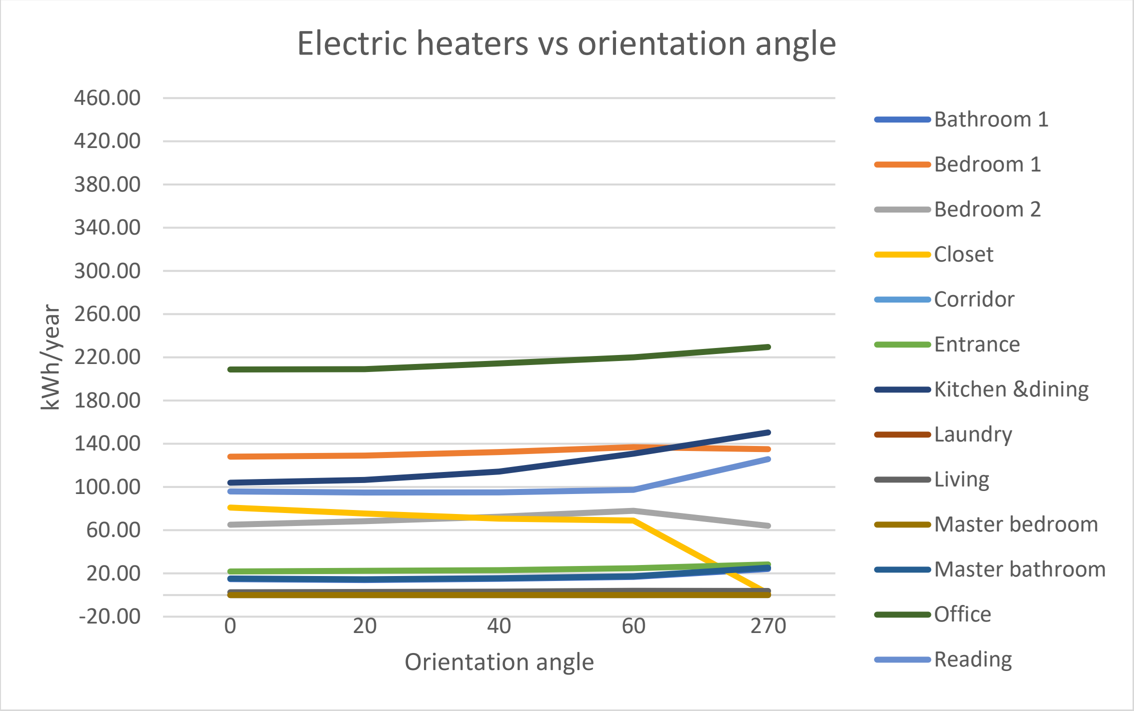


Figure 23. Effect of changing the orientation on electric heaters demand.

There is a progressive increase in heaters demand because rooms with the highest thermal demand are further away from the south orientation. These highest consumptions are in the kitchen & dining (because of its vast size), the office (located in a corner, so that heat losses are higher and do not have BH), and the reading room. Looking at the house indoor layout, see *Figure 20; all* of them except the Kitchen & dining room are on the same façade. Hence, changing the orientation similarly affect them. A progression from 0º to 270º results from facing West to North, where sun gains are the lowest.

As seen, the highest consumption is in the Office independently of the orientation. It is not a question of the size of the room since the Living room is more significant and heating demand is lower. Given this, that is caused by occupants inexistence of internal heat. In the table below, the total thermal energy demand based on the orientation angle of the building is summarised. See *Table 26.*

Table 26. Total thermal energy demand depending on the orientation.

Orientation	EP kWh/year	DHW kWh/year	AHU kWh/year	Total Thermal Energy Demand kWh/year
0º	738	2736	41.97	3516
20º	737	2736	41.98	3516
40º	757	2736	42.5	3536
60º	795	2736	43.34	3575
270º	788	2736	44.45	3569

As explained, the further away, the highest consumption rooms from the south are, the more heating demand is. This is detailed in the table above, where the highest total thermal energy consumption is reached at 60º.

8 Door influence on indoor heat distribution

In this subchapter, the influence of opening and closing doors on indoor temperature and energy demand is studied. Three scenarios will be compared. The first one is already studied previously, whose door schedule has been applied to the Realistic 4.50W/m^2; from now on, this will be the Realistic 4.50W/m^2-base door. The second is the simplest, where all doors are permanently closed; this will be called the Realistic 4.50W/m^2-doors closed. Finally, the third scenario has a schedule for each door, named the Realistic 4.50W/m^2-occupants door patterns. This list is based on the most common occupants behaviours timetable performed in subchapter 3.1 (see Table 4).

8.1 Realistic- 4.50W/m^2-Base door

The *Realistic 4.50W/m^2-Base door schedule* uses the exact timetable as the *Base 4 W/m^2* scenario. The table below, see *Table 27,* shows the schedule applied to each door.

Table 27. Door schedule of the Realistic4.50W/m^2-Base door schedule.

	Duration	**Open**
Entrance/Outside	Never opened	Never
Entrance/Kitchen and dining	Closed from 23h to 7h	form 7h to 23
Bedroom 1/Corridor	Closed from 23h to 7h	form 7h to 23
Bedroom 2/Kitchen & dining room	Closed from 23h to 7h	form 7h to 23
Master Bedroom/Kitchen & dining room	Never opened	Never
Bathroom 1/Corridor	Never opened	Never
Master Bathroom/Corridor	Never opened	Never
Laundry/Corridor	-	
Office/Corridor	Closed from 23h to 7h	form 7h to 23
Closet/Master Bedroom	Never opened	Never
Corridor/Kitchen & Dining	-	
Living/Kitchen & dining room	-	
Reading/Kitchen & dining room	Closed from 23h to 7h	form 7h to 23

8.2 Realistic- 4.50W/m^2-Doors closed

In this scenario, all the doors of the dwelling are permanently closed. Thanks to this, it allows analyzing each room independently without influencing the others.

8.3 Realistic- 4.50W/m^2-Occupants door patterns

This timetable is based on *Table 4* information. Because *Table 4* makes a difference between workdays and weekends, following the same procedure here makes sense. See *Table 28* and *Table 29*, being workdays (WD) the first and weekdays (WS) the second, respectively. Both tables represent the time when each door remains open or closed. The following symbol "/" is to determine which door is referencing. It means the door, and both, the previous and rear rooms, refer to the involved rooms. Additionally, the activity in each case is also included, shown in the "Activity" column, the same as in *Table 4* (Room and use). In both instances WD and WS, it is noticed that the doors Entrance/Outside and Entrance/Kitchen and dining have the same schedule. They are permanently closed. It is considered that both are always closed and opened simultaneously, and because the entrance door is usually closed, it is approximated to be closed permanently.

Table 28. Door schedule of Realistic- 4.50W/m^2-Occupant's patterns on weekdays.

WD		
Door	**Activity**	**Duration**
Entrance/Outside	Always closed	00:00-24:00
Entrance/Kitchen and dining	Always closed	00:00-24:00
Bedroom 1/Corridor	Getting up-Door open	6:30-15:00
	Relax-Door closed	15:00-17:00
	Several activities-Door open	17:00-23:00
Bedroom 2/Kitchen & dining room	Getting up-Door open	06:30-23:00
	Sleeping-Door closed	23:00-06:30
Bathroom 1/Corridor	Always closed	00:00-24:00
Master Bathroom/Corridor	Always closed	00:00-24:00
Laundry/Corridor	Always open	00:00-24:00
Office/Corridor	Always open	00:00-24:00
Corridor/Kitchen & dining room	Always open	00:00-24:00
Living/Kitchen & dining room	Always open	00:00-24:00
Reading/Kitchen & dining room	Not reading-Door open	00:00-17:00
	Reading-Door closed	17:00-19:00
	Not reading-Door open	19:00-24:00
Kitchen and dining/Corridor	Always open	00:00-24:00

Table 28 and *Table 29* establish that all sleeping rooms are closed only when occupants sleep, except when Bedroom 1 is used to relax, the teenager closes the door. The Master bedroom doors need to be permanently closed since the room temperature is set at 18ºC, whereas the rest is set up at 22ºC. Therefore, the AHU master bedroom system would remove all the excess heat transferred from the Closet and the Kitchen & dining room (warmer than the master bedroom). Both rooms would continue trying to set up the temperatures at 22ºC. Given this, the heat would be transferred among the warmer rooms to the coldest, so the heating system would provide more thermal energy. Hence, energy demand would increase without obtaining any benefit.

Table 29. Door schedule for Realistic- 4.50W/m2-Occupant's patterns at weekends.

WS		
Door	**Activity**	**Open-close door**
Entrance/Outside	Always closed	00:00-24:00
Entrance/Kitchen and dining	Always closed	00:00-24:00
Bedroom 1/Corridor	Getting up-Door open	08:30-12:30
	Relax time-Door closed	12:30-17:00
	Several activities-Door open	17:00-00:00
	Sleeping-Door closed-Door closed	00:00-08:30
Bedroom 2/Kitchen & dining room	Sleeping-Door closed	00:00-08:30
	Several activities-Door open	08:30-24:00
Bathroom 1/Corridor	Always closed	00:00-24:00
Master Bathroom/Corridor	Always closed	00:00-24:00
Laundry/Corridor	Always open	00:00-24:00
Office/Corridor	Always open	00:00-24:00
Living/Kitchen & dining room	Always open	00:00-24:00
Reading/Kitchen & dining room	Several activities-Door open	00:00-17:00
	Reading-Door close	17:00-19:30
	Several activities-Door open	19:30-24:00
Kitchen and dining/Corridor	Always open	00:00-24:00

8.4 Comparison among the three-door scenarios

The following bar chart, see *Figure 24*, shows the EP consumption for each room for the three scenarios.

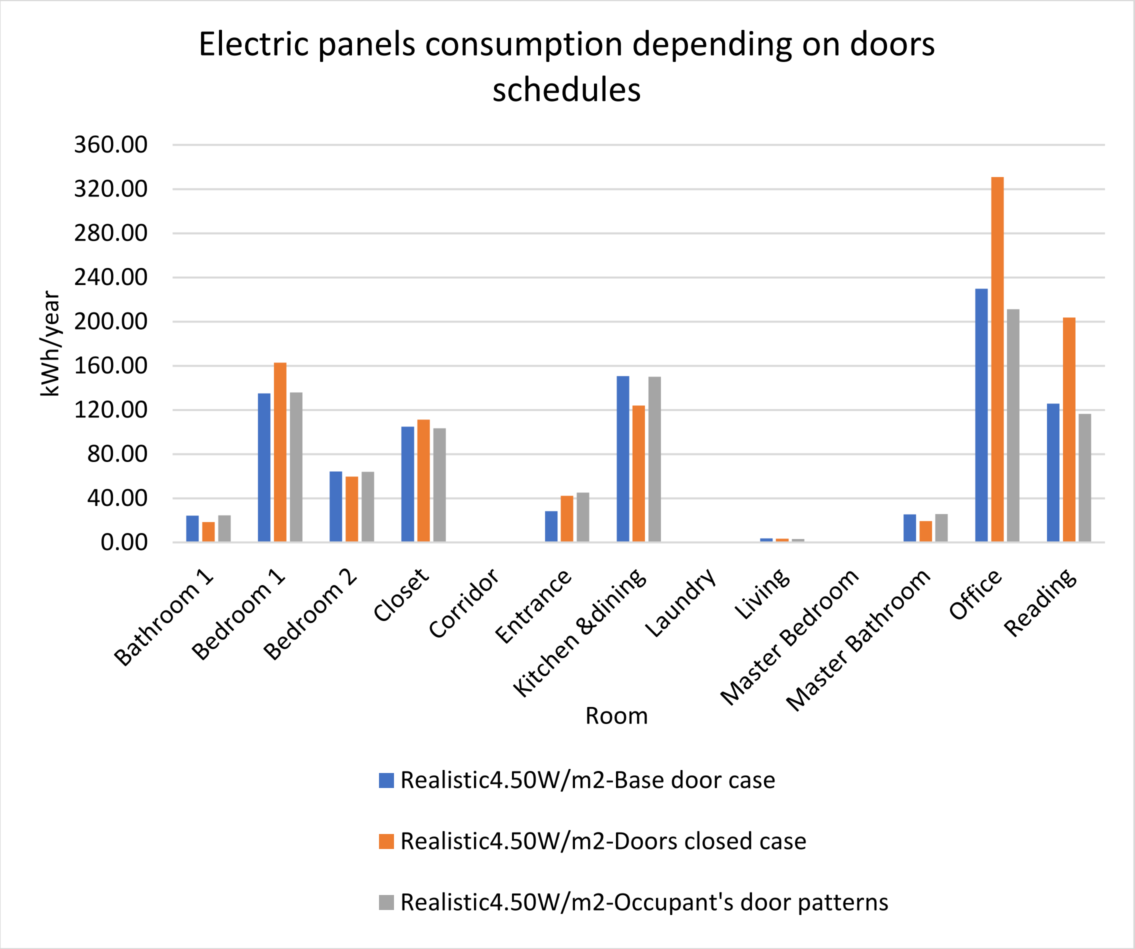


Figure 24. Electric panels consumption for each room depends on door schedules.

It is observed that the highest thermal consumptions are reached in some rooms when all doors are closed, i.e. in *the Realistic 4.50W/m^2-Doors closed*, increasing the total heating demand. The fact of not communicating the rooms creates thermal gradients. This is because doors significantly influence the internal and external heat gains distribution. Rooms that face South will achieve higher temperatures because the closer the south orientation, the more sun heat gain they receive. Opposite to them, others have lower heat gains contributions by facing North. Based on this explanation, should the excess of hot air not go from the warmer rooms to the colder ones, electric panels will have to provide that heat. In the *Realistic 4.50W/m^2-Doors* *closed*, the Office and the Reading have increased their consumption the most. That is because they face North and are isolated from the rest. Additionally, both rooms have windows, and in the Office case, it is in the corner. Given this, the size of the façade is bigger. These two features, the windows, and the length of the facade make them lose more heat through the thermal envelope.

On the contrary, if there was a good heat transfer by convection (mixing indoor hot and cold air), as happens in the *Realistic 4.50W/m^2-Based door* and *Realistic 4.50W/m^2-Occupants door patterns*, the heat from warmer rooms would be distributed along with the whole house. It would mean that those hot airs coming from the warmer rooms would cover part of the demand of the colder rooms; this is what happens in the other two cases: *Realistic 4.50W/m^2-Based door* and *Realistic 4.50W/m^2-Occupants door patterns* schedules. As shown in the figure above, see *Figure 24;* both cases have practically the same heating demand for each room. However, the *Realistic 4.50W/m^2-Occupants door patterns,* whose doors remain open longer, have a slightly lower consumption. Therefore, the longer the doors are open, the lower the heating demand is. The EP consumption depending on the duration of open doors is summarised below. See *Table 30.*

Table 30. Electric panels consumption depends on the duration of open doors.

Duration of doors being open	**Case**	**EP kWh/year**
The lowest	Realistic 4.50W/m^2-Occupant patterns door schedule	879
In the middle	Realistic 4.50W/m^2-Base door schedule	891
The most	Realistic 4.50W/m^2-Doors closed schedule	1075

In the following figure, see *Figure 25*, the number of h T>27ºC for each room is compared for the three scenarios.

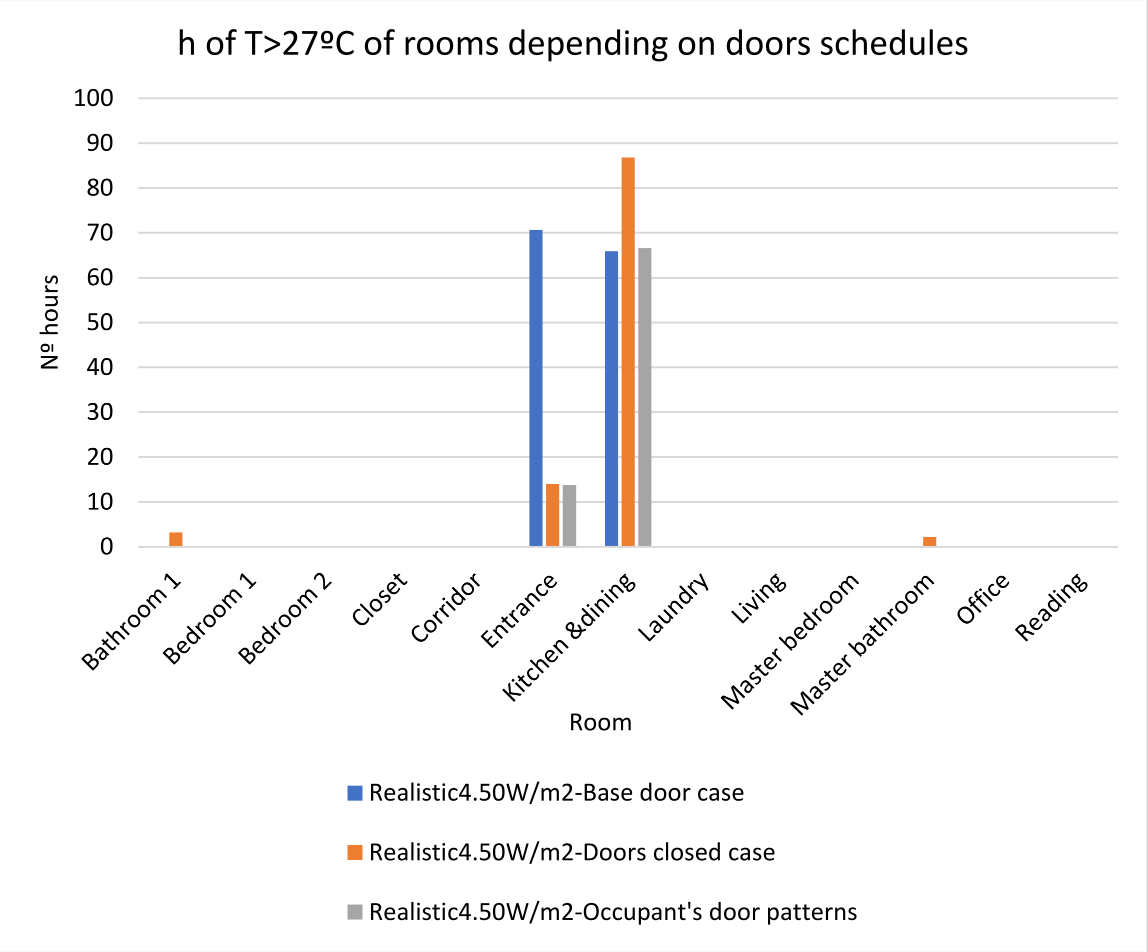


Figure 25. Several hours above 27ºC depending on the doors schedules.

Regarding the number of non-comfort hours, based on what illustrates in *Figure 25,* it is observed that when the Entrance/Kitchen & dining is open, which only occurs in the *Realistic 4.50W/m^2-Based door*, a vast number of hours in the Entrance is obtained. All the excess heat acquired from external and IHG in the Kitchen & dining room is transferred to the adjoining rooms. Except for the Entrance, none presents temperatures above 27ºC and 28ºC. That is explained as the Entrance volume is smaller than the Kitchen & dining and the other rooms. Consequently, the energy required to increase the entrance volume by one degree is much lower than any other room. Therefore, the number of hours in the entrance room rises quickly.

Looking at *Figure 25*, the *Realistic 4.50W/m^2-Doors closed* is the only scenario where Bathroom 1 and Master bathroom have non-comfort hours. The excess heat in both rooms cannot be transferred to other colder rooms by convection. Those colder rooms are Bedroom 1 and Office, which are also the closest ones to each other, respectively. Both colder rooms present higher heating consumptions when doors are closed; see *Figure 24*, when Bathroom 1 and Master Bathroom.

On the other hand, lower heating consumptions in the Office and Bedroom 1 are experienced if doors are open. Moreover, the number of non-comfort hours in the Bathroom 1 and Master Bathroom is reduced to zero.

The table below, see *Table 31*, summarizes the essential results commented in this chapter.

Table 31. The most relevant annual results are when changing the doors schedules.

Annual values			
	Realistic 4.50W/m^2-Base door schedule	**Realistic 4.50W/m^2-Doors closed schedule.**	**Realistic 4.50W/m^2-Occupants patterns door schedule**
BH kWh	2,318	2,318	2,318
EA kWh	5,059	5,059	5,059
Total IHG kWh	7,377	7,377	7,377
DHW kWh	2,736	2,736	2,736
AHU kWh	44.45	41.94	45.27
EP kWh	891	1,075	879
T>27ºC	137	106	80
T>28ºC	46	39	33
EC kWh	8,731	8,912	8,720
EC kWh/m2	46.43	47.39	46.37
SH kWh	3,672	3,853	3,661
SH kWh/m2	19.53	20.49	19.47

As illustrated in *Table 31*, the IHG and DHW do not vary from one scenario to another since doors schedules do not influence them. Concerning the EP consumption, as explained in this chapter, the longer the doors remain open, the lower the electricity consumption is. According to this, the *Realistic 4.50W/m^2-Occupants door patterns* has the lowest consumption. Opposite to this, the *Realistic 4.50W/m^2-Doors closed* case has the highest consumption. This also influences electricity and heat consumption because EP is included in both categories.

Regarding "h of T>27ºC and T>28ºC", the *Realistic 4.50W/m^2-Based door* case is the one with the highest number because the Entrance/Kitchen and dining door is open all time. The second case with the most significant number of non-comfort hours is the *Realistic 4.50W/m^2-Doors closed* because the heat in hotter rooms cannot be transferred to the colder ones.

9 Investigation into heat demand and indoor temperature of continuous heating compared to flexible heating

This chapter is focused on studying the effect of using a flexible heating system on heating demand and indoor temperatures. This flexible heating will only operate from 9 pm until 6 am, and both results, i.e. room temperatures and electric panels consumption, are compared with the continuous heating system. Finally, the feasibility of only using heating during the night is discussed.

9.1 Acceptable fluctuations in the indoor temperatures

As explained in the Thermal comfort subchapter, the following temperatures are set up for the different rooms:

- Master Bedroom: set up at 18ºC.
- Rest of rooms: set up at 22ºC- the temperature could fluctuate until reaching 20ºC in some periods, where occupants would not be uncomforted, as explained in the State of the Art.

The duration curve of the indoor temperature for each room is performed for the whole year. Establishing different temperatures in the indoor temperature curve, the total number of hours when the temperature is below the set points is obtained. That will depend on each setup temperature, i.e. T<18ºC for the Master Bedroom and T<22ºC for the rest of the rooms with occasional fluctuations that can reach 20ºC, which is still considered a comfortable temperature.

Firstly, it is studied in the worst scenario, when IHG are the lowest, the *Realistic Lowest 3.30W/m*^{2}. That is because; the fewer IHG, the lower temperature in rooms is. If there are few hours where temperatures are under the limits, the rest of the cases will have fewer since more heat is in all rooms. As shown in the table below, see *Table 32*, the number of non-comfort hours for this scenario is small. Given this, the other two typical electricity consumption scenarios are analysed. Only the three typical electricity consumptions are studied since their IHG establish the minimum, the average, and the maximum levels of emitted power per square meter of the five scenarios (*Standard 5W/m^2, Base-4W/m^2, Realistic lowest 3.30W/m^2, Realistic 4.50W/m^2 and Realistic highest 6.94W/m^2*). For that reason, studying the other two does not provide essential information. They would be only two examples more.

Table 32. Several hours when room temperatures are below the limits for the three most typical electricity consumption cases using a flexible heating system-only during the night.

Flexible heating system						
Room	**Realistic lowest 3.30W/m^2**		**Realistic 4.50W/m^2**		**Realistic highest 6.94W/m^2**	
	h T<20ºC	**h T<21ºC**	**h T<20ºC**	**h T<21ºC**	**h T<20ºC**	**h T<21ºC**
Bathroom 1	0.0	209.0	0.0	37.0	0.0	0.0
Bedroom 1	41.7	843.0	1.2	393.0	0.0	3.4
Bedroom 2	3.7	575.0	0.0	187.0	0.0	0.0
Closet	202.0	1,550.0	55.8	971.0	8.2	71.4
Corridor	0.3	357.0	0.0	59.4	0.0	0.0
Entrance	0.0	354.0	0.0	57.7	0.0	0.0
Kitchen & Dining	0.0	278.0	0.0	21.9	0.0	0.0
Laundry room	0.0	121.0	0.0	0.1	0.0	0.0
Living room	0.0	108.0	0.0	0.0	0.0	0.0
Master Bathroom	0.0	241.0	0.0	45.2	0.0	0.0
Office	85.1	1,110.0	11.9	595.0	0.0	20.3
Reading room	0.8	612.0	0.0	214.0	0.0	3.8
	h T<18ºC		**h T<18ºC**		**h T<18ºC**	
Master bedroom	2,540		1,840		531	
Continuous heating system						
Room	**Realistic lowest 3.30W/m^2**		**Realistic 4.50W/m^2**		**Realistic highest 6.94W/m^2**	
	h T<18ºC		**h T<18ºC**		**h T<18ºC**	
Master bedroom	2,320		1,610		495	

As shown in the table above, see *Table 32*; the results for all the cases are acceptable. However, the *Realistic lowest 3.30W/m^2* could not have been considered since there are many hours under 20ºC in the Office and closet. Nonetheless, both rooms are not for staying, so it is acceptable to have non-comfort hours there. Hence, based on the indoor temperatures requirements of at least 20ºC and the results obtained, *Table 32* demonstrates that using a flexible heating system that only works during the night is acceptable. In all the cases, some rooms do not experience T<20ºC and others that do. This means that those rooms would experience overheating, and others would require heating. This is a potential hurdle stated in the *Potential Hurdles* chapter *"However, in the flexible one could happen to have to overheat owing to internal heat gains in one room and heating demand in another?".*

Having temperatures under the setpoints can also occur in the continuous heating system since it is only used during the heating season. However, the quantity is much less. During the rest of the year, there can be sporadic days when the temperature goes below the setpoint of 22ºC. There is no big difference between Flexible and Continuous heating systems in energy terms. The Flexible system demands less energy from the EP, as is summarised in the table below; see *Table 33*.

Table 33. Comparison of the annual values of total IHG, electric panels and DHW, and AHU consumption for the flexible and continuous heating systems.

<table>
<tr><th colspan="5">Annual values</th></tr>
<tr><th colspan="5">Flexible heating system-Annual values</th></tr>
<tr><th></th><th>Total IHG kWh</th><th>EP kWh</th><th>DHW kWh</th><th>AHU kWh</th></tr>
<tr><td>Realistic Lowest Case- 3.30W/m^2</td><td>5,293</td><td>1,381</td><td>2,736</td><td>47.19</td></tr>
<tr><td>Realistic Case- 4.50W/m^2</td><td>7,377</td><td>791</td><td>2,736</td><td>42.58</td></tr>
<tr><td>Realistic Highest Case- 6.94W/m^2</td><td>11,424</td><td>101</td><td>2,736</td><td>33.03</td></tr>
<tr><th colspan="5">Continuous heating system-Annual values</th></tr>
<tr><th></th><th>Total internal heat gains kWh</th><th>Elec. Panels kWh</th><th>DHW kWh</th><th>AHU kWh</th></tr>
<tr><td>Realistic Lowest Case- 3.30W/m^2</td><td>5,293</td><td>1,520</td><td>2,736</td><td>48.56</td></tr>
<tr><td>Realistic Case- 4.50W/m^2</td><td>7,377</td><td>891</td><td>2,736</td><td>44.45</td></tr>
<tr><td>Realistic Highest Case- 6.94W/m^2</td><td>11,425</td><td>131</td><td>2,736</td><td>34.93</td></tr>
</table>

The reason to experience lower consumption in flexible heating is that the actual rooms temperatures resulting from the night-time heating is slightly lower, reducing the heating demand since there are fewer thermal losses. The higher the indoor temperature is, the more thermal losses to the outdoor are. The following table, see *Table 34,* which summarises the electricity and heat consumption, compares both results with the continuous heating system. In there, the electricity consumption includes:

- Electrical appliances consumption
- Electric panels consumption
- Domestic Hot Water (DHW) consumption
- Air handling unit (AHU) consumption

Likewise, heat consumption considers:

- Electric panels consumption
- Domestic Hot Water (DHW) consumption
- Air handling unit (AHU) consumption

Table 34. Annal electricity and heat consumptions for the flexible and continuous heating systems.

Annual values				
Flexible heating system-Annual values				
	Electricity consumption		**Heat consumption**	
	kWh	**kWh/m2**	**kWh**	**kWh/m2**
Realistic Lowest - 3.30W/m^2	7,139	37.96	4,164	22.14
Realistic 4.50W/m^2	8,629	45.88	3,570	18.98
Realistic Highest 6.94W/m^2	11,977	63.68	2,870	15.26
Continuous heating system-Annual values				
	Electricity consumption		**Heat consumption**	
	kWh	**kWh/m2**	**kWh**	**kWh/m2**
Realistic Lowest 3.30W/m^2	7,280	38.71	4,305	22.89
Realistic 4.50W/m^2	8,731	46.43	3,672	19.53
Realistic Highest 6.94W/m^2	12,009	63.86	2,903	15.43

In the table above, see *Table 34*; as expected, since EP consume electricity and provide heat, all the flexible results are slightly lower than in the other case. Therefore, it is cost-effective to use flexible heating in terms of electricity and heat consumption. Moreover, the monetary option is more attractive because the price of electricity is lower during night-time periods. However, an economic study is out of the scope of this project.

10 Discussion

This chapter focuses on evaluating and analysing the results obtained throughout the work.

Low-energy houses have very low thermal consumption due to the materials and techniques used for their construction. Thus, heat losses to the outside are shallow. Therefore, any thermal heat source inside the dwelling, however irrelevant it may be for a typical home, is considered an excellent value. This is the case for internal heat gains, i.e. heat emitted by people and appliances. Their values are standardised and have a constant distribution over time and space, whose influence on the heat demand for a traditional dwelling is not very decisive. However, based on the results obtained, this is not the case. There are different patterns in the behaviour of the users that can alter the electricity and human heat consumption to a large extent, which is reflected in the study.

To realise the variable distribution in time and space of both internal loads, the most common behaviour of the occupants was studied. As far as human heat is concerned, all the most common daily activities together with the heat given off during their execution were studied. In this way, a schedule detailing the human heat output was obtained. The same was applied to electricity consumption, which was distributed by room, presenting different hourly consumptions for each of them. This hourly and spatial distribution was used and adapted to Danish dwellings average, lowest and highest standardised daily consumption. The average consumption results, which should be close to the standardised ones, showed different values than the standardised ones, being 1.48W/m^2 and 3.02W/m^2, for occupants and appliances, respectively. Compared to the standards, 1.50W/m^2 and 3.50W/m^2 in the same order are slightly lower, leading to more accurate values for thermal loads.

This slight modification is reflected when comparing the results of the five scenarios. In the first two, both internal heat loads have a constant distribution in time and space, while the other three do not. For these three, the factor that changes from one to the other is the consumption of the appliances. These are the lowest, the average and the highest in Danish four-member dwellings. When comparing the five scenarios, the results show that the variable distribution leads to higher total heat consumption. As the loads are not uniformly distributed over time, heat peaks occur during particular periods. Therefore, outside these periods, the heating demand is still present, which means that it is not well utilised. A good utilisation would be if the heat loads were more evenly distributed over time. The main cause of these excess heat peaks is the human factor, as household appliances consume more uniformly. The latter is the decisive factor in reducing heating demand due to their more uniform heat distribution and contribution. For that reason, the more uniform the internal heat gain is, the more thermal energy is saved. Comparing the lowest and the highest typical consumption, the last saves 1,402kWh/year of thermal energy by simply changing the consumption habits of household appliances. These excess heat gains, as for the opposite case, could be avoided by using the two passive measures evaluated, namely: changing the orientation of the dwelling and keeping interior doors open or closed for more extended periods. Another option that, although not realised, could be feasible is to redistribute the rooms together with a different orientation.

The subsequent investigation carried out is the influence of the orientation of the dwelling on the thermal demand and indoor temperature conditions. The results of studying the four orientations of 0º, 20º, 40º and 60º show that the optimal orientation is 0º. For this orientation, the heating demand is the lowest, and the hours of non-comfort, T>27ºC and T>28ºC do not present a big difference concerning the other cases. Compared to the 270º orientation used for the whole project, it presents a reduction of 53kWh/year of thermal energy and only two more hours of non-comfort. However, this option is not considered because it would require a new interior layout of the house and there was not enough time to perform the study, but it could be considered for future research. In that case, the Master Bedroom and the Office would be interchanged due to their thermal demands. The Master Bedroom would be located to the north to minimise solar heat gain, while the Office would be found to the south to maximise it.

The last passive measure studied is the influence of the doors. From the results of the three cases evaluated, it is obtained that the thermal demand is directly proportional to the time the doors remain open. The longer the doors are closed, the higher the consumption of the EP. This is based on the heat transfer by air flows. If all doors remain open, the warmer rooms generate heat flows to the colder rooms due to temperature and the Buoyancy effect. Conversely, if they stay closed, spaces in which their orientation and load distribution allow higher temperatures to be reached may exceed the comfort temperature. In such a case, all the excess heat is not valid. If they were open, the excess heat would be distributed along the rest of the house. 3,853kWh/year and 3,672kWh/year of thermal demand is obtained for the extreme cases, i.e. permanently closed and the scenario where they remain open the longest, respectively. This effect of the doors is also reflected in the h T>27ºC and T>28ºC scenarios. Opening doors can lead to an increase in non-comfort hours, which is closely related to the air volume in each room. As demonstrated for the Entrance in the *Realistic 4.50W/m*^{2}*- Base door* and the others, having a small air volume requires little thermal energy to increase its temperature by one degree. Therefore, being next to the Kitchen & dining and living room, which has h T>27 and 28ºC, if the door between the two rooms is not closed, all the excess heat from the Kitchen & dining and living room has transferred to the Entrance. It is closed and open, respectively.

Finally, the study concludes by analysing the feasibility of implementing a flexible heating system that would only operate from 9 pm to 6 am for the internal heat gains model described above, that it could be relevant to be more implemented. Compared to the constant heating system, the thermal consumption of the flexible decreases for all three cases. This is because it is only operated during the night; the consumption of appliances and the human contribution is maximal during the day. This, together with shallow heat losses, means that the thermal demand during the day is deficient. Also, thanks to the excellent insulation of the thermal envelope, much of the heat emitted during the day is stored in the air/walls and objects of the house. Despite having a setpoint temperature of 22ºC, it is acceptable to reach 20ºC, given that in the vast majority of homes, no one is at home until late at night. That said, together with the analysis of the results, which shows non-relevant hours of T<20ºC for non of the three typical Danish consumptions, it is feasible from an energy and comfort point of view to use flexible heating system for this type of dwelling. An economic study has not been carried out. Still, since the price of electricity is usually lower during the night period, it can be expected that financial savings would also be perceived. This could be a starting point for future research on new buildings with minimum consumption. Said that, this last paragraph answers the question to if *"It is relevant to take internal heat gain into account combined with direct and flexible electric resistance heating at the new generation of low energy consumption building in a massive way".*

11 Conclusions

Throughout the project, different scenarios have been evaluated in which the internal heat gains vary for both people and appliances, although the latter varies the most. That is justified by using the three different levels of typical consumption in Danish households, i.e. the lowest, the average and the highest, and compared to the standards. Furthermore, as a main difference between the two cases, the first one has a uniform distribution over time and space, while the second one varies according to the period of the day and room.

The following conclusions can be drawn concerning the conclusions drawn from the analysis of the results.

Of the two internal loads, the decisive factor for reducing or increasing the heat demand in a dwelling is the domestic appliances, followed by the heat given off by human bodies. That is based on their consumption, and duration in time is much higher and more uniform.

The distribution in time and space of the internal heat gains conditions a good/bad use of their heat generation. It has been observed that the more variable the internal thermal loads are, the worse the heat utilisation can be. That is especially true for the human load of the occupants, as the proposed timetable understudy proposes the most common behavioural patterns in Denmark, which are highly non-conforming in terms of time and space, in contrast to domestic appliances. Consequently, during each activity, there are significant power peaks that increase the temperature in the room. During these short periods, heating is not required. That is only useful in rooms where the occupants stay longer. However, outside these periods, the heating continues to operate - good utilisation would mean that the heat emitted is over a longer time and not just for short periods. That is detailed when looking at the temperature and energy balance graph of the Laundry for the case of the direct and constant electric heating system in chapter *Comparison of heating demand for the different scenarios*. Applied to the *Realistic 4.50W/m*^{2} and compared to the *Standard 5W/m*^{2}, it shows a strong thermal peak during a short period when the action of the EP is required. The rest of the hours there is still a heating demand.

Both passive measures evaluated, which allow to study the effect on the house heating demand and indoor conditions, show the following conclusions.

Changes in facade orientation significantly reduce or increase heating consumption due to external solar heat gain. In general, all areas that demand more, either because they are bigger spaces or because the users spend more time there than others, should be oriented towards the south. In this way, the interior temperature of the room will increase passively, requiring a minor contribution from the EP. On the other hand, in the other rooms, such as the Master Bedroom with a temperature setpoint of 18°C, they should be placed to the north, where solar radiation is minimal. This phenomenon is advantageous for the heating season in the south-facing rooms but becomes a disadvantage during the warmer months. In these months, temperatures are above the maximum temperatures set for comfort, which are 27ºC and 28ºC.

However, these temperatures in some dwelling regions can be reduced by opening and closing the doors inside the building. All doors are permanently closed when analysing the three different schedules for opening and closing doors. It is observed that it is most beneficial for thermal demand and non-comfort hours to keep them open as long as possible. There is a heat transfer from the rooms with higher internal and external thermal loads, i.e. higher temperature, to the colder rooms. The excess heat is distributed along with the building. In this way, the excess heat covers part of the thermal demand of the colder rooms, resulting in thermal savings from the electric panels. That is the complete opposite of when they are closed. In this case, the south-facing areas receive extensive solar thermal radiation. Because they are closed, this heat is only used to raise the interior temperature of each room independently. These reach temperatures of over 27ºC and 28ºC so that the heat from comfort is not used. On the other hand, those located on the north facade have hardly any external gain, so they must be complemented by the heating system. Thus, significant thermal imbalances are created in the interior of the dwelling.

Finally, the last study, which evaluates the effect of this internal heat gains distribution according to time and space for a direct and flexible electric heating system, concludes that it could be implemented. Temperatures below the setpoint of 22°C and even below the limit temperature of 20°C are observed. However, for the three scenarios in which this night-time heating system is evaluated, it is only for the *Realistic lowest 3.30W/m*^{2} that there are the most hours below T<20ºC. However, as most of these occur in the Closet, there is no problem as it is a transit room. Furthermore, these temperatures are reached during the day, which is when the heating is not working, and the use of the dwelling is minimal, so the internal loads are also minimal - the dwelling is not usually inhabited. Thus, reaching temperatures below minimum temperatures are not a problem.

There is a slight decrease in heat consumption because the temperature for this system is slightly lower than for constant heating, what means that during the day there are less heat loses. Therefore, the energy study shows that it is energetically feasible. Although economic research has not been carried out nevertheless, in terms of the monetary cost of energy, this option is more cost-effective than the continuous heating system. In addition to this, electricity prices for nighttime are generally lower than during the day.

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