University of Aveiro
2013

Department of Civil Engineering

Piotr Marciniak

PASSIVE HOUSE FOR POLISH CLIMATE / PASSIVE HOUSE PARA O CLIMA POLACO

University of Aveiro
2013

Department of Civil Engineering

Piotr Marciniak

PASSIVE HOUSE FOR POLISH CLIMATE / PASSIVE HOUSE PARA O CLIMA POLACO

The dissertation thesis submitted to the University of Aveiro, to fulfill the requirements for the degree Master in Civil Engineering, conducted under the scientific guidance of Professor Dr. Romeu Vicente da Silva, Assistant Professor, Department of Civil Engineering, University of Aveiro and Polish Supervisor Ph. D. (Dr. Hab) Dariusz Heim, Assistant Professor, Department of Civil Engineering, Technical University of Lodz.

I dedicate this work to my parents, sisters, grandmother and grandfather.

Jury

President	Prof. Carlos Daniel Borges Coelho Assistant Professor, Department of Civil Engineering, University of Aveiro
	Prof. Romeu da Silva Vicente Assistant Professor, Department of Civil Engineering, University of Aveiro
	Prof. Dariusz Heim Assistant Professor, Department of Civil Engineering, Lodz University of Technology

Thanks

I would like to leave a word of appreciation and gratitude:

To my supervisor Professor Romeu Vicente, for numberless advices and accurate suggestions, for your precious time, for kindness demonstrated during the development of the work.

To Professor Carlos Coelho, for help with all formal issues regarding the process of dissertation of thesis at the University of Aveiro.

To Professor Dariusz Heim, for suggestions given during my work and patience demonstrated during the process of application on Campus Europae programme.

To Eliana Almeida for your help and hints.

To all of my friends from Erasmus programme and Portugal, for great time and wonderful moments that helped me with the hard work on thesis.

Finally, to my loving family, for being there for me.

Keywords

Passive house, energy demand, heating demand, low energy consumption, comperative study.

Abstract

This thesis refers to the viability of applying the Passive house concept to the Polish climate, focusing on city of Lodz. The Passive house concept introduces the construction of high energy efficient building, with the aim of fulfilling the requirements established by the Energy Performance of Buildings Directive (2010/31/UE, EPBD).

The study began with the introduction to Passive House concept. Therefore, the examples of construction solutions, specifications and overall requirements regarding Passive House were presented. The comparative study over the heating demand of the case study, between the European standard EN 13790 and the software "Passive House Planning Package" was performed. Afterwards, the accommodation of the case study to the Passive House standards with the use of "Passive House Planning Package" was executed. The accommodation was planned for the city of Lodz, Poland. To finalize, the economic study, with the aim of receiving the payback time of investment was presented.

Summarizing, this study presents the Passive House concept with the practical approach, performed for Polish climate.

Table of contents

Table of Figures

Table of Tables

Chapter 1

Introduction

1. Introduction

1.1 Scope of the work

1.2 Aims of the thesis dissertation

1.3 Structure and outline of the dissertation

1 Introduction

1.1 Scope of the work

The submitted dissertation refers to the subject of Passive Housing. Due to their high thermal performance, low energy demand and low carbon dioxide emission, passive houses have gained increasing attention among architects, engineers and end-users. The idea which was created in the early 90’s becomes a benchmark for modern standards and projects in the field of architecture and civil engineering. Since the development of engineering based on Passive House (PH) standards is expected to continue and increase, it is decisive for every open-minded person to know at least bases of the concept. Therefore, this dissertation was developed in order to study this concept for Polish climate. The dissertation consists of a more theoretical approach and subsequently a more practical content. The main objective of first, theoretical part is to introduce the Passive House standard by giving examples of construction solutions, specifications and overall requirements. Next, a practical approach to the subject will be presented, consisting on calculations referring to dwelling (case study) heating and energy demand according to different standards and consequent comparison. However, the main objective of the dissertation is the example calculation concerning a building which is expected to achieve Passive House requirements. As a result, insight on the theoretical and practical side of the subject is presented and discussed.

.

1.2 Aims of the thesis dissertation

The first main aim of this dissertation is to introduce the idea of a PH. It will be done by describing essential requirements of the PH standard, such as: construction technology means. Having briefly described the PH concept, a second aim of the dissertation may be introduced. Namely, it is a calculation of space heating demand of a typical one-family dwelling in Poland (case study) using two different standards – EN 13790 [41] and Passive House Planning Package (PHPP) [42]. Firstly, a part dedicated to the construction features and constitution of a house will be presented. Then the first calculation according to EN ISO 13790 will be carried out and thoroughly described. Having achieved this, the same case study will be implemented into PHPP programme and respective calculations will be performed. The main stress will be put to the requirements for particular construction elements, which are based on various parameters responsible for appropriate heat balance for a building. In conclusion, the differences between results of the calculation methods according to both standards will be presented, by comparing final results and pointing out the main differences in data used and calculation algorithm. Afterwards, the last part of the work will be presented - an adaptation of the case study to the Passive House Standards. The main aim of this part is firstly - adapt the building solutions so as it fulfills the Passive House requirements, and secondly - perform a vertification calculation in a PHPP. In order to meet Passive House criteria necessary changes in construction and materials will be implemented and presented. The dissertation is also an attempt to access a Passive House concept for Polish climate. Finally, an economical comparison between the original case study solution and the adapted Passive House will be presented. The main results will prove the profitability for the owner and access the payback time period after which a construction of a Passive House becomes a money saving investment.

1.3 Structure and outline of the dissertation

The dissertation is divided into 7 chapters and 18 annexes**.** The seven chapters are divided into a theoretical part, presenting the general concept of a Passive House, whereas a second practical part is dedicated to thermal and energy calculations of building. Below is presented a brief description of every chapter and annex:

In Chapter 1, here in, is presented the aim and the outline of the thesis. In Chapter 2 is presented the PH concept. It consists of the definition of the PH and the basic requirements, such as: limiting U-values, airtightness test, ventilation limits, avoiding thermal bridges, maximum primary energy demand. Furthermore, specific requirements and construction technologies are presented. This chapter includes the rules and solutions for design and construction which should be applied to the PH in order to meet the requirements from the previous section. In Chapter 3, the characterization of Polish climate and description of two first passive houses in Poland is included. Moreover, the description of the case study is presented. Chapter 4 consists on the description of a thermal design of a typical building according to EN 13790 [41]. Therefore, a calculation of annual heating demand is carried out. As a comparison respective calculation according to Passive House Planning Package (PHPP) is presented in Chapter 5. In Chapter 6 a thermal design of a PH is presented. It consists of implementing necessary PH systems and then a calculation of annual heating and cooling demand, primary energy of a PH according to PHPP tool. Finally, the economic issues of constructing a PH in Polish climate are described. Chapter 7 briefly describes the main conclusions made in the course of the thesis.

Regarding the annexes, Annexes from 1 to 15 present the calculation of annual heating demand of the code compliant house obtained in accordance with EN 13790. Annex 16 encloses PHPP worksheets used to calculate the annual heating demand of code compliant house according to PHPP standard. Annex 17 encloses PHPP worksheets used to calculate the annual heating demand of PH in accordance to PHPP tool. Finally, in Annex 18 is shown the plan of ventilation system for the PH.

Chapter 2

Passive House concept

2 Passive House concept

2 Passive House concept

2.1 Passive House definition

The idea of a Passive House (PH) was born in May 1988. After years of research, two professors; *Bo Adamson* of Lund University in Sweden and *Wolfgang Feist* of the Institute for Housing and Environment in Germany, developed the concept of a PH. It is a building which does not need a conventional heat or air-conditioning system to maintain a comfortable indoor climate. Hence, a PH can be defined as an extremely low-energy building. Due to high quality construction, it is able to be heated using 90% less energy than a building with common building techniques. That means that PH uses less than 1,5dm^3 of oil or 1,5m^3 of gas to heat 1m^2 of building area for a whole year, whereas the energy demand is of 15 $\frac{\mathrm{kWh}}{\mathrm{m}^2}$ annual. Obviously, it has huge consequences in the annual cost of energy to heat a building. This is particularly important having in mind that costs of energy sources have been increasing year by year in the past decade. This saving in energy consumption is possible because of an efficient use of energy from solar radiation, internal heat sources and heat recovery system (see Figure 1). Therefore, the most significant issue becomes the construction of the building thermal envelope and airtightness. It should have all the necessary systems and high quality materials to meet the PH requirements. [8, 11, 15]

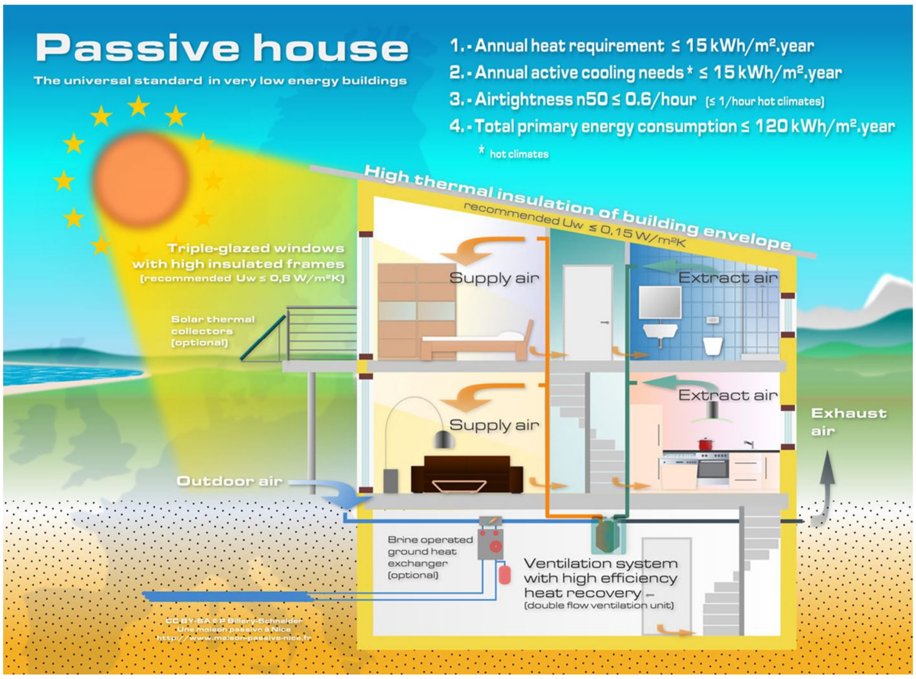


Figure 1: The idea of a PH. [38]

2.2 Requirements for a PH

A natural consequence of developing the idea of a PH through the years was the constitution of the Passive House Institute, originated in 1991 in Darmstadt (Germany). The employees of the Institute in Darmstadt invented and developed a thermal balance calculation tool to calculate and design a PH - Passive House Planning Package (PHPP) [42]. Passive House Institute has the sole power to assign the Passive House Certificate for a building. To be given a PH Certificate the construction of the building has to fulfill several requirements [8, 9]; in the design phase as follows:

2.2.1 Heating demand

The annual heating demand may not exceed 15 $\frac{\mathrm{kWh}}{\mathrm{m}^2\mathrm{a}}$ in accordance with the Passive House Planning Package. Moreover, the comfortable indoor climate (20°C in the winter and not over 25°C in the summer) has to be kept without resourcing to a separate heating system or an air conditioning system. [9]

2.2.2 Requirements concerning U-values

For Central and Northern Europe the recommended U-values are as follows:

- U-values for opaque building envelope must be less than 0.15 $\frac{\mathrm{W}}{\mathrm{m}^2K}$, with the aim of U of 0.10 $\frac{\mathrm{W}}{\mathrm{m}^2K}$;
- U-values for windows (glazing + frame) and other glazed areas must be less or equal to 0.8 $\frac{\mathrm{W}}{\mathrm{m}^2K}$ with g-values of about 50%. [9]

2.2.3 Requirements concerning glazed areas of the PH

There are different requirements for glazed areas of a PH. They are concerned with Treated Floor Area (TFA) on each side of the building as follows:

- South-oriented glazed areas must not exceed 25% of TFA served;
- East-oriented (±50°) or west-oriented (±50°) glazed areas must not exceed 15% of the TFA behind;

- Glazed areas inclined at an angle of 75° to the horizontal line may not exceed 15% of the useful area behind;
  If the condition of maximum TFA is not fulfilled, then the areas must be equipped with temporary shading, leading to a reduction factor value of at least 75%. [2, 9]

2.2.4 Requirements concerning ventilation

Ventilation of a PH must meet the following requirements:

- The temperature of the supply air from the room outlet must not be lower than 17°C;
- At least 75% of the heat from the exhaust air must be transferred to the fresh air by a heat exchanger (equipment efficiency of the Mechanical Ventilation heat recovery (MVHR));
- The ventilation must be efficient for every individual compartment;
- The air hygiene standards must be fulfilled by the uniform flow of air in each compartment;
- Each compartment must have at least one opening to the outdoor air, which enables free cooling during the summer period. [9]

2.2.5 Air tightness of the building

To be certified as a PH, a pressure test after the construction should be carried out. It consists on establishing 50Pa pressure difference between the interior and exterior of the building envelope. In result of this test the amount of uncontrolled air escape must be below 0.6 of the total air volume of the building per hour ($0.6h^{-1}$). [9, 27]

2.2.6 Minimizing of thermal bridges

It is greatly important to minimize thermal bridges as best as possible. When a “thermal bridge free” construction cannot be achieved, it is essential to reduce thermal bridges to minimum ($\Psi<0.01$ and $\Psi_{installation}<0.001$). The “thermal bridge free design” is a major aim of the PH design phase. [9]

2.2.7 Primary Energy

In accordance with PHPP [42] calculations, total use of primary energy for the PH (energy for heating; cooling; ventilation; domestic hot water; household appliances and lighting) must not exceed 120 $\frac{\mathrm{kWh}}{\mathrm{m^2a}}$. Figure 2 shows total energy demands for buildings constructed in the past and nowadays. It also shows the structure of energy demands which consists of energy demand for: ventilation, electrical devices, domestic hot water and heating and cooling if necessary. [12]

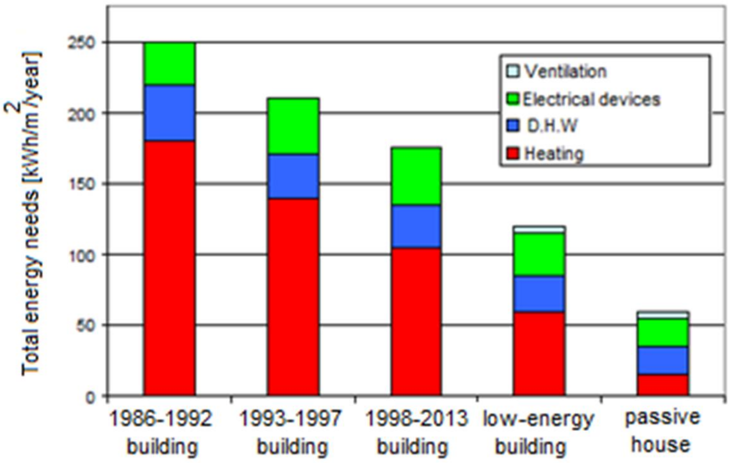


Figure 2: Total energy needs. [4]

2.3 Specific requirements and construction technologies

There have been developed several construction techniques and building solutions in the construction in order to meet all the requirements defined for a PH. These issues can be presented in the following order:

a) Architectural project;
b) Construction of the exterior thermal envelope: walls, roof, floors;
c) Thermal bridges;
d) Passive windows;
e) Controlled Ventilation;
f) Air tightness;
g) Domestic hot water and heating devices; appliances and lighting.

2.3.1 Architectural project

Since the idea of a PH counts out the presence of a conventional heating, the heat must be given to a building from other resources. One of the most important is energy of the sun. Naturally, the biggest amount of solar energy is provided from the south direction. That is why, the decisive issue becomes designing on the south side of a PH as many glazing surfaces as possible, without overheating and adopting shading devices. On the other hand, the north side of a PH is the least exposed side for sun radiation. Therefore, the designers must reduce the glazing surface on that side to a minimum (see Figure 3).

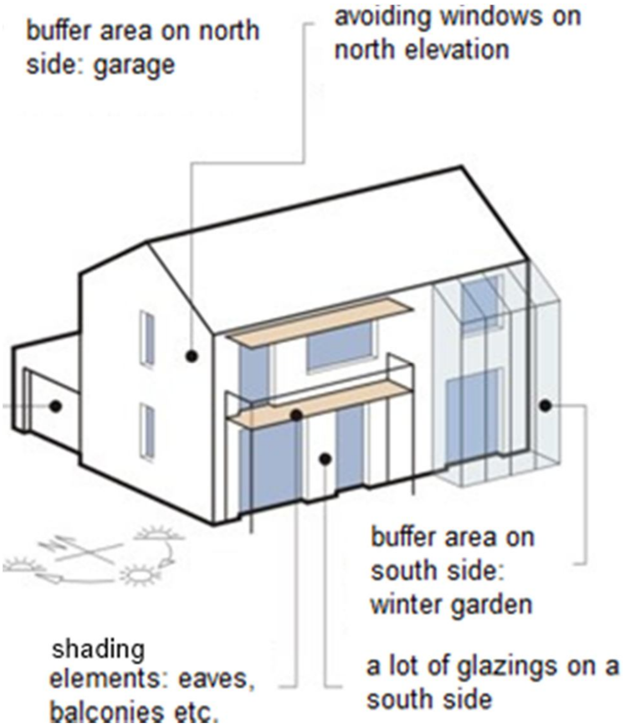
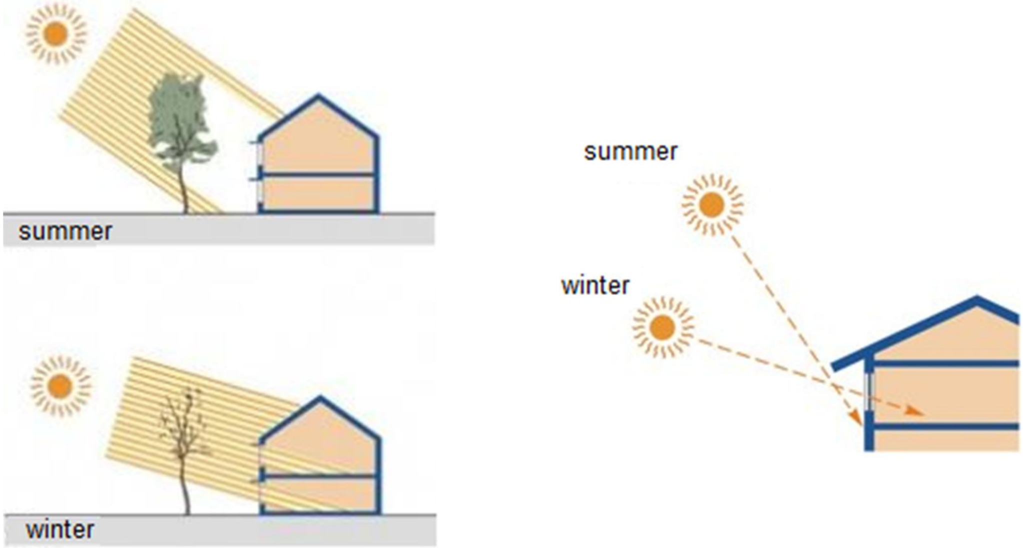


Figure 3: Architectural project designing principles for a PH. [6]

Despite the fact that glazed areas can allow significant solar energy, sometimes during the hottest months of the year, they can cause overheating. To avoid this undesirable process, it is common to design special shading elements. One of the most popular elements is an eave forwarded beyond the contour of the building or balconies. Thus, in the summer when the sun is high in the sky, it protects a PH from overheating, while in the winter when a sun is lower in the sky, it provides enough solar energy to the building (see Figure 4). Other possible shading elements are roller blinds or shutters fixed to the windows. Another interesting solution which brings better thermal balance for a PH, is planting leafy trees on the south side of the plot. They can reduce overheating risk during summer (see Figure 4). However, on the north side of the house conifer trees should be planted if possible. Since they do not lose needles in the winter, they are able to protect a building from the wind all year round.



Proper usage of leafy trees. [6]

Proper usage of forwarded eave. [6]

Figure 4: Passive architecture solutions.

The total heat loss depends on how extensive is the external envelope. It is obvious that as a total external surface increases the heat loss increases as well. Consequently, a PH should present low values of the A/V shape relation – a relation between total surface of the external envelope (A) and the cubature of the building (V). The lowest values of this relationship are obtained for buildings which are similar in shape with a cubic format. It gives some clues for designers when it comes to consider the shape of the PH. Definitely they must avoid complex walls construction and multi hipped roofs.

Terraced PH; first PH in Darmstadt (1990). [30] Terraced PH; first PH in Sweden (2001). [31]

Figure 5: Examples of Passive Houses.

On the other hand it is not desirable, from an aesthetic point of view, to design Passive Houses which have a shape like a “box of matches”. In accordance with [2], it is crucial to find a balance between low A/V value building and a practical, attractive building. The easiest way to design a PH with low A/V value is to group a few Passive Houses into one building – semi-detached houses or terraced houses (see Figure 5).

Next important issue for a PH architectural project is an adequate compartment distribution within the building. Generally, the north side of the PH is the most shaded and with the least glazed area. That fact forces designers to place on that side compartments which are rarely occupied by people, for example utility rooms. On the other hand, the south part of the PH is the most bright, sunny and with higher temperatures. Due to these issues, it is proper to place in that area rooms which are often occupied by people, for instance: kitchen, living room. Owing to that sort of compartments distribution, the indoor temperature in the daily area will be increased both by heat from electrical equipment used there and heat emitted by people. Other important issue is a suitable localization of sanitary compartments. Above all, they must not be placed near the exterior walls, because higher difference in temperatures between sanitary compartments and the exterior leads to significant heat losses. Last case is a proper garage design. The garage is an unheated compartment, therefore connecting garage or unheated spaces to the thermally treated areas can cause significant heat losses. To avoid this situation, usually in a PH project, the garage is designed as a separate building. The same situation refers to a basement. If there exists a basement, it must be separated, airtighted and free of thermal bridges. It should also be defined a specific compartment for technical room (north side), where all the ventilation system, DHW etc. is localized.

Fulfilling the requirements to be given a PH certificate is decisive. That is why taking care of each detail in the project from its beginning to the very end is so important. Taking advantage of every issue that might increase energetic and thermal conditions is crucial and leads to a successful end of the project. [1, 2, 6]

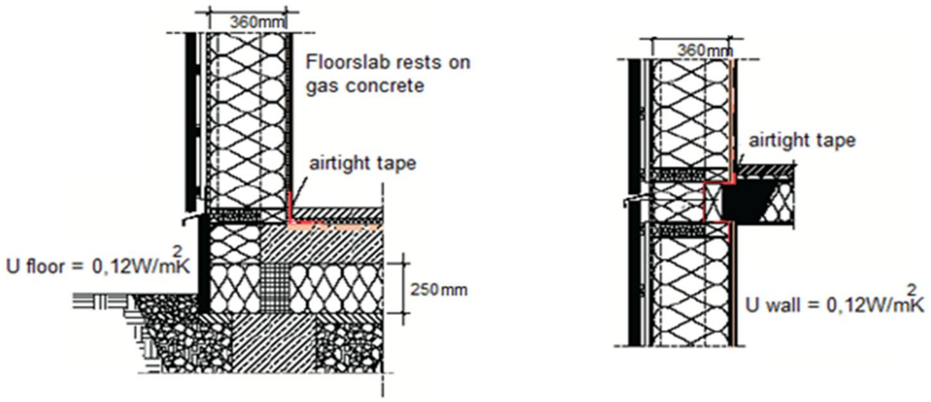
2.3.2 Construction of exterior envelope: walls, roof and floors

The PH requirements suggest the maximum U-value for the exterior opaque envelope (wall, roof, floor) of 0.15 $\frac{\mathrm{W}}{\mathrm{m}^2 K}$. It is crucial to construct very good insulated building envelope with highly airtight solutions to comply with the requirements. In order to achieve this, two issues should be ensured: continuity of thermal insulation and the layer airtightness. Both massive construction (made of concrete, brick) and lightweight construction (made of wood) are able to fulfill these conditions with different strategies. However, massive construction has a significant advantage over lightweight construction on this feature. It has a greater ability to accumulate heat inside itself due to higher inertia. Construction inertia is very important for maintaining a comfortable indoor environment. During sunny and warm days PH heat demand is low. However a massive construction can accumulate heat during the day and “give it back”, releasing energy when temperature inside drops. This process decreases indoor temperature swing, simultaneously increasing thermal comfort for the occupants. Furthermore, in accordance with [24], a single layer wall can accumulate energy only in one third of its section. In contrast to a massive wall construction with an exterior thermal insulation, all the wall section can be used to accumulate thermal energy. Finally, in a wall with an interior thermal insulation and in the case of lightweight walls construction only the interior layer of plaster board has an ability to accumulate energy.

In conclusion, to achieve the appropriate U-value for the exterior wall, it is possible to construct a typical wall with a proper sized thermal insulation. Next, is discussed and shown the examples of exterior walls solutions. These examples chosen are construction solutions, among many others. Despite the fact, they are not that common in Poland, still they are interesting and aid in the proper understanding of PH definition and specification of exterior walls. [1, 3, 23, 24]

2.3.3 Lightweight single leaf wall construction

In the case of lightweight solution, usually the load bearing elements are customary wooden posts. However, an interesting solution is the TGI frame wall. TGI is a common name for a TJI (Truss Joist I-beam). Generally, TGI is a wooden beam with two cords: top and bottom, with the OSB bound between the cords. In this solution the insulation is placed in between load bearing timber posts. Lightweight single wall construction is not airtight and is not a barrier for water-vapour itself. The common solution for this issue is using OSB boards (which have an ability to stop water-vapour) for the indoor layer of the wall. Furthermore, OSB boards brace the structure. To make a proper joint for this type of wall, tongues and grooves are sufficient. It is important to nail them above the posts. Other junctions, such as: window-wall, floor-wall connections can be connected with a special airtight taping. Usually in this kind of structure, it is hard to avoid some air leaks. To make sure that a wall is airtight, some crucial junctions can be extra protected with a foil or tape. In Figure 6 is shown crucial connections: between ground floor slab and exterior wall and between elevated floor slab and exterior wall. All joints in these connections are sealed with an airtight tape. [3, 34]

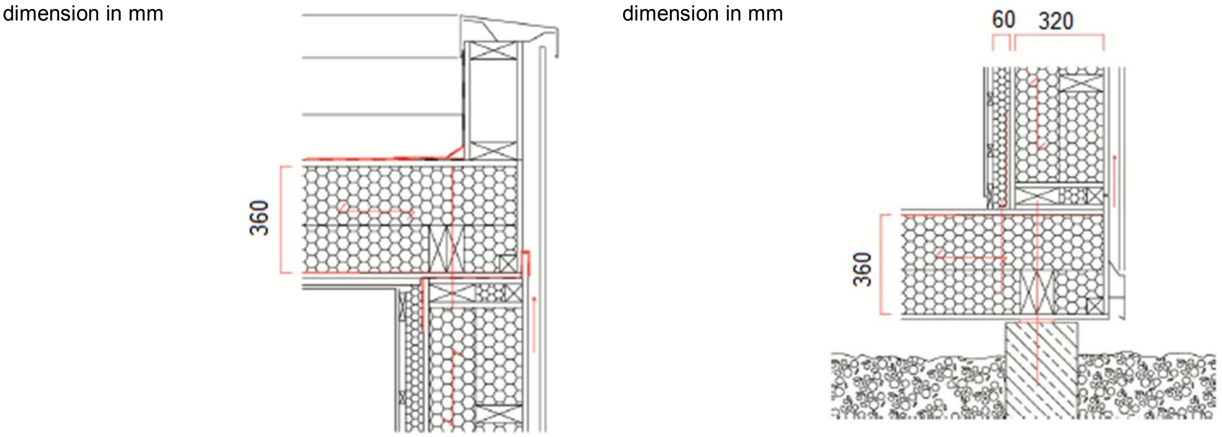


Connection between ground floor slab and wall. [3] Connection between elevated floor slab and wall. [3]

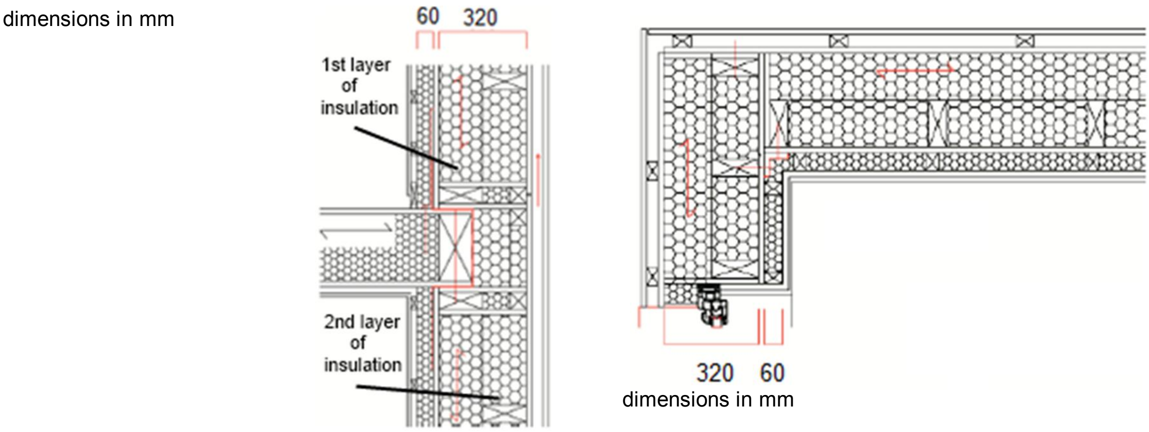
Figure 6: Detailed construction connections 1.

2.3.4 Lightweight double leaf wall construction

To begin with, a double leaf wall construction is more difficult to design and to construct than a single wall construction. Nevertheless, considering a prefabricated exterior wall solution, as shown in Figure 7, is a typical example. Starting the description from inside to the outside: the first layer on the indoor face is a 60 mm construction wall made of gypsum board, next an OSB board (as in the single wall, it works as a water-vapour barrier), next vertical posts (load-bearing elements) and horizontal posts (no load-bearing), DWD (diffusion open) and towards the outside a ventilated façade. All OSB boards' joints must be nailed to the posts. In addition, any junctions exposed to air leaks must be protected with a special foil or tape. In Figure 7 is shown the main connections concerning this construction: between ground floor slab and exterior wall, between floor slab and exterior wall, between roof and exterior wall, between two exterior walls – corner. [3]



Connection between roof and exterior wall. [3] Connection between ground floor slab and wall. [3]

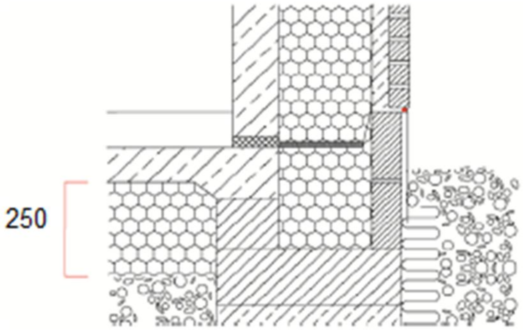


Connection between floor slab and wall. [3] Exterior walls' corner. [3]

Figure 7: Detailed construction connetctions 2.

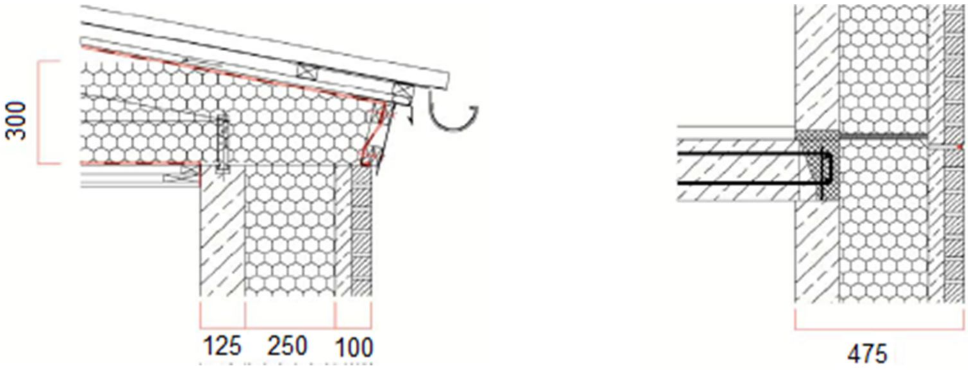
2.3.5 Massive wall

Regarding this construction a following structure (in description from the inside to the outside) was chosen: a load-bearing concrete wall, next there is a thermal insulation layer, a second slim layer of concrete, finally an outer layer of brickface façade (see Figure 8). Generally, the second layer of concrete is not necessary. Although, in this example is obligatory due to the presence of brick façade layer. Considering also this case, a specific water-vapour barrier is not necessary because this function is fulfilled by the concrete wall layer (it is also airtight). However, there is a possibility to seal the gaps resourcing to a special mortar. Any other junctions must be tightly filled with concrete or mortar. The connection between thermal insulation and the load bearing concrete layer is made resourcing to a special glue, which must be applied with the following rule: if a thermal insulation panel has a dimension of 50×100 cm, then according to actual requirements, it is necessary to apply 8 to 10 pointsand and a peripheral band with a width of 3 to 6 cm, 3 cm away from the edge of the panel. [3, 23]



dimension in mm

Connection between ground floor slab and exterior wall. [3]



dimensions in mm

dimension in mm

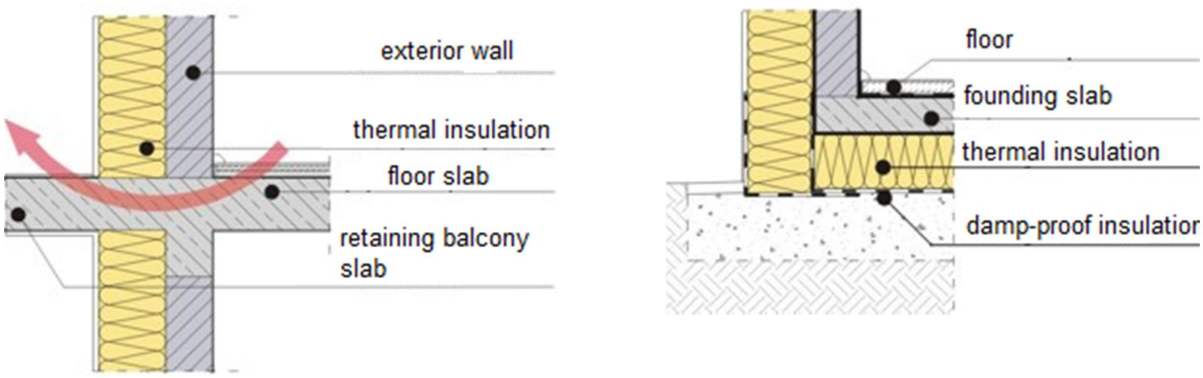
Connection between roof and exterior wall. [3]

Connection between floor slab and exterior wall. [3]

Figure 8: Detailed construction connetctions 3.

2.3.6 Thermal bridges

A priority issue for a PH is to minimize thermal bridges in the construction. As a first exercise, one should be able to draw a 25cm thick continuous line (of thermal insulation) around the building without any joints. Above all, areas which are most likely to become a thermal bridge are connections between parts of exterior envelope such as: wall-foundation and wall-roof connection.



Thermal bridge at balcony-exterior wall connection. [10] Proper founding on a foundation slab. [10]

Figure 9: Examples of opaque building envelope connections.

In classic foundation, with walls founded on continuous footing, thermal insulation is designed under the floor, in contact with the ground. The insulation must be thick enough to fulfill the suggested U-value (equal or less than 0.15 $\frac{\mathrm{W}}{\mathrm{m}^2K}$). In the foundation wall, at the insulation level, there must be a layer of aerated concrete or cellular glass in order to keep the continuity of the insulation layer. A common way to found a PH is resting it on a continuous foundation slab. However, a slab can be constructed on a layer of thermal insulation (see Figure 9). A slab designed in this way is able to carry the loads of a medium height building (2 to 3 floors).

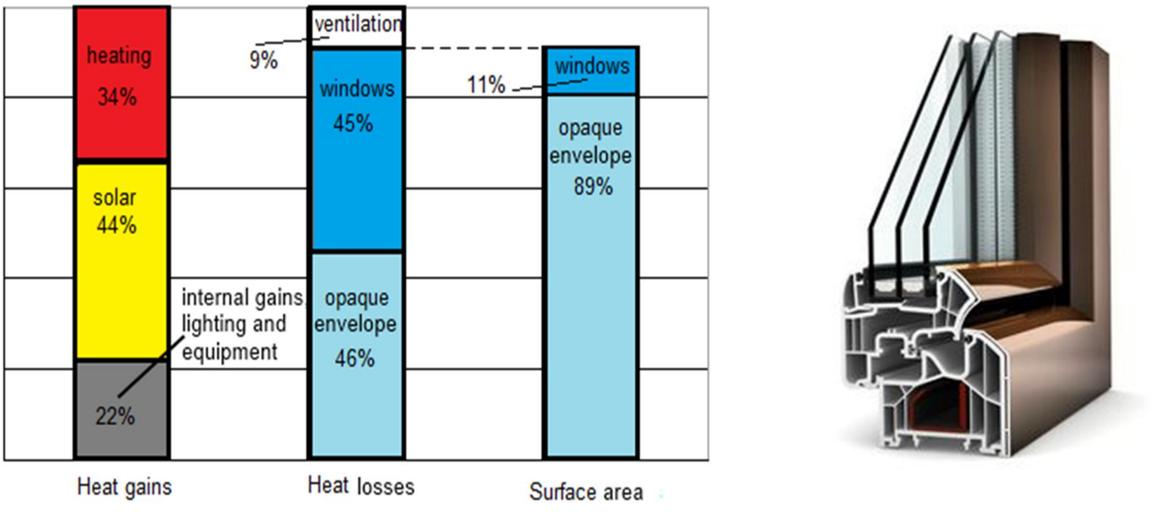
In a typical building the amount of heat which escapes through the roof construction represents approximately 25% of the total heat loss. Incorrect roof insulation causes not only significant heat loss, but also contributes to overheating of the building, particularly for occupants of roof space. In order to avoid this undesirable situation, the thermal insulation must have a thickness of about 30cm, with no thermal bridges. In the case of a lightweight roof construction, there are many ways to apply thermal insulation. Properly a layer of XPS, EPS or mineral wool can be applied between and below or over the rafters. Furthermore, it is common to design two layers of thermal insulation. One is constructed between the rafters, while the other is nailed to the bottom side. In Figure 10 is shown thermal image of a building that reveals the thermal bridges location.

Figure 10: Thermal bridges location on thermal image of a building. [29]

Other areas which are exposed to a presence of thermal bridges are connections between the building's external wall and balconies (see Figure 9), galleries or terraces. To avoid these construction joints in the PH thermal insulation layer, it is common to design separate bearing construction for above structures for balconies and galleries. [10, 28]

2.3.7 Passive windows

Heat loss through the windows can represent in some cases 45% of total heat loss of building (see Figure 11). In order to fulfill PH strict heat loss requirements, it is crucial to limit a heat loss through the windows areas. However, glazings are necessary for passive solar gains, thus it is important to take advantage of them by proper designing (positioning, shading, window type selection, frame material). As mentioned before, windows in a PH are recommended to have a total U-value under 0.8 $\frac{\mathrm{W}}{\mathrm{m}^2 K}$ (for the installed window is 0.85 $\frac{\mathrm{W}}{\mathrm{m}^2 K}$, with a solar factor (g) of about 0.5. In order to fulfill this requirement, total U-value for the glazing must not be higher than 0.7-0.8 $\frac{\mathrm{W}}{\mathrm{m}^2 K}$, whereas heat loss through the thermal bridges at the connection glazing-frame must be kept under $0.1\frac{\mathrm{W}}{\mathrm{m}K}$. Windows which are used in Passive Houses have usually two to three panes. Spaces between window panes are filled with a gas, most frequently with argon or krypton. The use of these gases, instead of air, increases thermal characteristics of the glazing.



Windows in a PH energetic balance. [4]

Triple glazing with the PVC frame. [39]

Figure 11: Passive windows

Another technique, often applied in cool climates, is covering two of glazed surfaces with low-emissive film. First covered surface is the inner surface of outer glazing and second – outer surface of inner glazing. An emissive film has an ability to let through the solar radiation (short wave radiation) and to stop the long wave radiation from penetrating inside of the building. As the result, this feature lets not only increase solar gains, but also reduces heat loss of the building.

Another issue worth mentioning is the installation. Usually, in a typical window, the connection between the glazing and window frame is a thermal bridge. However, for a PH window, use of spacer (made of highly heat resistant materials; see Figure 11) reduces heat loss to minimum. The spacer is installed between panes and window frame.

During the heating season in Warsaw, Poland, the amount of solar energy for $1\mathrm{m}^2$ of south-oriented wall equals 385kWh (the same amount of energy is gained by firing about 38 litres of heating oil). Unfortunately, this is not the amount of energy gained by a building. There are several factors which decrease the final solar gain [4]:

- 20% of sun rays do not reach the window due to obstacles (trees, other buildings, balconies);
- 5% of gains is lost, because of dirt on the window panes;
- 15% of solar radiation is reflected;
- 30% of energy does not go through the window because of the frame;

Therefore, 50% of energy that remains after previous reduction factors is not able to penetrate the glazing due to its g coefficient (assuming that g coefficient equals 0.5);

Remained energy must be decreased at the and by 5%. It is caused by the fact that during intermediate seasons solar gains cannot be fully used. It is easily understandable that heat gained from solar radiation is effectively a small part (about 10-15%) of the theoretical, incident energy. Nevertheless, these gains can have decisive influence on the appropriate PH energetic balance. In Figure 12 are shown heat gains and losses depending on orientation of window in a building.

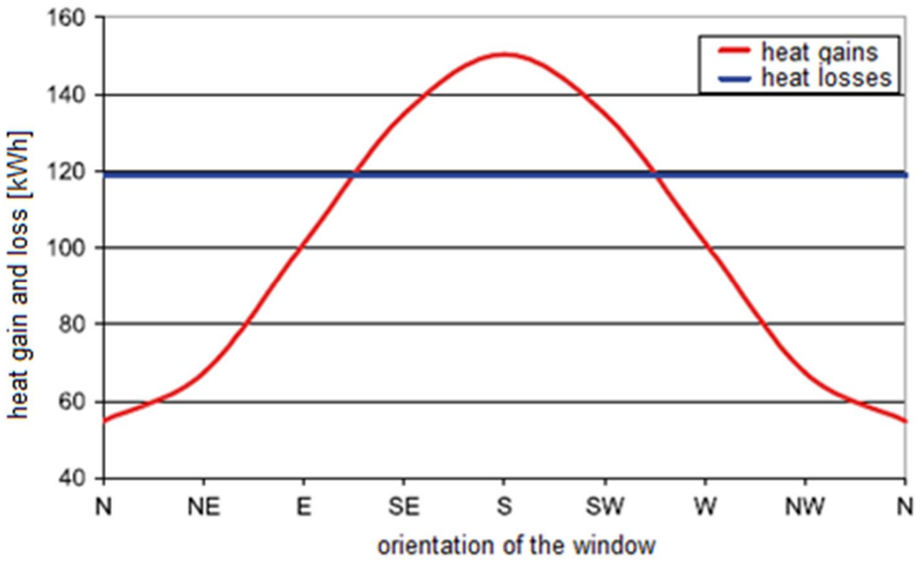


Figure 12: Gains/losses of the heat depending on a window orientation. [4]

The maximum U-value for the windows in a PH is not conditioned by the requirement of minimum heat loss demand, but by lowest permissible temperature of the inner surface of the window. The asymmetry of heat radiation of surfaces is important for indoor thermal comfort quality. This phenomenon can be easily understood with the following, simple example. A person stands in the center of the room; all surfaces: walls, ceiling, floor, have temperatures of 25°C, apart from one wall. This wall has a temperature of 10°C. Consequently, every surface of the compartment radiates heat which can be felt by a person in the center. Therefore, a person is exposed to a 15°C temperature difference (due to the asymmetry of heat radiation) which decreases thermal comfort. In order to avoid this situation, maximum temperature difference between surfaces in the compartment must not be higher than 8K, 10K or 12K (according to the regulation of Polish Minister of Labour and Social Policy) depending on comfort class of building. Depending on the construction of the windows in a PH, even the most demanding of the above conditions can be easily fulfilled. The temperature of windows surfaces is typically lower than the indoor air temperature. However, the difference is definitely less than 8K (see Figure 13). This condition is not met for a typical low-energy buildings, what even makes a PH more comfortable to live in.

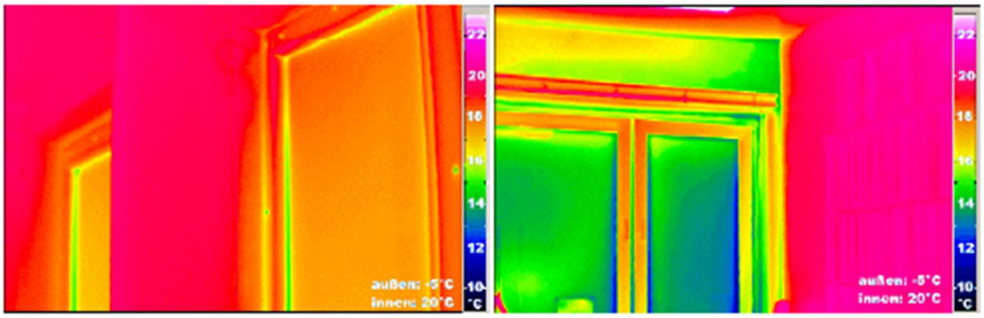


Figure 13: Comparison of surface temperatures between passive window (on the left) and a typical window (on the right). [4]

Another advantage of passive windows over typical windows is the lack of superficial condensation. For typical windows it is a common phenomenon, that usually occurs when the outside temperature is low and relative humidity inside of the building is high. The location which is the most threatened by the potential superficial condensation is the inner connection between the window pane and the frame (spacer). Since passive windows are very well isolated, with low Ψ values of thermal bridges, the risk of superficial condensation (that can lead also to mould growing) is very low. Last but not the least, the issue concerning passive windows is proper installation. In order to minimalize heat loss, before installing a window, the frame must be connected tightly to the wall. Just then a window is installed to the frame. Very important is to take care of every singular joint, where window, wall and isolation are next to each other. As a result it will ensure proper installation and lack of thermal bridges in these connections. [1, 4, 7, 9]

2.3.8 Controlled Ventilation

Due to very good insulating materials and quality assurance construction of a PH, with the aim of reducing heat loss, the installation of heavy central heating system is no longer necessary for maintaining indoor comfort. Although to obtain healthy indoor climate mechanical ventilation must be designed. Therefore, controlled ventilation is obligatory in every PH. Its way of action is simple and depends on a direct air flow management. Firstly, fresh air intakes to living room, office and bedrooms, then flows through halls (transfer areas) and in the end is extracted in humid areas such as kitchens and bathrooms. This air flow sequence is highly important due to the necessity to obtain high indoor air quality and thermal comfort. In order to achieve appropriate air flow direction, living room and bedrooms must be equipped with the air inlets, while kitchen and bathrooms must be equipped with air outlets (see Figure 14).

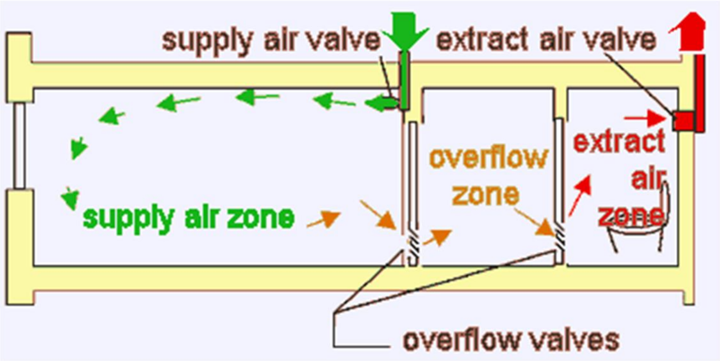


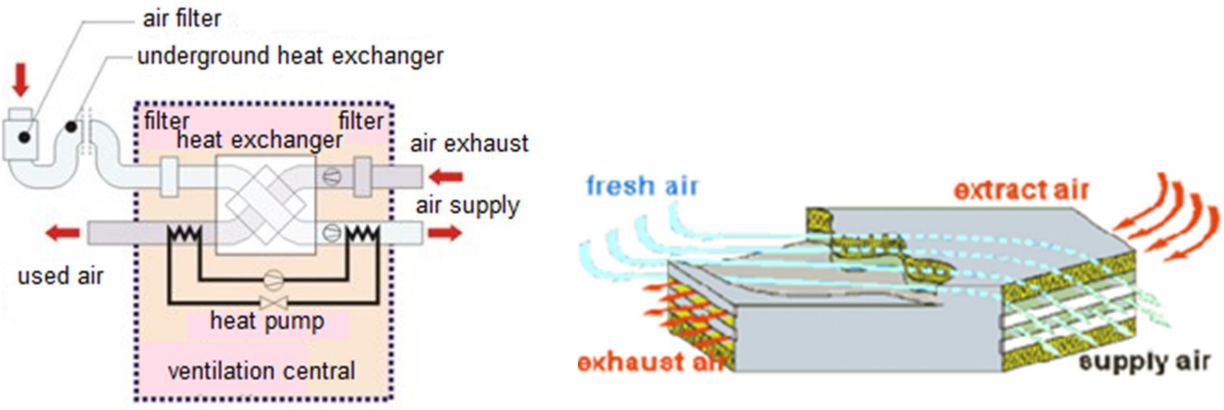
Figure 14: Proper air flow sequence for a PH. [32]

Furthermore, the ventilation system is efficient not only in winter (when the outdoor air is colder than indoor air), but also during the summer (when the outdoor air might be even warmer than indoor air). The ventilation system can be integrated with a brine system (long duct situated below PH's foundations) as follows:

During the winter, before fresh air is directed inside the building, firstly it must be warmed up through the brine system – heat is gained from the ground warmth.

Approximately 1.5m below the surface (for Polish climate) the temperature of soil is constant all year. Therefore, the air which was pushed into the underground duct is able to gain heat from the soil. The underground duct is usually made of polyvinyl chloride, smooth-walled, rigid or semi-rigid pipe of 100 to 600mm diameter. In order to avoid extra air resistance, it is not recommended to design bends for piping, especially higher than 90°. Next issue which is important is burying the pipe with a certain slope. A slope is demanded for efficiency, because of the possibility of the condensation. It can occur during the summer, while the air is cooled in the duct and has the ability to condensate.

The second phase of warming up the air occurs in a heat exchanger. This device is a main part of the ventilation central system. It takes advantage of heat from the used air (from the compartments) to warm up the fresh air. The streams of used air and fresh air are not mixed, because they are led in separate ducts. However, ducts are adjoined to each other, so as the heat could be transferred. Generally, the heat exchanger recovery rate is between 75% and 90%. Without this device, ventilation heat loss for a PH would increase to 20-30 $\frac{\mathrm{kWh}}{\mathrm{m}^2K}$ (annual). In order to avoid the risk of frosting the heat exchanger (in winter), fresh air must be warmed up to at least 0°C (even during the coldest days of winter) before entering the heating central. Particularly, frosting a heat exchanger is an undesirable effect, since it can reduce the recovery ability of this device.



Construction of ventilation central. [32]

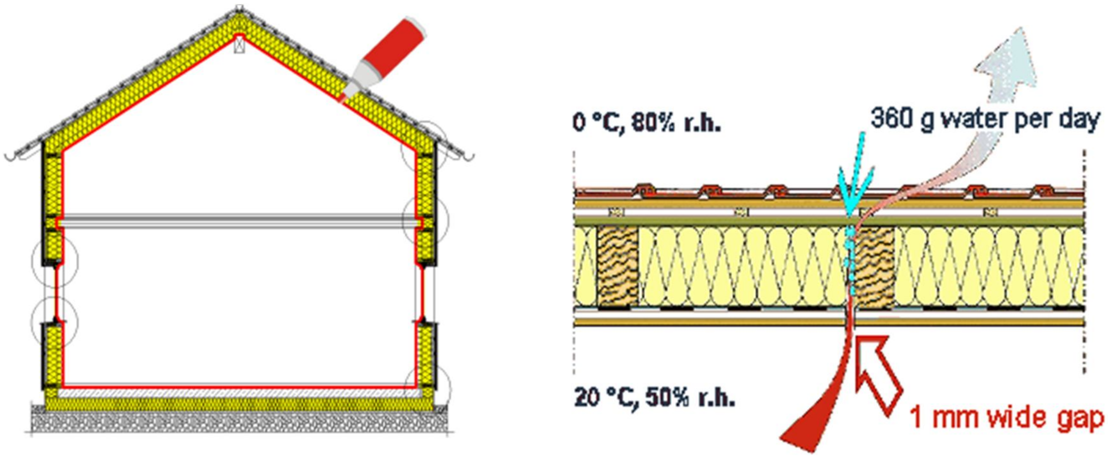
Principle of heat exchanger. [14]

Figure 15: Ventlation central and heat exchanger

Often in a cool climate, when it is necessary, fresh air is warmed up using an electric heating coil, having been warmed up in a heat exchanger. This solution is cheap to build, but rather expensive to maintain, because electric demands could be quite high. On the other hand, an alternative solution is provided by a heat pump. Despite the fact it is more expensive to build, it is much cheaper to maintain than the electric heater. During the summer PH ventilation is provided with the same ventilation ducts. However, in this season, outdoor air can be cooled, firstly resourcing to the brine system and secondly with the heat exchanger by incorporation of a cooling device. After these two cooling stages the temperature of air can drop about 10-15K. The effect of the controlled ventilation in summer is similar to the air-conditioning system with less energy consumption. The brine system is not obligatory. For instance, in climates where it is not profitable, a ventilation system can be designed without a brine system. In Figure 15 is shown the functional scheme of typical construction of ventilation central with a heat pump (instead of heat pump an electric heating coil can be installed) and the principle of the heat exchanger (heat transfer between air flows). [1, 5, 14, 16, 32, 40]

2.3.9 Air tightness

In a typical building, leaks in a construction are a natural issue. However, leaks are not desirable in a controlled ventilation construction, as they can cause significant increase in energy demand. Moreover, leaks can lead to water vapour condensing risk (due to the temperature difference and humidity levels indoor and outdoor). This can lead to serious damages due to damp (see Figure 16). Therefore, leaks must be avoided and controlled in a PH design as much as possible. First crucial issue for an airtight construction becomes proper planning. One should be able to draw a continuous, uninterrupted airtight line around the PH (red pencil method; see Figure 16). The line signifies that airtightness is a principle task to be implemented in a PH. It must be done by careful craftsmen and with attention paid to the most important singular points. Particularly, attention must be paid to any connections between different interfaces, for example wall-roof connections.



The principle of continuous, uninterrupted "airtight line" in a PH. [37]

Example of effect of 1mm thick leak. [36]

Figure 16: Importance of airtight construction

In order not to exceed the maximum level of air exchange for a PH, a building must have air tightness tests performed (blower door test). The air tightness test consists of establishing the pressure difference of 50Pa between indoor and outdoor environment. It is caused by fixing all the openings and then pumping or pulling a certain amount of air at a 50Pa difference (see Figure 17). Next, the device marks the amount of air coming into or going out of the building. If during the attempt some leaks in a construction are detected, they can be localized by resourcing to a manual device which measures the speed of airflow at these points (see Figure 17). The airtightness test is performed when all works both outside and inside the building are finished. In order to meet PH airtightness requirements the value of n_{50} factor must be less than 0.6. It signifies that during the hour of airtightness test the amount of exchanged air must be less than 0.6 of total indoor air volume. [13, 26, 36, 37]

Airtightness test device. [27] Detecting leaks after the airtightness test. [13]

Figure 17: Airtightness

2.3.10 Domestic hot water and heating devices

In a typical building preparation of domestic hot water is executed with use of conventional devices such as oil or gas furnaces. Generally this solution is also possible in a PH, however undesirable. In order to reach very low annual energy demand other solutions for preparation of domestic hot water are possible. One of the most popular is solar collector, where solar energy is changed into heat (see Figure 18). This solution despite of its natural advantages has one significant drawback. Namely, it is very difficult to fulfill energy demand during less sunny months. Therefore, solar collectors are very popular in countries with a significant global radiation during each season of the year as the case of Southern Europe. Other energy-saving solution to prepare domestic hot water is a heat pump. The heat pump takes advantage of used air and is able to recover some heat from it. The main advantage of heat pump over the solar collectors is the ability to produce constant amount of energy despite of the season. On the other hand, an alternative for these devices can be a fireplace. However, a PH's fireplace construction is very different from the typical one. The first significant difference is that the air which keeps a fire combusting cannot be taken from the inside of a PH, because it could bring uncontrolled air exchange and in the result in the disturbance of indoor air balance. PH adapted fireplace is equipped with a glass, tight door which does not allow any air exchange. Moreover, the air is brought to a fireplace with a separate duct, whereas the fumes are extracted and evacuated from the fireplace with another duct (see Figure 18). So as to maintain proper insulation of a PH, ducts must be insulated as well. The heat from a fireplace can be taken directly through radiation or integrated into the ventilation air ducts. [1, 17, 18]

Distribution of air in a fireplace with closed combustion chamber. [18]

Vacuum-tabular solar collector. [17]

Figure 18: Passive heating systems

Chapter 3

Passive House in Polish Climate

3 Passive House in Polish climate

3 Passive House in Polish climate

3.1 Introduction

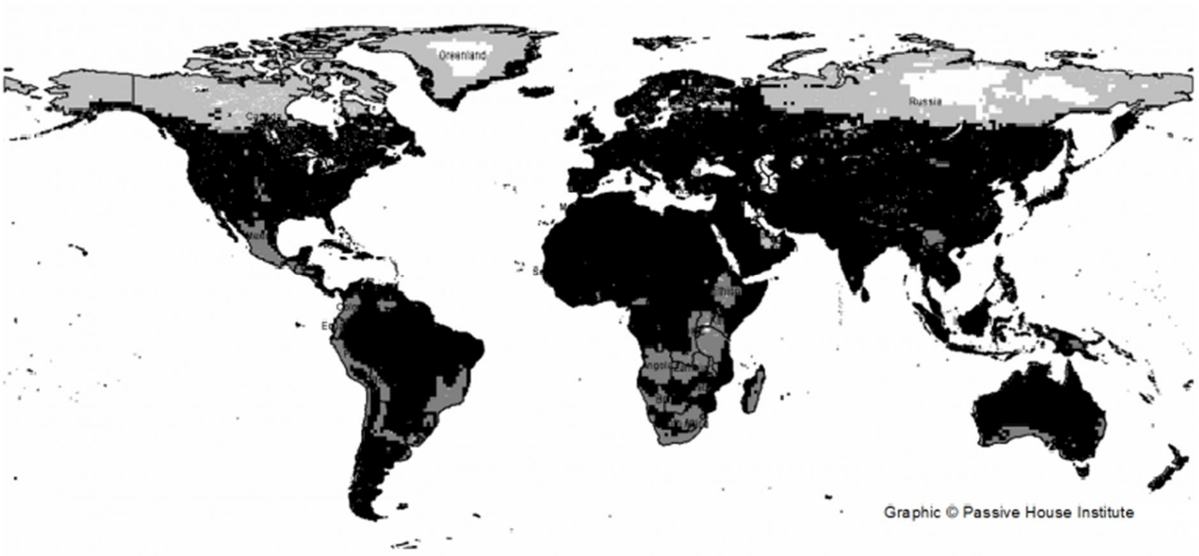
To begin with, there was provided a study over PH global feasibility by Passive House Institute in Darmstadt in 2011. The main aim of this work was to present that a PH can be constructed in most of the areas occupied by people on Earth. Firstly, five different locations (in various climate zones) to found a PH were chosen (Yekaterinburg, Tokyo/Hyakuri, Shanghai, Las Vegas, Dubai). First of all, these locations should be representative for larger areas with similar climatic conditions. Although, expected construction in the nearest future and availability of reliable climate data were chosen into consideration while choosing the locations. Next, a case study for a dynamic thermal building simulation was defined. All the PHs in this work were based on a small, two-storey house with 120m^2 of living area. Having accommodated a case study respectively to each location and having performed dynamic thermal building simulation, it was discovered, that in every of given locations is possible to construct a PH for which cooling or heating loads are less than 10 $\frac{\mathrm{W}}{\mathrm{m}^2}$ annual. [50]

Generally, only a few extremely hot or extremely cold areas such as: Australian outback or northern Canada seemed technically very difficult to meet the basic PH's requirement. Another issue, which must be fairly analysed, when it comes to design a PH for a specific region, is profitability for the owner of a PH in terms of energy saving and payback or at least for national economies. Obviously, if constructing a PH is not profitable, it is hard to convince people to build a PH. [21, 25]

Figure 19 shows financial optimal PHs worldwide, where:

- Black areas correspond to PHs with a ventilation unit with heat recovery system;
- Dark gray areas correspond to PHs with a ventilation without heat recovery system;
- Light gray areas correspond to PHs with a ventilation with heat recovery system and reduced glazing;

- White areas correspond to the situation when building a PH is not a profitable solution.



Graphic © Passive House Institute

Figure 19: Financial optimal PHs worldwide. [21]

3.2 Polish climate

Climate in Poland is defined as an intermediate climate, between continental and maritime. Polar, arctic, continental and tropical air masses have huge influence on Polish weather. As a result of this significant diversity of air masses, Polish climate is very unstable. One can see a difference in climate data not only between two consecutive years, but also comparing consecutive days of the same season. When short time weather periods are considered, it occurs that they are strongly related to the direction of air mass flow. Climate conditions depend not only on the altitude above the sea level but on the latitude as well. Generally climate in Poland is more continental to the East than to the West. Moreover, average temperatures also decrease from the West to the East. Winter conditions in Poland can be defined as follows:

- Number of days with the average 24h temperature below 0°C is approximately 55 for the North-West region and 120 for the North-East region;
- Number of days with the minimum temperature below 0°C is on average 105 (from 85 on the seaside region to 130 on the North-East region);

- Number of days with the maximum temperature below 0°C is on average 35 on predominant area (from 30 on the seaside area to 50 on the North-East region);
- Number of days with the maximum temperature below -10°C is approximately 10 on the North-East region;
- Average temperature in January (the coldest month) is from -0.5°C on the seaside region to -4.5°C on the North-East region;
- Average number of degree-days during the winter for the whole Poland may be taken as 4000.

Summertime, with 24h temperature above 15°C, lasts from 70 days on the seaside region to 90 days in a central part of Poland. During the summer, the number of days with maximum temperature above 25°C is from 20 on the seaside region to 40 on the South (excluding mountainous areas). The hottest zone during the summer is Upper Silesia, with approximately 8 days with maximum temperature above 30°C.

Total annual solar radiation in Poland is relatively high. However, it is very variable during the year. Basically, 80% of total annual solar radiation is provided to the six warmer months of the year – from April to September. Therefore, during those months, solar conditions are good and they create a great opportunity to take advantage. The rest of solar energy (20% of annual solar radiation) corresponds with six colder months of the year – from October to March. Values of solar radiation energy can be defined as following:

- Maximum annual intensity of solar radiation occurs on the coast and reaches 4000-4200 $\frac{\mathrm{MJ}}{\mathrm{m}^2}$ (about 1100-1160 $\frac{\mathrm{kWh}}{\mathrm{m}^2}$);
- Maximum momentary intensity of solar radiation can reach the level of 1000 $\frac{\mathrm{W}}{\mathrm{m}^2}$ on the seaside or high in the mountain region;
- Minimum annual intensity of solar radiation occurs in the Upper Silesia and reaches 3200 $\frac{\mathrm{MJ}}{\mathrm{m}^2}$ (about 900 $\frac{\mathrm{kWh}}{\mathrm{m}^2}$),
- Number of solar hours is approximately 1600.

In Figure 20 is shown the mean solar radiation distribution for Polish capital from the year 1903 to 1998.

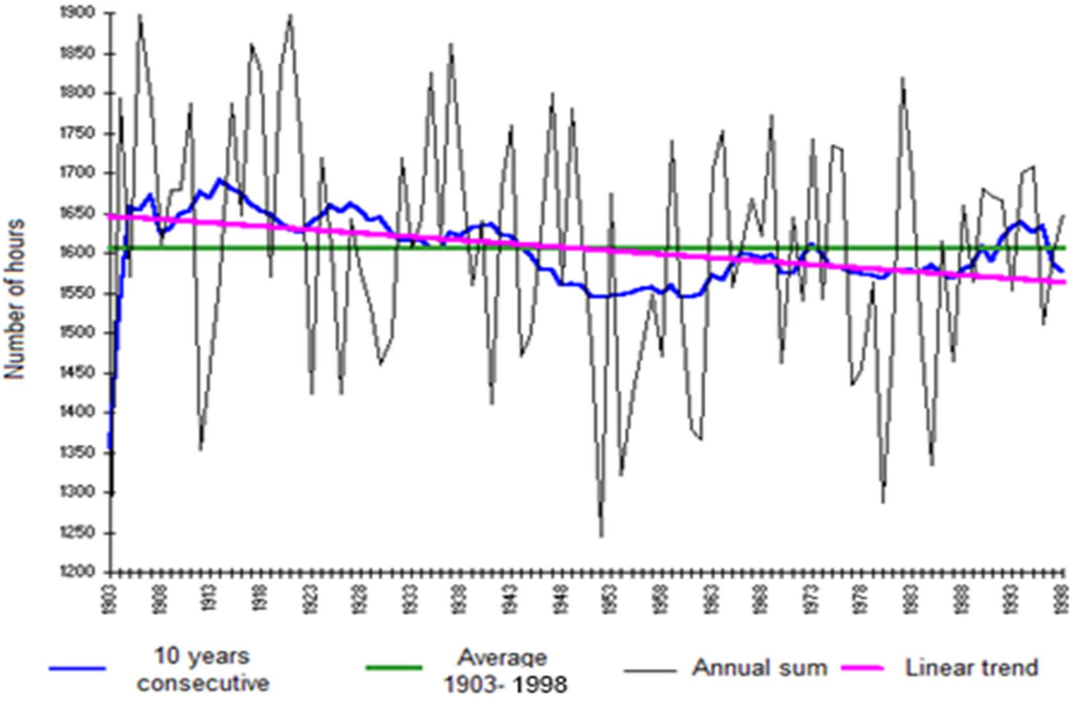


Figure 20: Solar radiation for Warsaw in years 1903-1998. [20]

Average annual contribution of diffused solar radiation in the total annual solar radiation reaches approximately 52%. However, during the time period between November and February it oscillates between 65% and 80%. Poland was divided in 11 climatic regions concerning level of usability of devices which recover solar energy (see Figure 21). Level I is the most suitable for collecting solar energy, while level XI is the least suitable [33, 35]:

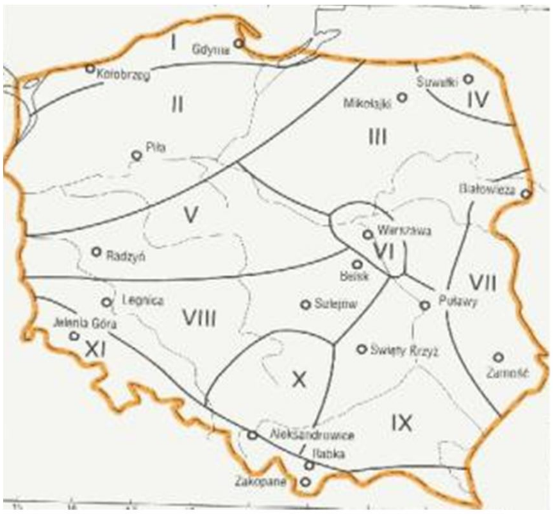


Figure 21: Mapping of the usability of solar energy devices. [20]

3.3 Examples of Passive Houses in Poland

There have been built over a dozen Passive Houses in Poland since the year 2004 when the first Polish Passive House had been constructed. Among typical residential houses, a passive sport hall and passive church were built. Below is briefly presented the first and the second Polish PH.

3.3.1 First Polish PH

A decision to build first Polish Passive House was made in 2004 (see Figure 22). PH was designed by a Design Office "Lipinscy Domy". The main ideas for the building were, that it must be: technological easy (from the construction point of view), economically viable, comfortable for 4-5 occupants. What was the most important issue was that building should have met all the requirements in order to gain a PH certificate. Finally, the house was built in Smolec near Wroclaw in 2007. The first PH in Poland was given its Passive House Certificate in the conference in Bregenz, 13 April 2007.

Figure 22: View from the south side. [19]

Some main characteristics for this PH are listed:

Surfaces:

Total area = 155.3 m^2;
TFA = 131.4 m^2;
Built surface = 128.8 m^2;
Cubature = 778 m^3.

Energy demands:

Total heating demand (E_A) = 13.5 $\frac{\mathrm{kWh}}{\mathrm{m}^2}$ annual (calculated according to PHPP [42]);

Total heating demand (E_A) = 12.67 $\frac{\mathrm{kWh}}{\mathrm{m}^2}$ annual (calculated according to CERTO (Polish programme for building energy performance));

Energy performance (EP) = 39.3 $\frac{\mathrm{kWh}}{\mathrm{m}^2}$ annual (calculated according to CERTO);

Cost of PH was 471 000 PLN (approximately 118 000 Euros) and was estimated to be 116 000 PLN (approximately 29 000 Euros) higher than the cost of typical building;

Expected heating costs were estimated as 12.5% of the heating costs of a typical building.

In Figure 23 is shown solutions and materials used in the PH constructed in Smolec. [19]

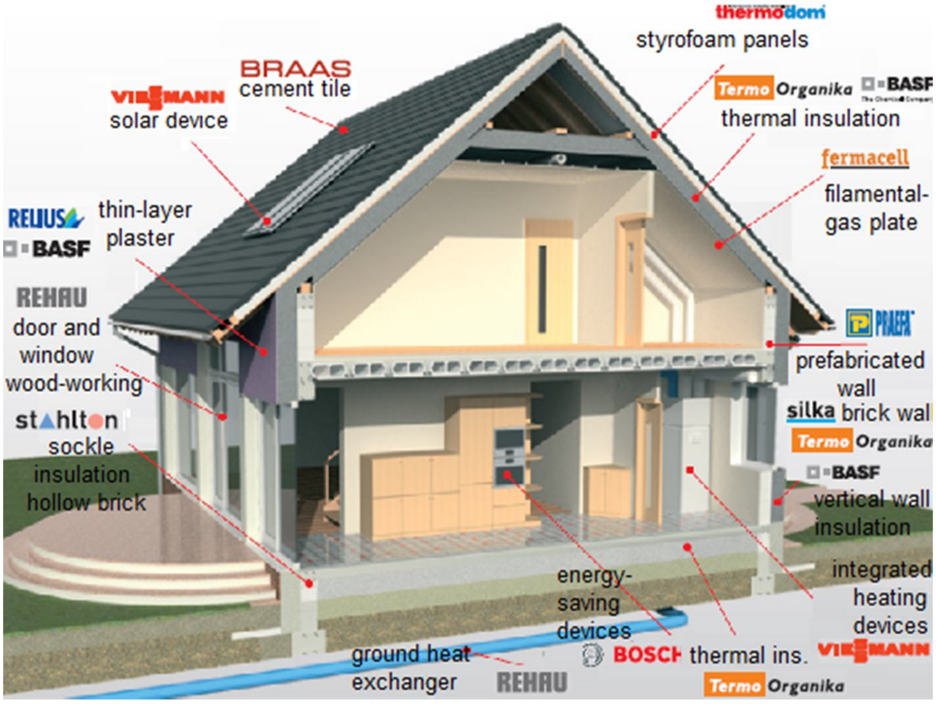


Figure 23: Provided solutions. [19]

3.3.2 Second Polish PH

The second Polish PH (see Figure 24) was to arise in Slomczyn near Warsaw. Construction process started in November 2009. The building was ready by September 2010. Despite the fact, that during the design and construction stages all the essential PH's techniques were implemented, the building did not get a PH Certificate. It occurred that walls were not able to meet requirements of airtightness during the blower door test. During the test it was easily understood that non airtight elements were electrical outlets and sockets.

The surface of the house is 162m^2.The cubature of the building is heated by a ventilation system with heat recovery integrated with a heat pump. The cost of the house was estimated at 340 000 PLN (approximately 85 000 Euros). Demands for energy heating demand of the building were estimated at 1354 $\frac{\mathrm{kWh}}{\mathrm{year}}$. According to the energy cost which equals 0.54 $\frac{\mathrm{PLN}}{\mathrm{kWh}}$ (0.135 Euro), the annual cost of heating the building equals to 731PLN (183 Euros). While annual cost of heating the same building designed and constructed according to Polish codes would consume approximately 8 times more – 5744 PLN (1436 Euros). The investor saves 30 000 PLN on installation of heating devices. [22]

View from east side. [22] View from north-west. [22]

Figure 24: Second Polish PH.

3.4 Final synthesis

To sum up, a study over PH global feasibility defined Poland as a country where constructing a PH is profitable. Moreover, in view of its climate conditions, constructing a PH in Poland may be not only profitable, but should pay back in a relatively short period (approximately 10 years). Owing to its location, Poland combines both maritime and continental climate features. Due to rather cold winter, particularly in the east regions, constructing a PH may be a little more demanding than in West European countries. However, from the same reason annual savings on heating can be slightly higher. Therefore, it was decided to design a PH in a city of Lodz. Lodz is a city localized in a center of Poland. As a result the temperatures in Lodz, both during summer and winter are rather average. Owing to that, results of heat demand and primary energy demand for a PH in Lodz can be a benchmark for whole Poland. On the one hand, it is predicted that heat demand for a PH built in regions on West to Lodz would be lower. On the other hand heat demand for PH built in regions on East to Lodz would be slightly higher.

In the next chapter, there is presented calculations concerning annual heating demand for a typical house situated in Lodz. The calculations are provided using different approaches. First refers directly to EN 13790 standard [41], two others refer to PHPP [42] calculation tool. At the end of the chapter a comparison between algorithms and results is presented. After that, a considered house will be adapted to PH requirements (every change in a construction will be listed) and calculations according PHPP [42] will be performed. In the end it is expected to obtain a house which fulfills all PH standards.

3.5 Case study

3.5.1 Geometry and internal compartment distribution

The case study is a one family, one storeyed, house. It is a good example of contemporary architecture for Polish conditions. The building has a flat roof and is composed from cubic compartments. The house has various compartments: an antechamber, a kitchen and a big living room, three bedrooms and two bathrooms connected with a corridor (see Figure 25). The house is designed with the aim of maximizing solar gains, therefore the living room is orientated towards South and West. The South wall of the living room is over nine meters long and almost totally glazed. The front façade of the building is orientated towards North, with the entrance opening orientated to the West side. An unheated garage is located on the North-East corner of the house. Between the “daily part” of the house and the garage there are two more compartments: a cloakroom and a utility room. The treated floor area (TFA) was calculated with the internal dimensions as 179.14 m^2. The A/V ratio of the house is 0.27. The areas of the compartments are listed in Table 1.

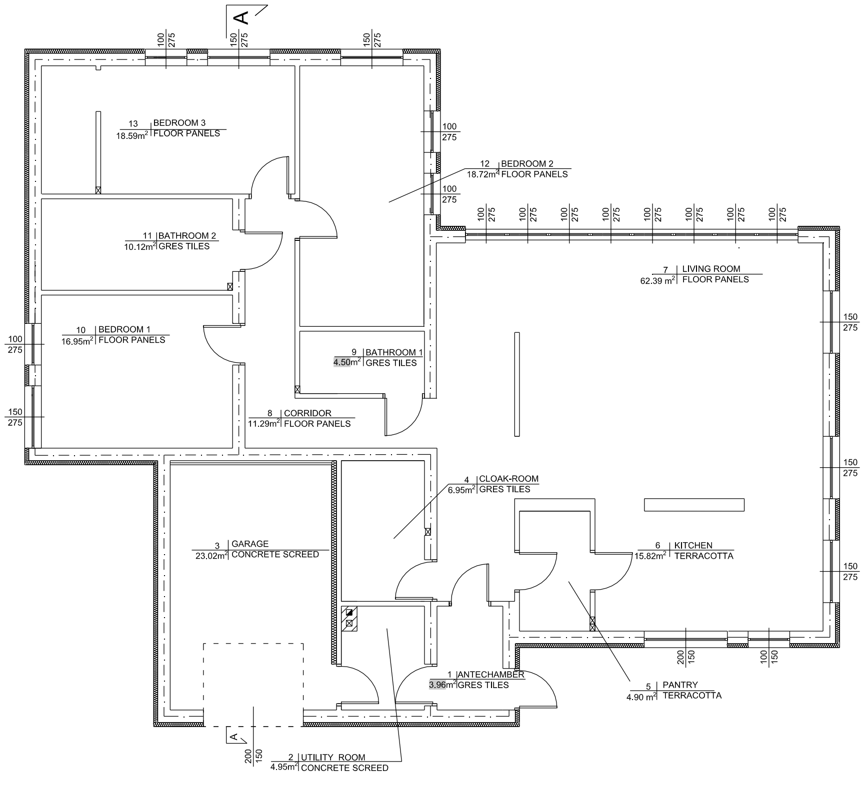


Figure 25: Plan of the house.

Table 1: Areas of compartments.

Nr	*Name of compartment*	*Final covering*	*Area [m^2]*
1	Antechamber	Gres tiles	3.96
2	Utility room	Concrete screed	4.95
3	Garage	Concrete screed	23.02
4	Cloak-room	Gres tiles	6.95
5	Pantry	Terracotta	4.90
6	Kitchen	Terracotta	15.82
7	Living room	Wooden panels	62.39
8	Corridor	Wooden panels	11.29
9	Bathroom 1	Gres tiles	4.50
10	Bedroom 1	Wooden panels	16.95
11	Bathroom 2	Gres tiles	10.12
12	Bedroom 2	Wooden panels	18.72
13	Bedroom 3	Wooden panels	18.59

3.5.2 Building construction description

The floor level of all compartments is the same. The clean height of all compartments is 3m, with the exception of the garage area, where the ceiling is slightly lower - 2.7m above the floor. Therefore, the roof above the garage part of the building is 30cm lower in comparison with the rest of the house. The gable roof of the house presents a 3° slope towards the West and East side. The mid-wall from which the roof slopes divides the “daily” and “night” parts of the building (see Figure 26).

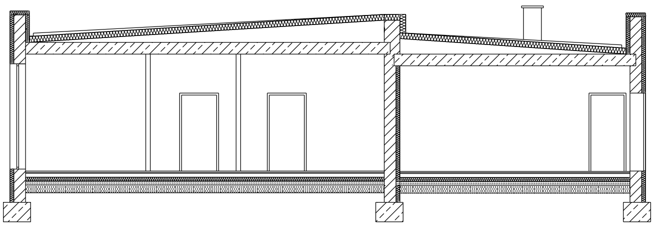


Figure 26: A-A cross-section.

3.5.3 External and internal walls solutions

The structure of the exterior wall is shown in Figure 27.

15mm of lime plaster

300mm of aerated concrete on thin dry set mortar

100mm of Styrofoam

15mm of lime plaster

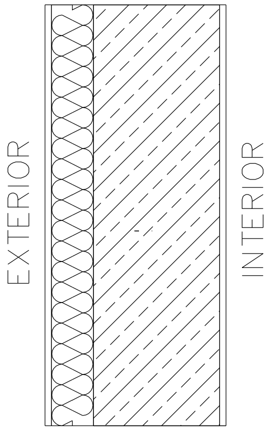


Figure 27: Structure of the exterior wall.

Interior walls, constructed from aerated concrete, covered on both sides with 15mm wide layer of lime plaster, are 30 cm wide (load-bearing wall) and 11.5 cm wide (internal division wall). The U-value for the exterior wall is 0.256 $\frac{\mathrm{W}}{\mathrm{m^2K}}$.

3.5.4 Floor and roof solutions

The structure of the floor is common for all areas and is composed of following layers as shown in Figure 28.

25mm of self-leveling concrete

100mm of base screed

100mm of Styrofoam

Airtight layer

100mm of concrete screed

200mm of firmed sand

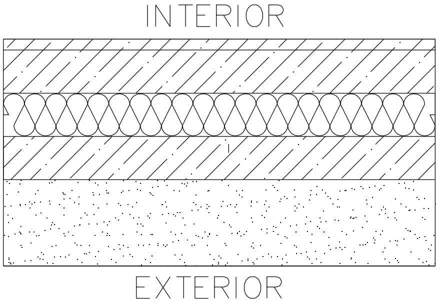
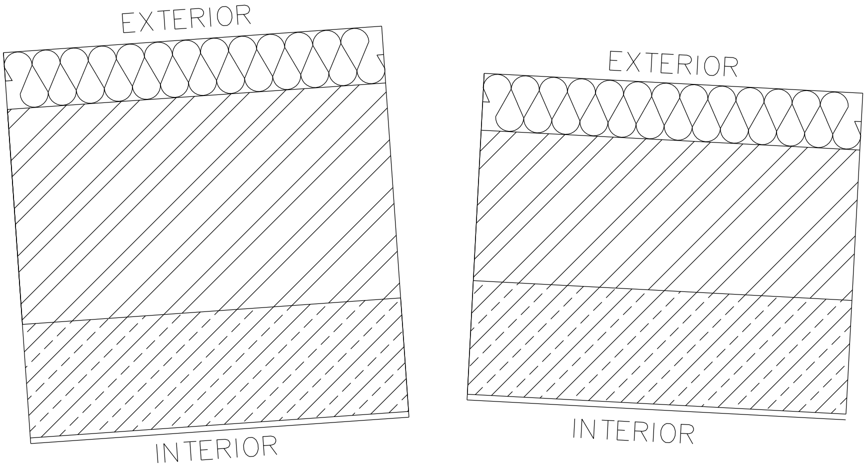


Figure 28: Structure of the floor.

The U-value for the floor is 0.322 $\frac{\mathrm{W}}{\mathrm{m^2K}}$.

The structure of the roof is the same in the whole building and its constitution is shown in Figure 29.

3 layers of building paper
From 0 to 75mm aggregate limestone (slope layer)
100mm of Styrofoam
Airtight layer
From 0 to 397mm (for garage area) and from 0 to 568mm (for conditioned area) of slope layer from aggregate limestone
300mm of concrete layer (load-bearing part)
15mm of limestone plaster



Structure of the roof above conditioned area; slope 4°.

Structure of the roof above garage area; slope 3°.

Figure 29: Structure of the roof.

Due to a small scale of Figure 29, the last layer of aggregate limestone (from 0 to 75 mm) is not presented. The mean U-value for the roof is 0.209 $\frac{\mathrm{W}}{\mathrm{m}^2\mathrm{K}}$.

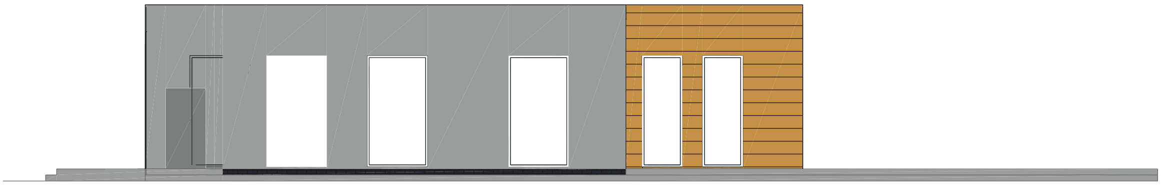
3.5.5 Windows and door

Four different sizes of single-framed, double glazed wooden windows are designed for the house. Placement of the windows is presented in Figure 30. In Table 2 are shown: dimensions, placement and quantity of each group of the windows:

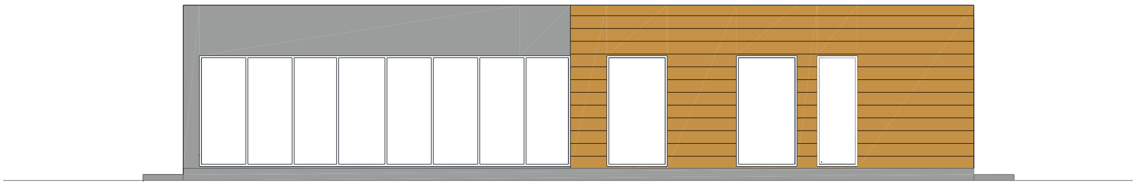
Table 2: Windows geometry.

Height x Width [m]	*Orientation*	*Quantity*
2.75 x 1.00	South	9
2.75 x 1.50	South	2
2.75 x 1.00	West	2
2.75 x 1.50	West	3
1.50 x 1.00	North	1
1.50 x 2.00	North	1
2.75 x 1.00	East	1
2.75 x 1.50	East	1

WEST ELEVATION



SOUTH ELEVATION



NORTH ELEVATION

EAST ELEVATION

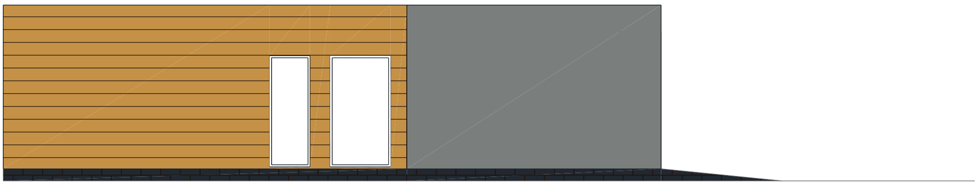


Figure 30: Elevations.

Chapter 4

Energy calculation according to EN 13790

4 Energy calculation according to EN 13790

4 Energy calculation according to EN 13790

4.1 Introduction

The first step to take in scope of this dissertation, was to calculate for the given building the annual heating demand according to the European standard. The suitable standard for the calculation was EN ISO 13790 “Energy performance of buildings – Calculation of energy use for space heating and cooling” [41].

Having considered Polish climatic data (see Chapter 3) it was decided not to calculate an annual cooling demand for this case study. It is obvious, that the energy demand for cooling would have is an inconsiderable value when compared to the heating demand. The heating season was estimated as 9 months, beginning from September, ending in May. Therefore, in further calculations the months of June, July and August are not taken under consideration for the heating period.

Among three available calculation methods (see chapter 5.3 of [41]), a fully prescribed monthly quasi-steady-state calculation method was chosen for this case. According to the chapter 6.3 of the EN 13790 [41] it was decided to assume the whole house as a single thermal zone. The set point temperature $\Theta_{int,H,set}$ was calculated in accordance with the Equation (1) from chapter 6.3.3.1.1 of EN 13790. In every heated space, excluding the two bathrooms, a set-point temperature was established as 20°C. A set-point temperature in bathrooms was considered as 24°C. These considerations lead to the overall temperature value as followed:

$$\theta_{int,H,set} = \frac{(10{,}12m^2+4{,}50m^2)\times 24℃+\left(179{,}14m^2-(10{,}12m^2+4{,}50m^2)\right)\times 20℃}{179{,}14m^2}=20.326℃ \quad (1)$$

where:

$10.12m^2$ and $4.50m^2$ - areas of bathrooms;
$179.14m^2$ - treated floor area (TFA);
20.326°C - final set-point temperature for the whole house.

4.2 Flow chart of calculation procedure according to EN 13790 [41]

In Figure 31 is presented the flow of calculation procedure for the energy use for heating the building according to EN 13790 [41].

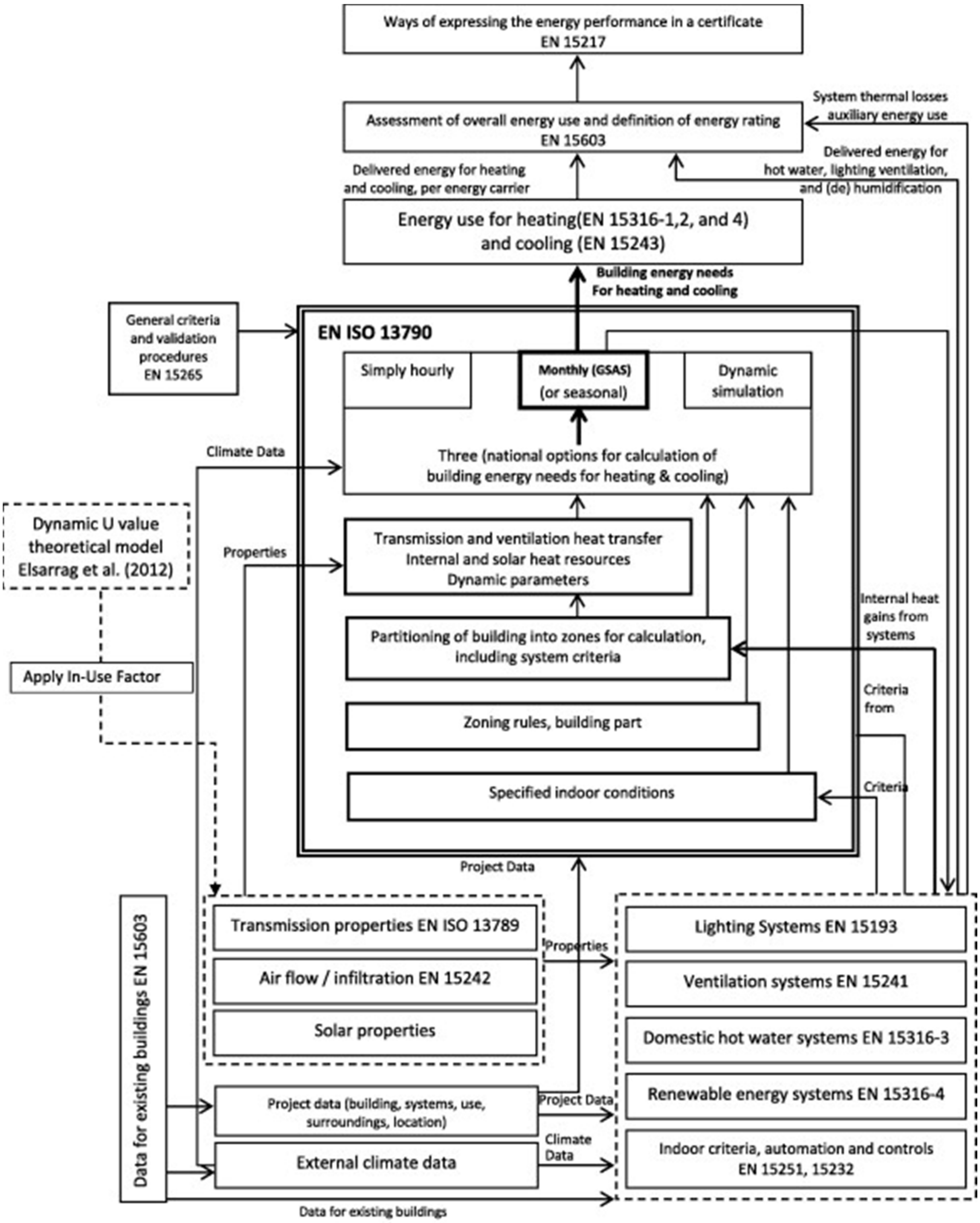


Figure 31: Flow chart of calculation procedure according to EN 13790

4.3 Energy need for heating ($Q_{h,nd}$)

According to chapter 7.2.1.1 of [41] building energy demand for space heating ($Q_{H,nd}$) is given by the value of total heat transfer for the heating mode ($Q_{H,ht}$), reduced by the multiplication of total heat gains for the heating mode ($Q_{H,gn}$) and utilization factor ($\eta_{H,gn}$). Therefore, total heat transfer for the heating mode ($Q_{H,ht}$) demands to be calculated first.

4.3.1 Heat transfer by transmission (Q_{tr})

In accordance to 7.2.1.3 of [41] total heat transfer for the heating mode ($Q_{H,ht}$) is a sum of two contributions: total heat transfer by transmission (Q_{tr}) and total heat transfer by ventilation (Q_{ve}). Firstly, the value of total heat transfer by transmission (Q_{tr}) will be calculated. The equation to calculate this value is given in chapter 8.2 of EN 13790 [41] as followed:

$$Q_{tr} = H_{tr,adj} \times \left(\theta_{int,set,H} - \theta_e\right) \times t \quad [\mathrm{J}] \qquad (2)$$

where:

$H_{tr,adj}$ – overall heat transfer coefficient by transmission, $[\frac{\mathrm{W}}{\mathrm{K}}]$;
$\theta_{int,set,H}$ – set-point temperature of the building zone for heating, [K];
θ_e – temperature of external environment, [K];
t – duration of the calculation step, [Ms].

4.3.2 Transmission heat transfer coefficient for opaque thermal envelope ($H_{tr,adj}$)

In order to calculate the total heat transfer by transmission (Q_{tr}), a transmission heat transfer coefficient ($H_{tr,adj}$) must be calculated. It is composed of four sources (according to the chapter 8.3.1 of [41]), as in the equation:

$$H_{tr,adj} = H_D + H_g + H_U + H_A \quad [\frac{\mathrm{W}}{\mathrm{K}}] \qquad (3)$$

H_D - direct heat transfer coefficient by transmission to the external environment $[\frac{\mathrm{W}}{\mathrm{K}}]$;

H_g - heat transfer coefficient by transmission to the ground $[\frac{\mathrm{W}}{\mathrm{K}}]$;

H_U - heat transfer coefficient by transmission through unconditioned spaces $[\frac{\mathrm{W}}{\mathrm{K}}]$;

H_A - heat transfer coefficient by transmission to adjacent buildings $[\frac{\mathrm{W}}{\mathrm{K}}]$.

In the presented case study, only the first three coefficients are applied, due to the fact that considered house is not connected to any adjacent buildings. The heat transfer coefficients were calculated in accordance to the standard EN ISO 13789:1999 “Thermal performance of buildings – Transmission heat loss coefficient – Calculation method” [43].

According to EN ISO 13789:1999, H_x coefficient, which represents all four specific heat transfer coefficients described above are given by the following Equation (4):

$$H_x = b_{tr,x} \times [\Sigma_i A_i U_i + \Sigma_k l_k \psi_k + \Sigma_j \chi_j] \quad [\frac{W}{K}] \tag{4}$$

where:

A_i – area of element *i* of the building envelope, [m^2];

U_i – thermal transmittance of element *i* of the building envelope, $[\frac{\mathrm{W}}{\mathrm{m}^2\mathrm{K}}]$;

(specific calculations for the values of elements thermal transmittance are given in Annex 1);

l_k – length of the linear thermal bridge *k*, [m];

ψ_k – linear thermal transmittance of thermal bridge *k*, $[\frac{\mathrm{W}}{\mathrm{m\,K}}]$;

χ_j – point thermal transmittance of point thermal bridge *j*, $[\frac{\mathrm{W}}{\mathrm{K}}]$; (in this project point thermal bridges were not considered);

$b_{tr,x}$ – adjustment factor, [dimensionless].

All the specific calculations of heat transfer coefficients can be found in the Annex 2. However, in Table 3, are listed results of heat transfer coefficients (H_x) for every element of the building envelope, with corresponding areas (*A*), thermal transmittance (*U*) and adjustment temperature correction factors ($b_{tr,x}$).

Table 3: Summary of heat transfer coefficients and specific heat transmission.

Building element	$A\ [m^2]$	$U\ [\frac{W}{m^2 \times K}]$	$b_{tr,x}$	$H_x\ (H_D, H_g, H_U)\ [\frac{W}{K}]$
Exterior wall	104.25	0.26	1.0	28.51
Windows	67.00	1.42	1.0	95.14
Roof	179.14	0.21	1.0	37.44
Floor	179.14	0.22	0.6	24.08
Garage wall	25.49	0.26	0.5	3.25

In order to obtain the most realistic results, a ring beam of 25 cm height is assumed for the exterior wall (see the U-value for the exterior wall in Table 3 and the cross-section in Figure 46). Furthermore, four columns were designed for the building. The value of thermal transmittance both for a ring beam and columns (substantial thermal bridges) is 0.346 $[\frac{\mathrm{W}}{\mathrm{m}^2\mathrm{K}}]$. As a result, their existence increased the value of direct heat transfer coefficient by transmission to the external environment (H_D).

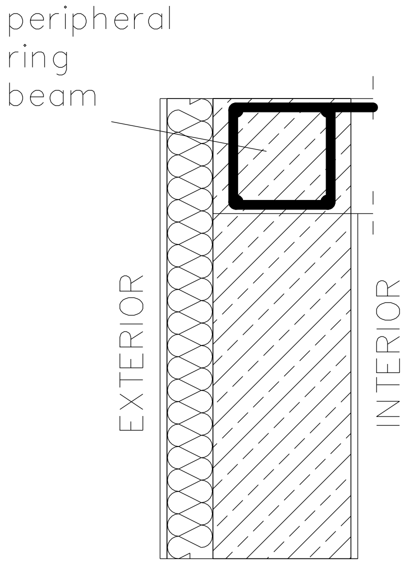


Figure 32: Cross-section through the ring beam.

The entrance door was also considered in the calculations of heat transfer coefficient calculation as the opaque building envelope element (included in “Windows” building element in Table 3).

Coefficients $b_{tr,x}$ for the roof and floor were applied in accordance with the EN 12831:2003 “Heating systems in buildings. Method for calculation of the design heat load.” [43] (see the $b_{tr,x}$ values for “floor” and “garage wall” in Table 3) . The values are temperature correction features for calculation.

Given thermal transmittance (U) value for a garage wall (see the U-value for “garage wall” in Table 3) is a mean value of the following elements: thermal transmittance of garage North wall – 0.248 $[\frac{\mathrm{W}}{\mathrm{m^2K}}]$, thermal transmittance of garage East wall 0.259 $[\frac{\mathrm{W}}{\mathrm{m^2K}}]$ and a concrete column which represents a substantial thermal bridge.

4.3.3 Transmission heat transfer coefficient through thermal bridges ($H_{tr,adj}$)

In Table 4 there are specified linear thermal bridges with their lengths (*l*), linear thermal transmittances (ψ), adjustment factors ($b_{tr,x}$) and heat transfer coefficients (H_x):

Table 4: Linear thermal bridges with heat transfer coefficients.

Thermal bridge	*l (m)*	ψ $(\frac{W}{m\ K})$	$b_{tr,x}$	H_D, H_g, H_U $(\frac{W}{K})$
Exterior-interior walls connection	3	0.09	1.0	0.27
Exterior walls corner	12	0.17	1.0	2.04
Window jamb	54	0.19	1.0	10.26
Window lintel	27	0.29	1.0	7.54
Windowsill	27	0.39	1.0	10.14
Exterior wall-roof connection	58	0.14	1.0	8.09
Garage exterior-interior walls connection	3	0.09	0.5	0.14
Garage exterior walls corner	3	0.18	0.5	0.27
Floor	73	0.80	0.6	34.88

Linear thermal transmittance values (see the third column in Table 4) were obtained from different resources: materials from “Building Phisics” course at Lodz University of Technology, Portuguese website (www.itecons.uc.pt) and the European Standard EN ISO 14683:2007 "Thermal bridges in building construction – Linear thermal transmittance – Simplified methods and default values" [44].

4.3.4 Total value of heat transfer by transmission (Q_{tr})

Having calculated heat transfer coefficients (H_x), the value of total heat transfer by transmission (Q_{tr}) may be obtained. All detailed calculations of the heat transfer by transmission are enclosed in Annex 3. Below is presented the annual value of heat transfer by transmission (in joules and in kilowatt-hours per square meter of TFA).

$$Q_{tr} = 9.353 \times 10^{10} J = 145.062\ kWh/m^2 \qquad (5)$$

4.3.5 Heat transfer by ventilation (Q_{ve})

The equation for heat transfer by ventilation (Q_{ve}; expressed in joules) is given in chapter 9.2 of [41] and has the following form:

$$Q_{ve} = H_{ve,adj} \times \left(\theta_{int,set,H} - \theta_e\right) \times t \qquad (6)$$

where:

$H_{ve,adj}$ – overall heat transfer coefficient by ventilation, $[\frac{\mathrm{W}}{\mathrm{K}}]$;
$\theta_{int,set,H}$ – set-point temperature of the building zone for heating, [K];
θ_e – temperature of external environment, [K];
t – duration of the calculation step, [Ms].

4.3.6 Heat transfer coefficient by ventilation

In order to obtain the value of heat transfer by ventilation (Q_{ve}) an overall heat transfer coefficient by ventilation ($H_{ve,adj}$; expressed in watts per kelvin) must be calculated. It is given by the following equation in accordance with chapter 9.3 of [41]:

$$H_{ve,adj} = \rho_a c_a (\Sigma_k b_{ve,k} q_{ve,k,mn}) \qquad (7)$$

where:

$\rho_a c_a$ – heat capacity of air per volume, $[\frac{\mathrm{J}}{\mathrm{m^3 K}}]$; (value established for the calculation as 1200 $\frac{\mathrm{J}}{\mathrm{m^3 K}}$);

$q_{ve,k,mn}$ - time-average airflow rate of air flow element *k*, $[\frac{\mathrm{m^3}}{\mathrm{s}}]$; estimated that airflow operation is uninterrupted (full-time);

$b_{ve,k}$ – temperature adjustment factor for air flow element; value established for the calculation as 1 for all the compartments, [dimensionless].

4.3.7 Time-average airflow rates ($q_{ve,k,mn}$)

Time-average airflow rates for every compartment ($q_{ve,k,mn}$; expressed in cubic meters per second) were established according to the Polish standard PN-83 B-03430 “Ventilation in dwelling and public buildings. Specifications” [45] and they are listed below with the appropriate airflow direction (Air supplied (S) or Air extracted (E)):

Table 5: Time-average airflow rates for supplied or extracted air.

Nr	*Name of compartment*	*Time-average airflow rate* $[\frac{m^3}{s}]$	*Air supplied (S)/ Air extracted (E)*
1	Antechamber	15	(S)
2	Utility room	15	(E)
3	Garage	-	-
4	Cloak-room	15	(S)
5	Pantry	15	(S)
6	Kitchen	50	(E)
7	Living room	30	(S)
8	Corridor	transfer	transfer
9	Bathroom 1	50	(E)
10	Bedroom 1	30	(S)
11	Bathroom 2	50	(E)
12	Bedroom 2	30	(S)
13	Bedroom 3	30	(S)

In order to obtain overall time-average airflow rate for the house, one must compare total supplied air and extracted air and choose the higher value from these two. However, in the PHPP [42] there is also a third condition which must be considered. Therefore, to make calculations according EN 13790 [41] and PHPP the most comparable, the additional condition from PHPP was considered in the EN 13790 calculations. The equation which represents the third condition has a following form:

$$q_{ve,extra,condition} = 1{,}3 \times 0{,}3 \times V \qquad (8)$$

where:

V – cubature of house, [m^3]; ($V=537.42m^3$ for this case study)

Finally, from these three conditions the maximum value for the time-average airflow rate must be chosen. This was obtained for the air supplied condition. Therefore, the air supplied value was considered in further calculations concerning heat transfer by ventilation.

4.3.8 Total value of heat transfer by ventilation (Q_{ve})

Having calculated heat transfer coefficient by ventilation ($H_{ve,adj}$), the value of total heat transfer by ventilation (Q_{ve}) may be obtained. All detailed calculations of the heat transfer by ventilation are enclosed in Annex 4. Below is presented the annual value of heat transfer by ventilation (in joules and in kilowatt-hours per square meter of TFA).

$$Q_{ve} = 2.499 \times 10^{10} J = 38.759\ kWh/m^2$$

4.4 Total heat gains (Q_{gn})

According to chapter 7.2.1.3 of [41] building total heat gains (Q_{gn}) are the sum of internal heat gains (Q_{int}) and solar heat gains (Q_{sol}). Therefore, in first place, internal heat gains (Q_{int}) demand to be calculated.

4.4.1 Internal heat gains (Q_{int})

According to chapter 10.1 of [41] internal heat gains account for several sources:

- Metabolic heat from occupants and dissipated from appliances;
- Heat dissipated from lighting devices;
- Heat dissipated, or absorbed by, hot and main water and sewage systems;
- Heat dissipated from, or absorbed by, heating, cooling and ventilation systems;
- Heat from or to processes and goods.

For this case study only metabolic heat from occupants and heat dissipated from appliances and lighting devices were considered.

4.4.2 Internal heat flow rate from occupants and appliances ($\theta_{int,Oc}$)

The internal heat flow rate from occupants and appliances ($\theta_{int,Oc}$; expressed in joules) is determined in accordance with 10.4.2 of [41]. Default values in the absence of national values for residential buildings are given in chapter G.8 from [41]. Since the national values in Polish standard are not determined, it was decided to use default values from [41], Default values given are:

- For the living room and kitchen heat flow rate sums up to 9 $\frac{W}{K}$;
- For other useful areas (e.g. bedrooms) heat flow rate amounts to 3 $\frac{W}{K}$.

Calculations of mean heat flow rate from the occupants and appliances for the house with the use of above default values summed up to 6.54 $\frac{W}{K}$. However, it was decided that the result might have been too optimistic (was clearly increased by the big area of the living room) and decreased it to 5 $\frac{W}{K}$. Therefore, the mean heat flow rate from the occupants and appliances ($\theta_{int,Oc}$) considered in calculations was 5 $\frac{W}{K}$. All detailed calculations of the heat flow rate from occupants and appliances ($\theta_{int,Oc}$) are presented in Annex 5.

Below is given the annual value of heat flow rate from the occupants and appliances ($\theta_{int,Oc}$) in joules and in kilowatt-hours per square meter of TFA.

$$\theta_{int,Oc} = 1.562 \times 10^{10} J = 24.226\ kWh/m^2$$

4.4.3 Internal heat flow rate from lighting ($\boldsymbol{\theta_{int,L}}$)

The internal heat flow rate from lighting ($\theta_{int,L}$; expressed in joules) is determined in accordance with 10.4.3 of [41]. A suitable standard to calculate the heat flow rate from lighting given by [41] is the EN 15193-1. Although to make calculations quicker and easier it was decided to use simplified equation which has a following form:

$$\phi_{int,L} = N \times [\beta + (1 - \beta) \times k_0] \times \varphi \qquad (9)$$

where:

N – total power of the lighting for the house, [W]; (value established for calculations was 40 bulbs, 40 watts each);

β – coefficient depended both on: type of lamp fixing to the wall or ceiling and type of the lamp; (for the calculations it was assumed freely suspended, fluorescent lamps. A suitable coefficient β for this case has a value of 0.5); [dimensionless];

k_0 – coefficient related to the accumulation of the partitions, for most of the buildings, unless they have massive partitions, this coefficient is taken as 1.0. For the calculations k_0 was assumed as 1.0; [dimensionless];

φ – coefficient of lighting simultaneously; it was assumed separately for each month (see Table 6); [dimensionless].

Table 6: Lighting simultaneously for each month.

Lighting simultaneously coefficient	*Month*	*Value*
φ_1	January	0.30
φ_2	February	0.15
φ_3	March	0.15
φ_4	April	0.10
φ_5	May	0.10
φ_9	September	0.10
φ_{10}	October	0.15
φ_{11}	November	0.3
φ_{12}	December	0.3

All detailed calculations of the heat flow rate from lighting ($\theta_{int,L}$) are the presented in Annex 6. Below is presented the annual value of heat flow rate from lighting ($\theta_{int,L}$) in joules and in kilowatt-hours per square meter of TFA.

$$Q_{int,Oc} = 6.94 \times 10^9 J = 10.764\ kWh/m^2$$

Moreover, in Annex 7 are presented the sums of monthly and annual heat losses by transmission and ventilation, as well as monthly and annual total internal heat gains.

4.4.4 Solar heat gains (Q_{sol})

In accordance with chapter 11.2.1 of [41] the overall solar heat gains (Q_{sol}; expressed in megajoules) must be calculated by the following equation:

$$Q_{sol} = \left(\sum_k \phi_{sol,mn,k}\right) \times t + \left(\sum_k (1 - b_{tr,l}) \times \phi_{sol,mn,u,l}\right) \times t \qquad (10)$$

where:

$b_{tr,l}$ – adjustment factor for the adjacent unconditioned space with internal heat source *l*; in this case, there is one unconditioned space, which is the garage, and the appropriate adjustment factor for garage exterior walls (on the East and North side) and roof is 0.5; [dimensionless];

$\phi_{sol,mn,k}$ – time-average heat flow rate from solar heat source *k*, [W];

$\phi_{sol,mn,u,l}$ - time-average heat flow rate from solar heat source *l* in the adjacent unconditioned space, [W];

t – timespan for each month, [Ms].

4.4.5 Effective solar collecting area of glazed elements (*$A_{sol,w}$*)

Firstly, in accordance with the chapter 11.3.3 of [41] in order to receive the overall solar heat gains through the glazed elements one must calculate effective solar collecting area of glazed elements ($A_{sol,w}$, expressed in m^2) with the use of following equation:

$$A_{sol,w} = F_{sh,gl} \times g_{gl} \times (1 - F_F) \times A_{w,p} \qquad (11)$$

where:

$F_{sh,gl}$ – shading reduction factor for movable provisions; assumed as 1.0; [dimensionless];

g_{gl} – coefficient of total solar energy transmittance of the transparent part of the element; established as 0.7; [dimensionless];

F_F – frame area fraction; assumed the same for every window as in the PHPP [42], to make the calculations according to both standards the most comparable. Therefore, for glazed elements on the:

South side; $F_F = 0.450$;
West side; $F_F = 0.440$;
North side; $F_F = 0.450$;
East side; $F_F = 0.438$;

$A_{w,p}$ – overall projected area of the glazed element [m^2].

4.4.6 Solar gains through the glazed elements *($\phi_{sol,k}$)*

Having calculated the effective solar collecting area of glazed elements, one can determine the solar gains through the glazed elements *($\phi_{sol,k}$)* with the use of the following equation:

$$\phi_{sol,k} = F_{sh,ob,k} A_{sol,k} I_{sol,k} - F_{r,k} \phi_{r,k} \qquad (12)$$

where

$F_{sh,ob,k}$ – shading reduction factor for the external obstacles; determined as 1.0; [dimensionless];

$A_{sol,k}$ – effective collecting area, [m^2];

$I_{sol,k}$ – solar irradiance, [$\frac{W}{m^2}$];

$F_{r,k}$ – form factor between the building element and the sky; assumed as 0.5; [dimensionless];

$\phi_{r,k}$ – extra heat flow due to thermal radiation to the sky from building element, [W]; and it is the result of the multiplication of five elements, as follows:

$$\phi_r = R_{se} \times U_C \times A_C \times h_r \times \Delta\theta_{er} \qquad (13)$$

where:

R_{se} – external surface heat resistance of the element, [$\frac{m^2K}{W}$]; assumed as 0.04 $\frac{m^2K}{W}$;

U_C – thermal transmittance of the element, [$\frac{W}{m^2K}$]; assumed as 1.42 $\frac{W}{m^2K}$;

A_C - projected area of the element, [m^2];

h_r - external radiative heat transfer coefficient, [$\frac{W}{m^2K}$]; assumed as 4 $\frac{W}{m^2K}$;

$\Delta\theta_{er}$ – average difference between the external air temperature and the apparent sky temperature, [°C]; assumed as 11°C.

4.4.7 Total solar heat gains through the glazed elements ($Q_{sol,w,TOTAL}$)

All detailed calculations of the solar heat gains through the glazed elements ($Q_{sol,w}$) are presented in Annex 8. In Annex 9 are presented all calculations which concern monthly and annual solar heat gains. Below is given the annual value of solar heat gains through the glazed elements in joules and in kilowatt-hours per square meter of TFA.

$$Q_{sol,w,TOTAL} = 4.492 \times 10^{10} J = 69.660\ kWh/m^2$$

4.4.8 Collecting area of opaque building elements ($A_{sol,W}$)

Secondly, even though the heat gains through the opaque envelope are very low, in accordance with the chapter 11.3.4 of [41] in order to receive the overall solar heat gains through the opaque building elements, one must calculate the effective collecting area of opaque building elements ($A_{sol,W}$; expressed in m^2) with the use of following equation:

$$A_{sol,W} = \alpha_{S,c} \times R_{se} \times U_C \times A_C \qquad (14)$$

where:

$\alpha_{S,c}$ – absorption coefficient for solar radiation of the opaque part; determined as 0.7 for the exterior walls and 0.9 for the roof; [dimensionless];

R_{se} – external surface heat resistance, $[\frac{m^2K}{W}]$; established as 0.04 $\frac{m^2K}{W}$;

U_C – thermal transmittance of the opaque part, $[\frac{W}{m^2K}]$; established as 0.256 $\frac{W}{m^2K}$ for the walls and 0.209 $\frac{W}{m^2K}$ for the roof;

A_C - projected area of the opaque part, $[m^2]$.

4.4.9 Total solar heat gains through the opaque building elements ($\phi_{sol,k}$)

Having calculated the effective collecting area of the opaque building elements, one can receive the heat flow by solar gains through the opaque building elements ($\phi_{sol,k}$) with the use of the Equation 12. Following data was used in the Equation 12 for the calculations concerning the heat flow by solar gains through the opaque building elements:

$F_{sh,ob,k}$ = 1.0 for the walls and the roof;

$F_{t,k}$ = 0.5 for the walls, and $F_{t,k}$ = 1.0 for the walls;

R_{se} = 0.04 $\frac{m^2K}{W}$ for the walls and the roof;

h_r = 4.5 $\frac{W}{m^2K}$ for the walls and h_r = 4 $\frac{W}{m^2K}$ for the roof;

$\Delta\theta_{er}$ = 11°C for the walls and the roof.

All detailed calculations of the solar heat gains through the opaque building elements ($Q_{sol,W}$) are presented in Annex 10 (walls) and in Annex 11 (roof). Moreover, in the Annex 12 it is presented the monthly and annual solar heat gains through the opaque building elements (walls and roof). Finally, in in the Annex 13 is presented the monthly and annual total heat gains, both solar heat gains and internal heat gains. Below is shown the annual value of solar heat gains through the opaque building elements (walls and roof) in joules and in kilowatt-hours per square meter of TFA.

$$Q_{sol.W.r} = 4.37 \times 10^9 J = 6.777\ kWh/m^2$$

4.5 Dynamic parameters

The last stage of calculations for the energy demand is to account for the gain utilization factors for heating ($\eta_{H,gn}$). Their values, in accordance to chapter 12.2.1.1 of [41], are given by the following equations:

$$\text{if } \gamma_H > 0\ and\ \gamma_H \neq 0 \qquad \eta_{H,gn} = \frac{1-{\gamma_H}^{a_H}}{1-{\gamma_H}^{a_H+1}} \qquad (15)$$

$$\text{if } \gamma_H = 1 \qquad \eta_{H,gn} = \frac{a_H}{a_H+1} \qquad (16)$$

$$\text{if } \gamma_H < 0 \qquad \eta_{H,gn} = \frac{1}{\gamma_H} \qquad (17)$$

where:

γ_H - heat-balance ratio, given by a quotient of heat gains and heat losses for each month: $\gamma_H = \frac{Q_{H,gn}}{Q_{H,ht}}$; [dimensionless];

a_H – numerical parameter, given by the equation: $a_H = a_{H,0} + \frac{\tau}{\tau_{H,0}}$

where

$a_{H,0}$ – numerical parameter; determined as 1.0 according to Table 9 of [41]; [dimensionless];

τ – time constant; calculated as 0.031 hour in accordance to chapter 12.2.1.3 of [41];

$\tau_{H,0}$ – reference time constant, determined as 15.0 hours according to Table 10 of [41].

In order to receive τ parameter, an internal heat capacity of the building must be known (C_m). It was estimated as the same value that was given by PHPP [42] - 269400 $\frac{J}{K}$, so as to make the calculations with both standards the most similar.

Detailed calculations concerning dynamic parameters for the house are presented in Annex 14. In Table 7 are listed the parameters for each month.

Table 7: Values of dynamic parameters.

Month	*Heat-balance ratio (γ_H)*	*Gain utilization factor ($\eta_{H,gn}$)*
January	0.333	0.751
February	0.319	0.759
March	0.613	0.620
April	0.963	0.510
May	2.187	0.501
September	1.41	0.501
October	0.618	0.619
November	0.378	0.727
December	0.290	0.776

4.6 Annual energy demand for heating

Below is presented the value of the annual energy demand for heating. Calculations for the energy demand for heating for every month of the heating period can be found in Annex 15.

$$Q_{H,nd} = 7.543 \times 10^{10} J = 2.095 \times 10^{4} kWh = 116.957 \frac{\mathrm{kWh}}{\mathrm{m^2a}}$$

Chapter 5

Energy calculation according to Passive House Planning Package (PHPP)

5 Energy calculation according to Passive House Planning Package (PHPP)

5.1 Introduction
5.2 Flow chart of sequence of entries according to PHPP
5.3 PHPP structure
    5.3.1 Introduction
    5.3.2 Brief instructions worksheet
    5.3.3 Vertification worksheet
    5.3.4 Areas determination worksheet
    5.3.5 U-List worksheet
    5.3.6 U-Values of building elements worksheet
    5.3.7 Heat losses via the ground worksheet
    5.3.8 Windows worksheet
    5.3.9 WinType worksheet
    5.3.10 Shading worksheet
    5.3.11 Ventilation data worksheet
    5.3.12 Specific annual heating demand worksheet
    5.3.13 Specific annual heating demand - monthly method workshe
    5.3.14 Climate data worksheet
5.4 Comparison between results
    5.4.1 Introduction
    5.4.2 Transmission heat losses
    5.4.3 Ventilation heat losses
    5.4.4 Solar gains
    5.4.5 Internal heat gains
    5.4.6 Summary

5 Energy calculation according to Passive House Planning Package (PHPP)

5.1 Introduction

PHPP [42] is a tool developed by the Passive House Institute in Darmstadt. It is based on EN 13790 [41] standard. PHPP aids to design buildings with the aim of fulfilling the requirements stated for a PH. The first edition of this programme was released in 1998. In this dissertation all the calculations will be provided with the use of the latest edition of PHPP from 2012. In spite of that PHPP main aim is to design a PH, one can use this programme to design a typical, non-passive building. Therefore, before meeting the PH standards in this case study, first the calculations according to EN 13790 will be carried out. Thus the main point of this chapter is to calculate the annual energy demand for heating, using the PHPP tool. Later a comparison between results of calculations in accordance with both standards will be possible.

5.2 Flow chart of sequence of entries according to PHPP

In Figure 33 is presented the flow chart of sequence of entries for respective worksheets according to PHPP.

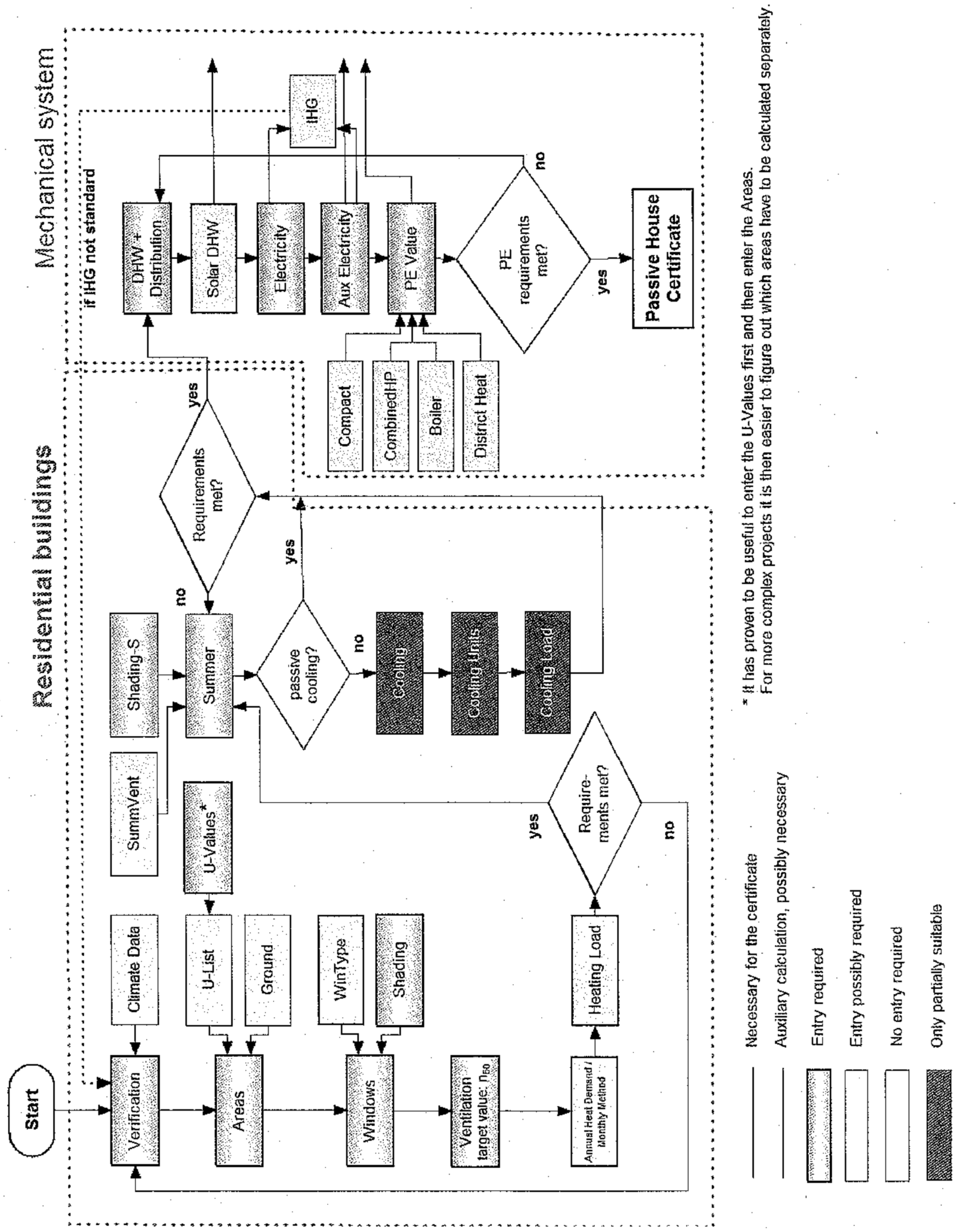


Figure 33: Flow chart of sequence of entries according to PHPP

5.3 PHPP structure

5.3.1 Introduction

PHPP [42] is the Microsoft Excel document which combines different worksheets responsible for specific calculations and results. In the next few subsections there will be a brief description of each worksheet and a characterization of the implemented data. Due to that at this stage only annual energy demand for heating will be calculated, therefore only necessary worksheets for this calculation will be described. All of these worksheets can be found in Annex 16.

5.3.2 Brief instructions worksheet

At the top of this worksheet there are given exemplary cells that can be found during the work with PHPP [42]: “input field”, “calculation field”, “field with references to another sheet” or “important result”. Furthermore, this worksheet describes very briefly each of the following worksheet. It also gives the information whether filling the specific worksheet is required for the certification or not. No data entry can be typed here.

5.3.3 Vertification worksheet

In this worksheet one can type the general data which refers to the building, such as: street, country etc. An important aspect is filling in the “Interior Temperature” cell which is the interior design temperature for the building. The default and recommended value for this cell is 20°C. However, to make PHPP [42] calculations the most similar to those according to EN 13790 [41] the “Interior Temperature” was set on 20.326°C. On the right side of the worksheet data concerning “Building type”, “Utilization pattern”, “Type of values used” and “Planned number of occupants” must be given. In this dissertation, for the one family house the utilization pattern is defined as dwelling. In addition, standard default values were used. The house was designed for four occupants.

Having filled all the necessary worksheets, one can receive the most important results in the “Vertification” worksheet i.a.: the values of annual heating demand, heating load or primary energy. Finally, there are also given the requirements which correspond with each result, verify if the building fulfills PH standards.

5.3.4 Areas determination worksheet

The main goal of this worksheet is to define the areas of opaque envelope elements. That data is necessary to obtain total heat losses through the opaque building envelope. Therefore, only the areas of thermal envelope are considered. In the “Area input” table, one should type data as follows:

- “Building element description”- the name of the area. For example, in this case, south exterior wall of the building is named “exterior wall south”;
- “Group Nr.” – the typed number should correspond with the appropriate area group from the table “Summary” at the top of this worksheet. For example, for area “exterior wall south” the corresponding number is 8;
- “Quantity” – quantity of considered areas;
- “a”, “b”, “User determined” – in the “a” and “b” columns user may enter the length and width of the area. Otherwise, user may type total area in “User determined” column*;
- “Selection of the corresponding building element assembly” – one should choose a corresponding building element assembly to the area. This option is available only after filling the “U-values” worksheet;

For exterior walls the area input must not be reduced by the areas of windows. Since the worksheet automatically subtracts areas of windows from walls’ areas (in the column “Subtraction window areas”).

In the table “Additional inputs for radiation balance” (on the right side of the “Area input” table) one must type the data concerning following features of the opaque building element: “Exterior absorptivity”, “Exterior emissivity”, “Deviation from north”, “Angle of inclination from the horizontal”, “Reduction factor shading”.

Below the “Area input” table there is a “Thermal Bridge Inputs” table. It allows list the linear thermal bridges (apart from windows thermal bridges which should be typed in “Windows worksheet”). The algorithm of introducing data is the same as in the table with the areas. The only difference is that in the “Thermal Bridge Inputs” table, it is necessary to enter the linear thermal transmittance value (ψ, in the last column) for each thermal bridge identified.

The table “Summary” (at the top of this worksheet) lists all of the area groups and thermal bridges with the related temperature zones: A (stands for interior air against ambient air) or B (stands for interior air against the ground or basement). Moreover, there are summed areas of each group, with the corresponding average U-value. As well, there are summed the lengths of thermal bridges with the corresponding average ψ value. Finally, an extra area group may be defined by the user in “Summary” table. In this case, an area of “Garage wall” was created. The temperature reduction factor was defined as X, with the value of 0.50.

Finally, the sum of all areas of opaque building envelope elements was calculated as 554.20m^2, whereas the average U-value was estimated of 0.571 $\frac{W}{m^2K}$.

5.3.5 U-List worksheet

The worksheet compiles the opaque envelope solutions characteristics (total thickness and U-value) for every element of building that is in the “U-Values” worksheet. Therefore, to obtain the compilation first “U-Values” worksheet must be filled. Moreover, from the row 110 there are listed U-values for typical building assemblies. No data entries are needed in the “U-List” worksheet. In Table 8 are listed all building assemblies with corresponding thickness and U-values:

Table 8: Assemblies with their thicknesses and U-values (for a typical house design).

Assembly description	*Total thickness [m]*	*U-value [$\frac{W}{m^2K}$]*
Exterior wall	0.430	0.256
Roof	0.791	0.209
Ground floor	0.357	0.322
Garage wall south	0.442	0.248
Garage wall west	0.284	0.259
Part of wall with a ring beam	0.430	0.346

5.3.6 U-Values of building elements worksheet

This worksheet enables to obtain total U-values for elements of opaque building envelope. At first, cells: “Assembly Number” and “Building assembly description” must be filled. Then, values of interior heat transfer coefficient (R_{si}) and exterior heat transfer coefficient (R_{se}) should be entered. At last, names of the layers with corresponding thermal conductivity (λ) and thickness must be filled in.

5.3.7 Heat losses via the ground worksheet

The worksheet is a tool used to calculate the heat losses through the below-ground building elements, in this case – slab on grade. Data which was entered for this study case was:

- “Thermal conductivity” (of the ground) – 2.0 $\frac{W}{mK}$, (assuming wet sand under the slab);
- “Heat capacity” (of the ground) – 2.0 $\frac{MJ}{m^3K}$, (assuming wet sand under the slab);
- “Floor slab area” – 179.1m^2;
- “Floor slab perimeter” – 72.7m;
- “Depth of the Groundwater Table” – 3m, (assumed value);
- “Groundwater Flow Rate” – 0.05$\frac{m}{d}$, (assumed average value from standard range).

The rest of the necessary data is entered automatically from other worksheets. However, it is decisive to select the appropriate floor slab type in “Floor Slab Type” table. In this case, the “x” mark was put in the “Slab on Grade” cell.

The results of this worksheet are as follows:

- “Ground reduction factor”, which is used in calculations for annual heating demand (worksheet “Annual Heating Demand”), resulted in 0.81;
- “Monthly Average Ground Temperatures” which are used in calculations for annual heating demand with the use of monthly method (worksheet “Monthly Method”) is shown in Table 9.

Table 9: Average ground temperatures for each month for a typical house (in °C).

Month	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Winter	5.6	4.2	4.5	6.5	9.6	12.9	15.7	17.1	16.8	14.9	11.8	8.4
Summer	6.2	4.8	5.1	7.1	10.2	13.5	16.3	17.7	17.4	15.5	12.4	9.0

- “Average value of ground temperature” for Winter method – 10.7°C;
- “Average value of ground temperature” for Summer method – 11.3°C;
- “Design Ground Temperature” which is used in calculations of the heating load in the “Heating Load” sheet, resulted in 4.2°C;
- “Design Ground Temperature” which is used in calculations of the cooling load in “Cooling Load” sheet – 17.7°C;

“Winter” and “Summer” methods (see Table 9) of “Monthly Average Ground Temperatures” calculations differ from the indoor temperatures.

5.3.8 Windows worksheet

In this worksheet all necessary data related to windows must be filled in. The entries are filled in the following order:

- “Quantity” – number of windows from each type;
- “Description” – name of each type of window;
- “Deviation from north” – 0° for North, 90° for East, 180° for South, 270° for West;
- “Angle of inclination from the horizontal” - 90° for vertical windows;
- “Width” and “Height” – dimensions of each type of window;
- “Installed” – one should choose appropriate area from the list of areas that was created upon the basis of “Areas” worksheet;
- “Glazing” - one should choose appropriate glazing from the list of glazings that was created upon the basis of “WinType” worksheet;
- “Frame” - one should choose appropriate frame from the list of frames that was created upon the basis of “WinType” worksheet;
- “Installation” – one should choose 1, if the window is an individual opening, or choose 0, if the window frame adjoins with another window frame; also there is a possibility to introduce thermal bridges in respect to windows’ installation.

Having introduced the required information concerning windows, all of the important results may be seen in a summary. It is a table above the one where user fills in entries. The most important values are annual transmission losses through the windows and heat gains from solar radiation. They are presented in Table 10:

Table 10: Annual transmission losses through the windows and heat gains from solar radiation for a typical house.

Window area orientation	*Transmission losses [kWh]*	*Heat gains[kWh]*
North	593	410
East	907	783
South	4351	5128
West	2357	1956
Σ	8208	8277

5.3.9 WinType worksheet

The first objective of this worksheet is to define type of glazing that is used for windows (upper table in this worksheet). Second objective is to define the type of frame for windows (lower table in this worksheet). However, it is also possible to choose both glazing and frame from the default list that is given in this worksheet. In the case of this case study it was defined a new type of:

- Glazing – “Custom glazing”, with the g-value of 0.70; U_g-value of 1.42$\frac{W}{m^2K}$;
- Frame – “Custom frame”, with U_f-values for all of the frame elements of 1.42$\frac{W}{m^2K}$; the width of all frame profiles is 12cm wide.

5.3.10 Shading worksheet

The main goal of this worksheet is to calculate the reduction factor (r_s) for solar gains. It corresponds to the quantity of solar energy (in percentage) that is transmitted through the window into the building spaces. A reduction factor of 100% means that window is completely unshaded. On the contrary, a reduction factor of 0% indicates that the window is completely shaded. In order to determine the respective reduction factors, one should fill in the necessary data, as follows:

- “Height of the shading object”, (h_{hori}) – if there is a shading object, which height is over the bottom window edge; (assumed 0.0m for every type of window);
- “Horizontal distance”, (d_{Hori}) – horizontal distance to the shading object; (assumed 0.0m for every type of window);
- “Window reveal depth”, (o_{Reveal}) – distance glazing level; (assumed 0.10m for every type of window);
- “Distance from glazing edge to reveal”, (d_{Reveal}) – lateral distance of glazing edge to edge of façade; (assumed 0.10m for every type of window);
- “Overhang depth”, (o_{over}) – for example, balcony overhanging; (assumed 0.0m for every type of window);
- “Distance from upper glazing edge to overhang”, (d_{over}) – vertical distance of glazing edge to edge of overhang; (assumed 0.0m for every type of window);
- “Additional shading reduction factor” – other obstacles, for example trees; (assumed 100% (1.0) that means no other obstacles).

Having introduced all required entries, the total reduction factor (r_s) may be calculated. In Table 11 is listed the total reduction factors and total glazing areas for each orientation:

Table 11: Reduction factors for solar gains for a typical house.

Orientation	*Glazing area [m^2]*	*Reduction factor [r_s]*
North	3.18	96%
East	5.07	93%
South	23.49	96%
West	13.30	93%

5.3.11 Ventilation data worksheet

This worksheet enables to define the air flow quantities and air change rate consequent effect over the heat losses caused by ventilation. Entries necessary for the Ventilation worksheet are:

- “Type of ventilation system” – one can choose between “Balanced PH ventilation” (for a building which is a PH) and “Pure extract air” (for not a PH building); in this case a cell next to “Pure extract air” type of ventilation has to be marked;

- “Wind protection coefficient”, (*e*) – for a building in a suburban development with several sides exposed to wind action, a moderate screening effect is assumed. As a result the value 0.07 was entered;
- “Wind protection coefficient”, (*f*) – in respect to case with several sides exposed, a value 15 is used;
- “Air Change Rate at Press. Test”, n_{50} – is the average air change rate at 50Pa pressure difference, assumed maximum value $n_{50} = 0.6h^{-1}$;
- “Net Air Volume for Press. Test” – the volume of heated space (537m^3) was entered;
- “Supply air per person” – assumed the typical value of 30 $\frac{m^3}{h}$;
- “Quantity” – amount of extract air rooms; (entered 1 kitchen and 2 bathrooms);
- “Type of operation” – standard operation with the air change rate value of 0.30^{-1} was chosen;
- “Daily operation duration” – assumed non-stop ventilation system (24 hours per day).

As a result the average air flow rate ($\frac{m^3}{h}$) was calculated. The highest value out of the following three conditions is assumed:

- Total supply air volume – 120$\frac{m^3}{h}$;
- Total extract air - 140$\frac{m^3}{h}$;
- Volume of heated space multiplied by 0.3 and 1.3 (130%) - 210$\frac{m^3}{h}$,

The highest value - 210$\frac{m^3}{h}$ is then reduced by the factor 0.77 corresponding to standard ventilation conditions. Finally, it was obtained a value of 161$\frac{m^3}{h}$ for the average air flow rate.

5.3.12 Specific annual heating demand worksheet

This worksheet sums up all of the heat losses and heat gains. Moreover, in the end it calculates the annual heating demand for a building according to PHPP [42] method. Normally no entries are required in “Annual heating demand worksheet”. However, in this case, it was decided to change clear room height value from default 2.50m to 3.00m (the same height that was applied for calculations according EN 13790 [41]). The change was made, so as the calculation concerning ventilation heat losses according PHPP [42] method would similar and comparable to the one according EN 13790.

Next is presented the final equations and results for total annual heat losses and heat gains:

Transmission Heat Losses (Q_T)

Is the sum of heat losses through the areas of building envelope (Q_{T1}) and through thermal bridges.

Heat losses through the areas of building envelope elements (Q_{T1}) are obtained from the following equation:

$$Q_{T1} = A \times U \times f_t \times G_t \qquad (17)$$

where:

A - building element area, transferred from “Areas” worksheet, [m^2];

U - building element U-value, transferred from “Areas” worksheet, $[\frac{\mathrm{W}}{\mathrm{m^2K}}]$;

f_T - reduction factor for reduced temperature differences, [dimensionless];

G_t - temperature difference time integral (heating degree hours), $[\frac{\mathrm{kKh}}{\mathrm{a}}]$.

Heat losses through the thermal bridges (Q_{T2}) are obtained from the following equation:

$$Q_{T2} = \lambda \times \psi \times f_t \times G_t \qquad (18)$$

where:

λ – length of thermal bridge, [m];

ψ – thermal bridge heat loss coefficient, $[\frac{\mathrm{W}}{\mathrm{mK}}]$;

f_T - reduction factor for reduced temperature differences, [dimensionless];

G_t - temperature difference time integral (heating degree hours), $[\frac{\mathrm{kKh}}{\mathrm{a}}]$.

The total annual transmission heat losses (Q_T) attained in this case study:

$$Q_T = 150.4 kWh/m^2$$

Ventilation Heat Losses (Q_V)

Heat losses through the ventilation (Q_V) are obtained from the following equation:

$$Q_V = V_V \times n_V \times c_{Air} \times G_t \quad (19)$$

where:

V_V – reference volume of the ventilation system, [m^3];

n_v – energetically effective air exchange rate, [dimensionless];

c_{Air} – specific heat capacity of air, assumed $0.33 \frac{\mathrm{Wh}}{\mathrm{m^3K}}$;

G_t – heating degree hours referenced to ambient air, $[\frac{\mathrm{kKh}}{\mathrm{a}}]$.

The total annual ventilation heat losses (Q_V) attained in this case study:

$$Q_V = 27.7 kWh/m^2$$

Available Solar Heat Gains (Q_S)

Available solar heat gains (Q_S) are obtained from the following equation:

$$Q_S = r \times s \times A_W \times G \qquad (20)$$

where:

r – reduction factor, [dimensionless];
g – solar energy transmission coefficient for the glazing, [dimensionless];
A_W – window area, [m^2];
G – total radiation during the heating period, $[\frac{\mathrm{kWh}}{\mathrm{m}^2 a}]$.

The total, annual available solar heat gains (Q_S) in this case study is:

$$Q_S = 46.2 kWh/m^2$$

Internal Heat Gains (Q_I)

Internal heat gains (Q_I) are obtained from the following equation:

$$Q_I = 0.024 \times L \times P \times A \qquad (21)$$

where:

0.024 – hour-day conversion rate, $[\frac{\mathrm{kh}}{\mathrm{d}}]$;
L – length of heating period, days; entered 273 days;
P – specific power gains, $5\frac{\mathrm{W}}{\mathrm{m}^2}$;
A – area; treated floor area; 179.1m^2.

The total, annual internal heat gains (Q_I) attained is:

$$Q_I = 32.8 kWh/m^2$$

Annual Heating Demand (Q_H)

The difference between annual total heat losses and total heat gains (after consideration of gains' utilization factor – η=0.99) is the annual heating demand:

$$Q_H = 100 kWh/m^2$$

On the left side of the worksheet a graph considering heating energy balance is presented. It consists of two columns which stand for total heat losses and total heat gains. Each column is divided into parts that correspond to different fractions of total heat losses and heat gains.

5.3.13 Specific annual heating demand - monthly method worksheet

This worksheet also enables calculation of the annual heating demand. However, due to the use of the monthly method of the EN 13790 [41] the final result may be slightly different than the one obtained from a previous worksheet (Specific annual heating demand; according to EN 13790 annual method). Next is presented differences in the final equations and comparison of results between the two methods:

Transmission Heat Losses (Q_T)

- Apart from the losses through the garage wall, it is not used a reduction factor (f_t) for any other opaque building envelope element;
- Temperature difference time integral (heating degree hours) is different. For ground element - floor slab it is 78$\frac{\text{kKh}}{\text{a}}$, whereas for ambient elements - rest of the opaque building envelope elements it is 104$\frac{\text{kKh}}{\text{a}}$.

The total annual transmission heat losses (Q_T) amounts to:

$$Q_T = 165.0kWh/m^2$$

Ventilation Heat Losses (Q_V)

- Temperature difference time integral (heating degree hours) is different.

The total annual ventilation heat losses (Q_V) calculated is:

$$Q_V = 31.1kWh/m^2$$

Available Solar Heat Gains (Q_S)

- The total radiation during the heating period is different.

The total annual available solar heat gains (Q_S) calculated is:

$$Q_S = 93.4kWh/m^2$$

Internal Heat Gains (Q_I)

- Length of heating period is longer.

The total, annual internal heat gains (Q_I) calculated is:

$$Q_I = 36.4kWh/m^2$$

Annual Heating Demand (Q_H)

The difference between the annual total heat losses and annual total heat gains (after consideration of gains' utilization factor - 0.78) is the annual heating demand:

$$Q_H = 95kWh/m^2$$

On the right side of the worksheet is a table which presents heat losses and heat gains corresponding to each month. Moreover, on the graph below the table are shown monthly heating demands, specific gains and losses.

5.3.14 Climate data worksheet

This worksheet contains all the necessary climate information that is used in all worksheets. Climate data may be chosen from the list with the available locations. Otherwise, it may be defined by the user. In this case, it was decided to use the same data as in the calculations according to EN 13790 [41]. As a result, data from meteorological station in Lodz was provided.

In the case when a different indoor temperature than 20.0°C was determined for a house (for this house was 20.326°C), it is decisive to change formula data in the cell X89. The default value of 20 must be changed to the desirable one. Otherwise, the specific annual heating demand is calculated with the use of 20.0°C what decreases or increases the demand, depending on the value of set indoor temperature. For the specific annual heating demand obtained with the monthly method no changes are required. This worksheet requires no more entries.

5.4 Comparison between results

5.4.1 Introduction

To sum up, annual total heating demand (ATHD) for this case study was calculated with approaches. Firstly, the calculations were done according to EN ISO 13790 “Energy performance of buildings – Calculation of energy use for space heating and cooling” [41]. Secondly, the calculations of ATHD were executed with the use of Passive House Planning Package (PHPP) [42]. In the second approach two final results of ATHD were obtained: first one - according to PHPP-AM (annual method) method and second one - according to PHPP-MM (monthly method). Despite the fact, all of approaches follow EN 13790, the final results are different. Therefore, the main aim of this section is to point out the differences in algorithms which led to final discrepancy between the results. In order to make clarifications simpler and more friendly for the reader, the differences in calculations will be explained in the following order:

i Heat losses:
  - Transmission heat losses
  - Ventilation heat losses

ii Heat gains:
  - Solar gains
  - Internal heat gains

In Table 12 is presented results of calculations for ATHD with the use of different approaches. Moreover, there are listed results of heat losses (transmission and ventilation) and heat gains (solar, internal) obtained for different approaches. All values are given in kilowatt-hours per square meter, year ($\mathrm{kWh/m^2a}$).

Table 12: Comparison of results obtained with different approaches.

		Approach		
		EN 13790	*PHPP*	
			PHPP-AM (Annual Method)	*PHPP-MM (Monthly Method)*
Heat losses	*Transmission*	145.06	150.40	165.00
	Ventilation	38.77	27.70	31.10
Heat gains	*Solar*	76.44	46.20	93.40
	Internal	34.99	32.80	36.40
Annual total heat demand		116.96	100.00	95.00

5.4.2 Transmission heat losses

The differences between transmission heat losses are not relatively high. It refers particularly to the difference between EN 13970 [41] method and PHPP-AM [42] method which is almost 3.6%. Despite the slight difference in results, there are significant dissimilarities in algorithms. The first aspect refers to the ground reduction factor. The calculation values are the following for the different approaches:

- for EN 13790: 0.60;
- for PHPP-AM [42]: 0.81;
- for PHPP-MM [42]: 1.00 (practically no reduction factor).

Thus, it is easily seen that the lowest ground floor losses will be obtained in the calculation according to EN 13790 [41], whereas the highest losses through the ground will be obtained with the calculation according to PHPP-MM [42].

A second dissimilarity was found in the amount of degree days. As it was mentioned at the beginning of Chapter 4, heating will be provided during 9 months – from September to May (without June, July and August). As a result the degree days which should be taken into account are from September to May. However, it is defined only by the EN 13790 [41] method. Despite the fact the information of the heating period was applied to PHPP [42] programme, the amount of degree days differs from the entered one. Thus, PHPP-AM approach takes into account only degree days from October to May. Additionally, a 0.939 reduction factor for degree days from April and 0.499 reduction factor for degree days from May are used. As a result, this reduces transmission heat losses. On the other hand, PHPP-MM approach takes into account degree days from September to June. The presence of June in the calculation of transmission heat losses increases the overall value.

To sum up, higher ground reduction factor (which leads to increased heat losses) and lower value of degree days (which reduces heat losses) for PHPP-AM [42] method bring the result balanced and similar to the one obtained with EN 13790 [41] algorithm. On the contrary, absence of ground reduction factor (which increases heat losses) and higher value of degree days (which increases heat losses even more) for PHPP-MM lead to the highest transmission heat losses.

5.4.3 Ventilation heat losses

In this case, results differ quite significantly. When one compares EN 13790 [41] and PHPP-AM [42] outcomes, it occurs that the difference between them is almost 29%. The reason for significant difference is simple. Namely, in the final equation for ventilation heat losses (19) the air volume (both in PHPP-AM and PHPP-MM method) is not multiplied by 1.3.

As it was shown in the chapter 4.2.7 the decisive air volume condition for EN 13790 [41] calculations is the supply air result of $0.0583\frac{\mathrm{m}^3}{s}$. However, the result of the condition with the factors 1.3 and 0.3 is $0.0582\frac{\mathrm{m}^3}{s}$. Both outcomes are almost the same. That signifies that, if only the 1.3 factor was used in PHPP and PHPP-MM [42] equations it would bring the result of ventilation heat losses very similar to the one obtained with the use of EN 13790. Nevertheless, the results would not be the same due to different values of degree days (which applies to ventilation heat losses the same as was explained in chapter 5.4.2). For the same reason PHPP-AM and PHPP-MM ventilation heat losses are not equal.

5.4.4 Solar gains

Solar gains' difference is the biggest among all heat transfers. Comparing PHPP-AM and PHPP-MM [42] solar gains, it occurs that PHPP-MM gains are twice higher

(200%) than the PHPP-AM result. The result of solar gains obtained with the use of EN 13790 [41] is somewhere in the middle of those values. The reason of these huge discrepancies is again time degree days' case. As it was mentioned in chapter 5.4.2 the value of degree days is the highest for PHPP-MM approach, the lowest for PHPP-AM approach and average in between value for EN 13790 approach. Therefore, in PHPP-MM case, what at first made transmission heat losses the largest of all, now makes the same referring to the solar gains. On the other hand, in the PHPP-AM case, not considering September and reducing the value of degree days for April and May causes a significant drop in solar gains.

Another slight difference related to solar gains is considering opaque areas. In EN 13790 [41] and PHPP-MM [42] algorithm solar gains through the opaque building envelope are considered. It increases total solar heat gains by about 10%. On the contrary, in the PHPP-AM approach solar gains through the opaque building envelope are not considered. As a result it leads to even smaller solar gains.

5.4.5 Internal heat gains

Internal heat gains' results seem to be the most equivalent. The differences between values are between 6 and 10%. However, that does not mean there were not any discrepancies in algorithms. First of all, in EN 13790 [41] approach internal heat gains consist of two sources: internal gains from occupants (and appliances) and internal gains from lighting. The value of heat flow rate from occupants and appliances is the same as in PHPP-AM and PHPP-MM [42] calculations – 5W/m^2. However, the area size varied. In EN 13790 the area which was given for the final equation, that quantifies internal heat gains, consisted only of the following surfaces: living room, kitchen, three bedrooms. In contrast, in PHPP-AM and PHPP-MM algorithms the value of treated floor area was introduced. That fact brought the result of heat gains according to EN 13790 lower in comparison to the result obtained with the use of PHPP-AM or PHPP-MM method. On the other hand, in EN 13790, gains from lighting were taken into consideration, whereas in PHPP-AM and PHPP-MM were not. Due to lighting gains, final results of total internal gains obtained with the EN 13790 approach were very similar to two other approaches.

When one compares results of internal heat gains calculated with the use of PHPP-AM and PHPP-MM there is a 10% difference. It is caused by the duration of heating period. In PHPP-AM the heat period lasts for 8 months (273 days), whereas in PHPP-MM it lasts for 9 months (303 days).

5.4.6 Summary

All in all, despite the discrepancies in PHPP-AM [4] and PHPP-MM [42] algorithms the final results of annual total heating demand differ only by 5%. The main difference between these two approaches is mainly due to the value of degree days. Related to PHPP-MM algorithm higher value leads to higher transmission heat losses (which increases ATHD) and higher solar heat gains (which decreases ATHD). As a result, in the end ATHD is balanced. Furthermore, in PHPP-MM method the utilization factor for gains is used (in PHPP-AM there is also the utilization factor, although its value is 0.99). It is assumed as value of 0.78 and decreases heat gains which at the starting point were much higher than in PHPP-AM method.

The partial results of heat gains and heat losses suggested that EN 13790 [41] algorithm provides the outcomes between those obtained with the use of PHPP-AM and PHPP-MM. However, in the end the ATHD differs about of 15% (in comparison to PHPP-AM method) and 19% (in comparison to PHPP-MM method). This discrepancy is caused mainly by the utilization factor. In EN 13790 [41] method, average utilization is about 64%. It means that heat gains are reduced significantly. As a result the ATHD is clearly higher.

Chapter 6

Energy calculation of a PH according to Passive House Planning Package

6 Energy calculation of a PH according to PHPP

6 Energy calculation of a PH according to Passive House Planning Package (PHPP)

6.1 Introduction

Having calculated a heating demand for a typical contemporary one-family house in Poland, calculations concerning the PH may be presented. In the two previous chapters only annual heating demand was under consideration, since the cooling demand is not an issue for Polish climate. In order to calculate annual heating demand with the use of PHPP [42], only a part of the programme worksheets were used. On the contrary, for a PH also annual cooling demand and primary energy are the decisive results. Therefore, in this chapter, in order to make a PH certification valid all of the PHPP worksheets are necessary to be fulfilled. It was decided that worksheets which have been already described once in the previous chapter, will not be again. In these cases, only changes in data input are listed. Firstly, to make the case study passive, some essential changes in the construction typology of the house were considered. For this reason, in the next subsection are listed alterations in the construction solutions and additional configurations.

6.2 Changes in construction and systems

It is known, that a characteristic feature of every PH is a low U-value of the opaque building envelope elements. Despite, the U-values of the home elements were relatively low, they did not fulfill strict requirements for a PH. The U-value for opaque building envelope element is usually lower than 0.15 $\frac{\mathrm{W}}{\mathrm{m^2K}}$ and less than 0.80 $\frac{\mathrm{W}}{\mathrm{m^2K}}$ for windows (glazing + frame). In order to fulfill these requirements the following changes in construction were implemented:

6.2.1 New external and internal walls solutions

The structure of new exterior wall is shown in Figure 34.

15mm of lime plaster

250mm of aerated concrete on thin dry set mortar (instead of 300mm)

250mm of Styrofoam (instead of 100mm)

15mm of lime plaster

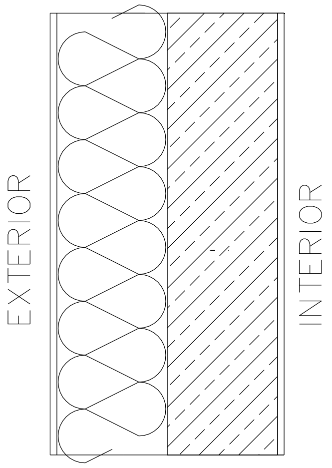


Figure 34: Structure of the new exterior wall.

Interior walls, constructed from aerated concrete, covered on both sides with 15mm wide layer of lime plaster, are 30 cm wide (load-bearing wall) and 11.5 cm wide (internal division wall). The U-value for the exterior wall is 0.130 $\frac{\mathrm{W}}{\mathrm{m^2K}}$.

6.2.2 New floor and roof solutions

The structure of new floor is common for all areas and is composed of following layers as shown in Figure 35.

25mm of self-leveling concrete
100mm of base screed
300mm of Styrofoam (instead of 100mm)
Airtight layer
100mm of concrete screed
200mm of firmed sand

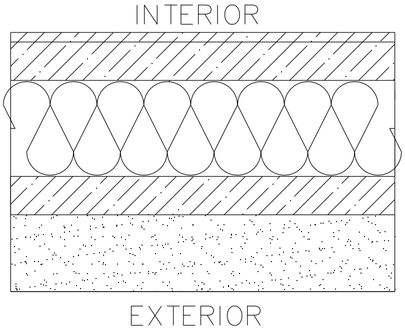
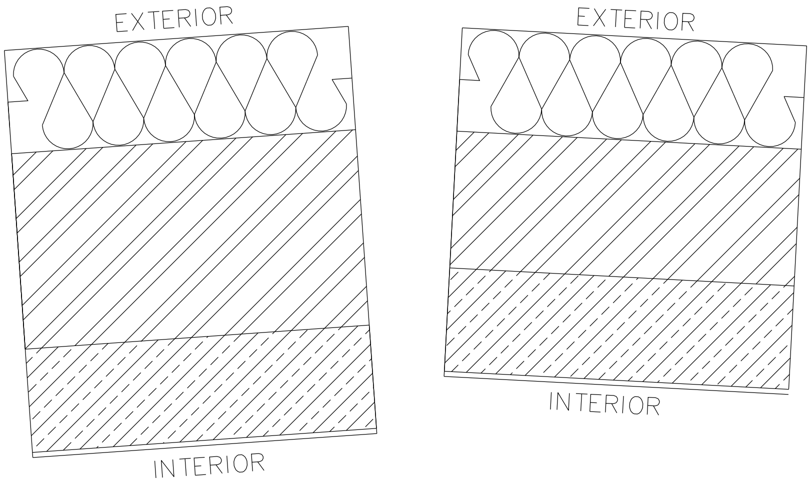


Figure 35: Structure of the floor.

The U-value for new floor is 0.124 $\frac{\mathrm{W}}{\mathrm{m^2K}}$.

The structure of new roof is the same in the whole building and its constitution is shown in Figure 36.

3 layers of building paper
From 0 to 75mm aggregate limestone (slope layer)
300mm of Styrofoam (instead of 100mm)
Airtight layer
From 0 to 397mm (for garage area) and from 0 to 568mm (for conditioned area) of slope layer from aggregate limestone
300mm of concrete layer (load-bearing part)
15mm of limestone plaster



Structure of the roof above conditioned area; slope 4°.

Structure of the roof above garage area; slope 3°.

Figure 36: Structure of new roof.

Due to a small scale of Figure 36, last layers of aggregate limestone (from 0 to 75 mm) are not presented. The U-value for new roof is 0.118 $\frac{\mathrm{W}}{\mathrm{m^2K}}$.

6.2.3 Windows and door

New, passive windows adopted have the U-value for glazing of 0.49 $\frac{\mathrm{W}}{\mathrm{m^2K}}$ and 0.58 $\frac{\mathrm{W}}{\mathrm{m^2K}}$ for window frame (without consideration of glazing and installation thermal bridges). Windows from the code compliant house design had a final U-value of 1.42 $\frac{\mathrm{W}}{\mathrm{m^2K}}$.

6.2.4 Passive systems

In order to meet the respective PH requirements, the house was equipped with several passive systems. To achieve a low value of heating demand and avoid overheating the mechanical ventilation with heat recovery, summer blinds and night summer ventilation are considered. Moreover, so as to decrease the energy demand for DHW preparation a solar panel with the storage of hot water was implemented.

Finally, in order to reduce primary energy demand, energy-saving electric appliances and a combination of two small heat pumps (responsible for producing energy for DHW and space heating) were applied.

6.3 Achieving a PH

6.3.1 Introduction

In the next few subsections there will be a brief description of each worksheet and a characterization of the changed implemented data. However, worksheets which have been already described in the previous chapter will not be described again. Calculating a PH's annual demand requires filling the worksheets which did not need to be filled for a code compliant house. Therefore, in this chapter there are new subsections related directly to a PH design. All of the worksheets for the PH design can be found in Annex 17.

6.3.2 Brief instructions worksheet

The worksheet was described in the 5.3.2 subsection. No additional data entry can be typed here.

6.3.3 Vertification worksheet

The worksheet was described in the 5.3.3 subsection. One change was introduced - the value of “Interior Temperature” was set on 20.0°C instead of 20.326°C

6.3.4 Areas determination

The worksheet was described in the 5.3.4 subsection. Changes in “Thermal Bridge Input” table were implemented:

- Thermal bridges related to windows and exterior door were not considered in this worksheet. They will be considered only in “WinType” worksheet, since “WinType” worksheet provides specific cells for frame and installation thermal bridges.
- After changes in the construction of the opaque envelope elements, it occurred that only two thermal bridge calculations are still valid: Corners between exterior walls (“Ext. wall corner”) and Connection between interior wall and garage wall (“Corner Ext-Int. Wall- garage”). Since the rest of the

thermal bridges changed configuration (the ψ-value changed to lower value due to higher thermal insulation layer), it was decided not to enter them in “Thermal Bridge Input” for a PH design (since they are very low – below 0).

Finally, the sum of all areas of opaque building envelope elements was calculated - 554.20m^2 (the same as in the previous calculation). The average U-value of thermal envelope (opaque envelope + windows) reduced from 0.571 $\frac{\mathrm{W}}{\mathrm{m}^2\mathrm{K}}$ to 0.183 $\frac{\mathrm{W}}{\mathrm{m}^2\mathrm{K}}$.

6.3.5 U-List worksheet

The worksheet was described in the 5.3.5 subsection. No additional data entry is needed in this worksheet. In Table 13 are listed building assemblies with corresponding thickness and U-values for the opaque envelope.

Table 13: Assemblies with their thicknesses and U-values (for a PH design).

Assembly description	*Total thickness [m]*	*U [$\frac{W}{m^2K}$]*
Exterior wall	0.580	0.130
Roof	0.909	0.118
Ground floor	0.557	0.124
Garage wall south[1]	0.592	0.128
Garage wall west[1]	0.414	0.141
Part of exterior wall with the ring beam	0.580	0.151

6.3.6 U-Values of building elements worksheet

The worksheet was described in the 6.2.6 subsection. Changes in construction of opaque building envelope according to subsection 6.2 were entered.

6.3.7 Heat losses via the ground worksheet

The worksheet was described in the 5.3.7 subsection. The most important results of this worksheet are as follows:

- “Ground reduction factor”, which is used in calculations for annual heating demand (“Annual Heating Demand” worksheet) - 0.65 (instead of 0.81);

- “Monthly Average Ground Temperatures” which are used in calculations for annual heating demand with the use of monthly method (worksheet “Monthly Method”) is shown in Table 14.

Table 14: Average ground temperatures from January to December for a PH (in °C).

Month	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Winter[1]	7.4	6.3	6.4	7.6	9.6	11.9	13.8	14.8	14.7	13.5	11.5	9.3
Summer[1]	8.0	6.9	7.0	8.2	10.2	12.5	14.4	15.4	15.3	14.1	12.1	9.9

- “Average value of ground temperature” for Winter method – 10.6°C (instead of 10.7°C);
- “Average value of ground temperature” for Summer method – 11.2°C (instead of 11.3°C);
- “Design Ground Temperature” which is used in calculations of the heating load in “Heating Load” sheet - 6.3°C (instead of 4.2°C);
- “Design Ground Temperature” which is used in calculations of the cooling load in “Cooling Load” sheet – 15.4°C (instead of 17.7°C);

Winter and Summer methods of “Monthly Average Ground Temperatures” calculations differ from the indoor temperatures.

6.3.8 Windows worksheet

The worksheet was described in the 5.3.8 subsection. The data concerning installation and frame thermal bridges was automatically transferred from the “WinType” worksheet. The most important results of annual transmission losses through the windows and heat gains from solar radiation are presented in a Table 15:

Table 15: Annual transmission losses through the windows and heat gains from solar radiation for a PH.

Window area orientation	*Transmission losses [kWh]*	*Heat gains[kWh]*
North	266	162
East	401	539
South	1814	5098
West	1035	1408
Sum	3516	7207

6.3.9 WinType worksheet

The worksheet was described in the 5.3.9 subsection. New data was implemented for glazing and window frame selection. Types of glazing and window frame were chosen from the default lists:

- Glazing – “INTERPANE - iplus 3CE (4:/12/4/12/:4 Krypton 90%)”, with the g-value of 0.50; U_g-value equals 0.49 $\frac{\mathrm{W}}{\mathrm{m^2K}}$;
- Frame – “FIX Glas Trösch - Composite Glazing - Festverglasung - withSuperSp. TriSeal PU”, with U_f-values for frame elements of 0.58 $\frac{\mathrm{W}}{\mathrm{m^2K}}$; the width of posts and beams are assumed 0.016m (previously 0.12m).

Moreover, the values of installation and glazing edge thermal bridges were generated:

- Glazing edge thermal bridge - for left, right, bottom and top glazing edge - $\psi_g = 0.029\,\frac{\mathrm{W}}{\mathrm{mK}}$;
- Installation thermal bridge – for all sides - $\psi_{inst} = 0.040\,\frac{\mathrm{W}}{\mathrm{mK}}$;

6.3.10 Shading worksheet

The worksheet was described in the 5.3.10 subsection. Entries that were changed are listed below:

- “Window reveal depth”, (o_{Reveal}) – distance glazing level; assumed 0.20m for every type of window (previously 0.10m);

- “Distance from glazing edge to reveal”, (d_{Reveal}) – lateral distance of glazing edge to edge of façade; assumed 0.08m for every type of window (previously 0.12m);

Having introduced all of the required entries, a total reduction factor (r_s) may be calculated. In Table 16 is shown total reduction factors and sums of glazing areas for each side of the house:

Table 16: Reduction factors for solar gains for a PH.

Orientation	*Glazing area [m^2]*	*Reduction factor [r_s]*
North	4.31	93%
East	6.62	88%
South	31.66	93%
West	17.23	88%

6.3.11 Ventilation data worksheet

The worksheet was described in the 5.3.11 subsection. Entries that changed are:

- “Type of ventilation system” – “Balanced PH ventilation” instead of “Pure extract air” ventilation was chosen;
- “Net Air Volume for Press. Test” – the result of multiplication the TFA (179.1m^2) and the height (2.5m instead of 3.0m) was entered;

The value of 2.5m of height was entered, because it is a recommended maximum value of room height for calculations concerning a PH (according to PHPP manual).

As a result, the average air flow rate was calculated. It is to be assumed the highest value out of the following three:

- Supply air volume – 120$\frac{m^3}{h}$;
- Total extract air - 140$\frac{m^3}{h}$;
- Volume of heated space multiplied by 0.3 and 1.3 - 175$\frac{m^3}{h}$,

The highest value - $175\frac{\mathrm{m}^3}{\mathrm{h}}$ is then reduced by the factor 0.77. Finally, it was obtained a value of $134\frac{\mathrm{m}^3}{\mathrm{h}}$ for the average air flow rate.

In Figure 37 is shown the scheme of ventilation ducts in a considered PH (the sheme with smaller scale is also presented in Annex 18). Green ducts and areas correspond to supply air, whereas red correspond to extract air. Next to every ventilation outlet is presented the value (in $\frac{\mathrm{m}^3}{\mathrm{h}}$) which refers to amount of air supplied or extracted, respectively.

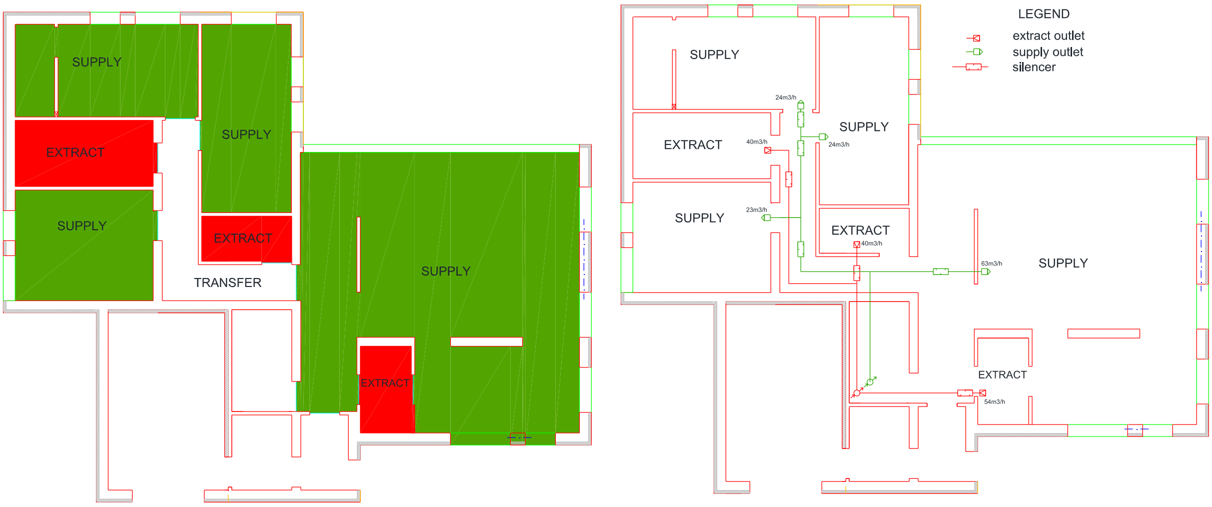


Figure 37: Supply and extract air ventilation ducts and areas.

After entering all above data, some more entries must be made. In “Selection of ventilation unit with heat recovery” section one of two cells must be filled in with the “x” sign. The choice depends on whether a central unit is within the thermal envelope or outside of the thermal envelope. Below, a type of ventilation unit (from the list in “Ventilation unit selection” section) must be chosen. The list with certified heat recovery units with their characteristics is available at the bottom of the worksheet. A few next entries refer to air duct characterization. One must fill in the cells:

- “Length of outdoor air duct” – assumed 25.0m;
- “Length of exhaust air duct” - assumed 20.0m;

- "Temperature of mechanical services room" - assumed 20.0°C
- "SHX efficiency" – assumed 33%;
- "Nominal width of the ambient air duct" – assumed 150mm;
- "Insulation Thickness of the ambient air duct" - assumed 200mm;
- Whether the ambient air duct is reflective or not – assumed not reflective;
- "Thermal conductivity of the ambient air duct" – assumed 0.05 $\frac{W}{mK}$;
- "Nominal width of the exhaust air duct" – assumed 150mm;
- "Insulation Thickness of the exhaust air duct" - assumed 200mm;
- Whether the exhaust air duct is reflective or not – assumed not reflective;
- "Thermal conductivity of the exhaust air duct" – assumed 0.05 $\frac{W}{mK}$.

Having filled all the necessary data, the effective heat recovery efficiency may be calculated. For this particular case the result is 77.5%.

6.3.12 Specific annual heating demand worksheet

The worksheet was described in the 5.3.12 subsection. No additional data entry is needed in this worksheet. Below are presented final results of total annual heat losses and heat gains:

Transmission Heat Losses (Q_T)

$$Q_T = 45.6 \ \frac{\mathrm{kWh}}{\mathrm{m}^2}$$

Ventilation Heat Losses (Q_V)

$$Q_V = 7.5 \ \frac{\mathrm{kWh}}{\mathrm{m}^2}$$

Available Solar Heat Gains (Q_S)

$$Q_S = 40.2 \frac{\mathrm{kWh}}{\mathrm{m}^2}$$

Internal Heat Gains (Q_I)

$$Q_I = 11.0 \frac{\text{kWh}}{\text{m}^2}$$

Annual Heating Demand (Q_H)

The difference between annual total heat losses and annual total heat gains (after consideration of gains’ utilization factor - 0.85) leads to the annual heating demand of:

$$Q_H = 9.6 \frac{\text{kWh}}{\text{m}^2}$$

6.3.13 Specific annual heating demand - monthly method

The worksheet was described in the 5.3.13 subsection. No additional data entry is needed in this worksheet. Below are presented final results of total annual heat losses and heat gains:

Transmission Heat Losses (Q_T)

$$Q_T = 36.6 \frac{\text{kWh}}{\text{m}^2}$$

Ventilation Heat Losses (Q_V)

$$Q_V = 6.0 \frac{\text{kWh}}{\text{m}^2}$$

Available Solar Heat Gains (Q_S)

$$Q_S = 23.3 \frac{\text{kWh}}{\text{m}^2}$$

Internal Heat Gains (Q_I)

$$Q_I = 7.6 \frac{\text{kWh}}{\text{m}^2}$$

Annual Heating Demand (Q_H)

The difference between annual total heat losses and annual total heat gains (after consideration of gains' utilization factor - 0.94) is the annual heating demand:

$$Q_H = 13.5 \frac{\mathrm{kWh}}{\mathrm{m^2}}$$

The obtained difference of 3.9 $\frac{\mathrm{kWh}}{\mathrm{m^2}}$ between the result of heating demand with the use of annual method and monthly method is the cause of discrepancies in both algorithms. These discrepancies were described in subsection 5.4.

6.3.14 Specific space heating load worksheet

Annual demand for space heating may be calculated according to "Specific annual heating demand" or "Specific annual heating demand - monthly method" worksheet. In order to meet PH space heating requirement at least one of these demands must be less than 15 $\frac{\mathrm{kWh}}{\mathrm{m^2}}$. However, there exists also a third approach to calculate heating demand of a PH – "Specific space heating load" worksheet. Based on the result of dynamic building simulation with specific datasets, it was proven that the maximum heating load occurs in one of two situations [PHPP]:

i) On a cold but sunny winter day with a cloudless sky, or;
ii) On a moderately cold but overcast day with minimal solar radiation. (in accordance with PHPP).

Therefore, in the "Heating load" worksheet a comparison of the heating load for these two different climate conditions is provided. The structure of the algorithm is the same as in "Specific annual heating demand" and "Specific annual heating demand - monthly method" worksheets. Firstly, the transmission heat losses and ventilation heat losses are calculated. Then, solar heat gains and internal heating gains are obtained. Nevertheless, the main difference (in comparison to two previous worksheets) is that all the results are obtained for only two design days (not for the whole year). Moreover, the results are in Watts. The maximum, acceptable value of heating load is 10 $\frac{\mathrm{W}}{\mathrm{m^2}}$. The heating load ($P_H$) for this particular case is 14.7 $\frac{\mathrm{W}}{\mathrm{m^2}}$.

Clearly, the requirement of heating load is not fulfilled. However, it is not a decisive factor since the two previous requirements of 15 $\frac{\mathrm{kWh}}{\mathrm{m}^2 a}$ of heating demand were fulfilled. The only data entry needed in this part of worksheet is the value of “Input Maximum Supply Air Temperature”. For the considered house a value of 52°C was assumed.

At the bottom of the “Specific space heating load” worksheet one more crucial answer is given - whether the additional heating system to maintain set indoor temperature is necessary or not. In this case, when the value of heating load (P_H) is bigger than a value of supply air max ($P_{supply,max}$) the additional heating system is necessary. For the considered house the value of $P_{supply,max}$ is 9.3 $\frac{\mathrm{W}}{\mathrm{m}^2}$, whereas the value of P_H is 14.7 $\frac{\mathrm{W}}{\mathrm{m}^2}$. Since P_H is bigger than $P_{supply,max}$ an additional heating system must be provided – small radiators in the biggest compartment and bathrooms.

On the right side of the “Specific space heating load” worksheet is one more calculation tool – “Risk Determination of Group Heating for a Critical Room”. It determines if the critical heating load applies to the specific room. In this particular case the following data concerning living room the biggest compartment of the house and extensively glazed was entered:

- “Room floor area” – 62m^2;
- “Planned ambient air quantity for the room” – 63m^3/h;
- Area of the “Aboveground Exterior Wall” – 45.1m^2;
- U-value of the “Aboveground Exterior Wall” – 0.13$\frac{\mathrm{W}}{\mathrm{m}^2\mathrm{K}}$;
- Area of the “Roof” – 62.0m^2;
- U-value of the “Roof” – 0.12$\frac{\mathrm{W}}{\mathrm{m}^2\mathrm{K}}$;
- Area of the “Windows” – 27.5m^2;
- U-value of the “Windows” – 0.65$\frac{\mathrm{W}}{\mathrm{m}^2\mathrm{K}}$;

Below, more data must be entered. One must put “1” if the described situation applies to the considered room or “0” if it does not. The value of “1” was put only in the section named “Room is on the ground floor”. Rest of the cases did not apply for this room. Finally, total room risk value with the appropriate comment may be obtained. For the living room the value of 15.9% was a result. The score was commented as “normally not a problem”

6.3.15 Summer worksheet

This worksheet gives the response if the additional window protection measures are necessary for the PH. First two entries (at the top of the worksheet) that must be made are:

- “Specific Capacity” – the effective thermal storage capacity of the building; assumed 204 $\frac{\mathrm{Wh}}{\mathrm{m^2K}}$;
- “Overheating limit” – the maximum temperature for an indoor comfort; assumed 25°C.

Next, data in the “Summer ventilation” section must be entered. In this part of the worksheet, one defines a type of the summer ventilation. For the considered PH, it was assumed that two types of summer ventilation will be provided. First - mechanical ventilation (with the sub-soil heat exchanger) with the corresponding exchange rate of 0.30 per hour. Second - ventilation through the windows during the night, with the corresponding exchange rate of 0.43 per hour (data from “Summer ventilation” worksheet). Last cell to fill is “Minimum Acceptable Indoor Temperature”. A temperature of 22°C was given as a minimum acceptable indoor temperature.

Having entered all the necessary data, a “Frequency of Overheating” value may be received. If this value exceeds 10%, then additional measures to protect against summer heat waves are necessary. In the considered case a value of 0.0% was obtained. As a result, no additional measures are needed.

6.3.16 Shading – Summer worksheet

This worksheet enables to calculate the shading factor for solar gains in summer. It consists of two tables: first at the top of the worksheet - with the final results of shading factors with respect to each side of the building, second - lower to the previous one – with the necessary data. Most of the data is transferred to this table from the “Shading” worksheet. However, two columns must be filled in:

- “Additional Shading Reduction Factor (Summer)”, (r_{other}) – assumed the same as in “Shading” worksheet – no additional shading;
- “Reduction factor z for temporary sun protection”, (z) – entered a value of 0.37. It is the result of the assumption of that blinds, lamellas at the angle of 45° on the exterior position will be provided for the house [PHPP].The results of this worksheet are shown in Table 17:

Table 17: Summer shading factors with respect to the orientation.

Orientation	*Glazing area [m^2]*	*Summer shading factor (r_s)*
North	4.31	35%
East	6.62	35%
South	31.66	34%
West	17.23	35%

6.3.17 Summer Ventilation worksheet

Calculations in “Summer Ventilation” worksheet lead to a value to for the air change rate during the summer may be obtained. In order to calculate this value the following entries must be made:

- “Description” – it was decided, that additional ventilation will be provided through the windows opening on the South (first group - “south narrow”, second group - “south wide”) and East (third group - “east narrow”, fourth group - “east wide”).
- “Fraction of Opening Duration” – it was decided, that considered windows will be opened during 12 cooler hours of the summer day (21h in the evening to 9h in the morning). Therefore, a value of 50% was entered.
- “Temperature Diff Interior – Exterior” – for a night ventilation a default value of 1K of difference was applied;
- “Wind Velocity” - for a night ventilation a default value of 0 $\frac{\mathrm{m}}{\mathrm{s}}$ was applied;
- “Quantity” – 8 of “south narrow”, 2 of “south wide”, 2 of “east narrow”, 1 of “east wide” windows. Attention: if a cross ventilation situation is modeled (like

in the considered case) the rest of the information considering windows on the other side of the house (in this example groups three and four) must be put in a lower part of the table (“Cross Ventilation”);

- “Clear width” – 1.00m for narrow windows and 1.50m for wide windows;
- “Clear height” – 2.75m for all the windows;
- “Tilting Windows?” – assumed that all the windows are tilted;
- “Opening Width (for tilting windows)” – assumed 5cm of opening width for all the windows.

At the bottom of the worksheet a contribution to the air change rate with the respect to every group of windows is calculated. Overall contribution to the air change rate equals 0.43 per hour. This value was used in the “Summer” worksheet when the “Additional Summer Ventilation for Cooling” was considered.

6.3.18 Cooling worksheet

The main objective of this worksheet is to calculate the cooling demand – how much heat (only sensible portion) must be extracted from the house to obtain a comfortable indoor climate. Therefore, firstly heat losses (Q_L) are calculated. Then, heat loads are estimated (Q_F). At the end, the sum of heat loads (Q_F) is reduced by useful heat losses ($Q_{V,n}$) (heat losses multiplied by the utilization factor). The result of the last reduction is the value of cooling demand. All the results in this worksheet refer only to the cooling period. Below are presented final results for heat losses and heat loads:

Transmission Heat Losses (Q_T)

$$Q_T = 4.9\,\frac{\mathrm{kWh}}{\mathrm{m}^2}$$

Ventilation Heat Losses (increased by summer ventilation heat losses) *(Q_V)*

$$Q_V = 7.9\,\frac{\mathrm{kWh}}{\mathrm{m}^2}$$

Available Solar Heat Gains (Q_S)

$$Q_S = 8.9\,\frac{\mathrm{kWh}}{\mathrm{m}^2}$$

Internal Heat Gains (Q_I)

$$Q_I = 2.4\,\frac{\mathrm{kWh}}{\mathrm{m}^2}$$

Annual Cooling Demand (Q_K)

$$Q_K = 0.5\,\frac{\mathrm{kWh}}{\mathrm{m}^2}$$

A limiting value of PH requirement concerning cooling demand is 15 $\frac{\mathrm{kWh}}{\mathrm{m}^2}$. Obviously a requirement is easily fulfilled.

On the right side of this worksheet is a table which presents heat losses and heat gains corresponding to each month. Moreover, on the graph below the table are presented monthly heat losses and gains as well as specific cooling demand. No additional data entry is needed in this worksheet.

6.3.19 Compressor cooling units worksheet

This worksheet enables to calculate the latent energy required for dehumidification. One can also choose one out of four systems of indoor air cooling strategy: “Supply Air Cooling”, “Recirculation Cooling”, “Additional Dehumidification” and “Panel Cooling”. Upon the calculations in the previous worksheet, cooling is practically not a case in the considered house. However, in order to obtain the final results for cooling one of the systems must be chosen. Therefore, a “Supply Air Cooling” system with “On/Off Mode” was assumed. The “Minimum Temperature of Cooling Coil Surface” was set as 5°C. As a result 0.07 $\frac{\mathrm{kWh}}{\mathrm{m}^2}$ of energy is needed for dehumidification. The value is so low that it is negligible.

6.3.20 Cooling load worksheet

This worksheet has an analogous arrangement as the “Specific space heating load” worksheet. Its main objective is to calculate the cooling load during the summer design day. In order to do this, firstly ventilation and transmission heat losses are calculated. Then, solar and internal heat loads are generated. In the end, difference between heat losses and heat gains determines the specific maximum cooling load.

The result for the considered house is 10.7 $\frac{\mathrm{W}}{\mathrm{m}^2}$. The last row of this worksheet presents “Daily Temperature Swing due to Solar Load”. Its value should be less than 3K. For this particular case the value of 1.5K was obtained. As a result the requirement concerning daily temperature swing is fulfilled. No additional data entry in needed in this worksheet.

6.3.21 DHW+Distribution worksheet

This tool enables to calculate heat losses associated to the space heating distribution system, preparation of domestic hot water (DHW) and distribution and storage of DHW. In order to calculate heat losses through the heating distribution system, the following information must be provided:

- “Length of Distribution Pipes” – 25.00m of pipe in the warm region and 0m in the cold region;
- “Heat Loss Coefficient per m of pipe” – 0.172$\frac{\mathrm{W}}{\mathrm{mK}}$; the value calculated with the use of calculation tool – “Secondary Calculation: Ψ-Values of Plumbing” on the right side of the worksheet; assumptions made: “nominal width” - 155mm, “insulation thickness” – 100mm, reflective duct, “thermal conductivity” - 0.024$\frac{\mathrm{W}}{\mathrm{mK}}$;
- “Temperature of the Room Through Which the Pipes Pass” – 20.0°C for the warm region and 9.2°C for the cold region;
- “Design Flow Temperature” – 55.0°C (hot water in radiators);
- “Design System heating load” – 2.0kW;
- “Flow Temperature Control“ – checked.

The annual losses of the space heating system were estimated as 124 $\frac{\mathrm{kWh}}{\mathrm{a}}$, that is 0.7 $\frac{\mathrm{kWh}}{\mathrm{m}^2\mathrm{a}}$.

Next, heat losses for preparing DHW were calculated. It was assumed that 25 litres of DHW is consumed per person. As a result, annual losses for preparing DHW were estimated on 2148 $\frac{\mathrm{kWh}}{\mathrm{a}}$, that is 12.0 $\frac{\mathrm{kWh}}{\mathrm{m}^2\mathrm{a}}$.

Finally, heat losses of the distribution and storage of DHW were calculated. The following entries were given:

- “Length of Circulation Pipes” – 25.00m of pipes in the warm region and 1.50m in the cold region;
- “Heat Loss Coefficient per m of pipe” – 0.193$\frac{\mathrm{W}}{\mathrm{mK}}$; the value calculated with the use of calculation tool – “Secondary Calculation: Y-Values of Plumbing”;
- “Temperature of the Room Through Which the Pipes Pass” – 20.0°C for the warm region and 9.2°C for the cold region;
- “Design Flow Temperature” – 60.0°C (standard);
- “Daily circulation period of operation“ – 18 hours a day;
- “Total Length of Individual Pipes” – 28.0m (only in warm region);
- “Exterior Pipe Diameter” – 0.016m (only in warm region);
- “Average Heat Released From Storage” – 104W; the value calculated with the use of calculation tool – “Secondary Calculation Storage Losses”

As a result, annual heat losses on distribution and storage of DHW were estimated on 3159 $\frac{\mathrm{kWh}}{\mathrm{a}}$, that is 17.6 $\frac{\mathrm{kWh}}{\mathrm{m^2a}}$.

6.3.22 Solar DHW worksheet

In this worksheet one is able to obtain an amount of solar energy (with the use of solar collectors) that is used to prepare DHW. The entries that must put in this worksheet are:

- “Selection of collector from list” – Improved flat plate collector (number 7 from the list) was chosen;
- “Solar Collector Area” – assumed 5.0m^2;
- “Deviation from North” - 180°C;
- “Angle of Inclination from the Horizontal” - 3°;
- “Height of the Collector Field” – 1.0m;
- “Height of Horizon” (height of the shading object above lower edge of the collector) – 0.40m;
- “Horizontal Distance” (distance from the shading object) – 6.0m;

- “Additional Reduction Factor Shading” – 100% (no additional shading).

Having filled all the necessary cells, the result of “Estimated Solar Fraction of DHW Production” was 37% (1956 $\frac{\mathrm{kWh}}{\mathrm{a}}$ that is 11 $\frac{\mathrm{kWh}}{\mathrm{m^2a}}$). Below is a tool that calculates heat losses by DHW storage. Having chosen from the list a “Stratified solar storage” with the identifier number of “10”, total storage losses were estimated as 104W. Below the calculation tool is a graph that shows “Radiation on Tilted Collector Surface”, “Monthly Solar Fraction”, “Total Monthly Heating Load DHW Production” and “Monthly Heating Load Covered by Solar”.

6.3.23 Electricity worksheet

This worksheet sums up the electricity energy demand of all electricity powered appliances (apart from services for DHW and heat pumps). The calculation of electricity may be provided in two ways. First - using the value of planned number of occupants as a basis and second - using the TFA value. In this case, it was considered the number of occupants, therefore a “Design” option must have been chosen in the “Vertification” worksheet. Generally, the maximum recommended electricity demand for a PH (Primary Energy demand) is 50 $\frac{\mathrm{kWh}}{\mathrm{m^2a}}$. However, this value may be exceeded, because it is not a decisive requirement. The decisive requirement is the one with the overall Primary Energy demand - 120 $\frac{\mathrm{kWh}}{\mathrm{m^2a}}$. The final result for electricity demand for the considered house was 62.2 $\frac{\mathrm{kWh}}{\mathrm{m^2a}}$. No additional data entry was provided in this worksheet.

6.3.24 Aux Electricity worksheet

This worksheet calculates the electricity that is consumed on running and controlling the following systems: heating, ventilation, solar thermal systems and DHW. In respect to the considered PH, it was decided that auxiliary electricity will be spent on: winter and summer ventilation systems, heat exchanger defroster, circulation pump of heating system, circulation pump and storage load pump for DHW system and solar auxiliary electricity systems. Furthermore, it was decided that all of the above appliances (apart from the solar auxiliary electricity system) will be placed within the thermal envelope. Finally, the result of the primary energy for auxiliary electricity was 12.7 $\frac{\mathrm{kWh}}{\mathrm{m^2a}}$.

6.3.25 Primary energy value worksheet

In this worksheet one can determine the way how space heating and DHW demands are covered. One can choose the source of the energy from the following types:

- Electric space heating and DHW boilers;
- Heat pump;
- PH compact units with electric heat pump;
- Combined heat pump;
- Boilers;
- District heating;
- Others solutions.

Moreover, there is a possibility to combine different heating and DHW systems. In order to do this, one should put the percentage of total demand in “Covered Fraction of Space Heating Demand” cell (for space heating) and the percentage of total demand in “Covered Fraction of DHW Demand” cell (for DHW) for each source. Having chosen appropriate types of energy sources, at the bottom of the worksheet the final result of primary energy is shown. The PH primary energy limiting requirement is 120 $\frac{\mathrm{kWh}}{\mathrm{m^2a}}$. Moreover, below the primary energy result, is presented the equivalent total annual emission of carbon dioxide. For the considered house it was decided that both space heating and DHW demand will be fully satisfied by a combined heat pump device. Therefore, a value of 100% was entered in the cells corresponding to this type of system. Finally, the result of 93.9 $\frac{\mathrm{kWh}}{\mathrm{m^2a}}$ of primary energy was obtained and 24.6 $\frac{\mathrm{kg}}{\mathrm{m^2a}}$ of carbon dioxide emission equivalent.

Next, few worksheets refer to the different types of energy systems. However, for the considered house only a combined heat pump system was chosen. Therefore, only this worksheet will be described.

6.3.26 Combined heat pump worksheet

Combined heat pump works in the same manner as a compact heat unit. Nevertheless, the main difference between these two systems is that a combined heat pump uses separate heat pumps for space heating and DHW production. The only entries that must be made in this worksheet are: first - the choice of combined heat pump device from the list, second -whether the heat for the frost protection is fed by the heat pump or using direct electricity, third – subsoil heat exchanger efficiency. For the considered house a HP-Combi, type 1 Proxon-PH-S was chosen. Frost protection will be provided with the use of auxiliary energy. Finally, efficiency of subsoil heat exchanger was estimated as 33%.

Having chosen a combined heat pump unit and filled in all the necessary data, the total primary energy demand may be obtained. For this case, it was obtained 31.3 $\frac{\mathrm{kWh}}{\mathrm{m^2a}}$, whereas the annual carbon dioxide emission equivalent was 8.2 $\frac{\mathrm{kg}}{\mathrm{m^2a}}$. These two values were automatically transferred to the “Primary Energy” worksheet.

6.3.27 Climate data worksheet

Last considered worksheet is “Climate data”. In contrast to calculations concerning a code compliant house, it was decided to use a default climatic data from PHPP. Therefore, “Regional climate data” option was chosen from the first list, “N-Europe” region was chosen from the second list, and finally “PL-Strefa 2 (Poznan/Pila) was chosen as a regional climate. No more additional entries are needed in this worksheet.

6.4 Synthesis of PH design strategy

The main goal of this chapter was to adapt the project the code compliant house to the PH standards. First requirement to fulfill was the annual heating demand. The value of this parameter before implemented changes was:

- 116.97 $\frac{\mathrm{kWh}}{\mathrm{m^2a}}$ calculated in accordance with EN 13790 [41];
- 100 $\frac{\mathrm{kWh}}{\mathrm{m^2a}}$ calculated in accordance with PHPP standard (annual method) [42];
- 95 $\frac{\mathrm{kWh}}{\mathrm{m^2a}}$ calculated in accordance with PHPP standard (monthly method) [42].

Redefining the insulation layer of all opaque building envelope elements and implementing passive windows decreased the annual space heating demand to 9.6 $\frac{\mathrm{kWh}}{\mathrm{m^2a}}$ (calculated in accordance with PHPP standard) or 13.5 $\frac{\mathrm{kWh}}{\mathrm{m^2a}}$ (calculated in accordance with PHPP standard, monthly method). The limiting value of the annual space heating demand for a PH is 15 $\frac{\mathrm{kWh}}{\mathrm{m^2a}}$. Even though, it is necessary that only one of the calculated demands is less than 15 $\frac{\mathrm{kWh}}{\mathrm{m^2a}}$, both obtained values were lower than 15 $\frac{\mathrm{kWh}}{\mathrm{m^2a}}$ for the PH. Therefore, the fact that the heating load is higher than required (4.7 $\frac{\mathrm{W}}{\mathrm{m^2}}$ more than required) is not relevant. Thus, the a house fulfills the first compliance criteria for a PH.

The second, requirement that must be met in order to obtain a PH design approval contains of the annual space cooling demand and overheating maximum percentage. The limiting value for annual space cooling demand is 15 $\frac{\mathrm{kWh}}{\mathrm{m^2a}}$, whereas for overheating is 10%. Due to the use of mechanical ventilation and summer night ventilation the result of calculations of annual space cooling demand decreased to 0.5 $\frac{\mathrm{kWh}}{\mathrm{m^2a}}$, whereas overheating to 0%. Thus, the considered house fulfills the second compliance criteria for a PH.

Third and last requirement regarding primary energy must be met by a PH. In order to fulfill this requirement the value of annual primary energy must be less than 120 $\frac{\mathrm{kWh}}{\mathrm{m^2a}}$. The calculated value in the project was 93.9 $\frac{\mathrm{kWh}}{\mathrm{m^2a}}$. The factors that contributed to such a low demand for primary energy were well isolated space heating and DHW ducts, use of solar energy to support the production of DHW, energy saving heat pumps and efficient electricity appliances and lighting.

To summarize, the considered house meets all of the requirements given for a PH. Nevertheless, in order to obtain calculated demands in reality, it is crucial to construct the building using the same materials and appliances that were introduced in the PHPP calculations. Moreover, reasonable and serious planning, as will be further on discussed is decisive. Owing to this, one can be sure that designed house will gain a

PH certificate. In Table 18 is shown basic demands and features obtained for the considered PH.

Table 18: Most important results.

Demand/feature	*Result*
Space heating demand	13.5 $\frac{\mathrm{kWh}}{\mathrm{m^2a}}$
Heating load	14.7 $\frac{\mathrm{W}}{\mathrm{m^2}}$
Cooling load	0.5 $\frac{\mathrm{kWh}}{\mathrm{m^2a}}$
Frequency of overheating	0.0%
DHW, space heating and auxiliary electricity	43.9 $\frac{\mathrm{kWh}}{\mathrm{m^2a}}$
Primary energy	93.9 $\frac{\mathrm{kWh}}{\mathrm{m^2a}}$
Airtightness	0.6 h^{-1}

6.5 Economic analysis

6.5.1 Introduction

The purpose of this subsection is to give a reliable answer for the economic viability of a PH in Polish climate as a cost-effective approach. In order to do this a comparison between costs of the code compliant house and the PH will be presented. The most important result will be the payback period of the PH, before becoming profitable.

The investment evaluation was performed based on the mathematical model - Net Present Value. The Net Present Value determines the net present value of an investment using discount rates. This method is rigorous and technically flawless. The equation for the net present value looks as follows:

$$NPV = \sum_{t=0}^{N} \frac{CF}{(1+p)^t} \qquad (18)$$

where:

N - number of time intervals;
t - reference range from the reference point; (year);
CF - capital at a given time; (year);
p - the interest rate.

6.5.2 Costs and rates

This economical study describes the situation when both a PH and a code compliant house are constructed in Lodz, Poland. In Tabel 19 presented the approximate costs of code compliant house and a PH in Poland. Moreover, in the Table 19 presented the additional investment which must be made to construct a PH. These costs were estimated with the assumption that a price of a code compliant house is 575 Euros (2500 PLN; with the exchange rate of Euro/PLN of 4.35) per square meter of TFA. The total cost of constructing the PH was determined by increasing that total price of code compliant house by of 20%.

Table 19: Costs of code compliant and passive houses in Lodz; extra investment.

	Location: Lodz, Poland
Code compliant house	103 000,00 €
Passive House	123 600,00 €
Extra investment	20 600,00 €

To carry out this economic study, it was necessary to obtain the prices for electricity and gas distribution (it was decided that space heating of the code compliant house will be with the use of gas) and the annual inflation rates for both. Determined values correspond with economic data for Poland in 2013 [54-59]. Finally the interest rate corresponding to the bank loan was assumed as 5%. All of these values are presented in the Table 20.

Table 20: Prices and inflation rates of energy sources; interest rate.

Price of electricity	0.1264 €/kWh
Price of gas	0.0574 €/kWh
Inflation rate of electricity	8.0%
Inflation rate of gas	14.9%
Interest rate	5.0%

In Table 21 are presented the electricity and gas demands for the code compliant house and a PH.

Table 21: Electricity and gas demand.

	Passive House	*Code compliant house*
Electricity demand [kWh/a]	16 835	18 805
Gas demand [kWh/a]	0	17 015

6.5.3 Payback time

The next part of the study was to use the data presented in the Tables 18 to 20 for the calculation in accordance with the Net Present Value method. As a result, the sum of yearly savings with a PH was obtained. The payback was obtained when the difference between the cumulative savings over the years and the additional investment at a 5.0% of interest rate per annum was zero. In Figure 37 is presented graphically the payback period for the considered case and the curves which represent the accumulated savings and investment affected by the interest rate.

The result of the analysis is a payback period of 12 years (see Figure 37). It seems a slightly longer period than in Northern European countries. The most important factor that influences on longer payback period is the cost of constructing a PH in Poland. Estimation of 20% higher price of constructing a PH than a code compliant house leads to a more extensive payback period. However, it is expected that during a few following years a price of building a PH will decrease significally. Finally it will reach the level that is seen in Germany of about 5 to 8 % more costly than for a code compliant house.

When one compares the higher durability and quality of components used to construct the building thermal envelope of a PH, the payback period renders to be economically very interesting.

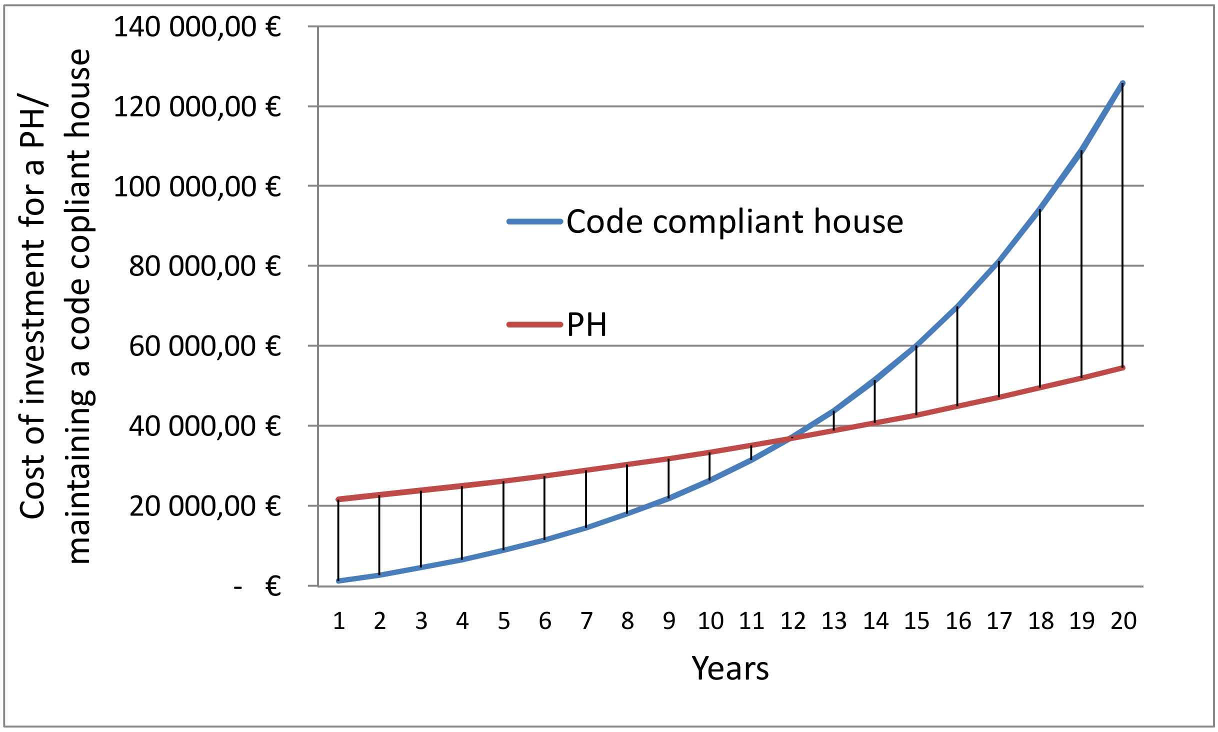


Figure 38: Payback period.

In Figure 39 is presented the influence of costs during the building's life cycle. Initially, the phase projection is characterized by the biggest influence on the total costs of the life cycle. At this stage are defined the requirements for the building, which can significantly influence the construction and running costs. When it reaches the stage of planning the influence on the costs decreases to 80-85%. After this point only the costs can be influenced in a sustainable way only by crucial financial input. It is crucial to decide upfront on the implementation of a PH in the project design phase from the very beginning. Thus, better results without higher additional costs may be obtained. On the contrary, when one decides to apply a PH standard for the building at the later stage, the costs for replanning become significant. For this reason, all the technicians involved in the project should meet at the early stage to draw the energy profile of the house with the PHPP tool.

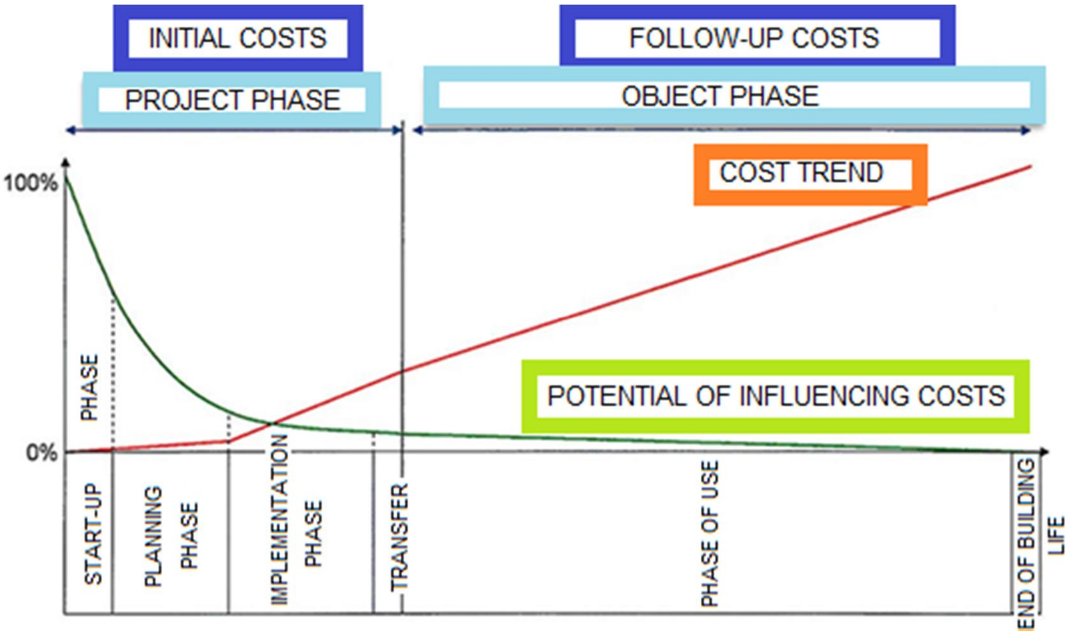


Figure 39: Influence of costs during the cycle of building's life

As shown in Figure 40, the implementation of the PH is only feasible if a full planning is applied. Until now, each phase of the project is treated almost separately. There is little involvement of all technicians in the implementation phase. In order to obtain desired results for a PH, full cooperation of all elements taking part in the project must be achieved. In short, the better balance of the investment throughout the project, the better results in energy consumption, thermal comfort and indoor air quality are achieved at the end.

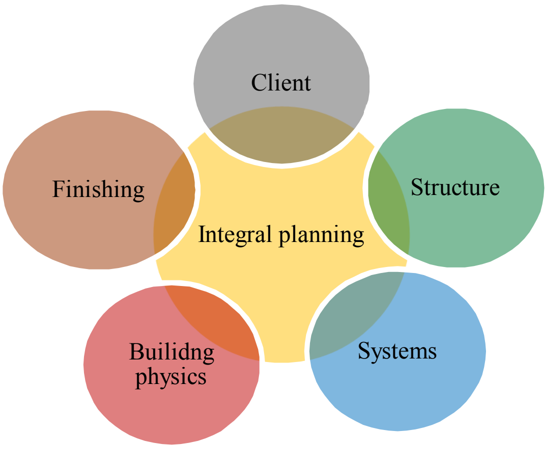


Figure 40: Rule of full planning.

Chapter 7

Conclusions and future perspectives

7 Conclusions and future perspectives

7 Conclusions and future perspectives

A few crucial conclusions may be drawn from the practical part of the dissertation. First of all, it was shown that despite the PHPP tool being based on EN 13790 [41] standard, the space heating demands obtained with the use of both algorithms differed significantly due to various issues. The main difference detected was the number of degree days applied for each method. Moreover, the different utilization factors for heat gains increased the difference in final demands. Generally, it seems that the calculation according to EN 13790 gives the highest demands for space heating.

Furthermore, it was shown that by increasing the thickness of insulation of the opaque thermal envelope of about 200 to 250% and applying passive windows, it was possible to decrease the annual space heating demand from about 100 $\frac{\mathrm{kWh}}{\mathrm{m^2a}}$ to 13.5 $\frac{\mathrm{kWh}}{\mathrm{m^2a}}$ (9.6 $\frac{\mathrm{kWh}}{\mathrm{m^2a}}$ obtained with the monthly method). Despite the heating load requirement was not fulfilled (obtained 14.7 $\frac{\mathrm{W}}{\mathrm{m^2}}$, whereas the limiting value is 10 $\frac{\mathrm{W}}{\mathrm{m^2}}$) it is not limiting, since the space heating requirement was met. Due to summer shading, mechanical ventilation system and natural night ventilation it was obtained only 0.5 $\frac{\mathrm{kWh}}{\mathrm{m^2a}}$ demand for cooling and 0% of overheating frequency.

Next, it was presented that by following the PHPP approach and implementing all necessary passive design and systems to the house, the basic requirements considering space heating and cooling and primary energy demand may be easily fulfilled. The final results and requirements to be met for the considered house are listed in Table 22.

Table 22: Final results in comparison with the requirements.

	Result	*PH Requirement*
Heating demand	13.9 $\frac{\mathrm{kWh}}{\mathrm{m^2a}}$	15.0 $\frac{\mathrm{kWh}}{\mathrm{m^2a}}$
Heating load	14.7 $\frac{\mathrm{W}}{\mathrm{m^2}}$	10.0 $\frac{\mathrm{W}}{\mathrm{m^2}}$
Cooling demand	0.5 $\frac{\mathrm{kWh}}{\mathrm{m^2a}}$	15.0 $\frac{\mathrm{kWh}}{\mathrm{m^2a}}$
Cooling load	10.7 $\frac{\mathrm{W}}{\mathrm{m^2}}$	10.0 $\frac{\mathrm{W}}{\mathrm{m^2}}$
Overheating frequency	0%	10%
Primary energy	93.9 $\frac{\mathrm{kWh}}{\mathrm{m^2a}}$	120.0 $\frac{\mathrm{kWh}}{\mathrm{m^2a}}$

Finally, the economic evaluation of the project was made. The main conclusion of this part was the payback period of about 12 years. A slightly longer period (in comparison to Northern European countries) was a result of 20% higher price of constructing a PH in comparison to the code compliant house. However, it is believed that in future years the price of a PH in Poland will be constantly decreasing. Moreover, if the interest rate was lower than 5% the payback period would be shorten. Therefore, it is decisive to look for the best bank offer. Due to high quality of materials used to construct the PH, the building life span can reach about 50 years (until major retrofitting actions). In comparison to 12 years of payback period it seems a good investment, particularly when the price of energy will be increasing constantly. To sum up, constructing a PH will become even more profitable and a common practice.

With regard to future perspectives of passive housing in Poland, a few issues should be improved. First of all, a dynamic simulation of a PH for Polish conditions must be carried out, attaining more precise results and could be a benchmark for passive housing in Poland. This dynamic simulation should be performed for different zones in Poland. Therefore, engineers could have guidelines for a PH constructed in more severe or warmer parts of the country. Secondly, more information with regard to passive housing should be delivered to investors. Knowing the advantages of a PH over the standard house more people would decide to build a PH. Finally, more attention to passive housing from companies producing construction elements must be paid. If more companies start to produce passive house solutions and systems, constructing a PH in Poland shall even more profitable, since the additional cost will decrease.

Bibliography

1. Firlag Sz.: *Introduction to Passive Building.* Passive House Institute by National Agency of Energy Respect.
2. Idczak M.: *General concept of Passive House.* Passive House Institute by National Agency of Energy Respect.
3. Bosselmann Ch.: *Construction of exterior walls in a Passive House.* Available on the Internet: http://www.ibp.com.pl/Portals/IBP/docs/tagi/wall_constr_pass_house.pdf
4. Idczak M., Firlag Sz.: *Windows in Passive Houses – functions, requirements, energetic balance, heat comfort.* Passive House Institute by National Agency of Energy Respect.
5. Firlag Sz.: *Ventilation in Passive Houses.* Passive House Institute by National Agency of Energy Respect.
6. *Designing of Passive Houses' architecture.* Available on the Internet: http://www.budynkipasywne.pl/modules.php?op=modload&name=PagEd&file=index&topic_id=5&page_id=53
7. *Exterior envelope – windows.* Available on the Internet: http://www.budynkipasywne.pl/modules.php?op=modload&name=PagEd&file=index&topic_id=5&page_id=54
8. *About Passive House - What is a Passive House?* Available on the Internet: http://passiv.de/en/02_informations/01_whatisapassivehouse/01_whatisapassivehouse.htm
9. *Passive House requirements.* Available on the Internet: http://passiv.de/en/02_informations/02_passive-house-requirements/02_passive-house-requirements.htm
10. *Exterior envelope – walls, roof, foundations.* Available on the Internet: http://www.budynkipasywne.pl/modules.php?op=modload&name=PagEd&file=index&topic_id=5&page_id=55
11. *Passive House.* Available on the Internet: http://en.wikipedia.org/wiki/Passive_house
12. *Passive House check list.* Available on the Internet: http://passiv.de/en/02_informations/07_resources/02_check-list/02_check-list.htm

13. *Tightness examination with pressure test.* Available on the Internet: http://www.budynkipasywne.pl/modules.php?op=modload&name=PagEd&file=index&topic_id=5&page_id=57
14. *Ventilation and heating.* Available on the Internet: http://www.budynkipasywne.pl/modules.php?op=modload&name=PagEd&file=index&topic_id=5&page_id=58
15. *Passive Building in Poland and in the world.* Available on the Internet: http://www.energiaidom.pl/rozwoj-budownictwa-pasywnego-w-europie-i-na-swiecie
16. *Ground heat exchanger.* Available on the Internet: http://www.budynkipasywne.pl/modules.php?op=modload&name=PagEd&file=index&topic_id=5&page_id=59
17. *Preparation of hot domestic water.* Available on the Internet: http://www.budynkipasywne.pl/modules.php?op=modload&name=PagEd&file=index&topic_id=5&page_id=60
18. *Fireplaces in Passive Houses.* Available on the Internet: http://www.budynkipasywne.pl/modules.php?op=modload&name=PagEd&file=index&topic_id=5&page_id=62
19. Juchniewicz-Lipinska L., Lipinski M. *Why is it worth to build low-energy buildings with an example of first certificated Passive House in Poland. “Lipinscy Domy” d*esign office.
20. Podgrocki J. *Climatic and meteorological conditions with the aim of using solar radiation energy in Poland. “*Netmark ecological house” Conference in 1998.
21. *Passive House in different climate zones - building services.* Available on the Internet (for logged users of Passipedia): http://www.passipedia.org/passipedia_en/basics/passive_houses_in_different_climates/passive_houses_in_various_climate_zones_-_technical_and_economic_aspects/building_services
22. Weglarz A., Stepien R. *Passive House.* Institute of Ecological Development with cooperation of National Agency of Energy Respect. Warsaw 2011.

23. *Designing of exterior walls in Passive Houses – technical problems*. Available on the Internet: http://www.izolacje.com.pl/artykul/id1313,projektowanie-scian-zewnetrznych-w-budynkach-pasywnych-problemy-techniczne
24. *Heat accumulation*. Available on the Internet: http://www.grupasilikaty.pl/leksykon_budowlany.php?A_11_akumulacja_cieplna.php
25. *Passive House in different climate zones - technical and economic feasibility* Available on the Internet (for logged users of Passipedia): http://www.passipedia.org/passipedia_en/basics/passive_houses_in_different_climates/passive_houses_in_various_climate_zones_-_technical_and_economic_aspects/technical_and_economic_feasibility
26. *Tightness of building envelope.* Available on the Internet: http://www.budynkipasywne.pl/modules.php?op=modload&name=PagEd&file=index&topic_id=5&page_id=56
27. *Tightness tests.* Available on the Internet: http://www.ibp.com.pl/oferta/testy-szczelnosci.aspx
28. *Thermal bridges.* Available on the Internet: http://www.ibp.com.pl/oferta/mostki-cieplne.aspx
29. Sojczynski L. *Thermal bridges.* Available on the Internet: http://www.ibp.com.pl/oferta/mostki-cieplne.aspx
30. Feist W. *Examples of residential Passive Houses.* Passive House Institute Available on the Internet: http://www.passivhaustagung.de/Passive_House_E/Examples_passive_houses.html
31. *Passive Terrace Houses – Lindas.* Available on the Internet: http://www.flickr.com/photos/28402310@N06/3904187585/
32. *Types of ventilation.* Available on the Internet: http://passipedia.passiv.de/passipedia_en/planning/building_services/ventilation/basics/types_of_ventilation
33. Gerylo R. *Conditions for energy-saving building industry.* Available on the Internet: http://termodom.pl/epbd/energooszczednosc/uwarunkowania_budownictwa_energooszczednego

34. *What is TGI joist?* Available on the Internet: http://wiki.answers.com/Q/What_is_tgi_joist
35. Gornicz J. *Solar energy.* Available on the Internet: http://dolinka.eu/energia-soneczna.html
36. *Airtight construction.* Available on the Internet: *http://passipedia.passiv.de/passipedia_en/planning/airtight_construction*
37. *General principles for improving airtightness.* Available on the Internet: http://passipedia.passiv.de/passipedia_en/planning/airtight_construction/general_principles/principles_for_improving_airtightness
38. *Effect of window size on Energy Consumption.* Available on the Internet: http://ssirrpassivehouse.blogspot.pt/
39. *Do you know how to choose safe windows?* Available on the Internet: *http://www.budnet.pl/Okna_i_drzwi_dobrze_izolujace,Izolacje_cieplne,114281-czytaj.html*
40. *Ground-coupled heat exchanger.* Available on the Internet: http://en.wikipedia.org/wiki/Ground-coupled_heat_exchanger
41. EN ISO 13790 “Energy performance of buildings – Calculation of energy use for space heating and cooling”.
42. PHPP (Passive House Planning Package); Version 7 (2012), Passive House Institute.
43. EN ISO 13789:1999 “Thermal performance of buildings – Transmission heat loss coefficient – Calculation method”.
44. EN 12831:2003 “Heating systems in buildings. Method for calculation of the design heat load”.
45. EN ISO 14683:2007 “Thermal bridges in building construction – Linear thermal transmittance – Simplified methods and default values”.
46. PN-83 B-03430 “Ventilation in dwelling and public utility buildings. Specifications.”
47. *Thermal bridges calculation.* Available on the Internet: www.itecons.uc.pt
48. PN EN ISO 6946 “Komponenty budowlane i elementy budynku. Opór cieplny i współczynnik przenikania ciepła. Metoda obliczania”.
49. PN-EN 15193 “Energetyczne właściwości użytkowe budynków – Wymagania energetyczne dotyczące oświetlenia”

50. Wolfgang Feist, Passive Institut and University of Innsbruck: *“Passive houses for different climate zones*” Darmstadt 2011
51. *Indoor heat gains.* Available on the Internet: www.instsani.webd.pl/projwe2.htm
52. *Base indoor temperature*. Available on the Internet: http://www.info-ogrzewanie.pl/artykul,id_m-100255,t-wyznaczanie_temperatury_bazowej_budynku.html
53. *Monthly temperatures in Lodz*. Available on the Internet: http://www.transport.gov.pl/2-482be1a920074-1787537-p_1.htm
54. *Price of energy and gas in Poland*. Available on the Internet: http://www.cenapradu.republika.pl/
55. *Inflation of Energy in Poland*. Available on the Internet:
56. http://budzet-domowy.wieszjak.pl/oszczedzanie/297804,2,O-ile-podrozala-energia-elektryczna.html
57. *Inflation of gas end energy in Poland*. Available on the Internet: http://www.ure.gov.pl/portal/pl/497/3245/Informacja.html
58. *Interest rate*. Available on the Internet: http://www.ehipoteka.com.pl/kalkulatory-kredytowe/rzeczywista-stopa-procentowa.html
59. *Price of m^2 of building area.* Available on the Internet: *http://www.efefarchitekci.pl/jak-zbudowac-dom/68-koszty-budowy-metra-kwadratowego-domu.html*
60. *Investment rate of a PH.* Available on the Internet: *http://www.dompasywny.org/index.php/dom-pasywny/informacje-ogolne/64-koszt-budowy-domu-pasywnego.html*

Annex 1

Thermal transmittance of building envelope elements

1 Thermal transmittance of the exterior wall without concidering a ring beam ($U_{exterior.wall}$):

- Thermal resistance of the exterior wall without concidering a ring beam ($R_{exterior.wall}$)

$$R_{exterior.wall} := 0.04\frac{m^2\cdot K}{W} + \frac{0.015m}{0.7\frac{W}{m\cdot K}} + \frac{0.3m}{0.25\frac{W}{m\cdot K}} + \frac{0.1m}{0.04\frac{W}{m\cdot K}} + \frac{0.015m}{0.7\frac{W}{m\cdot K}} + 0.13\frac{m^2\cdot K}{W} = 3.913\cdot\frac{m^2\cdot K}{W}$$

$$U_{exterior.wall} := \frac{1}{R_{exterior.wall}} = 0.256\cdot\frac{W}{m^2\cdot K}$$

2 Thermal transmittance of the part of the exterior wall with a ring beam ($U_{exterior.wall.STB}$):

- Thermal resistance of the part of the exterior wall with a ring beam ($R_{exterior.wall.STB}$):

$$R_{exterior.wall.STB} := 0.04\frac{m^2\cdot K}{W} + \frac{0.015m}{0.7\frac{W}{m\cdot K}} + \frac{0.3m}{1.7\frac{W}{m\cdot K}} + \frac{0.1m}{0.04\frac{W}{m\cdot K}} + \frac{0.015m}{0.7\frac{W}{m\cdot K}} + 0.13\frac{m^2\cdot K}{W} = 2.889\cdot\frac{m^2\cdot K}{W}$$

$$U_{exterior.wall.STB} := \frac{1}{R_{exterior.wall.STB}} = 0.346\cdot\frac{W}{m^2K}$$

3 Thermal transmittance of window (U_{window})

:

$$U_{window} := 1.42\frac{W}{m^2\cdot K}$$

4 Thermal transmittance of the West-orientatated garage wall ($U_{garage.west.wall}$):

- Thermal resistance of the unheated area (garage) ($R_{u.garage}$):

$$R_{u.garage} := \frac{9.78m\cdot 2.7m}{[(5.9m + 3.88m)\cdot 2.7m]\cdot 0.634\frac{W}{m^2K} + (5.9m\cdot 3.88m)\cdot 0.217\frac{W}{m^2K} + 0.33\cdot 3\cdot\left(5.9m\cdot 3.88m\cdot 2.7\frac{m}{1m}\right)\cdot\frac{W}{m^2K}}$$

$$R_{u.garage} = 0.319\cdot\frac{m^2\cdot K}{W}$$

- Thermal resistance of the West-orientatated garage wall ($R_{garage.east.wall}$)

$$R_{garage.west.wall} := 0.04\frac{m^2\cdot K}{W} + \frac{0.015m}{0.7\frac{W}{m\cdot K}} + \frac{0.115m}{0.25\frac{W}{m\cdot K}} + \frac{0.12m}{0.04\frac{W}{m\cdot K}} + \frac{0.015m}{0.7\frac{W}{m\cdot K}} + 0.13\frac{m^2\cdot K}{W} = 3.673\cdot\frac{m^2\cdot K}{W}$$

$$U_{garage.west.wall} := \frac{1}{R_{garage.west.wall} + 0.195\cdot\frac{m^2K}{W}} = 0.259\cdot\frac{W}{m^2K}$$

5 Thermal transmittance of the South-orientated garage wall ($U_{garage.south.wall}$):

- Thermal resistance of the South-orientated garage wall ($R_{garage.south.wall}$):

$$R_{garage.south.wall} := 0.04\frac{m^2\cdot K}{W} + \frac{0.015m}{0.7\frac{W}{m\cdot K}} + \frac{0.3m}{0.25\frac{W}{m\cdot K}} + \frac{0.10m}{0.04\frac{W}{m\cdot K}} + \frac{0.015m}{0.7\frac{W}{m\cdot K}} + 0.13\frac{m^2\cdot K}{W} = 3.913\cdot\frac{m^2\cdot K}{W}$$

$$U_{garage.south.wall} := \frac{1}{R_{garage.south.wall} + 0.127\cdot\frac{m^2K}{W}} = 0.248\cdot\frac{W}{m^2K}$$

6 Thermal transmittance of the garage exterior wall ($U_{garage.exterior}$)

:

- Thermal resistance of the garage exterior wall ($R_{garage.exterior}$):

$$R_{garage.exterior} := 0.04\frac{m^2\cdot K}{W} + \frac{0.015m}{0.7\frac{W}{m\cdot K}} + \frac{0.3m}{0.25\frac{W}{m\cdot K}} + \frac{0.015m}{0.7\frac{W}{m\cdot K}} = 1.283\cdot\frac{m^2K}{W}$$

$$U_{garage.exterior} := \frac{1}{R_{garage.exterior}} = 0.78\cdot\frac{W}{m^2K}$$

7 Thermal transmittance of the roof (U_{roof})

:

- Thermal resistance of the variable part of the South-orientated roof ($R_{variable.shape.1}$)

$$R_{variable.shape.1} := \frac{0.568m + 0.075m + 0.075m}{0.5\frac{W}{m\cdot K}} = 1.436\cdot\frac{m^2\cdot K}{W}$$

- Thermal resistance of the variable part of North-orientated roof ($R_{variable.shape.garage}$)

.

$$R_{variable.shape.garage} := \frac{0.4m + 0.075m + 0.075m}{0.5\frac{W}{m\cdot K}} = 1.1\cdot\frac{m^2\cdot K}{W}$$

- Thermal resistance of the constant part of the roof ($R_{constant.shape}$):

$$R_{constant.shape} := 0.10\frac{m^2\cdot K}{W} + \frac{0.015m}{0.7\frac{W}{m\cdot K}} + \frac{0.3m}{1.7\frac{W}{m\cdot K}} + \frac{0.15m}{0.04\frac{W}{m\cdot K}} + \frac{0.01m}{0.18\frac{W}{m\cdot K}} + 0.04\cdot\frac{m^2\cdot K}{W} = 4.143\cdot\frac{m^2\cdot K}{W}$$

- Thermal transmittance of the South-orientated roof roof ($U_{roof.South}$)

$$U_{roof.South} := \frac{1}{R_{variable.shape.1}}\ln\left(1 + \frac{R_{variable.shape.1}}{R_{constant.shape}}\right) = 0.207\cdot\frac{W}{m^2\cdot K}$$

- Thermal transmittance of the North-orientated roof roof ($U_{roof.North}$

$$U_{roof.North} := \frac{1}{R_{variable.shape.garage}}\ln\left(1 + \frac{R_{variable.shape.garage}}{R_{constant.shape}}\right) = 0.214\cdot\frac{W}{m^2\cdot K}$$

$$U_{roof} := \frac{U_{roof.South}\cdot\left(179.14m^2 - 54.73m^2\right) + U_{roof.North}\cdot 54.73m^2}{179.14m^2} = 0.209\cdot\frac{W}{m^2\cdot K}$$

Annex 2

Heat transfer coefficients

1 Calculation of direct heat transfer coefficient by transmission to the external environment (H_D) :

1.1 Direct heat transfer coefficient by transmission through the area of exterior walls to the external environment ($H_{D.walls}$):

$$
\begin{aligned}
H_{D.walls} := {} & \left(9.185\mathrm{m}\cdot 2.75\mathrm{m} - 2\cdot 4.125\mathrm{m}^2 - 1\cdot 2.75\cdot \mathrm{m}^2\right)\cdot\left(0.256\,\frac{W}{m^2\cdot K}\right) + \left(4\mathrm{m}\cdot 2.75\mathrm{m} - 2\cdot 2.75\mathrm{m}^2\right)\cdot\left(0.256\,\frac{W}{m^2\cdot K}\right) \ldots = 28. \\
& + \left(9.2\mathrm{m}\cdot 2.75\mathrm{m} - 9\cdot 2.75\mathrm{m}^2\right)\cdot\left(0.256\,\frac{W}{m^2\cdot K}\right) + \left(9.340\mathrm{m}\cdot 2.75\mathrm{m} - 3\cdot 4.125\mathrm{m}^2\right)\cdot\left(0.256\,\frac{W}{m^2\cdot K}\right) \ldots \\
& + \left(7.3\mathrm{m}\cdot 2.75\mathrm{m} - 1\cdot 3\mathrm{m}^2 - 1\cdot 1.5\mathrm{m}^2\right)\cdot\left(0.256\,\frac{W}{m^2\cdot K}\right) + \left(1.6\mathrm{m}\cdot 2.75\mathrm{m} - 1\cdot 2\mathrm{m}^2\right)\cdot\left(0.256\,\frac{W}{m^2\cdot K}\right) \ldots \\
& + (4.285\mathrm{m}\cdot 2.75\mathrm{m})\cdot\left(0.256\,\frac{W}{m^2\cdot K}\right) + (2.7\mathrm{m}\cdot 2.75\mathrm{m})\cdot\left(0.256\,\frac{W}{m^2\cdot K}\right) \ldots \\
& + \left(9.2\mathrm{m}\cdot 2.75\mathrm{m} - 1\cdot 4.125\mathrm{m}^2 - 1\cdot 2.75\cdot \mathrm{m}^2\right)\cdot\left(0.256\,\frac{W}{m^2\cdot K}\right) + (9.185\mathrm{m}\cdot 0.25\mathrm{m})\cdot\left(0.346\,\frac{W}{m^2\cdot K}\right) \ldots \\
& + (4\mathrm{m}\cdot 0.25\mathrm{m})\cdot\left(0.346\,\frac{W}{m^2\cdot K}\right) + (9.2\mathrm{m}\cdot 0.25\mathrm{m})\cdot\left(0.346\,\frac{W}{m^2\cdot K}\right) \ldots \\
& + (9.34\mathrm{m}\cdot 0.25\mathrm{m})\cdot\left(0.346\,\frac{W}{m^2\cdot K}\right) + (2.7\mathrm{m}\cdot 0.25\mathrm{m})\cdot 0.346\,\frac{W}{m^2\cdot K} \ldots \\
& + (7.3\mathrm{m}\cdot 0.25\mathrm{m})\cdot\left(0.346\,\frac{W}{m^2\cdot K}\right) + (1.6\mathrm{m}\cdot 0.25\mathrm{m})\cdot\left(0.346\,\frac{W}{m^2\cdot K}\right) + (4.285\mathrm{m}\cdot 0.25\mathrm{m})\cdot\left(0.346\,\frac{W}{m^2\cdot K}\right) \ldots \\
& + (3.1\mathrm{m}\cdot 0.25\mathrm{m})\cdot\left(0.346\,\frac{W}{m^2\cdot K}\right) + (9.2\mathrm{m}\cdot 0.25\mathrm{m})\cdot\left(0.346\,\frac{W}{m^2\cdot K}\right) \ldots \\
& + (2.75\mathrm{m}\cdot 1.975\mathrm{m})\cdot\left(0.346\,\frac{W}{m^2\cdot K}\right) - (2.75\mathrm{m}\cdot 1.975\mathrm{m})\cdot\left(0.256\,\frac{W}{m^2\cdot K}\right)
\end{aligned}
$$

1.2 Direct heat transfer coefficient by transmission through the thermal bridges in the exterior walls to the external environment ($H_{D.walls.thermal.bridges}$):

- Thermal bridge at the connection between exterior and interior wall:

$$H_{D.connection.exterior.interior.walls.T} := 1\cdot 3\mathrm{m}\cdot 0.09\,\frac{W}{m\cdot K} = 0.27\cdot\frac{W}{K}$$

- Thermal bridges at the corners between exterior walls:

$$H_{D.corner.exterior.walls.T} := 4\cdot 3\mathrm{m}\cdot 0.17\,\frac{W}{m\cdot K} = 2.04\cdot\frac{W}{K}$$

$$H_{D.walls.thermal.bridges} := H_{D.connection.exterior.interior.walls.T} + H_{D.corner.exterior.walls.T} = 2.31\cdot\frac{W}{K}$$

1.3 Direct heat transfer coefficient by transmission through the area of windows and entrance door to the external environment ($H_{D.windows.door}$):

$$H_{D.windows.door} := \left(2.75\mathrm{m}^2\cdot 13 + 4.125\mathrm{m}^2\cdot 6 + 1.5\mathrm{m}^2\cdot 1 + 3\mathrm{m}^2\cdot 1 + 1\cdot 2\mathrm{m}^2\right)\cdot 1.42\,\frac{W}{m^2\cdot K} = 95.14\cdot\frac{W}{K}$$

1.4 Direct heat transfer coefficient by transmission through the thermal bridges in windows and entrance door to the external environment ($H_{D.windows.door.T}$):

$$\begin{aligned} H_{D.windows.door.T} := {} & (1m\cdot 13\cdot 2 + 1.5m\cdot 6\cdot 2 + 1m\cdot 1\cdot 2 + 2m\cdot 1\cdot 2 + 2m\cdot 1\cdot 2)\cdot 0.19\cdot\frac{W}{m\cdot K} \;\ldots = 27.94\cdot\frac{W}{K} \\ & + (1m\cdot 13 + 1.5m\cdot 6 + 1m\cdot 1 + 2m\cdot 1 + 1m\cdot 1\cdot 1)\cdot 0.29\cdot\frac{W}{m\cdot K} \;\ldots \\ & + (1m\cdot 13 + 1.5m\cdot 6 + 1m\cdot 1 + 2m\cdot 1 + 1m\cdot 1\cdot 1)\cdot 0.39\cdot\frac{W}{m\cdot K} \end{aligned}$$

1.5 Direct heat transfer coefficient by transmission through the area of roof to the external environment ($H_{D.roof}$):

$$H_{D.roof} := 179.14m^2\cdot 0.209\frac{W}{m^2K} = 37.44\cdot\frac{W}{K}$$

1.6 Direct heat transfer coefficient by transmission through the thermal bridges in roof to the external environment ($H_{D.roof.exterior.wall.T}$):

$$H_{D.roof.exterior.wall.T} := 57.786m\cdot 0.14\cdot\frac{W}{m\cdot K} = 8.09\cdot\frac{W}{K}$$

$$\begin{aligned} H_D := {} & H_{D.walls} + H_{D.walls.thermal.bridges} + H_{D.windows.door} \;\ldots = 199.434\cdot\frac{W}{K} \\ & + H_{D.windows.door.T} + H_{D.roof} + H_{D.roof.exterior.wall.T} \end{aligned}$$

2 Calculation of heat transfer coefficient by transmission through unheated spaces (H_U):

2.1 Heat transfer coefficient by transmission through the area of the garage walls to the unheated space (garage), ($H_{U.garage.walls}$):

$$H_{U.garage.walls} := 0.5\left[\begin{aligned} & 4.18m\cdot 2.45m\cdot\left(0.259\,\frac{W}{m^2K}\right) + (6m\cdot 2.45m - 1m\cdot 2m)\cdot\left(0.248\,\frac{W}{m^2K}\right) \;\ldots \\ & + 4.18m\cdot 0.25m\cdot\left(0.259\,\frac{W}{m^2K}\right) + 6m\cdot 0.25m\cdot\left(0.248\,\frac{W}{m^2K}\right) \;\ldots \\ & + 0.3m\cdot 2.45m\cdot\left(0.346\,\frac{W}{m^2K}\right) - 0.3m\cdot 2.45m\cdot\left(0.259\,\frac{W}{m^2K}\right) \end{aligned}\right] = 3.254\cdot\frac{W}{K}$$

2.2 Heat transfer coefficient by transmission through the thermal bridges in the garage walls to the unheated space (garage) ($H_{U.garage.walls.T}$):

- Thermal bridge at the connection between garage walls and interior walls:

  $$H_{U.connection.exterior.interior.walls.garage.T} := 0.5\cdot\left(1\cdot 3m\cdot 0.09\frac{W}{m\cdot K}\right) = 0.135\cdot\frac{W}{K}$$

- Thermal bridge at the corner of garage walls:

  $$H_{U.corner.exterior.walls.garage.T} := 0.5\cdot\left(1\cdot 3m\cdot 0.18\frac{W}{m\cdot K}\right) = 0.27\cdot\frac{W}{K}$$

$$H_{U.garage.walls.T} := H_{U.connection.exterior.interior.walls.garage.T} + H_{U.corner.exterior.walls.garage.T} = 0.405\cdot\frac{W}{K}$$

$$H_U := H_{U.garage.walls} + H_{U.garage.walls.T} = 3.659\cdot\frac{W}{K}$$

3 Calculation of heat transfer coefficient by transmission to the ground (H_g):

- Treated floor area (TFA):

  $$TFA = 179.14m^2$$

- Perimeter of the floor (P):

  $$P := 72.663m$$

- Characteristic dimension of floor (B):

$$B := \frac{TFA}{\frac{P}{2}} = 4.931\,\mathrm{m}$$

- Thermal resistance of the floor (R_{floor})

.

$$R_{floor} := \frac{0.032\mathrm{m}}{0.16\frac{W}{m\cdot K}} + \frac{0.025\mathrm{m}}{1.7\frac{W}{m\cdot K}} + \frac{0.1\mathrm{m}}{1.7\frac{W}{m\cdot K}} + \frac{0.1\mathrm{m}}{0.04\frac{W}{m\cdot K}} + \frac{0.1\mathrm{m}}{1.7\frac{W}{m\cdot K}} = 2.832\cdot\frac{m^2\cdot K}{W}$$

- Total equivalent thickness slab-on-ground floor (d_t):

$w := 0.4\mathrm{m}$

$\lambda := 2\frac{W}{m\cdot K}$ I assume the sand beneath the ground floor

$R_{si.f} := 0.17\frac{m^2\cdot K}{W}$ $R_{se.f} := 0.10\cdot\frac{m^2\cdot K}{W}$

$$d_t := w + \lambda\cdot\left(R_{si.f} + R_{floor} + R_{se.f}\right) = 6.605\,\mathrm{m}$$

$d_t > B$ therefore, floor is well insulated

- Thermal transmittance of floor (U_f)

$$U_f := \frac{\lambda}{0.475\cdot B + d_t} = 0.224\cdot\frac{W}{m^2\cdot K}$$

- Heat transfer coefficient by transmission through the ground floor area to the ground ($H_{g.A}$):

$$H_{g.A} := U_f\cdot TFA = 40.046\cdot\frac{W}{K}$$

- Heat transfer coefficient by transmission through the thermal bridges in the ground floor to the ground ($H_{g.T}$):

$$H_{g.T} := 0.8\cdot\frac{W}{m\cdot K}\cdot P = 58.13\cdot\frac{W}{K}$$

- Heat transfer coefficient by transmission through the ground floor to the ground (H_g)

$$H_g := 0.6\cdot\left(H_{g.A} + H_{g.T}\right) = 58.906\cdot\frac{W}{K}$$ 0.6 - reduction factor

4. Transmission heat transfer coefficient ($H_{tr.adj}$)

$$H_{tr.adj} := H_D + H_g + H_U = 261.999\cdot\frac{W}{K}$$

Annex 3

Total heat transfer by transmission

- Set point-temperature for the home for heating ($\theta_{int.set.H}$):

$\theta_{int.set.H} := 20.326°C$

- Temperatures of external environment for each month ($\theta_{\theta.i}$):

$\theta_{\theta.01} := -1.0°C$ $\theta_{\theta.05} := 13.5°C$ $\theta_{\theta.09} := 12.9°C$

$\theta_{\theta.02} := -1.0°C$ $\theta_{\theta.10} := 6.6°C$

$\theta_{\theta.03} := 3.3°C$ $\theta_{\theta.11} := 3.8°C$

$\theta_{\theta.04} := 7.6°C$ $\theta_{\theta.12} := 0.7°C$

- Duration of each month (calculations step), (t_i)

$t_{01} := 2678400 \cdot s$ $t_{05} := 2678400s$ $t_{09} := 2592000s$

$t_{02} := 2419200s$ $t_{10} := 2678400s$

$t_{03} := 2678400s$ $t_{11} := 2592000s$

$t_{04} := 2592000s$ $t_{12} := 2678400s$

- Total heat transfer by transsmision in each month ($Q_{tr.i}$)

$Q_{tr.01} := H_{tr.adj} \cdot \left(\theta_{int.set.H} - \theta_{\theta.01}\right) t_{01} = 1.497 \times 10^{10} J$

$Q_{tr.02} := H_{tr.adj} \cdot \left(\theta_{int.set.H} - \theta_{\theta.02}\right) t_{02} = 1.352 \times 10^{10} J$

$Q_{tr.03} := H_{tr.adj} \cdot \left(\theta_{int.set.H} - \theta_{\theta.03}\right) t_{03} = 1.195 \times 10^{10} J$

$Q_{tr.04} := H_{tr.adj} \cdot \left(\theta_{int.set.H} - \theta_{\theta.04}\right) t_{04} = 8.642 \times 10^{9} J$

$Q_{tr.05} := H_{tr.adj} \cdot \left(\theta_{int.set.H} - \theta_{\theta.05}\right) t_{05} = 4.79 \times 10^{9} J$

$Q_{tr.09} := H_{tr.adj} \cdot \left(\theta_{int.set.H} - \theta_{\theta.09}\right) t_{09} = 5.043 \times 10^{9} J$

$Q_{tr.10} := H_{tr.adj} \cdot \left(\theta_{int.set.H} - \theta_{\theta.10}\right) t_{10} = 9.632 \times 10^{9} J$

$Q_{tr.11} := H_{tr.adj} \cdot \left(\theta_{int.set.H} - \theta_{\theta.11}\right) t_{11} = 1.122 \times 10^{10} \cdot J$

$Q_{tr.12} := H_{tr.adj} \cdot \left(\theta_{int.set.H} - \theta_{\theta.12}\right) t_{12} = 1.377 \times 10^{10} \cdot J$

- Annual heat transfer by transsmision (Q_{tr}):

$Q_{tr} := Q_{tr.01} + Q_{tr.02} + Q_{tr.03} + Q_{tr.04} + Q_{tr.05} + Q_{tr.09} + Q_{tr.10} + Q_{tr.11} + Q_{tr.12} = 9.353 \times 10^{10} J$

Annex 4

Total heat transfer by ventilation

- Time avarage airflow rate for compartments ($q_{ve.i}$

$q_{ve.kitchen} := 50\frac{m^3}{h} = 0.014\frac{m^3}{s}$ $q_{ve.bathroom} := 50\frac{m^3}{h} = 0.014\frac{m^3}{s}$

$q_{ve.room} := 30\frac{m^3}{h} = 8.333 \times 10^{-3}\frac{m^3}{s}$ $q_{ve.closet} := 15\frac{m^3}{h} = 4.167 \times 10^{-3}\frac{m^3}{s}$

- Supplied air condition ($q_{ve.supplied}$):

$$q_{ve.supplied} := 5q_{ve.room} + 4q_{ve.closet} = 0.0583\frac{m^3}{s}$$

- Extracted air condition ($q_{ve.extracted}$):

$$q_{ve.extracted} := q_{ve.kitchen} + 2q_{ve.bathroom} = 0.042\frac{m^3}{s}$$

- Extra PHPP air condition ($q_{ve.extra.condition}$):

$$q_{ve.extra.condition} := 1.3 \cdot 0.3 \cdot \frac{V}{h} = 0.0582\frac{1}{s} \cdot m^3$$

- Overall heat transfer coefficient by ventilation ($H_{ve.adj}$) $V = 537.42 \cdot m^3$

$$H_{ve.adj} := \rho_{aca} \cdot \left(b_{ve.k} \cdot q_{ve.supplied}\right) = 70 \cdot \frac{W}{K}$$

- Heat transfer by ventilation in each month ($Q_{ve.i}$)

$$Q_{ve.01} := H_{ve.adj} \cdot \left(\theta_{int.set.H} - \theta_{\theta.01}\right)t_{01} = 3.998 \times 10^9\ J$$

$$Q_{ve.02} := H_{ve.adj} \cdot \left(\theta_{int.set.H} - \theta_{\theta.02}\right)t_{02} = 3.611 \times 10^9\ J$$

$$Q_{ve.03} := H_{ve.adj} \cdot \left(\theta_{int.set.H} - \theta_{\theta.03}\right)t_{03} = 3.192 \times 10^9\ J$$

$$Q_{ve.04} := H_{ve.adj} \cdot \left(\theta_{int.set.H} - \theta_{\theta.04}\right)t_{04} = 2.309 \times 10^9\ J$$

$$Q_{ve.05} := H_{ve.adj} \cdot \left(\theta_{int.set.H} - \theta_{\theta.05}\right)t_{05} = 1.28 \times 10^9\ J$$

$$Q_{ve.09} := H_{ve.adj} \cdot \left(\theta_{int.set.H} - \theta_{\theta.09}\right)t_{09} = 1.347 \times 10^9\ J$$

$$Q_{ve.10} := H_{ve.adj} \cdot \left(\theta_{int.set.H} - \theta_{\theta.10}\right)t_{10} = 2.573 \times 10^9\ J$$

$$Q_{ve.11} := H_{ve.adj} \cdot \left(\theta_{int.set.H} - \theta_{\theta.11}\right)t_{11} = 2.998 \times 10^9\ J$$

$$Q_{ve.12} := H_{ve.adj} \cdot \left(\theta_{int.set.H} - \theta_{\theta.12}\right)t_{12} = 3.68 \times 10^9\ J$$

- Annual heat transfer by ventilation (Q_{ve}):

$$Q_{ve} := Q_{ve.01} + Q_{ve.02} + Q_{ve.03} + Q_{ve.04} + Q_{ve.05} + Q_{ve.09} + Q_{ve.10} + Q_{ve.11} + Q_{ve.12} = 2.499 \times 10^{10}\ J$$

Annex 5

Internal heat gains from occupants and appliances

- Mean heat flow rate from occupants and appliances:

for the living room and kitchen:

$$\phi_{int.Oc.1} := 5 \cdot \frac{W}{m^2}$$

for bedrooms:

$$\phi_{int.Oc.2} := 5 \cdot \frac{W}{m^2}$$

- Areas of compartments:

$$living_{room.and.kitchen} := 78.21 m^2$$

$$bedroom_1 := 16.95 \cdot m^2$$

$$bedroom_2 := 18.72 m^2$$

$$bedroom_3 := 18.59 \cdot m^2$$

- Heat flow rate from occupants and appliances for the living room and kitchen in each month ($\phi_{int.Oc.A.1.i}$):

$$\phi_{int.Oc.1.01} := \phi_{int.Oc.1} \cdot living_{room.and.kitchen} \cdot t_{01} = 1.047 \times 10^9 J$$

$$\phi_{int.Oc.1.02} := \phi_{int.Oc.1} \cdot living_{room.and.kitchen} \cdot t_{02} = 9.46 \times 10^8 J$$

$$\phi_{int.Oc.1.03} := \phi_{int.Oc.1} \cdot living_{room.and.kitchen} \cdot t_{03} = 1.047 \times 10^9 J$$

$$\phi_{int.Oc.1.04} := \phi_{int.Oc.1} \cdot living_{room.and.kitchen} \cdot t_{04} = 1.014 \times 10^9 J$$

$$\phi_{int.Oc.1.05} := \phi_{int.Oc.1} \cdot living_{room.and.kitchen} \cdot t_{05} = 1.047 \times 10^9 J$$

$$\phi_{int.Oc.1.09} := \phi_{int.Oc.1} \cdot living_{room.and.kitchen} \cdot t_{09} = 1.014 \times 10^9 J$$

$$\phi_{int.Oc.1.10} := \phi_{int.Oc.1} \cdot living_{room.and.kitchen} \cdot t_{10} = 1.047 \times 10^9 J$$

$$\phi_{int.Oc.1.11} := \phi_{int.Oc.1} \cdot living_{room.and.kitchen} \cdot t_{11} = 1.014 \times 10^9 J$$

$$\phi_{int.Oc.1.12} := \phi_{int.Oc.1} \cdot living_{room.and.kitchen} \cdot t_{12} = 1.047 \times 10^9 J$$

- Heat flow rate from occupants and appliances for bedrooms in each month ($\phi_{int.Oc.A.2.i}$

$$\phi_{int.Oc.2.01} := \phi_{int.Oc.2} \cdot \left(bedroom_3 + bedroom_2 + bedroom_1\right) \cdot t_{01} = 7.266 \times 10^8 J$$

$$\phi_{int.Oc.2.02} := \phi_{int.Oc.2} \cdot \left(bedroom_3 + bedroom_2 + bedroom_1\right) \cdot t_{02} = 6.563 \times 10^8 J$$

$$\phi_{int.Oc.2.03} := \phi_{int.Oc.2} \cdot \left(bedroom_3 + bedroom_2 + bedroom_1\right) \cdot t_{03} = 7.266 \times 10^8 J$$

$$\phi_{int.Oc.2.04} := \phi_{int.Oc.2} \cdot \left(bedroom_3 + bedroom_2 + bedroom_1\right) \cdot t_{04} = 7.032 \times 10^8 J$$

$$\phi_{int.Oc.2.05} := \phi_{int.Oc.2} \cdot \left(bedroom_3 + bedroom_2 + bedroom_1\right) \cdot t_{05} = 7.266 \times 10^8 J$$

$$\phi_{int.Oc.2.09} := \phi_{int.Oc.2} \cdot \left(bedroom_3 + bedroom_2 + bedroom_1\right) \cdot t_{09} = 7.032 \times 10^8 J$$

$$\phi_{int.Oc.2.10} := \phi_{int.Oc.2} \cdot \left(bedroom_3 + bedroom_2 + bedroom_1\right) \cdot t_{10} = 7.266 \times 10^8 J$$

$$\phi_{int.Oc.2.11} := \phi_{int.Oc.2} \cdot \left(bedroom_3 + bedroom_2 + bedroom_1\right) \cdot t_{11} = 7.032 \times 10^8 J$$

$$\phi_{int.Oc.2.12} := \phi_{int.Oc.2} \cdot \left(bedroom_3 + bedroom_2 + bedroom_1\right) \cdot t_{12} = 7.266 \times 10^8 J$$

- Annual heat flow rate from occupants and appliances for the home ($\phi_{int.Oc.A}$):

$$\begin{aligned} \phi_{int.Oc} := {} & \phi_{int.Oc.1.01} + \phi_{int.Oc.1.02} + \phi_{int.Oc.1.03} + \phi_{int.Oc.1.04} + \phi_{int.Oc.1.05} + \phi_{int.Oc.1.09} \cdots = 1.562 \times 10^1 \\ & + \phi_{int.Oc.1.10} + \phi_{int.Oc.1.11} + \phi_{int.Oc.1.12} + \phi_{int.Oc.2.01} + \phi_{int.Oc.2.02} + \phi_{int.Oc.2.03} \cdots \\ & + \phi_{int.Oc.2.04} + \phi_{int.Oc.2.05} + \phi_{int.Oc.2.09} + \phi_{int.Oc.2.10} + \phi_{int.Oc.2.11} + \phi_{int.Oc.2.12} \end{aligned}$$

Annex 6

Internal heat gains from lighting

- Heat flow rate from lighting in each month ($\phi_{int.L.i}$

$$\phi_{int.L.01} := N\cdot\left[\beta + (1-\beta)\cdot k_0\right]\cdot\varphi_{01}\cdot t_{01} = 1.286\times 10^{9}\ J$$

$$\phi_{int.L.02} := N\cdot\left[\beta + (1-\beta)\cdot k_0\right]\cdot\varphi_{02}\cdot t_{02} = 5.806\times 10^{8}\ J$$

$$\phi_{int.L.03} := N\cdot\left[\beta + (1-\beta)\cdot k_0\right]\cdot\varphi_{03}\cdot t_{03} = 6.428\times 10^{8}\ J$$

$$\phi_{int.L.04} := N\cdot\left[\beta + (1-\beta)\cdot k_0\right]\cdot\varphi_{04}\cdot t_{04} = 4.147\times 10^{8}\ J$$

$$\phi_{int.L.05} := N\cdot\left[\beta + (1-\beta)\cdot k_0\right]\cdot\varphi_{05}\cdot t_{05} = 4.285\times 10^{8}\ J$$

$$\phi_{int.L.09} := N\cdot\left[\beta + (1-\beta)\cdot k_0\right]\cdot\varphi_{09}\cdot t_{09} = 4.147\times 10^{8}\ J$$

$$\phi_{int.L.10} := N\cdot\left[\beta + (1-\beta)\cdot k_0\right]\cdot\varphi_{10}\cdot t_{10} = 6.428\times 10^{8}\ J$$

$$\phi_{int.L.11} := N\cdot\left[\beta + (1-\beta)\cdot k_0\right]\cdot\varphi_{11}\cdot t_{11} = 1.244\times 10^{9}\ J$$

$$\phi_{int.L.12} := N\cdot\left[\beta + (1-\beta)\cdot k_0\right]\cdot\varphi_{12}\cdot t_{12} = 1.286\times 10^{9}\ J$$

- Annual heat flow rate from lighting ($\phi_{int.L}$):

$$\phi_{int.L} := \phi_{int.L.01} + \phi_{int.L.02} + \phi_{int.L.03} + \phi_{int.L.04} + \phi_{int.L.05} \cdots = 6.94\times 10^{9}\ J$$
$$+ \phi_{int.L.09} + \phi_{int.L.10} + \phi_{int.L.11} + \phi_{int.L.12}$$

Annex 7

Monthly and annual heat losses and internal heat gains

- Monthly heat losses by transmission and ventilation ($Q_{ht.i}$):

$$Q_{ht.01} := Q_{tr.01} + Q_{ve.01} = 1.896 \times 10^{10}\ J$$

$$Q_{ht.02} := Q_{tr.02} + Q_{ve.02} = 1.713 \times 10^{10}\ J$$

$$Q_{ht.03} := Q_{tr.03} + Q_{ve.03} = 1.514 \times 10^{10}\ J$$

$$Q_{ht.04} := Q_{tr.04} + Q_{ve.04} = 1.095 \times 10^{10}\ J$$

$$Q_{ht.05} := Q_{tr.05} + Q_{ve.05} = 6.07 \times 10^{9}\ J$$

$$Q_{ht.09} := Q_{tr.09} + Q_{ve.09} = 6.39 \times 10^{9}\ J$$

$$Q_{ht.10} := Q_{tr.10} + Q_{ve.10} = 1.221 \times 10^{10}\ J$$

$$Q_{ht.11} := Q_{tr.11} + Q_{ve.11} = 1.422 \times 10^{10}\ J$$

$$Q_{ht.12} := Q_{tr.12} + Q_{ve.12} = 1.745 \times 10^{10}\ J$$

- Annual heat losses by transmission and ventilation (Q_{ht})

$$Q_{ht} := Q_{ht.01} + Q_{ht.02} + Q_{ht.03} + Q_{ht.04} + Q_{ht.05} + Q_{ht.09} + Q_{ht.10} + Q_{ht.11} + Q_{ht.12} = 1.185 \times 10^{11}\ J$$

- Monthly heat gains from occupants, appliances and lighting ($Q_{int.i}$):

$$Q_{.int.01} := \phi_{int.Oc.1.01} + \phi_{int.Oc.2.01} + \phi_{int.L.01} = 3.06 \times 10^{9}\ J$$

$$Q_{.int.02} := \phi_{int.Oc.1.02} + \phi_{int.Oc.2.02} + \phi_{int.L.02} = 2.183 \times 10^{9}\ J$$

$$Q_{.int.03} := \phi_{int.Oc.1.03} + \phi_{int.Oc.2.03} + \phi_{int.L.03} = 2.417 \times 10^{9}\ J$$

$$Q_{.int.04} := \phi_{int.Oc.1.04} + \phi_{int.Oc.2.04} + \phi_{int.L.04} = 2.132 \times 10^{9}\ J$$

$$Q_{.int.05} := \phi_{int.Oc.1.05} + \phi_{int.Oc.2.05} + \phi_{int.L.05} = 2.203 \times 10^{9}\ J$$

$$Q_{.int.09} := \phi_{int.Oc.1.09} + \phi_{int.Oc.2.09} + \phi_{int.L.09} = 2.132 \times 10^{9}\ J$$

$$Q_{.int.10} := \phi_{int.Oc.1.10} + \phi_{int.Oc.2.10} + \phi_{int.L.10} = 2.417 \times 10^{9}\ J$$

$$Q_{.int.11} := \phi_{int.Oc.1.11} + \phi_{int.Oc.2.11} + \phi_{int.L.11} = 2.961 \times 10^{9}\ J$$

$$Q_{.int.12} := \phi_{int.Oc.1.12} + \phi_{int.Oc.2.12} + \phi_{int.L.12} = 3.06 \times 10^{9}\ J$$

- Anual heat gains from occupants, appliances and lighting (Q_{int}):

$$Q_{int} := Q_{.int.01} + Q_{.int.02} + Q_{.int.03} + Q_{.int.04} + Q_{.int.05} + Q_{.int.09} + Q_{.int.10} + Q_{.int.11} + Q_{.int.12} = 2.256 \times 10^{10}.$$

Annex 8

Solar heat gains through the glazed elements

- Types and areas of windows $\left(A_{window.i.k}\right)$:

$A_{window.high.narrow} := 1m \cdot 2.75m = 2.75\,m^2$ $\quad A_{window.short.narrow} := 1.5m \cdot 1m = 1.5\,m^2$

$A_{window.high.wide} := 1.5m \cdot 2.75m = 4.125\,m^2$ $\quad A_{window.short.wide} := 1.5m \cdot 2m = 3\,m^2$

1. Solar heat gains through the glazed elements for the south wall:

- Effective solar collecting area of glazed elements on the south wall ($A_{sol.w.south}$):

$A_{w.south} := 9 \cdot A_{window.high.narrow} + 2 \cdot A_{window.high.wide} = 33\,m^2$

$A_{sol.w.south} := F_{sh.gl} \cdot g_{gl} \cdot \left(1 - F_{F.s}\right) \cdot A_{w.south} = 12.705\,m^2$

- Solar irradiance on the south wall for each month ($I_{sol.s.i}$) :

$I_{sol.s.01} := 46.632 \cdot \frac{kW \cdot h}{m^2}$ $\quad I_{sol.s.04} := 93.453 \cdot \frac{kW \cdot h}{m^2}$ $\quad I_{sol.s.10} := 64.958 \cdot \frac{kW \cdot h}{m^2}$

$I_{sol.s.02} := 43.624 \cdot \frac{kW \cdot h}{m^2}$ $\quad I_{sol.s.05} := 118.333 \cdot \frac{kW \cdot h}{m^2}$ $\quad I_{sol.s.11} := 30.334 \cdot \frac{kW \cdot h}{m^2}$

$I_{sol.s.03} := 86.490 \cdot \frac{kW \cdot h}{m^2}$ $\quad I_{sol.s.09} := 78.571 \cdot \frac{kW \cdot h}{m^2}$ $\quad I_{sol.s.12} := 23.201 \cdot \frac{kW \cdot h}{m^2}$

- Heat flow due to thermal radiation to the sky from the glazed elements on the south wall ($\phi_{r.w.south}$):

$\phi_{r.w.south} := R_{se.window} \cdot U_{window} \cdot A_{w.south} \cdot h_{r.window} \cdot \Delta\theta_{er} \cdot h = 0.082 \cdot kW \cdot h$

- Solar gains through the glazed elements for each month ($Q_{sol.w.south.i}$):

$\phi_{sol.w.south.01} := F_{sh.o} \cdot A_{sol.w.south} \cdot I_{sol.s.01} - F_{r.k} \cdot \phi_{r.w.south} = 592.418 \cdot kW \cdot h$

$Q_{sol.w.south.01} := \phi_{sol.w.south.01} = 2.133 \times 10^9 \cdot J$

$\phi_{sol.w.south.02} := F_{sh.o} \cdot A_{sol.w.south} \cdot I_{sol.s.02} - F_{r.k} \cdot \phi_{r.w.south} = 554.202 \cdot kW \cdot h$

$Q_{sol.w.south.02} := \phi_{sol.w.south.02} = 1.995 \times 10^9 \cdot J$

$\phi_{sol.w.south.03} := F_{sh.o} \cdot A_{sol.w.south} \cdot I_{sol.s.03} - F_{r.k} \cdot \phi_{r.w.south} = 1.099 \times 10^3 \cdot kW \cdot h$

$Q_{sol.w.south.03} := \phi_{sol.w.south.03} = 3.956 \times 10^9\,J$

$\phi_{sol.w.south.04} := F_{sh.o} \cdot A_{sol.w.south} \cdot I_{sol.s.04} - F_{r.k} \cdot \phi_{r.w.south} = 1.187 \times 10^3 \cdot kW \cdot h$

$Q_{sol.w.south.04} := \phi_{sol.w.south.04} = 4.274 \times 10^9\,J$

$\phi_{sol.w.south.05} := F_{sh.o} \cdot A_{sol.w.south} \cdot I_{sol.s.05} - F_{r.k} \cdot \phi_{r.w.south} = 1.503 \times 10^3 \cdot kW \cdot h$

$Q_{sol.w.south.05} := \phi_{sol.w.south.05} = 5.412 \times 10^9\,J$

$\phi_{sol.w.south.09} := F_{sh.o} \cdot A_{sol.w.south} \cdot I_{sol.s.09} - F_{r.k} \cdot \phi_{r.w.south} = 998.203 \cdot kW \cdot h$

$Q_{sol.w.south.09} := \phi_{sol.w.south.09} = 3.594 \times 10^9\,J$

$$\phi_{sol.w.south.10} := F_{sh.o} \cdot A_{sol.w.south} \cdot I_{sol.s.10} - F_{r.k} \cdot \phi_{r.w.south} = 825.25 \cdot kW \cdot h$$

$$Q_{sol.w.south.10} := \phi_{sol.w.south.10} = 2.971 \times 10^{9} J$$

$$\phi_{sol.w.south.11} := F_{sh.o} \cdot A_{sol.w.south} \cdot I_{sol.s.11} - F_{r.k} \cdot \phi_{r.w.south} = 385.352 \cdot kW \cdot h$$

$$Q_{sol.w.south.11} := \phi_{sol.w.south.11} = 1.387 \times 10^{9} J$$

$$\phi_{sol.w.south.12} := F_{sh.o} \cdot A_{sol.w.south} \cdot I_{sol.s.12} - F_{r.k} \cdot \phi_{r.w.south} = 294.727 \cdot kW \cdot h$$

$$Q_{sol.w.south.12} := \phi_{sol.w.south.12} = 1.061 \times 10^{9} \cdot J$$

- Annual solar gains through the glazed elements for the south wall in joules ($Q_{sol.w.south}$) and in kilowatt-hours ($\phi_{sol.w.south}$):

$$\begin{aligned} Q_{sol.w.south} := {} & Q_{sol.w.south.01} + Q_{sol.w.south.02} + Q_{sol.w.south.03} + Q_{sol.w.south.04} \cdots = 2.678 \times 10^{10} J \\ & + Q_{sol.w.south.05} + Q_{sol.w.south.09} + Q_{sol.w.south.10} \cdots \\ & + Q_{sol.w.south.11} + Q_{sol.w.south.12} \end{aligned}$$

$$\begin{aligned} \phi_{sol.w.south} := {} & \phi_{sol.w.south.01} + \phi_{sol.w.south.02} + \phi_{sol.w.south.03} + \phi_{sol.w.south.04} \cdots = 7.44 \times 10^{3} \cdot kW \cdot h \\ & + \phi_{sol.w.south.05} + \phi_{sol.w.south.09} + \phi_{sol.w.south.10} \cdots \\ & + \phi_{sol.w.south.11} + \phi_{sol.w.south.12} \end{aligned}$$

2. Solar heat gains through the glazed elements for the west wall

- Effective solar collecting area of glazed elements on the west wall ($A_{sol.w.west}$):

$$A_{w.west} := 2 \cdot A_{window.high.narrow} + 3 \cdot A_{window.high.wide} = 17.875\, m^{2}$$

$$A_{sol.w.west} := F_{sh.gl} \cdot g_{gl} \cdot \left(1 - F_{F.w}\right) \cdot A_{w.west} = 7.007\, m^{2}$$

- Solar irradiance on the west wall for each month ($I_{sol.w.i}$)

.

$I_{sol.w.01} := 21.986 \cdot \frac{kW \cdot h}{m^{2}}$ $I_{sol.w.04} := 81.626 \cdot \frac{kW \cdot h}{m^{2}}$ $I_{sol.w.10} := 43.718 \cdot \frac{kW \cdot h}{m^{2}}$

$I_{sol.w.02} := 25.533 \cdot \frac{kW \cdot h}{m^{2}}$ $I_{sol.w.05} := 110.467 \cdot \frac{kW \cdot h}{m^{2}}$ $I_{sol.w.11} := 20.464 \cdot \frac{kW \cdot h}{m^{2}}$

$I_{sol.w.03} := 56.429 \cdot \frac{kW \cdot h}{m^{2}}$ $I_{sol.w.09} := 66.702 \cdot \frac{kW \cdot h}{m^{2}}$ $I_{sol.w.12} := 20.734 \cdot \frac{kW \cdot h}{m^{2}}$

- Heat flow due to thermal radiation to the sky from the glazed elements on the west wall ($\phi_{r.w.west}$)

$$\phi_{r.w.west} := R_{se.window} \cdot U_{window} \cdot A_{w.west} \cdot h_{r.window} \cdot \Delta\theta_{er} \cdot h = 0.045 \cdot kW \cdot h$$

- Solar gains through the glazed elements for each month ($Q_{sol.w.west.i}$):

$$\phi_{sol.w.west.01} := F_{sh.o} \cdot A_{sol.w.west} \cdot I_{sol.w.01} - F_{r.k} \cdot \phi_{r.w.west} = 1.54 \times 10^{5} \cdot W \cdot h$$

$$Q_{sol.w.west.01} := \phi_{sol.w.west.01} = 5.545 \times 10^{8} \cdot J$$

$$\phi_{sol.w.west.02} := F_{sh.o} \cdot A_{sol.w.west} \cdot I_{sol.w.02} - F_{r.k} \cdot \phi_{r.w.west} = 1.789 \times 10^{5} \cdot W \cdot h$$

$$Q_{sol.w.west.02} := \phi_{sol.w.west.02} = 6.44 \times 10^{8} J$$

$$\phi_{sol.w.west.03} := F_{sh.o} \cdot A_{sol.w.west} \cdot I_{sol.w.03} - F_{r.k} \cdot \phi_{r.w.west} = 3.954 \times 10^{5} \cdot W \cdot h$$

$$Q_{sol.w.west.03} := \phi_{sol.w.west.03} = 1.423 \times 10^{9}\, J$$

$$\phi_{sol.w.west.04} := F_{sh.o} \cdot A_{sol.w.west} \cdot I_{sol.w.04} - F_{r.k} \cdot \phi_{r.w.west} = 5.719 \times 10^{5} \cdot W \cdot h$$

$$Q_{sol.w.west.04} := \phi_{sol.w.west.04} = 2.059 \times 10^{9}\, J$$

$$\phi_{sol.w.west.05} := F_{sh.o} \cdot A_{sol.w.west} \cdot I_{sol.w.05} - F_{r.k} \cdot \phi_{r.w.west} = 7.74 \times 10^{5} \cdot W \cdot h$$

$$Q_{sol.w.west.05} := \phi_{sol.w.west.05} = 2.786 \times 10^{9}\, J$$

$$\phi_{sol.w.west.09} := F_{sh.o} \cdot A_{sol.w.west} \cdot I_{sol.w.09} - F_{r.k} \cdot \phi_{r.w.west} = 4.674 \times 10^{5} \cdot W \cdot h$$

$$Q_{sol.w.west.09} := \phi_{sol.w.west.09} = 1.682 \times 10^{9}\, J$$

$$\phi_{sol.w.west.10} := F_{sh.o} \cdot A_{sol.w.west} \cdot I_{sol.w.10} - F_{r.k} \cdot \phi_{r.w.west} = 3.063 \times 10^{5} \cdot W \cdot h$$

$$Q_{sol.w.west.10} := \phi_{sol.w.west.10} = 1.103 \times 10^{9}\, J$$

$$\phi_{sol.w.west.11} := F_{sh.o} \cdot A_{sol.w.west} \cdot I_{sol.w.11} - F_{r.k} \cdot \phi_{r.w.west} = 1.434 \times 10^{5} \cdot W \cdot h$$

$$Q_{sol.w.west.11} := \phi_{sol.w.west.11} = 5.161 \times 10^{8}\, J$$

$$\phi_{sol.w.west.12} := F_{sh.o} \cdot A_{sol.w.west} \cdot I_{sol.w.12} - F_{r.k} \cdot \phi_{r.w.west} = 1.453 \times 10^{5} \cdot W \cdot h$$

$$Q_{sol.w.west.12} := \phi_{sol.w.west.12} = 5.229 \times 10^{8}\, J$$

- Annual solar gains through the glazed elements for the west wall in joules ($Q_{sol.w.west}$) and in kilowatt-hours ($\phi_{sol.w.west}$):

$$\begin{aligned} Q_{sol.w.west} := {} & Q_{sol.w.west.01} + Q_{sol.w.west.02} + Q_{sol.w.west.03} + Q_{sol.w.west.04} \cdots = 1.129 \times 10^{10}\, J \\ & + Q_{sol.w.west.05} + Q_{sol.w.west.09} + Q_{sol.w.west.10} \cdots \\ & + Q_{sol.w.west.11} + Q_{sol.w.west.12} \end{aligned}$$

$$\begin{aligned} \phi_{sol.w.west} := {} & \phi_{sol.w.west.01} + \phi_{sol.w.west.02} + \phi_{sol.w.west.03} + \phi_{sol.w.west.04} \cdots = 3.137 \times 10^{3} \cdot kW \cdot h \\ & + \phi_{sol.w.west.05} + \phi_{sol.w.west.09} + \phi_{sol.w.west.10} \cdots \\ & + \phi_{sol.w.west.11} + \phi_{sol.w.west.12} \end{aligned}$$

3. Solar heat gains through the glazed elements for the north wall

- Effective solar collecting area of glazed elements on the north wall ($A_{sol.w.north}$):

$$A_{w.north} := 1 \cdot A_{window.short.narrow} + 1 \cdot A_{window.short.wide} = 4.5\, m^{2}$$

$$A_{window.short.narrow} = 1.5\, m^{2}$$

$$A_{sol.w.north} := F_{sh.gl} \cdot g_{gl} \cdot \left(1 - F_{F.n}\right) \cdot A_{w.north} = 1.732\, m^{2}$$

$$A_{window.short.wide} = 3\, m^{2}$$

- Solar irradiance on the north wall for each month ($I_{sol.n.01}$)
.

$I_{sol.n.01} := 19.379 \cdot \frac{kW \cdot h}{m^2}$ $I_{sol.n.04} := 70.721 \cdot \frac{kW \cdot h}{m^2}$ $I_{sol.n.10} := 35.688 \cdot \frac{kW \cdot h}{m^2}$

$I_{sol.n.02} := 21.512 \cdot \frac{kW \cdot h}{m^2}$ $I_{sol.n.05} := 86.539 \cdot \frac{kW \cdot h}{m^2}$ $I_{sol.n.11} := 18.650 \cdot \frac{kW \cdot h}{m^2}$

$I_{sol.n.03} := 46.900 \cdot \frac{kW \cdot h}{m^2}$ $I_{sol.n.09} := 57.424 \cdot \frac{kW \cdot h}{m^2}$ $I_{sol.n.12} := 15.698 \cdot \frac{kW \cdot h}{m^2}$

- Heat flow due to thermal radiation to the sky from the glazed elements on the north wall ($\phi_{r.w.north}$)
.

$\phi_{r.w.north} := R_{se.window} \cdot U_{window} \cdot A_{w.north} \cdot h_{r.window} \cdot \Delta\theta_{er} \cdot h = 0.011 \cdot kW \cdot h$

- Solar gains through the glazed elements for each month ($Q_{sol.w.north.i}$):

$\phi_{sol.w.north.01} := F_{sh.o} \cdot A_{sol.w.north} \cdot I_{sol.n.01} - F_{r.k} \cdot \phi_{r.w.north} = 33.568 \cdot kW \cdot h$

$Q_{sol.w.north.01} := \phi_{sol.w.north.01} = 1.208 \times 10^8 J$

$\phi_{sol.w.north.02} := F_{sh.o} \cdot A_{sol.w.north} \cdot I_{sol.n.02} - F_{r.k} \cdot \phi_{r.w.north} = 37.264 \cdot kW \cdot h$

$Q_{sol.w.north.02} := \phi_{sol.w.north.02} = 1.342 \times 10^8 J$

$\phi_{sol.w.north.03} := F_{sh.o} \cdot A_{sol.w.north} \cdot I_{sol.n.03} - F_{r.k} \cdot \phi_{r.w.north} = 81.249 \cdot kW \cdot h$

$Q_{sol.w.north.03} := \phi_{sol.w.north.03} = 2.925 \times 10^8 J$

$\phi_{sol.w.north.04} := F_{sh.o} \cdot A_{sol.w.north} \cdot I_{sol.n.04} - F_{r.k} \cdot \phi_{r.w.north} = 122.519 \cdot kW \cdot h$

$Q_{sol.w.north.04} := \phi_{sol.w.north.04} = 4.411 \times 10^8 J$

$\phi_{sol.w.north.05} := F_{sh.o} \cdot A_{sol.w.north} \cdot I_{sol.n.05} - F_{r.k} \cdot \phi_{r.w.north} = 149.923 \cdot kW \cdot h$

$Q_{sol.w.north.05} := \phi_{sol.w.north.05} = 5.397 \times 10^8 J$

$\phi_{sol.w.north.09} := F_{sh.o} \cdot A_{sol.w.north} \cdot I_{sol.n.09} - F_{r.k} \cdot \phi_{r.w.north} = 99.481 \cdot kW \cdot h$

$Q_{sol.w.north.09} := \phi_{sol.w.north.09} = 3.581 \times 10^8 J$

$\phi_{sol.w.north.10} := F_{sh.o} \cdot A_{sol.w.north} \cdot I_{sol.n.10} - F_{r.k} \cdot \phi_{r.w.north} = 61.824 \cdot kW \cdot h$

$Q_{sol.w.north.10} := \phi_{sol.w.north.10} = 2.226 \times 10^8 J$

$\phi_{sol.w.north.11} := F_{sh.o} \cdot A_{sol.w.north} \cdot I_{sol.n.11} - F_{r.k} \cdot \phi_{r.w.north} = 32.306 \cdot kW \cdot h$

$Q_{sol.w.north.11} := \phi_{sol.w.north.11} = 1.163 \times 10^8 J$

$\phi_{sol.w.north.12} := F_{sh.o} \cdot A_{sol.w.north} \cdot I_{sol.n.12} - F_{r.k} \cdot \phi_{r.w.north} = 27.191 \cdot kW \cdot h$

$Q_{sol.w.north.12} := \phi_{sol.w.north.12} = 9.789 \times 10^7 J$

- Annual solar gains through the glazed elements for the north wall in joules ($Q_{sol.w.north}$) and in kilowatt-hours ($\phi_{sol.w.north}$):

$$Q_{sol.w.north} := Q_{sol.w.north.01} + Q_{sol.w.north.02} + Q_{sol.w.north.03} + Q_{sol.w.north.04} \cdots + Q_{sol.w.north.05} + Q_{sol.w.north.09} + Q_{sol.w.north.10} \cdots + Q_{sol.w.north.11} + Q_{sol.w.north.12} = 2.323 \times 10^{9}\,J$$

$$\phi_{sol.w.north} := \phi_{sol.w.north.01} + \phi_{sol.w.north.02} + \phi_{sol.w.north.03} + \phi_{sol.w.north.04} \cdots + \phi_{sol.w.north.05} + \phi_{sol.w.north.09} + \phi_{sol.w.north.10} \cdots + \phi_{sol.w.north.11} + \phi_{sol.w.north.12} = 645.325 \cdot kW \cdot h$$

4. Solar heat gains through the glazed elements for the east wall

- Effective solar collecting area of glazed elements on the north wall ($A_{sol.w.east}$):

$$A_{w.east} := 1 \cdot A_{window.high.narrow} + 1 \cdot A_{window.high.wide} = 6.875\,m^2$$

$$A_{sol.w.east} := F_{sh.gl} \cdot g_{gl} \cdot \left(1 - F_{F.e}\right) \cdot A_{w.east} = 2.705\,m^2$$

- Solar irradiance on the east wall for each month ($I_{sol.e.01}$)

$$I_{sol.e.01} := 22.642 \cdot \frac{kW \cdot h}{m^2} \qquad I_{sol.e.04} := 87.704 \cdot \frac{kW \cdot h}{m^2} \qquad I_{sol.e.10} := 42.172 \cdot \frac{kW \cdot h}{m^2}$$

$$I_{sol.e.02} := 26.219 \cdot \frac{kW \cdot h}{m^2} \qquad I_{sol.e.05} := 120.847 \cdot \frac{kW \cdot h}{m^2} \qquad I_{sol.e.11} := 20.378 \cdot \frac{kW \cdot h}{m^2}$$

$$I_{sol.e.03} := 63.803 \cdot \frac{kW \cdot h}{m^2} \qquad I_{sol.e.09} := 64.857 \cdot \frac{kW \cdot h}{m^2} \qquad I_{sol.e.12} := 16.388 \cdot \frac{kW \cdot h}{m^2}$$

- Heat flow due to thermal radiation to the sky from the glazed elements on the east wall ($\phi_{r.w.east}$)

$$\phi_{r.w.east} := R_{se.window} \cdot U_{window} \cdot A_{w.west} \cdot h_{r.window} \cdot \Delta\theta_{er} \cdot h = 0.045 \cdot kW \cdot h$$

- Solar gains through the glazed elements for each month ($Q_{sol.w.east.i}$):

$$\phi_{sol.w.east.01} := F_{sh.o} \cdot A_{sol.w.east} \cdot I_{sol.e.01} - F_{r.k} \cdot \phi_{r.w.east} = 61.216 \cdot kW \cdot h$$

$$Q_{sol.w.east.01} := \phi_{sol.w.east.01} = 2.204 \times 10^{8}\,J$$

$$\phi_{sol.w.east.02} := F_{sh.o} \cdot A_{sol.w.east} \cdot I_{sol.e.02} - F_{r.k} \cdot \phi_{r.w.east} = 70.89 \cdot kW \cdot h$$

$$Q_{sol.w.east.02} := \phi_{sol.w.east.02} = 2.552 \times 10^{8}\,J$$

$$\phi_{sol.w.east.03} := F_{sh.o} \cdot A_{sol.w.east} \cdot I_{sol.e.03} - F_{r.k} \cdot \phi_{r.w.east} = 172.541 \cdot kW \cdot h$$

$$Q_{sol.w.east.03} := \phi_{sol.w.east.03} = 6.211 \times 10^{8}\,J$$

$$\phi_{sol.w.east.04} := F_{sh.o} \cdot A_{sol.w.east} \cdot I_{sol.e.04} - F_{r.k} \cdot \phi_{r.w.east} = 237.184 \cdot kW \cdot h$$

$$Q_{sol.w.east.04} := \phi_{sol.w.east.04} = 8.539 \times 10^{8}\,J$$

$$\phi_{sol.w.east.05} := F_{sh.o} \cdot A_{sol.w.east} \cdot I_{sol.e.05} - F_{r.k} \cdot \phi_{r.w.east} = 326.823 \cdot kW \cdot h$$

$$Q_{sol.w.east.05} := \phi_{sol.w.east.05} = 1.177 \times 10^{9}\,J$$

$$\phi_{sol.w.east.09} := F_{sh.o} \cdot A_{sol.w.east} \cdot I_{sol.e.09} - F_{r.k} \cdot \phi_{r.w.east} = 175.392 \cdot kW \cdot h$$

$$Q_{sol.w.east.09} := \phi_{sol.w.east.09} = 6.314 \times 10^{8}\,J$$

$$\phi_{sol.w.east.10} := F_{sh.o} \cdot A_{sol.w.east} \cdot I_{sol.e.10} - F_{r.k} \cdot \phi_{r.w.east} = 114.037 \cdot kW \cdot h$$

$$Q_{sol.w.east.10} := \phi_{sol.w.east.10} = 4.105 \times 10^{8}\,J$$

$$\phi_{sol.w.east.11} := F_{sh.o} \cdot A_{sol.w.east} \cdot I_{sol.e.11} - F_{r.k} \cdot \phi_{r.w.east} = 55.093 \cdot kW \cdot h$$

$$Q_{sol.w.east.11} := \phi_{sol.w.east.11} = 1.983 \times 10^{8}\,J$$

$$\phi_{sol.w.east.12} := F_{sh.o} \cdot A_{sol.w.east} \cdot I_{sol.e.12} - F_{r.k} \cdot \phi_{r.w.east} = 44.301 \cdot kW \cdot h$$

$$Q_{sol.w.east.12} := \phi_{sol.w.east.12} = 1.595 \times 10^{8}\,J$$

- Annual solar gains through the glazed elements for the east wall in joules ($Q_{sol.w.east}$) and in kilowatt-hours ($\phi_{sol.w.east}$):

$$\begin{aligned} Q_{sol.w.east} := {} & Q_{sol.w.east.01} + Q_{sol.w.east.02} + Q_{sol.w.east.03} + Q_{sol.w.east.04} \cdots = 4.527 \times 10^{9}\,J \\ & + Q_{sol.w.east.05} + Q_{sol.w.east.09} + Q_{sol.w.east.10} \cdots \\ & + Q_{sol.w.east.11} + Q_{sol.w.east.12} \end{aligned}$$

$$\begin{aligned} \phi_{sol.w.east} := {} & \phi_{sol.w.east.01} + \phi_{sol.w.east.02} + \phi_{sol.w.east.03} + \phi_{sol.w.east.04} \cdots = 1.257 \times 10^{3} \cdot kW \cdot h \\ & + \phi_{sol.w.east.05} + \phi_{sol.w.east.09} + \phi_{sol.w.east.10} \cdots \\ & + \phi_{sol.w.east.11} + \phi_{sol.w.east.12} \end{aligned}$$

Annex 9

Total solar heat gains through the glazed elements

- Monthly solar heat gains through the glazed elements ($Q_{sol.w.i}$):

$$Q_{sol.w.01} := Q_{sol.w.south.01} + Q_{sol.w.west.01} + Q_{sol.w.north.01} + Q_{sol.w.east.01} = 3.028 \times 10^{9}\ J$$

$$Q_{sol.w.02} := Q_{sol.w.south.02} + Q_{sol.w.west.02} + Q_{sol.w.north.02} + Q_{sol.w.east.02} = 3.028 \times 10^{9}\ J$$

$$Q_{sol.w.03} := Q_{sol.w.south.03} + Q_{sol.w.west.03} + Q_{sol.w.north.03} + Q_{sol.w.east.03} = 6.293 \times 10^{9}\ J$$

$$Q_{sol.w.04} := Q_{sol.w.south.04} + Q_{sol.w.west.04} + Q_{sol.w.north.04} + Q_{sol.w.east.04} = 7.628 \times 10^{9}\ J$$

$$Q_{sol.w.05} := Q_{sol.w.south.05} + Q_{sol.w.west.05} + Q_{sol.w.north.05} + Q_{sol.w.east.05} = 9.915 \times 10^{9}\ J$$

$$Q_{sol.w.09} := Q_{sol.w.south.09} + Q_{sol.w.west.09} + Q_{sol.w.north.09} + Q_{sol.w.east.09} = 6.266 \times 10^{9}\ J$$

$$Q_{sol.w.10} := Q_{sol.w.south.10} + Q_{sol.w.west.10} + Q_{sol.w.north.10} + Q_{sol.w.east.10} = 4.707 \times 10^{9}\ J$$

$$Q_{sol.w.11} := Q_{sol.w.south.11} + Q_{sol.w.west.11} + Q_{sol.w.north.11} + Q_{sol.w.east.11} = 2.218 \times 10^{9}\ J$$

$$Q_{sol.w.12} := Q_{sol.w.south.12} + Q_{sol.w.west.12} + Q_{sol.w.north.12} + Q_{sol.w.east.12} = 1.841 \times 10^{9}\ J$$

- Annual solar heat gains through the glazed elements in joules ($Q_{sol.w.TOTAL.joules}$) in kilowatt-hours ($Q_{sol.w.TOTAL.kWh}$) and in kilowatt-hours per squere meter of conditioned area ($Q_{sol.w.TOTAL.kWh.m2}$):

$$\begin{aligned} Q_{sol.w.TOTAL.joules} := {} & Q_{sol.w.01} + Q_{sol.w.02} + Q_{sol.w.03} + Q_{sol.w.04} \cdots = 4.492 \times 10^{10}\ J \\ & + Q_{sol.w.05} + Q_{sol.w.09} + Q_{sol.w.10} \cdots \\ & + Q_{sol.w.11} + Q_{sol.w.12} \end{aligned}$$

$$Q_{sol.w.TOTAL.kWh} := Q_{sol.w.TOTAL.joules} = 1.248 \times 10^{4} \cdot kW \cdot h$$

$$Q_{sol.w.TOTAL.kWh.m2} := \frac{Q_{sol.w.TOTAL.joules}}{A_{conditioned.area}} = 69.66 \cdot \frac{kW \cdot h}{m^{2}}$$

Annex 10

Solar heat gains through the opaque building envelope - walls

1. Solar heat gains through the south exterior wall

- Effective solar collecting area of the south wall ($A_{sol.W.south}$):

  $A_{W.south} := 3m\cdot(9.185m + 9.2m) - \left(9\cdot A_{window.high.narrow} + 2\cdot A_{window.high.wide}\right) = 22.155\,m^2$

  $A_{sol.W.south} := \alpha_{s.c}\cdot R_{se}\cdot U_{exterior.wall}\cdot A_{W.south} = 0.159\,m^2$

- Solar irradiance on the south wall for each month ($I_{sol.s.i}$):

  The same as for south-oriented windows

- Heat flow due to thermal radiation to the sky from the south wall ($\phi_{r.W.south}$):

  $\phi_{r.W.south} := R_{se}\cdot U_{exterior.wall}\cdot A_{W.south}\cdot h_{r.wall}\cdot\Delta\theta_{er}\cdot h = 0.011\cdot kW\cdot h$

- Solar gains through the south wall for each month ($Q_{sol.W.south.i}$):

  $\phi_{sol.W.south.01} := F_{sh.o}\cdot A_{sol.W.south}\cdot I_{sol.s.01} - F_{r.k}\cdot\phi_{r.W.south} = 7.387\cdot kW\cdot h$

  $Q_{sol.W.south.01} := \phi_{sol.W.south.01} = 2.659\times10^7\,J$

  $\phi_{sol.W.south.02} := F_{sh.o}\cdot A_{sol.W.south}\cdot I_{sol.s.02} - F_{r.k}\cdot\phi_{r.W.south} = 6.91\cdot kW\cdot h$

  $Q_{sol.W.south.02} := \phi_{sol.W.south.02} = 2.488\times10^7\,J$

  $\phi_{sol.W.south.03} := F_{sh.o}\cdot A_{sol.W.south}\cdot I_{sol.s.03} - F_{r.k}\cdot\phi_{r.W.south} = 13.706\cdot kW\cdot h$

  $Q_{sol.W.south.03} := \phi_{sol.W.south.03} = 4.934\times10^7\,J$

  $\phi_{sol.W.south.04} := F_{sh.o}\cdot A_{sol.W.south}\cdot I_{sol.s.04} - F_{r.k}\cdot\phi_{r.W.south} = 14.81\cdot kW\cdot h$

  $Q_{sol.W.south.04} := \phi_{sol.W.south.04} = 5.332\times10^7\,J$

  $\phi_{sol.W.south.05} := F_{sh.o}\cdot A_{sol.W.south}\cdot I_{sol.s.05} - F_{r.k}\cdot\phi_{r.W.south} = 18.755\cdot kW\cdot h$

  $Q_{sol.W.south.05} := \phi_{sol.W.south.05} = 6.752\times10^7\,J$

  $\phi_{sol.W.south.09} := F_{sh.o}\cdot A_{sol.W.south}\cdot I_{sol.s.09} - F_{r.k}\cdot\phi_{r.W.south} = 12.451\cdot kW\cdot h$

  $Q_{sol.W.south.09} := \phi_{sol.W.south.09} = 4.482\times10^7\,J$

  $\phi_{sol.W.south.10} := F_{sh.o}\cdot A_{sol.W.south}\cdot I_{sol.s.10} - F_{r.k}\cdot\phi_{r.W.south} = 10.293\cdot kW\cdot h$

  $Q_{sol.W.south.10} := \phi_{sol.W.south.10} = 3.705\times10^7\,J$

  $\phi_{sol.W.south.11} := F_{sh.o}\cdot A_{sol.W.south}\cdot I_{sol.s.11} - F_{r.k}\cdot\phi_{r.W.south} = 4.804\cdot kW\cdot h$

  $Q_{sol.W.south.11} := \phi_{sol.W.south.11} = 1.729\times10^7\,J$

$$\phi_{sol.W.south.12} := F_{sh.o} \cdot A_{sol.W.south} \cdot I_{sol.s.12} - F_{r.k} \cdot \phi_{r.W.south} = 3.673 \cdot kW \cdot h$$

$$Q_{sol.W.south.12} := \phi_{sol.W.south.12} = 1.322 \times 10^{7}\,J$$

- Annual solar gains through the south wall in joules ($Q_{sol.W.south}$) and in kilowatt-hours ($\phi_{sol.W.south}$):

$$Q_{sol.W.south} := Q_{sol.W.south.01} + Q_{sol.W.south.02} + Q_{sol.W.south.03} + Q_{sol.W.south.04} \cdots + Q_{sol.W.south.05} + Q_{sol.W.south.09} + Q_{sol.W.south.10} \cdots + Q_{sol.W.south.11} + Q_{sol.W.south.12} = 3.34 \times 10^{8}\,J$$

$$\phi_{sol.W.south} := \phi_{sol.W.south.01} + \phi_{sol.W.south.02} + \phi_{sol.W.south.03} + \phi_{sol.W.south.04} \cdots + \phi_{sol.W.south.05} + \phi_{sol.W.south.09} + \phi_{sol.W.south.10} \cdots + \phi_{sol.W.south.11} + \phi_{sol.W.south.12} = 92.789 \cdot kW \cdot h$$

2. Solar heat gains through the west exterior wall

- Effective solar collecting area of the west wall ($A_{sol.W.west}$):

$$A_{W.west} := 3m \cdot (4m + 9.340m + 1.5m) - \left(2 \cdot A_{window.high.narrow} + 3 \cdot A_{window.high.wide} + A_{door}\right) = 24.645\,m^{2}$$

$$A_{sol.W.west} := \alpha_{s.c} \cdot R_{se} \cdot U_{exterior.wall} \cdot A_{W.west} = 0.176\,m^{2}$$

- Solar irradiance on the west wall for each month ($I_{sol.w.i}$):

  The same as for west-oriented windows

- Heat flow due to thermal radiation to the sky from the west wall ($\phi_{r.W.west}$):

$$\phi_{r.W.west} := R_{se} \cdot U_{exterior.wall} \cdot A_{W.west} \cdot h_{r.wall} \cdot \Delta\theta_{er} \cdot h = 0.012 \cdot kW \cdot h$$

- Solar gains through the west wall for each month ($Q_{sol.W.west.i}$):

$$\phi_{sol.W.west.01} := F_{sh.o} \cdot A_{sol.W.west} \cdot I_{sol.w.01} - F_{r.k} \cdot \phi_{r.W.west} = 3.871 \cdot kW \cdot h$$

$$Q_{sol.W.west.01} := \phi_{sol.W.west.01} = 1.394 \times 10^{7}\,J$$

$$\phi_{sol.W.west.02} := F_{sh.o} \cdot A_{sol.W.west} \cdot I_{sol.w.02} - F_{r.k} \cdot \phi_{r.W.west} = 4.497 \cdot kW \cdot h$$

$$Q_{sol.W.west.02} := \phi_{sol.W.west.02} = 1.619 \times 10^{7}\,J$$

$$\phi_{sol.W.west.03} := F_{sh.o} \cdot A_{sol.W.west} \cdot I_{sol.w.03} - F_{r.k} \cdot \phi_{r.W.west} = 9.945 \cdot kW \cdot h$$

$$Q_{sol.W.west.03} := \phi_{sol.W.west.03} = 3.58 \times 10^{7}\,J$$

$$\phi_{sol.W.west.04} := F_{sh.o} \cdot A_{sol.W.west} \cdot I_{sol.w.04} - F_{r.k} \cdot \phi_{r.W.west} = 14.389 \cdot kW \cdot h$$

$$Q_{sol.W.west.04} := \phi_{sol.W.west.04} = 5.18 \times 10^{7}\,J$$

$$\phi_{sol.W.west.05} := F_{sh.o} \cdot A_{sol.W.west} \cdot I_{sol.w.05} - F_{r.k} \cdot \phi_{r.W.west} = 19.475 \cdot kW \cdot h$$

$$Q_{sol.W.west.05} := \phi_{sol.W.west.05} = 7.011 \times 10^{7}\,J$$

$$\phi_{sol.W.west.09} := F_{sh.o} \cdot A_{sol.W.west} \cdot I_{sol.w.09} - F_{r.k} \cdot \phi_{r.W.west} = 11.757 \cdot kW \cdot h$$

$$Q_{sol.W.west.09} := \phi_{sol.W.west.09} = 4.233 \times 10^{7}\,J$$

$$\phi_{sol.W.west.10} := F_{sh.o} \cdot A_{sol.W.west} \cdot I_{sol.w.10} - F_{r.k} \cdot \phi_{r.W.west} = 7.704 \cdot kW \cdot h$$

$$Q_{sol.W.west.10} := \phi_{sol.W.west.10} = 2.773 \times 10^{7}\,J$$

$$\phi_{sol.W.west.11} := F_{sh.o} \cdot A_{sol.W.west} \cdot I_{sol.w.11} - F_{r.k} \cdot \phi_{r.W.west} = 3.603 \cdot kW \cdot h$$

$$Q_{sol.W.west.11} := \phi_{sol.W.west.11} = 1.297 \times 10^{7}\,J$$

$$\phi_{sol.W.west.12} := F_{sh.o} \cdot A_{sol.W.west} \cdot I_{sol.w.12} - F_{r.k} \cdot \phi_{r.W.west} = 3.65 \cdot kW \cdot h$$

$$Q_{sol.W.west.12} := \phi_{sol.W.west.12} = 1.314 \times 10^{7}\,J$$

- Annual solar gains through the west wall in joules ($Q_{sol.W.west}$) and in kilowatt-hours ($\phi_{sol.W.west}$):

$$\begin{aligned}Q_{sol.W.west} := {} & Q_{sol.W.west.01} + Q_{sol.W.west.02} + Q_{sol.W.west.03} + Q_{sol.W.west.04} \cdots = 2.84 \times 10^{8}\,J \\ & + Q_{sol.W.west.05} + Q_{sol.W.west.09} + Q_{sol.W.west.10} \cdots \\ & + Q_{sol.W.west.11} + Q_{sol.W.west.12}\end{aligned}$$

$$\begin{aligned}\phi_{sol.W.west} := {} & \phi_{sol.W.west.01} + \phi_{sol.W.west.02} + \phi_{sol.W.west.03} + \phi_{sol.W.west.04} \cdots = 78.892 \cdot kW \cdot h \\ & + \phi_{sol.W.west.05} + \phi_{sol.W.west.09} + \phi_{sol.W.west.10} \cdots \\ & + \phi_{sol.W.west.11} + \phi_{sol.W.west.12}\end{aligned}$$

3. Solar heat gains through the north exterior wall

- Effective solar collecting area of the north wall ($A_{sol.W.north}$):

$$\begin{aligned}A_{W.north} := {} & 3m \cdot (7.3m + 4.285m + 2.8m) + 0.5 \cdot 2.7m \cdot 4.115m \ldots = 53.21\,m^{2} \\ & + \left(1 \cdot A_{window.short.narrow} + 1 \cdot A_{window.short.wide}\right)\end{aligned}$$

$$A_{sol.W.north} := \alpha_{s.c} \cdot R_{se} \cdot U_{exterior.wall} \cdot A_{W.north} = 0.381\,m^{2}$$

- Solar irradiance on the north wall for each month ($I_{sol.n.i}$):

  The same as for north-oriented windows

- Heat flow due to thermal radiation to the sky from the north wall ($\phi_{r.W.north}$):

$$\phi_{r.W.north} := R_{se} \cdot U_{exterior.wall} \cdot A_{W.north} \cdot h_{r.wall} \cdot \Delta\theta_{er} \cdot h = 26.926 \cdot W \cdot h$$

- Solar gains through the north wall for each month ($Q_{sol.W.north.i}$):

$$\phi_{sol.W.north.01} := F_{sh.o} \cdot A_{sol.W.north} \cdot I_{sol.n.01} - F_{r.k} \cdot \phi_{r.W.north} = 7.365 \cdot kW \cdot h$$

$$Q_{sol.W.north.01} := \phi_{sol.W.north.01} = 2.652 \times 10^{7}\,J$$

$$\phi_{sol.W.north.02} := F_{sh.o} \cdot A_{sol.W.north} \cdot I_{sol.n.02} - F_{r.k} \cdot \phi_{r.W.north} = 8.178 \cdot kW \cdot h$$

$$Q_{sol.W.north.02} := \phi_{sol.W.north.02} = 2.944 \times 10^{7}\,J$$

$$\phi_{sol.W.north.03} := F_{sh.o} \cdot A_{sol.W.north} \cdot I_{sol.n.03} - F_{r.k} \cdot \phi_{r.W.north} = 17.845 \cdot kW \cdot h$$

$$Q_{sol.W.north.03} := \phi_{sol.W.north.03} = 6.424 \times 10^{7}\,J$$

$$\phi_{sol.W.north.04} := F_{sh.o} \cdot A_{sol.W.north} \cdot I_{sol.n.04} - F_{r.k} \cdot \phi_{r.W.north} = 26.915 \cdot kW \cdot h$$

$$Q_{sol.W.north.04} := \phi_{sol.W.north.04} = 9.689 \times 10^{7} \, J$$

$$\phi_{sol.W.north.05} := F_{sh.o} \cdot A_{sol.W.north} \cdot I_{sol.n.05} - F_{r.k} \cdot \phi_{r.W.north} = 32.938 \cdot kW \cdot h$$

$$Q_{sol.W.north.05} := \phi_{sol.W.north.05} = 1.186 \times 10^{8} \, J$$

$$\phi_{sol.W.north.09} := F_{sh.o} \cdot A_{sol.W.north} \cdot I_{sol.n.09} - F_{r.k} \cdot \phi_{r.W.north} = 21.852 \cdot kW \cdot h$$

$$Q_{sol.W.north.09} := \phi_{sol.W.north.09} = 7.867 \times 10^{7} \, J$$

$$\phi_{sol.W.north.10} := F_{sh.o} \cdot A_{sol.W.north} \cdot I_{sol.n.10} - F_{r.k} \cdot \phi_{r.W.north} = 13.575 \cdot kW \cdot h$$

$$Q_{sol.W.north.10} := \phi_{sol.W.north.10} = 4.887 \times 10^{7} \, J$$

$$\phi_{sol.W.north.11} := F_{sh.o} \cdot A_{sol.W.north} \cdot I_{sol.n.11} - F_{r.k} \cdot \phi_{r.W.north} = 7.088 \cdot kW \cdot h$$

$$Q_{sol.W.north.11} := \phi_{sol.W.north.11} = 2.552 \times 10^{7} \, J$$

$$\phi_{sol.W.north.12} := F_{sh.o} \cdot A_{sol.W.north} \cdot I_{sol.n.12} - F_{r.k} \cdot \phi_{r.W.north} = 5.964 \cdot kW \cdot h$$

$$Q_{sol.W.north.12} := \phi_{sol.W.north.12} = 2.147 \times 10^{7} \, J$$

- Annual solar gains through the north wall in joules ($Q_{sol.W.north}$) and in kilowatt-hours ($\phi_{sol.W.north}$):

$$\begin{aligned} Q_{sol.W.north} := {} & Q_{sol.W.north.01} + Q_{sol.W.north.02} + Q_{sol.W.north.03} + Q_{sol.W.north.04} \cdots = 5.102 \times 10^{8} \, J \\ & + Q_{sol.W.north.05} + Q_{sol.W.north.09} + Q_{sol.W.north.10} \cdots \\ & + Q_{sol.W.north.11} + Q_{sol.W.north.12} \end{aligned}$$

$$\begin{aligned} \phi_{sol.W.north} := {} & \phi_{sol.W.north.01} + \phi_{sol.W.north.02} + \phi_{sol.W.north.03} + \phi_{sol.W.north.04} \cdots = 141.719 \cdot kW \cdot h \\ & + \phi_{sol.W.north.05} + \phi_{sol.W.north.09} + \phi_{sol.W.north.10} \cdots \\ & + \phi_{sol.W.north.11} + \phi_{sol.W.north.12} \end{aligned}$$

4. Solar heat gains through the east exterior wall

- Effective solar collecting area of the east wall ($A_{sol.W.east}$):

$$A_{W.east} := 3m \cdot 9.2m + 0.5 \cdot 2.7m \cdot 6m - \left(1 \cdot A_{window.high.narrow} + 1 \cdot A_{window.high.wide}\right) = 28.825 \, m^{2}$$

$$A_{sol.W.east} := \alpha_{s.c} \cdot R_{se} \cdot U_{exterior.wall} \cdot A_{W.east} = 0.206 \, m^{2}$$

- Solar irradiance on the east wall for each month ($I_{sol.e.i}$):

  The same as for east-oriented windows

- Heat flow due to thermal radiation to the sky from the east wall ($\phi_{r.W.east}$):

$$\phi_{r.W.east} := R_{se} \cdot U_{exterior.wall} \cdot A_{W.east} \cdot h_{r.wall} \cdot \Delta\theta_{er} \cdot h = 0.015 \cdot kW \cdot h$$

- Solar gains through the east wall for each month ($Q_{sol.W.east.i}$):

$$\phi_{sol.W.east.01} := F_{sh.o} \cdot A_{sol.W.east} \cdot I_{sol.e.01} - F_{r.k} \cdot \phi_{r.W.east} = 4.663 \cdot kW \cdot h$$

$$Q_{sol.W.east.01} := \phi_{sol.W.east.01} = 1.679 \times 10^{7} J$$

$$\phi_{sol.W.east.02} := F_{sh.o} \cdot A_{sol.W.east} \cdot I_{sol.e.02} - F_{r.k} \cdot \phi_{r.W.east} = 5.401 \cdot kW \cdot h$$

$$Q_{sol.W.east.02} := \phi_{sol.W.east.02} = 1.944 \times 10^{7} J$$

$$\phi_{sol.W.east.03} := F_{sh.o} \cdot A_{sol.W.east} \cdot I_{sol.e.03} - F_{r.k} \cdot \phi_{r.W.east} = 13.153 \cdot kW \cdot h$$

$$Q_{sol.W.east.03} := \phi_{sol.W.east.03} = 4.735 \times 10^{7} J$$

$$\phi_{sol.W.east.04} := F_{sh.o} \cdot A_{sol.W.east} \cdot I_{sol.e.04} - F_{r.k} \cdot \phi_{r.W.east} = 18.083 \cdot kW \cdot h$$

$$Q_{sol.W.east.04} := \phi_{sol.W.east.04} = 6.51 \times 10^{7} J$$

$$\phi_{sol.W.east.05} := F_{sh.o} \cdot A_{sol.W.east} \cdot I_{sol.e.05} - F_{r.k} \cdot \phi_{r.W.east} = 24.92 \cdot kW \cdot h$$

$$Q_{sol.W.east.05} := \phi_{sol.W.east.05} = 8.971 \times 10^{7} J$$

$$\phi_{sol.W.east.09} := F_{sh.o} \cdot A_{sol.W.east} \cdot I_{sol.e.09} - F_{r.k} \cdot \phi_{r.W.east} = 13.371 \cdot kW \cdot h$$

$$Q_{sol.W.east.09} := \phi_{sol.W.east.09} = 4.813 \times 10^{7} J$$

$$\phi_{sol.W.east.10} := F_{sh.o} \cdot A_{sol.W.east} \cdot I_{sol.e.10} - F_{r.k} \cdot \phi_{r.W.east} = 8.691 \cdot kW \cdot h$$

$$Q_{sol.W.east.10} := \phi_{sol.W.east.10} = 3.129 \times 10^{7} J$$

$$\phi_{sol.W.east.11} := F_{sh.o} \cdot A_{sol.W.east} \cdot I_{sol.e.11} - F_{r.k} \cdot \phi_{r.W.east} = 4.196 \cdot kW \cdot h$$

$$Q_{sol.W.east.11} := \phi_{sol.W.east.11} = 1.511 \times 10^{7} J$$

$$\phi_{sol.W.east.12} := F_{sh.o} \cdot A_{sol.W.east} \cdot I_{sol.e.12} - F_{r.k} \cdot \phi_{r.W.east} = 3.373 \cdot kW \cdot h$$

$$Q_{sol.W.east.12} := \phi_{sol.W.east.12} = 1.214 \times 10^{7} J$$

- Annual solar gains through the east wall in joules ($Q_{sol.W.east}$) and in kilowatt-hours ($\phi_{sol.W.east}$):

$$\begin{aligned} Q_{sol.W.east} := {} & Q_{sol.W.east.01} + Q_{sol.W.east.02} + Q_{sol.W.east.03} + Q_{sol.W.east.04} \cdots = 3.451 \times 10^{8} J \\ & + Q_{sol.W.east.05} + Q_{sol.W.east.09} + Q_{sol.W.east.10} \cdots \\ & + Q_{sol.W.east.11} + Q_{sol.W.east.12} \end{aligned}$$

$$\begin{aligned} \phi_{sol.W.east} := {} & \phi_{sol.W.east.01} + \phi_{sol.W.east.02} + \phi_{sol.W.east.03} + \phi_{sol.W.east.04} \cdots = 95.851 \cdot kW \cdot h \\ & + \phi_{sol.W.east.05} + \phi_{sol.W.east.09} + \phi_{sol.W.east.10} \cdots \\ & + \phi_{sol.W.east.11} + \phi_{sol.W.east.12} \end{aligned}$$

Annex 11

Total solar heat gains through the opaque building envelope - roof

- Effective solar collecting area of the roof ($A_{sol.r}$):

$A_r := A_{conditioned.area} + 0.5 \cdot 25.925m^2 = 192.102\, m^2$ $25.925m^2$ is a garage area

$A_{sol.r} := \alpha_{s.c} \cdot R_{se} \cdot U_{roof} \cdot A_r = 1.447\, m^2$

- Solar irradiance on the roof for each month ($I_{sol.r.i}$):

$I_{sol.r.01} := 27.962 \cdot \frac{kW \cdot h}{m^2}$ $I_{sol.r.04} := 99.324 \cdot \frac{kW \cdot h}{m^2}$ $I_{sol.r.10} := 51.570 \cdot \frac{kW \cdot h}{m^2}$

$I_{sol.r.02} := 31.503 \cdot \frac{kW \cdot h}{m^2}$ $I_{sol.r.05} := 155.522 \cdot \frac{kW \cdot h}{m^2}$ $I_{sol.r.11} := 22.963 \cdot \frac{kW \cdot h}{m^2}$

$I_{sol.r.03} := 73.137 \cdot \frac{kW \cdot h}{m^2}$ $I_{sol.r.09} := 76.655 \cdot \frac{kW \cdot h}{m^2}$ $I_{sol.r.12} := 17.769 \cdot \frac{kW \cdot h}{m^2}$

- Heat flow due to thermal radiation to the sky from the roof ($\phi_{r.r}$):

$\phi_{r.r} := R_{se} \cdot U_{roof} \cdot A_r \cdot h_{r.roof} \cdot \Delta\theta_{er} \cdot h = 0.071 \cdot kW \cdot h$

- Solar gains through the roof for each month ($Q_{sol.r.i}$):

$\phi_{sol.r.01} := F_{sh.o} \cdot A_{sol.r} \cdot I_{sol.r.01} - F_{r.k} \cdot \phi_{r.r} = 40.403 \cdot kW \cdot h$

$Q_{sol.r.01} := \phi_{sol.r.01} = 1.455 \times 10^8\, J$

$\phi_{sol.r.02} := F_{sh.o} \cdot A_{sol.r} \cdot I_{sol.r.02} - F_{r.k} \cdot \phi_{r.r} = 45.529 \cdot kW \cdot h$

$Q_{sol.r.02} := \phi_{sol.r.02} = 1.639 \times 10^8\, J$

$\phi_{sol.r.03} := F_{sh.o} \cdot A_{sol.r} \cdot I_{sol.r.03} - F_{r.k} \cdot \phi_{r.r} = 105.793 \cdot kW \cdot h$

$Q_{sol.r.03} := \phi_{sol.r.03} = 3.809 \times 10^8\, J$

$\phi_{sol.r.04} := F_{sh.o} \cdot A_{sol.r} \cdot I_{sol.r.04} - F_{r.k} \cdot \phi_{r.r} = 143.698 \cdot kW \cdot h$

$Q_{sol.r.04} := \phi_{sol.r.04} = 5.173 \times 10^8\, J$

$\phi_{sol.r.05} := F_{sh.o} \cdot A_{sol.r} \cdot I_{sol.r.05} - F_{r.k} \cdot \phi_{r.r} = 225.043 \cdot kW \cdot h$

$Q_{sol.r.05} := \phi_{sol.r.05} = 8.102 \times 10^8\, J$

$\phi_{sol.r.09} := F_{sh.o} \cdot A_{sol.r} \cdot I_{sol.r.09} - F_{r.k} \cdot \phi_{r.r} = 110.885 \cdot kW \cdot h$

$Q_{sol.r.09} := \phi_{sol.r.09} = 3.992 \times 10^8\, J$

$\phi_{sol.r.10} := F_{sh.o} \cdot A_{sol.r} \cdot I_{sol.r.10} - F_{r.k} \cdot \phi_{r.r} = 74.575 \cdot kW \cdot h$

$Q_{sol.r.10} := \phi_{sol.r.10} = 2.685 \times 10^8\, J$

$$\phi_{sol.r.11} := F_{sh.o} \cdot A_{sol.r} \cdot I_{sol.r.11} - F_{r.k} \cdot \phi_{r.r} = 33.167 \cdot kW \cdot h$$

$$Q_{sol.r.11} := \phi_{sol.r.11} = 1.194 \times 10^{8} J$$

$$\phi_{sol.r.12} := F_{sh.o} \cdot A_{sol.r} \cdot I_{sol.r.12} - F_{r.k} \cdot \phi_{r.r} = 25.649 \cdot kW \cdot h$$

$$Q_{sol.r.12} := \phi_{sol.r.12} = 9.234 \times 10^{7} J$$

- Annual solar gains through the roof in joules ($Q_{sol.r}$) and in kilowatt-hours ($\phi_{sol.r}$):

$$\begin{aligned} Q_{sol.r} := {} & Q_{sol.r.01} + Q_{sol.r.02} + Q_{sol.r.03} + Q_{sol.r.04} \cdots = 2.897 \times 10^{9} J \\ & + Q_{sol.r.05} + Q_{sol.r.09} + Q_{sol.r.10} \cdots \\ & + Q_{sol.r.11} + Q_{sol.r.12} \end{aligned}$$

$$\begin{aligned} \phi_{sol.r} := {} & \phi_{sol.r.01} + \phi_{sol.r.02} + \phi_{sol.r.03} + \phi_{sol.r.04} \cdots = 804.742 \cdot kW \cdot h \\ & + \phi_{sol.r.05} + \phi_{sol.r.09} + \phi_{sol.r.10} \cdots \\ & + \phi_{sol.r.11} + \phi_{sol.r.12} \end{aligned}$$

Annex 12

Solar heat gains through the opaque building envelope - walls + roof

- Monthly solar heat gains through the opaque building envelope - walls + roof ($Q_{sol.W.r.i}$):

$$Q_{sol.W.r.01} := Q_{sol.W.south.01} + Q_{sol.W.west.01} + Q_{sol.W.north.01} + Q_{sol.W.east.01} + Q_{sol.r.01} = 2.293 \times 10^{8}\,J$$

$$Q_{sol.W.r.02} := Q_{sol.W.south.02} + Q_{sol.W.west.02} + Q_{sol.W.north.02} + Q_{sol.W.east.02} + Q_{sol.r.02} = 2.539 \times 10^{8}\,J$$

$$Q_{sol.W.r.03} := Q_{sol.W.south.03} + Q_{sol.W.west.03} + Q_{sol.W.north.03} + Q_{sol.W.east.03} + Q_{sol.r.03} = 5.776 \times 10^{8}\,J$$

$$Q_{sol.W.r.04} := Q_{sol.W.south.04} + Q_{sol.W.west.04} + Q_{sol.W.north.04} + Q_{sol.W.east.04} + Q_{sol.r.04} = 7.844 \times 10^{8}\,J$$

$$Q_{sol.W.r.05} := Q_{sol.W.south.05} + Q_{sol.W.west.05} + Q_{sol.W.north.05} + Q_{sol.W.east.05} + Q_{sol.r.05} = 1.156 \times 10^{9}\,J$$

$$Q_{sol.W.r.09} := Q_{sol.W.south.09} + Q_{sol.W.west.09} + Q_{sol.W.north.09} + Q_{sol.W.east.09} + Q_{sol.r.09} = 6.131 \times 10^{8}\,J$$

$$Q_{sol.W.r.10} := Q_{sol.W.south.10} + Q_{sol.W.west.10} + Q_{sol.W.north.10} + Q_{sol.W.east.10} + Q_{sol.r.10} = 4.134 \times 10^{8}\,J$$

$$Q_{sol.W.r.11} := Q_{sol.W.south.11} + Q_{sol.W.west.11} + Q_{sol.W.north.11} + Q_{sol.W.east.11} + Q_{sol.r.11} = 1.903 \times 10^{8}\,J$$

$$Q_{sol.W.r.12} := Q_{sol.W.south.12} + Q_{sol.W.west.12} + Q_{sol.W.north.12} + Q_{sol.W.east.12} + Q_{sol.r.12} = 1.523 \times 10^{8}\,J$$

- Annual solar heat gains through the opaque building envelope in joules ($Q_{sol.W.r.TOTAL.joules}$) in kilowatt-hours ($Q_{sol.W.r.TOTAL.kWh}$) and in kilowatt-hours per squere meter of conditioned area ($Q_{sol.W.r.TOTAL.kWh.m2}$):

$$\begin{aligned} Q_{sol.W.r.TOTAL.joules} := {} & Q_{sol.W.r.01} + Q_{sol.W.r.02} + Q_{sol.W.r.03} + Q_{sol.W.r.04} \cdots = 4.37 \times 10^{9}\,J \\ & + Q_{sol.W.r.05} + Q_{sol.W.r.09} + Q_{sol.W.r.10} \cdots \\ & + Q_{sol.W.r.11} + Q_{sol.W.r.12} \end{aligned}$$

$$Q_{sol.W.TOTAL.kWh} := Q_{sol.W.r.TOTAL.joules} = 1.214 \times 10^{3} \cdot kW \cdot h$$

$$Q_{sol.W.TOTAL.kWh.m2} := \frac{Q_{sol.W.r.TOTAL.joules}}{A_{conditioned.area}} = 6.777 \cdot \frac{kW \cdot h}{m^{2}}$$

Annex 13

Total heat gains

- Monthly heat gains ($Q_{gn.i}$):

$$Q_{gn.01} := Q_{.int.01} + Q_{sol.w.01} + Q_{sol.W.r.01} = 6.317 \times 10^{9}\,J$$

$$Q_{gn.02} := Q_{.int.02} + Q_{sol.w.02} + Q_{sol.W.r.02} = 5.465 \times 10^{9}\,J$$

$$Q_{gn.03} := Q_{.int.03} + Q_{sol.w.03} + Q_{sol.W.r.03} = 9.287 \times 10^{9}\,J$$

$$Q_{gn.04} := Q_{.int.04} + Q_{sol.w.04} + Q_{sol.W.r.04} = 1.054 \times 10^{10}\,J$$

$$Q_{gn.05} := Q_{.int.05} + Q_{sol.w.05} + Q_{sol.W.r.05} = 1.327 \times 10^{10}\,J$$

$$Q_{gn.09} := Q_{.int.09} + Q_{sol.w.09} + Q_{sol.W.r.09} = 9.01 \times 10^{9}\,J$$

$$Q_{gn.10} := Q_{.int.10} + Q_{sol.w.10} + Q_{sol.W.r.10} = 7.537 \times 10^{9}\,J$$

$$Q_{gn.11} := Q_{.int.11} + Q_{sol.w.11} + Q_{sol.W.r.11} = 5.369 \times 10^{9}\,J$$

$$Q_{gn.12} := Q_{.int.12} + Q_{sol.w.12} + Q_{sol.W.r.12} = 5.053 \times 10^{9}\,J$$

- Annual total heat gains in joules ($Q_{gn.joules}$) in kilowatt-hours ($Q_{gn.kWh}$) and in kilowatt-hours per squere meter of conditioned area ($Q_{gn.kWh.m2}$):

$$Q_{gn.joules} := Q_{gn.01} + Q_{gn.02} + Q_{gn.03} + Q_{gn.04} + Q_{gn.05} + Q_{gn.09} + Q_{gn.10} + Q_{gn.11} + Q_{gn.12} = 7.186 \times 10^{10}\,J$$

$$Q_{gn.kWh} := Q_{gn.joules} = 1.996 \times 10^{4} \cdot kW \cdot h$$

$$Q_{gn.kWh.m2} := \frac{Q_{gn.joules}}{A_{conditioned.area}} = 111.423 \cdot \frac{kW \cdot h}{m^{2}}$$

Annex 14

Dynamic parameters

- Heat-balance ratio for each month ($\gamma_{H.i}$):

$$\gamma_{H.01} := \frac{Q_{gn.01}}{Q_{ht.01}} = 0.333 \qquad \gamma_{H.04} := \frac{Q_{gn.04}}{Q_{ht.04}} = 0.963 \qquad \gamma_{H.10} := \frac{Q_{gn.10}}{Q_{ht.10}} = 0.618$$

$$\gamma_{H.02} := \frac{Q_{gn.02}}{Q_{ht.02}} = 0.319 \qquad \gamma_{H.05} := \frac{Q_{gn.05}}{Q_{ht.05}} = 2.187 \qquad \gamma_{H.11} := \frac{Q_{gn.11}}{Q_{ht.11}} = 0.378$$

$$\gamma_{H.03} := \frac{Q_{gn.03}}{Q_{ht.03}} = 0.613 \qquad \gamma_{H.09} := \frac{Q_{gn.09}}{Q_{ht.09}} = 1.41 \qquad \gamma_{H.12} := \frac{Q_{gn.12}}{Q_{ht.12}} = 0.29$$

- Time constant (τ):

$$\tau := \frac{\frac{C_m}{3600}}{H_{tr.adj} + H_{ve.adj}} = 0.031 \cdot h$$

- Numerical parameter (a_H):

$$a_H := a_{H.0} + \frac{\tau}{\tau_{H.0}} = 1.002$$

- Gain utilization factors for each month ($\eta_{H.gn.i}$):

$$\eta_{H.gn.01} := \frac{1 - \gamma_{H.01}{}^{a_H}}{1 - \gamma_{H.01}{}^{a_H+1}} = 0.751 \qquad \eta_{H.gn.09} := \frac{a_H}{a_H + 1} = 0.501$$

$$\eta_{H.gn.02} := \frac{1 - \gamma_{H.02}{}^{a_H}}{1 - \gamma_{H.02}{}^{a_H+1}} = 0.759 \qquad \eta_{H.gn.10} := \frac{1 - \gamma_{H.10}{}^{a_H}}{1 - \gamma_{H.10}{}^{a_H+1}} = 0.619$$

$$\eta_{H.gn.03} := \frac{1 - \gamma_{H.03}{}^{a_H}}{1 - \gamma_{H.03}{}^{a_H+1}} = 0.62 \qquad \eta_{H.gn.11} := \frac{1 - \gamma_{H.11}{}^{a_H}}{1 - \gamma_{H.11}{}^{a_H+1}} = 0.727$$

$$\eta_{H.gn.04} := \frac{1 - \gamma_{H.04}{}^{a_H}}{1 - \gamma_{H.04}{}^{a_H+1}} = 0.51 \qquad \eta_{H.gn.12} := \frac{1 - \gamma_{H.12}{}^{a_H}}{1 - \gamma_{H.12}{}^{a_H+1}} = 0.776$$

$$\eta_{H.gn.05} := \frac{a_H}{a_H + 1} = 0.501$$

Annex 15

Total energy need for heating

- Energy need for heating for each month ($Q_{H.nd.i}$):

$Q_{H.nd.01} := Q_{ht.01} - \eta_{H.gn.01} \cdot Q_{gn.01} = 1.422 \times 10^{10}\,J$

$Q_{H.nd.02} := Q_{ht.02} - \eta_{H.gn.02} \cdot Q_{gn.02} = 1.298 \times 10^{10}\,J$

$Q_{H.nd.03} := Q_{ht.03} - \eta_{H.gn.03} \cdot Q_{gn.03} = 9.378 \times 10^{9}\,J$

$Q_{H.nd.04} := Q_{ht.04} - \eta_{H.gn.04} \cdot Q_{gn.04} = 5.574 \times 10^{9}\,J$

$Q_{H.nd.05} := Q_{ht.05} - \eta_{H.gn.05} \cdot Q_{gn.05} = -5.738 \times 10^{8}\,J$ - considered value in the annual demand for May is 0

$Q_{H.nd.09} := Q_{ht.09} - \eta_{H.gn.09} \cdot Q_{gn.09} = 1.881 \times 10^{9}\,J$

$Q_{H.nd.10} := Q_{ht.10} - \eta_{H.gn.10} \cdot Q_{gn.10} = 7.541 \times 10^{9}\,J$

$Q_{H.nd.11} := Q_{ht.11} - \eta_{H.gn.11} \cdot Q_{gn.11} = 1.032 \times 10^{10}\,J$

$Q_{H.nd.12} := Q_{ht.12} - \eta_{H.gn.12} \cdot Q_{gn.12} = 1.353 \times 10^{10}\,J$

- Annual total energy need for heating in joules ($Q_{H.nd.joules}$) in kilowatt-hours ($Q_{H.nd.kWh}$) and in kilowatt-hours per squere meter of conditioned area ($Q_{H.nd.kWh.m2}$):

$$\begin{aligned} Q_{H.nd.joules} := {} & Q_{H.nd.01} + Q_{H.nd.02} + Q_{H.nd.03} + Q_{H.nd.04} \cdots = 7.543 \times 10^{10}\,J \\ & + Q_{H.nd.05} + Q_{H.nd.09} + Q_{H.nd.10} \cdots \\ & + Q_{H.nd.11} + Q_{H.nd.12} \end{aligned}$$

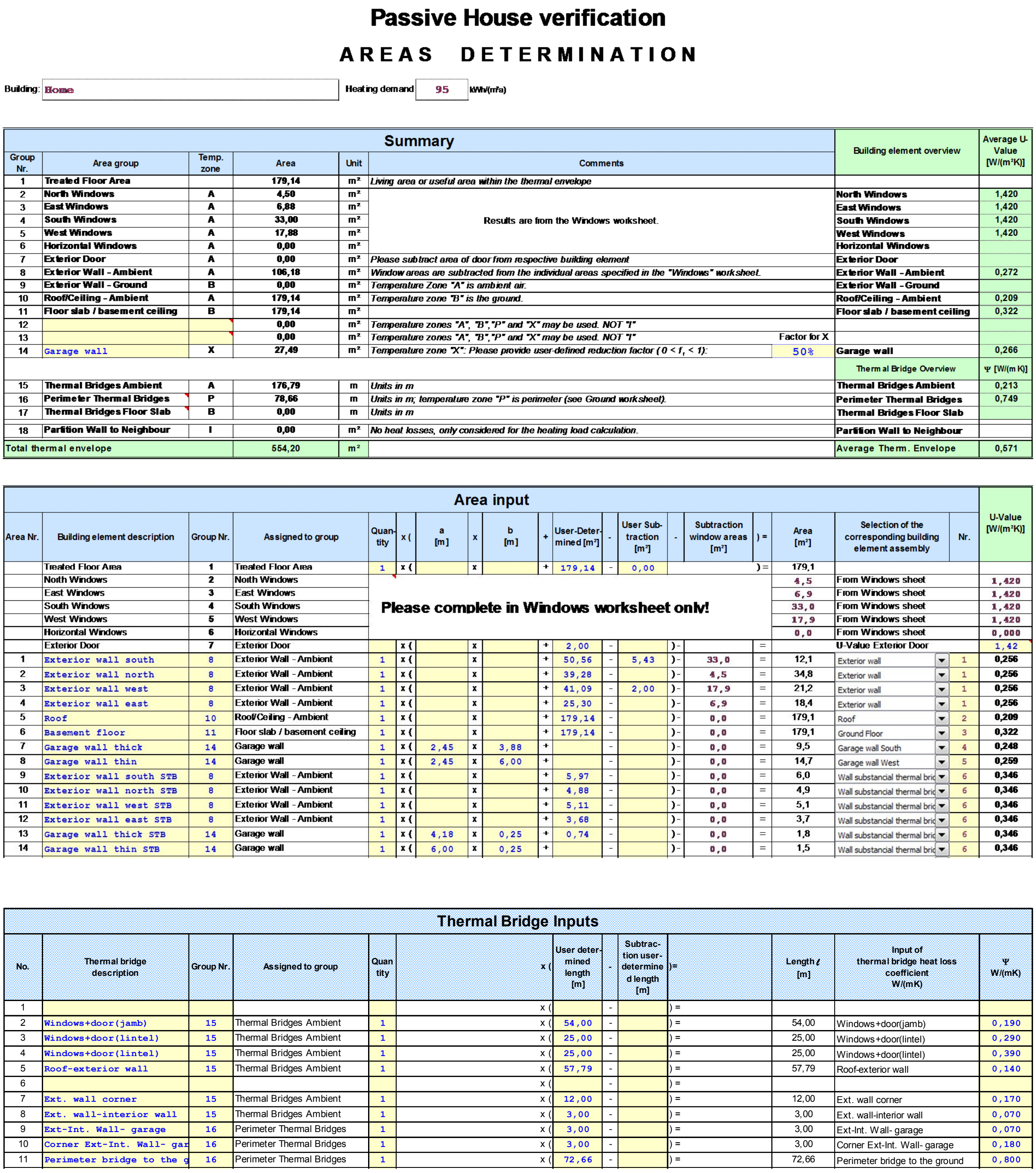
$Q_{H.nd.joules.kWh} := Q_{H.nd.joules} = 2.095 \times 10^{4} \cdot kW \cdot h$

Requirement:

$Q_{H.nd.kWh.m2} := \dfrac{Q_{H.nd.joules}}{A_{conditioned.area}} = 116.957 \cdot \dfrac{kW \cdot h}{m^2}$

$E_{0.conditioned.area} := 124.72 \cdot kW \cdot \dfrac{h}{m^3}$

Annex 16



Passive House verification

AREAS DETERMINATION

Building: Home | Heating demand 95 kWh/(m²a)

Group Nr.	Area group	Temp. zone	Area	Unit	Comments	Building element overview	Average U-Value [W/(m²K)]
1	**Treated Floor Area**		179,14	m²	*Living area or useful area within the thermal envelope*		
2	**North Windows**	A	4,50	m²	Results are from the Windows worksheet.	**North Windows**	1,420
3	**East Windows**	A	6,88	m²		**East Windows**	1,420
4	**South Windows**	A	33,00	m²		**South Windows**	1,420
5	**West Windows**	A	17,88	m²		**West Windows**	1,420
6	**Horizontal Windows**	A	0,00	m²		**Horizontal Windows**	
7	**Exterior Door**	A	0,00	m²	*Please subtract area of door from respective building element*	**Exterior Door**	
8	**Exterior Wall - Ambient**	A	106,18	m²	*Window areas are subtracted from the individual areas specified in the "Windows" worksheet.*	**Exterior Wall - Ambient**	0,272
9	**Exterior Wall - Ground**	B	0,00	m²	*Temperature Zone "A" is ambient air.*	**Exterior Wall - Ground**	
10	**Roof/Ceiling - Ambient**	A	179,14	m²	*Temperature zone "B" is the ground.*	**Roof/Ceiling - Ambient**	0,209
11	**Floor slab / basement ceiling**	B	179,14	m²		**Floor slab / basement ceiling**	0,322
12			0,00	m²	*Temperature zones "A", "B","P" and "X" may be used. NOT "I"*		
13			0,00	m²	*Temperature zones "A", "B","P" and "X" may be used. NOT "I"* Factor for X		
14	Garage wall	X	27,49	m²	*Temperature zone "X": Please provide user-defined reduction factor (0 < f_t < 1):* 50%	**Garage wall**	0,266
						Thermal Bridge Overview	Ψ [W/(m K)]
15	**Thermal Bridges Ambient**	A	176,79	m	*Units in m*	**Thermal Bridges Ambient**	0,213
16	**Perimeter Thermal Bridges**	P	78,66	m	*Units in m; temperature zone "P" is perimeter (see Ground worksheet).*	**Perimeter Thermal Bridges**	0,749
17	**Thermal Bridges Floor Slab**	B	0,00	m	*Units in m*	**Thermal Bridges Floor Slab**	
18	**Partition Wall to Neighbour**	I	0,00	m²	*No heat losses, only considered for the heating load calculation.*	**Partition Wall to Neighbour**	
Total thermal envelope			554,20	m²		Average Therm. Envelope	0,571

Area input

Area Nr.	Building element description	Group Nr.	Assigned to group	Quantity	x (	a [m]	x	b [m]	+	User-Determined [m²]	-	User Subtraction [m²]	-	Subtraction window areas [m²]	) =	Area [m²]	Selection of the corresponding building element assembly	Nr.	U-Value [W/(m²K)]
	Treated Floor Area	1	Treated Floor Area	1	x (		x		+	179,14	-	0,00			) =	179,1			
	North Windows	2	North Windows	**Please complete in Windows worksheet only!**												4,5	From Windows sheet		1,420
	East Windows	3	East Windows													6,9	From Windows sheet		1,420
	South Windows	4	South Windows													33,0	From Windows sheet		1,420
	West Windows	5	West Windows													17,9	From Windows sheet		1,420
	Horizontal Windows	6	Horizontal Windows													0,0	From Windows sheet		0,000
	Exterior Door	7	Exterior Door		x (		x		+	2,00	-		)-		=		U-Value Exterior Door		1,42
1	Exterior wall south	8	Exterior Wall - Ambient	1	x (		x		+	50,56	-	5,43	)-	33,0	=	12,1	Exterior wall	1	0,256
2	Exterior wall north	8	Exterior Wall - Ambient	1	x (		x		+	39,28	-		)-	4,5	=	34,8	Exterior wall	1	0,256
3	Exterior wall west	8	Exterior Wall - Ambient	1	x (		x		+	41,09	-	2,00	)-	17,9	=	21,2	Exterior wall	1	0,256
4	Exterior wall east	8	Exterior Wall - Ambient	1	x (		x		+	25,30	-		)-	6,9	=	18,4	Exterior wall	1	0,256
5	Roof	10	Roof/Ceiling - Ambient	1	x (		x		+	179,14	-		)-	0,0	=	179,1	Roof	2	0,209
6	Basement floor	11	Floor slab / basement ceiling	1	x (		x		+	179,14	-		)-	0,0	=	179,1	Ground Floor	3	0,322
7	Garage wall thick	14	Garage wall	1	x (	2,45	x	3,88	+		-		)-	0,0	=	9,5	Garage wall South	4	0,248
8	Garage wall thin	14	Garage wall	1	x (	2,45	x	6,00	+		-		)-	0,0	=	14,7	Garage wall West	5	0,259
9	Exterior wall south STB	8	Exterior Wall - Ambient	1	x (		x		+	5,97	-		)-	0,0	=	6,0	Wall substancial thermal bric	6	0,346
10	Exterior wall north STB	8	Exterior Wall - Ambient	1	x (		x		+	4,88	-		)-	0,0	=	4,9	Wall substancial thermal bric	6	0,346
11	Exterior wall west STB	8	Exterior Wall - Ambient	1	x (		x		+	5,11	-		)-	0,0	=	5,1	Wall substancial thermal bric	6	0,346
12	Exterior wall east STB	8	Exterior Wall - Ambient	1	x (		x		+	3,68	-		)-	0,0	=	3,7	Wall substancial thermal bric	6	0,346
13	Garage wall thick STB	14	Garage wall	1	x (	4,18	x	0,25	+	0,74	-		)-	0,0	=	1,8	Wall substancial thermal bric	6	0,346
14	Garage wall thin STB	14	Garage wall	1	x (	6,00	x	0,25	+		-		)-	0,0	=	1,5	Wall substancial thermal bric	6	0,346

Thermal Bridge Inputs

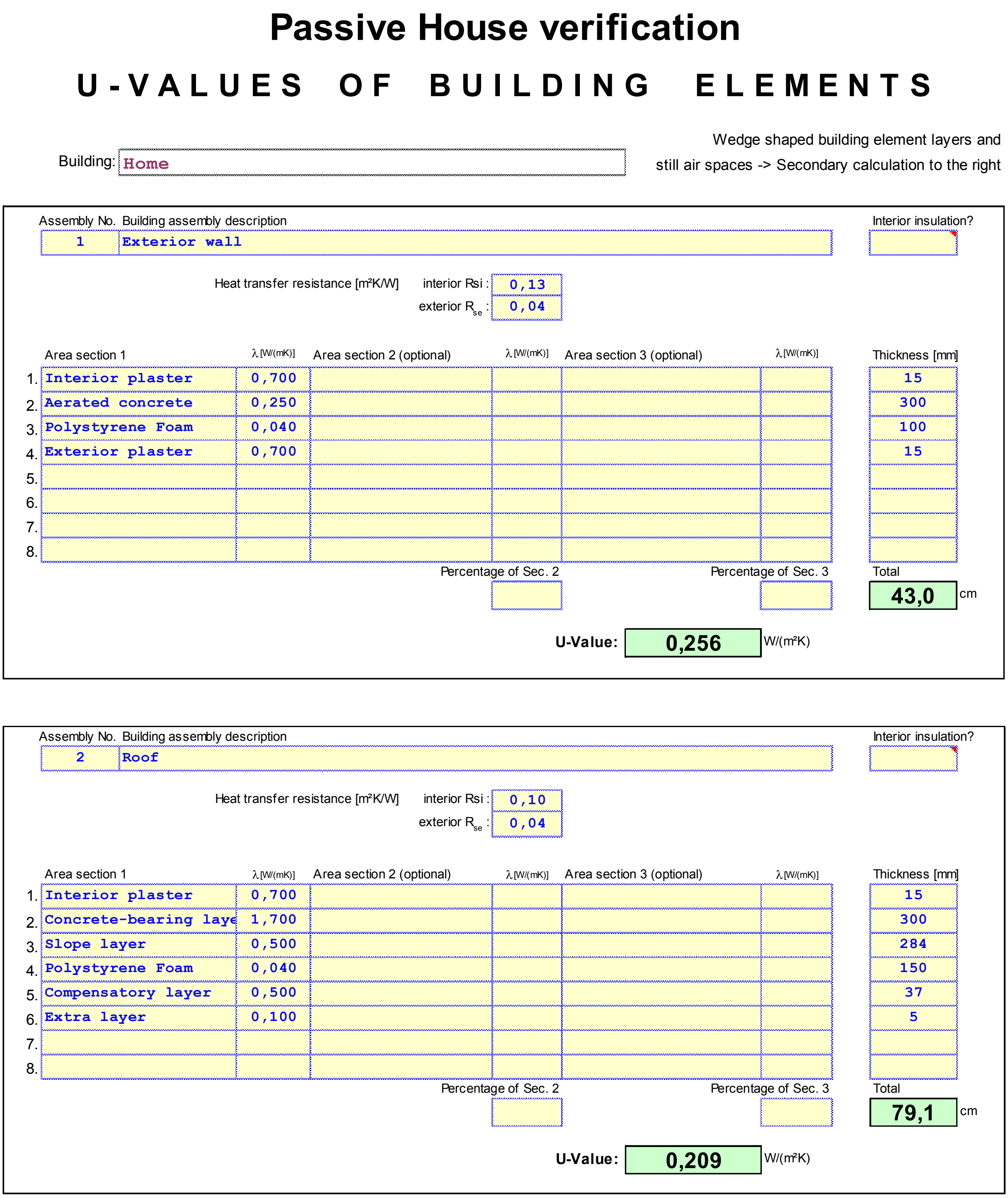
No.	Thermal bridge description	Group Nr.	Assigned to group	Quantity	x (	User determined length [m]	-	Subtraction user-determined length [m]	)=	Length ℓ [m]	Input of thermal bridge heat loss coefficient W/(mK)	Ψ W/(mK)
1					x (		-		) =			
2	Windows+door(jamb)	15	Thermal Bridges Ambient	1	x (	54,00	-		) =	54,00	Windows+door(jamb)	0,190
3	Windows+door(lintel)	15	Thermal Bridges Ambient	1	x (	25,00	-		) =	25,00	Windows+door(lintel)	0,290
4	Windows+door(lintel)	15	Thermal Bridges Ambient	1	x (	25,00	-		) =	25,00	Windows+door(lintel)	0,390
5	Roof-exterior wall	15	Thermal Bridges Ambient	1	x (	57,79	-		) =	57,79	Roof-exterior wall	0,140
6					x (		-		) =			
7	Ext. wall corner	15	Thermal Bridges Ambient	1	x (	12,00	-		) =	12,00	Ext. wall corner	0,170
8	Ext. wall-interior wall	15	Thermal Bridges Ambient	1	x (	3,00	-		) =	3,00	Ext. wall-interior wall	0,070
9	Ext-Int. Wall- garage	16	Perimeter Thermal Bridges	1	x (	3,00	-		) =	3,00	Ext-Int. Wall- garage	0,070
10	Corner Ext-Int. Wall- gar	16	Perimeter Thermal Bridges	1	x (	3,00	-		) =	3,00	Corner Ext-Int. Wall- garage	0,180
11	Perimeter bridge to the g	16	Perimeter Thermal Bridges	1	x (	72,66	-		) =	72,66	Perimeter bridge to the ground	0,800

Passive House verification

U - LIST

Compilation of the building elements calculated in the U-Values worksheet and other construction types from databases.

	Type		
Assembly No.	Assembly description	Total thickness	U-Value
		m	W/(m²K)
1	Exterior wall	0,430	0,256
2	Roof	0,791	0,209
3	Ground Floor	0,357	0,322
4	Garage wall South	0,442	0,248
5	Garage wall West	0,284	0,259
6	Wall substancial thermal bridges	0,430	0,346



Passive House verification

U-VALUES OF BUILDING ELEMENTS

Building: Home

Wedge shaped building element layers and still air spaces -> Secondary calculation to the right

Assembly No. 1 Building assembly description: Exterior wall

Interior insulation?

Heat transfer resistance [m²K/W] interior Rsi : 0,13

exterior R_{se} : 0,04

	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Interior plaster	0,700					15
2.	Aerated concrete	0,250					300
3.	Polystyrene Foam	0,040					100
4.	Exterior plaster	0,700					15
5.							
6.							
7.							
8.							

Percentage of Sec. 2

Percentage of Sec. 3

Total 43,0 cm

U-Value: 0,256 W/(m²K)

Assembly No. 2 Building assembly description: Roof

Interior insulation?

Heat transfer resistance [m²K/W] interior Rsi : 0,10

exterior R_{se} : 0,04

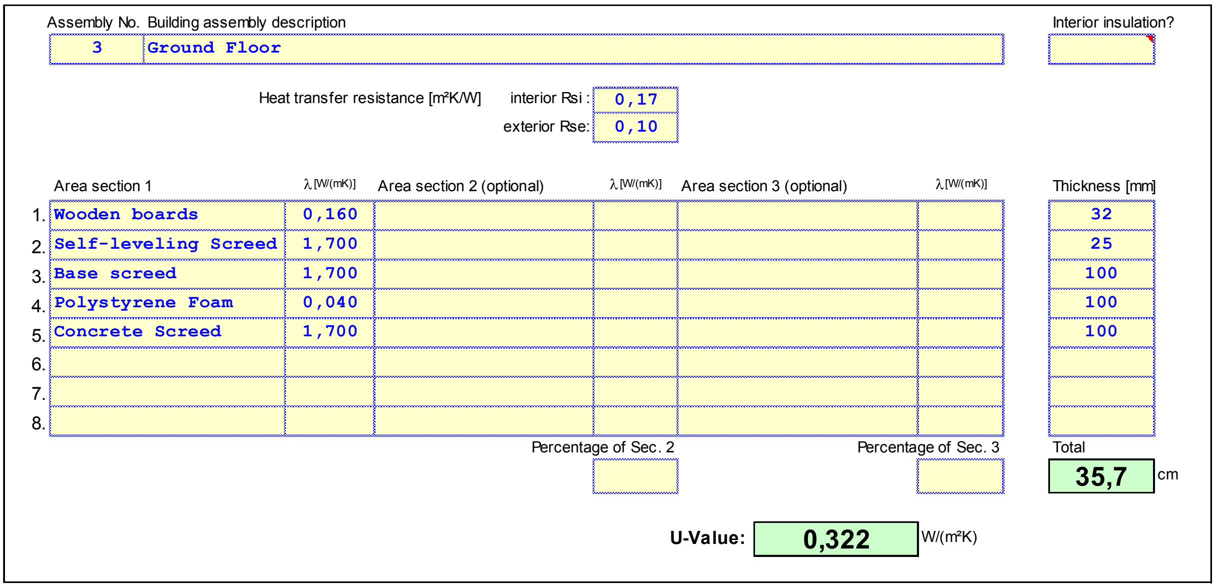
	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Interior plaster	0,700					15
2.	Concrete-bearing laye	1,700					300
3.	Slope layer	0,500					284
4.	Polystyrene Foam	0,040					150
5.	Compensatory layer	0,500					37
6.	Extra layer	0,100					5
7.							
8.							

Percentage of Sec. 2

Percentage of Sec. 3

Total 79,1 cm

U-Value: 0,209 W/(m²K)



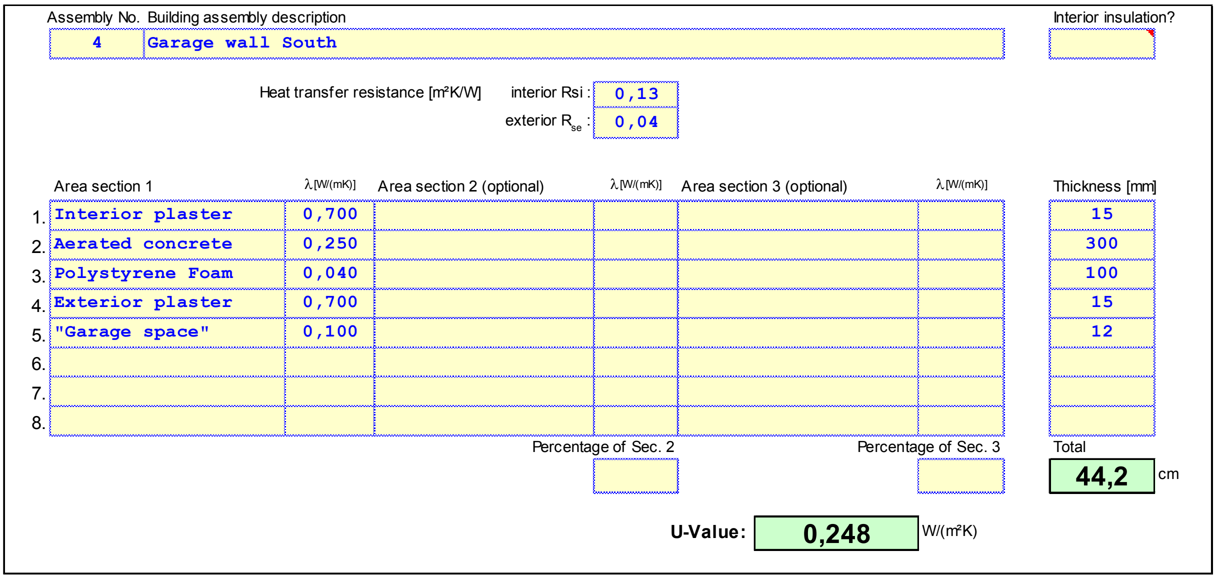
Assembly No.	Building assembly description	Interior insulation?
3	Ground Floor	

Heat transfer resistance [m^{2}K/W] interior Rsi : 0,17

exterior Rse: 0,10

	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Wooden boards	0,160					32
2.	Self-leveling Screed	1,700					25
3.	Base screed	1,700					100
4.	Polystyrene Foam	0,040					100
5.	Concrete Screed	1,700					100
6.							
7.							
8.							
				Percentage of Sec. 2		Percentage of Sec. 3	Total
							35,7 cm

U-Value: 0,322 W/(m^{2}K)



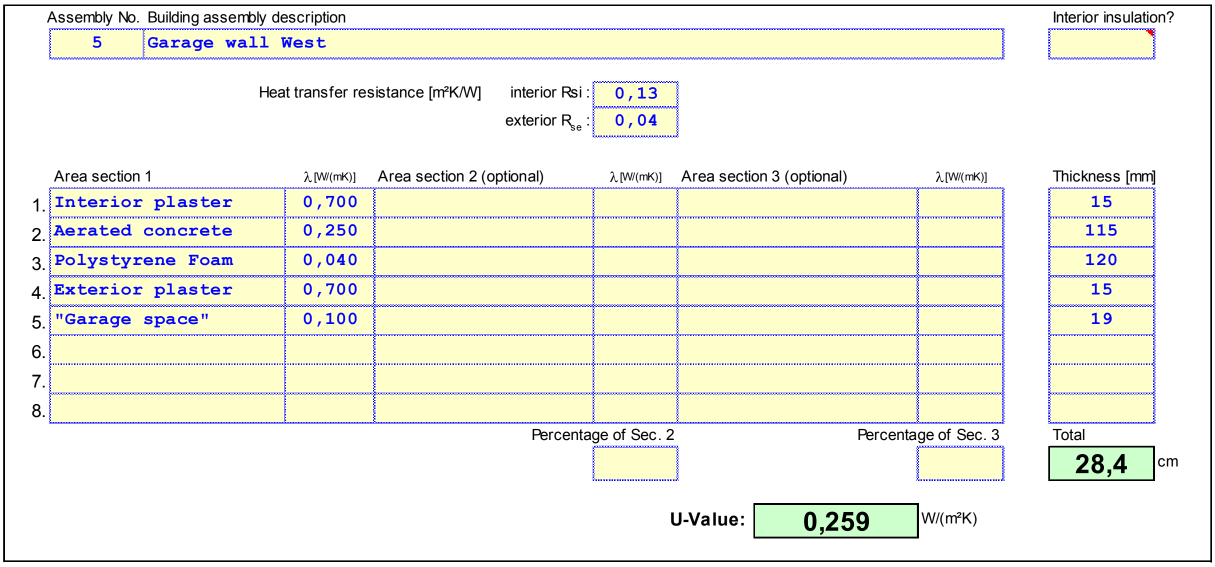
Assembly No.	Building assembly description	Interior insulation?
4	Garage wall South	

Heat transfer resistance [m^{2}K/W] interior Rsi : 0,13

exterior R_{se} : 0,04

	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Interior plaster	0,700					15
2.	Aerated concrete	0,250					300
3.	Polystyrene Foam	0,040					100
4.	Exterior plaster	0,700					15
5.	"Garage space"	0,100					12
6.							
7.							
8.							
				Percentage of Sec. 2		Percentage of Sec. 3	Total
							44,2 cm

U-Value: 0,248 W/(m^{2}K)



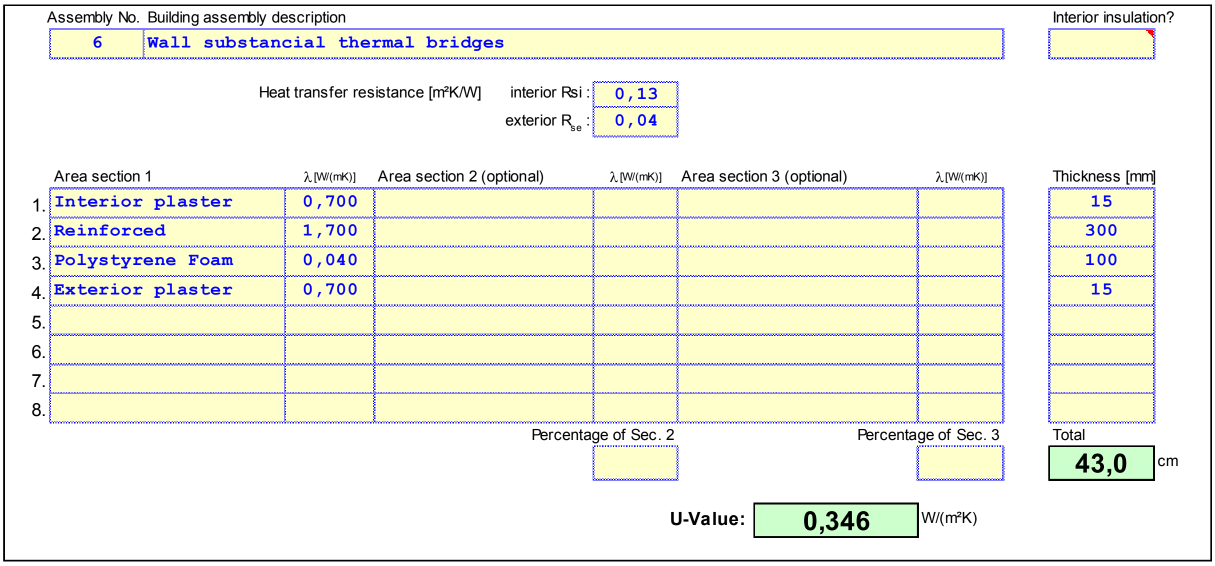
Assembly No.	Building assembly description	Interior insulation?
5	Garage wall West	

Heat transfer resistance [m^{2}K/W] interior Rsi : 0,13

exterior R_{se} : 0,04

	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Interior plaster	0,700					15
2.	Aerated concrete	0,250					115
3.	Polystyrene Foam	0,040					120
4.	Exterior plaster	0,700					15
5.	"Garage space"	0,100					19
6.							
7.							
8.							
				Percentage of Sec. 2		Percentage of Sec. 3	Total
							28,4 cm

U-Value: 0,259 W/(m^{2}K)



Assembly No. Building assembly description: 6 Wall substancial thermal bridges

Interior insulation?

Heat transfer resistance [m²K/W] interior Rsi : 0,13

exterior R_{se} : 0,04

	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Interior plaster	0,700					15
2.	Reinforced	1,700					300
3.	Polystyrene Foam	0,040					100
4.	Exterior plaster	0,700					15
5.							
6.							
7.							
8.							

Percentage of Sec. 2

Percentage of Sec. 3

Total 43,0 cm

U-Value: 0,346 W/(m²K)

Passive House verification

HEAT LOSSES VIA THE GROUND

Ground Characteristics			
Thermal Conductivity	λ	2,0	W/(mK)
Heat Capacity	ρc	2,0	MJ/(m³K)
Periodic Penetration Depth	δ	3,17	m

Climate Data			
Av. Indoor Temp. Winter	T_i	20,3	°C
Av. Indoor Temp. Summer	T_i	25,0	°C
Average Ground Surface Temperatur	$T_{g,ave}$	9,3	°C
Amplitude of $T_{g,ave}$	$T_{g,\wedge}$	9,5	°C
Length of the Heating Period	n	9,0	months
Heating Degree Hours - Exterior	G_t	90,7	kKh/a

Building Data							
				U-value floor slab/basement ceiling	U_f	0,322	W/(m²K)
Floor Slab Area	A	179,1	m²	Thermal bridges floor slab/basement	Ψ_B*l	0,00	W/K
Floor Slab Perimeter	P	72,6	m	U-value floor slab/basement ceiling ir	U_f'	0,322	W/(m²K)
Charact. Dimension of Floor Slab	B'	4,93	m	Eq. Thickness Floor	d_t	6,20	m

Floor Slab Type (select only one)

	Heated Basement or Underground Floor Slab		Unheated basement
x	Slab on Grade		Suspended Floor

Additional Thermal Bridge Heat Losses at Perimeter				Steady-State Fraction	$\Psi_{P,stat}$*l	58,880	W/K
Phase Shift	β		months	Harmonic Fraction	$\Psi_{P,harm}$*l	58,880	W/K

Groundwater Correction							
Depth of the Groundwater Table	z_W	3,0	m	Transm. Belowground El. (w/o Ground)	L_{reg}	116,62	W/K
Groundwater Flow Rate	q_W	0,05	m/d	Relative Insulation Standard	d_t/B'	0,62	-
				Relative Groundwater Depth	z_W/B'	0,61	-
Groundwater Correction Factor	G_W	1,0099204	-	Relative Groundwater Velocity	l/B'	0,17	-

Basement or Underground Floor Slab							
Eq. Thickness Floor Slab	d_t		m	Phase Shift	β		months
U-Value Floor Slab	U_{bf}		W/(m²K)	Exterior Periodic Transmittance	L_{pe}		W/K
Eq. Thickness Basement Wall	d_w		m				
U-Value Wall	U_{bw}		W/(m²K)				
Steady-State Transmittance	L_S		W/K				

Unheated Basement							
Steady-State Transmittance	L_S		W/K	Phase Shift	β		months
				Exterior Periodic Transmittance	L_{pe}		W/K

Slab on Grade							
Heat Transfer Coefficient	U_0	0,24	W/(m²K)	Phase Shift	β	1,33	months
Eq. Ins. Thickness Perimeter Ins.	d'	0,00	m	Exterior Periodic Transmittance	L_{pe}	22,17	W/K
Perimeter Insulation Correction	$\Delta\Psi$		W/(mK)				
Steady-State Transmittance	L_S	42,78	W/K				

Suspended Floor Above a Ventilated Crawl Space (at max. 0.5 m Below Ground)							
Eq. Ins. Thickness Crawl Space	d_g		m	Phase Shift	β		months
U-Value Crawl Space Floor Slab	U_g		W/(m²K)	Exterior Periodic Transmittance	L_{pe}		W/K
U-Value Crawl Space Wall & Vent.	U_X		W/(m²K)				
Steady-State Transmittance	L_S		W/K				

Interim Results							
Phase Shift	β	1,33	months	Steady-State Heat Flow	Φ_{stat}	1125,6	W
Steady-State Transmittance	L_S	101,66	W/K	Periodic Heat Flow	Φ_{harm}	178,2	W
Exterior Periodic Transmittance	L_{pe}	81,05	W/K	Heat Losses During Heating Period	Q_{tot}	8543	kWh

Ground reduction factor for "Annual Heating Demand" sheet **0,81**

Monthly Average Ground Temperatures for Monthly Method

Month	1	2	3	4	5	6	7	8	9	10	11	12	Average Val
Winter	5,6	4,2	4,5	6,5	9,6	12,9	15,7	17,1	16,8	14,9	11,8	8,4	10,7
Summer	6,2	4,8	5,1	7,1	10,2	13,5	16,3	17,7	17,4	15,5	12,4	9,0	11,3

Design Ground Temperature for Heating Load Sheet 4,2 **for Cooling Load Sheet** 17,7

Passive House verification

REDUCTION FACTOR SOLAR RADIATION, WINDOW U-VALUE

Building: Home

Annual heating demand: 95 kWh/(m²a)

Heating degree hours: 92,9

Climate: PL - Strefa II (Poznan/Pila)

Window area orientation	Global radiation (cardinal points)	Shading	Dirt	Non-perpendicular incident radiation	Glazing fraction	g-Value	Reduction factor for solar radiation	Window area	Window U-Value	Glazing area	Average global radiation	Transmission losses	Heat gains solar radiation
maximum:	kWh/(m²a)	0,75	0,95	0,85				m²	W/(m²K)	m²	kWh/(m²a)	kWh/a	kWh/a
North	237	0,96	0,95	0,85	0,706	0,70	0,55	4,50	1,42	3,2	237	593	410
East	293	0,93	0,95	0,85	0,737	0,70	0,56	6,88	1,42	5,1	293	907	783
South	401	0,96	0,95	0,85	0,712	0,70	0,55	33,00	1,42	23,5	401	4351	5128
West	278	0,93	0,95	0,85	0,744	0,70	0,56	17,88	1,42	13,3	278	2357	1956
Horizontal	344	1,00	0,95	0,85	0,000	0,00	0,00	0,00	0,00	0,0	344	0	0
	Total or Average Value for All Windows.					0,70	0,56	62,25	1,42	45,0		8208	8277

					Window rough openings		Installed		Glazing		Frame		g-Value	U-Value		Ψ-Spacer	Installation								
Quantity	Description	Deviation from north	Angle of inclination from the horizontal	Orientation	Width	Height	In Area in the Areas worksheet	Nr.	Select glazing from the WinType worksheet	Nr.	Select window from the WinType worksheet	Nr.	Perpendicular Radiation	Glazing	Frames (centre)	Ψ_{spacer} (centre)	Left 1/0	Right 1/0	Bottom 1/0	Top 1/0	$\Psi_{Installation}$ left	$\Psi_{Installation}$ right	$\Psi_{Installation}$ bottom	$\Psi_{Installation}$ top	$\Psi_{Installation}$ Average value
		Degrees	Degrees		m	m	Select:		Select:		Select:		-	W/(m²K)	W/(m²K)	W/(mK)					W/(mK)	W/(mK)	W/(mK)	W/(mK)	W/(mK)
2	South	180	90	South	1,500	2,750	Exterior wall sou	1	Custom glazing	1	Custom frame	1	0,70	1,42	1,42	0,000	1	1	1	1	0,000	0,000	0,000	0,000	0,000
7	South	180	90	South	1,000	2,750	Exterior wall sou	1	Custom glazing	1	Custom frame	1	0,70	1,42	1,42	0,000	0	0	1	1	0,000	0,000	0,000	0,000	0,000
1	East	90	90	East	1,000	2,750	Exterior wall eas	4	Custom glazing	1	Custom frame	1	0,70	1,42	1,42	0,000	1	1	1	1	0,000	0,000	0,000	0,000	0,000
1	East	90	90	East	1,500	2,750	Exterior wall eas	4	Custom glazing	1	Custom frame	1	0,70	1,42	1,42	0,000	1	1	1	1	0,000	0,000	0,000	0,000	0,000
2	West	270	90	West	1,000	2,750	Exterior wall we	3	Custom glazing	1	Custom frame	1	0,70	1,42	1,42	0,000	1	1	1	1	0,000	0,000	0,000	0,000	0,000
3	West	270	90	West	1,500	2,750	Exterior wall we	3	Custom glazing	1	Custom frame	1	0,70	1,42	1,42	0,000	1	1	1	1	0,000	0,000	0,000	0,000	0,000
1	North	0	90	North	1,000	1,500	Exterior wall no	2	Custom glazing	1	Custom frame	1	0,70	1,42	1,42	0,000	1	1	1	1	0,000	0,000	0,000	0,000	0,000
1	North	0	90	North	2,000	1,500	Exterior wall no	2	Custom glazing	1	Custom frame	1	0,70	1,42	1,42	0,000	1	0	1	1	0,000	0,000	0,000	0,000	0,000
2	South	180	90	South	1,000	2,750	Exterior wall sou	1	Custom glazing	1	Custom frame	1	0,70	1,42	1,42	0,000	1	0	1	1	0,000	0,000	0,000	0,000	0,000

Results (unhide cells to make U- & Ψ-values from WinType worksheet visible)				Frame-U-values from WinTpye worksheet				Frame measures from WinType worksheet																	
Window Area	Glazing Area	U-Value Window	Glazed Fraction per Window	Frame left	Frame right	Frame bottom	Frame top	Width - Left	Width - Right	Width - Below	Width - Above	Area left	Area right	Area bottom	Area top	Total area	Glazing edge length left	Glazing edge length right	Glazing edge length bottom	Glazing edge length top	Total glazing edge length	Installation length left	Installation length right	Installation length bottom	Installation length top	Total installation length
m²	m²	W/(m²K)	%	W/(m²K)	W/(m²K)	W/(m²K)	W/(m²K)	m	m	m	m	m²	m²	m²	m²	m²	m	m	m	m	m	m	m	m	m	m
8,3	6,33	1,42	77%	1,42	1,42	1,42	1,42	0,12	0,12	0,12	0,12	0,30	0,30	0,18	0,18	0,96	2,51	2,51	1,26	1,26	7,54	2,75	2,75	1,50	1,50	8,50
19,3	13,35	1,42	69%	1,42	1,42	1,42	1,42	0,12	0,12	0,12	0,12	0,30	0,30	0,12	0,12	0,84	2,51	2,51	0,76	0,76	6,54	0,00	0,00	1,00	1,00	2,00
2,8	1,91	1,42	69%	1,42	1,42	1,42	1,42	0,12	0,12	0,12	0,12	0,30	0,30	0,12	0,12	0,84	2,51	2,51	0,76	0,76	6,54	2,75	2,75	1,00	1,00	7,50
4,1	3,16	1,42	77%	1,42	1,42	1,42	1,42	0,12	0,12	0,12	0,12	0,30	0,30	0,18	0,18	0,96	2,51	2,51	1,26	1,26	7,54	2,75	2,75	1,50	1,50	8,50
5,5	3,82	1,42	69%	1,42	1,42	1,42	1,42	0,12	0,12	0,12	0,12	0,30	0,30	0,12	0,12	0,84	2,51	2,51	0,76	0,76	6,54	2,75	2,75	1,00	1,00	7,50
12,4	9,49	1,42	77%	1,42	1,42	1,42	1,42	0,12	0,12	0,12	0,12	0,30	0,30	0,18	0,18	0,96	2,51	2,51	1,26	1,26	7,54	2,75	2,75	1,50	1,50	8,50
1,5	0,96	1,42	64%	1,42	1,42	1,42	1,42	0,12	0,12	0,12	0,12	0,15	0,15	0,12	0,12	0,54	1,26	1,26	0,76	0,76	4,04	1,50	1,50	1,00	1,00	5,00
3,0	2,22	1,42	74%	1,42	1,42	1,42	1,42	0,12	0,12	0,12	0,12	0,15	0,15	0,24	0,24	0,78	1,26	1,26	1,76	1,76	6,04	1,50	0,00	2,00	2,00	5,50
5,5	3,82	1,42	69%	1,42	1,42	1,42	1,42	0,12	0,12	0,12	0,12	0,30	0,30	0,12	0,12	0,84	2,51	2,51	0,76	0,76	6,54	2,75	0,00	1,00	1,00	4,75

Thermal bridges									Installation length	
$\Psi_{\text{glazing edge}}$ **left**	$\Psi_{\text{glazing edge}}$ **right**	$\Psi_{\text{glazing edge}}$ **bottom**	$\Psi_{\text{glazing edge}}$ **top**	$\Psi_{\text{installation}}$ **left**	$\Psi_{\text{installation}}$ **right**	$\Psi_{\text{installation}}$ **bottom**	$\Psi_{\text{installation}}$ **top**	**Descrip-tion**	**Glazing**	**Frames**
W/(mK)	W/(mK)	W/(mK)	W/(mK)	W/(mK)	W/(mK)	W/(mK)	W/(mK)		m	m
0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	South	15,1	17,0
0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	South	45,8	14,0
0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	East	6,5	7,5
0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	East	7,5	8,5
0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	West	13,1	15,0
0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	West	22,6	25,5
0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	North	4,0	5,0
0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	North	6,0	5,5
0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	South	13,1	9,5

Passive House verification

GLAZING ACCORDING TO CERTIFICATION

Go to curtain wall facades / window frames from line 99 onwards

	Type		
Assem-bly No.	Glazing	g-Value	U_g-Value
			W/(m²K)
1	Custom glazing	0,70	1,42

CURTAIN WALL FACADE / WINDOW FRAME AS PER CERTIFICAT

	Type	U_f-Value				Frame Dimensions			
Assem-bly No.	Window frame	Frame left	Frame right	Frame bottom	Frame top	Width - Left	Width - Right	Width - Below	Width - Above
	Curtain wall facade	Post left	Post right	Beam bottom	Beam top	Post left	Post right	Beam bottom	Beam top
		W/(m²K)	W/(m²K)	W/(m²K)	W/(m²K)	m	m	m	m
1	Custom frame	1,42	1,42	1,42	1,42	0,120	0,120	0,120	0,120

Passive House verification

CALCULATING SHADING FACTORS

Orientation	Glazing area m²	Reduction factor r_S
North	3,18	96%
East	5,07	93%
South	23,49	96%
West	13,30	93%
Horizontal	0,00	100%

Quantity	Description	Deviation from North	Angle of Inclination from the Horizontal	Orientation	Glazing width	Glazing height	Glazing area	Height of the shading object	Horizontal distance	Window reveal depth	Distance from glazing edge to reveal
		Degrees	Degrees		m	m		m	m	m	m
					w_G	h_G	A_G	h_{Hori}	d_{Hori}	o_{Reveal}	d_{Reveal}
2	South	180	90	South	1,26	2,51	6,3	0,00	0,00	0,10	0,12
7	South	180	90	South	0,76	2,51	13,4	0,00	0,00	0,10	0,12
1	East	90	90	East	0,76	2,51	1,9	0,00	0,00	0,10	0,12
1	East	90	90	East	1,26	2,51	3,2	0,00	0,00	0,10	0,12
2	West	270	90	West	0,76	2,51	3,8	0,00	0,00	0,10	0,12
3	West	270	90	West	1,26	2,51	9,5	0,00	0,00	0,10	0,12
1	North	0	90	North	0,76	1,26	1,0	0,00	0,00	0,10	0,12
1	North	0	90	North	1,76	1,26	2,2	0,00	0,00	0,10	0,12
2	South	180	90	South	0,76	2,51	3,8	0,00	0,00	0,10	0,12

Horizontal distance	Window reveal depth	Distance from glazing edge to reveal	Overhang depth	Distance from upper glazing edge to overhang	Additional shading reduction factor	Horizontal shading reduction factor	Reveal Shading Reduction Factor	Overhang shading reduction factor	Total shading reduction factor
m	m	m	m	m	%	%	%	%	%
d_{Hori}	o_{Reveal}	d_{Reveal}	o_{over}	d_{over}	r_{other}	r_H	r_R	r_O	r_S
0,00	0,10	0,12	0,00	0,00	1,00	100%	97%	100%	97%
0,00	0,10	0,12	0,00	0,00	1,00	100%	96%	100%	96%
0,00	0,10	0,12	0,00	0,00	1,00	100%	92%	100%	92%
0,00	0,10	0,12	0,00	0,00	1,00	100%	94%	100%	94%
0,00	0,10	0,12	0,00	0,00	1,00	100%	92%	100%	92%
0,00	0,10	0,12	0,00	0,00	1,00	100%	94%	100%	94%
0,00	0,10	0,12	0,00	0,00	1,00	100%	94%	100%	94%
0,00	0,10	0,12	0,00	0,00	1,00	100%	97%	100%	97%
0,00	0,10	0,12	0,00	0,00	1,00	100%	96%	100%	96%

Passive House verification

VENTILATION DATA

Building: Home

Treated floor area A_{TFA}		m²	179	*(Areas worksheet)*
Room height h		m	3,0	*(Annual Heating Demand worksheet)*
Room ventilation volume (A_{TFA}*h) =	V_V	m³	537	*(Annual Heating Demand worksheet)*

Type of ventilation system

☐ Balanced PH ventilation *Please Check*

x Pure extract air

Infiltration air change rate

Wind protection coefficients e and f		
Coefficient e for screening class	Several sides exposed	One side exposed
No screening	0,10	0,03
Moderate screening	0,07	0,02
High screening	0,04	0,01
Coefficient f	15	20

			for Annual Demand:	for Heating Load:					
Wind protection coefficient, e			0,07	0,18					
Wind protection coefficient, f			15	15	Net Air Volume for Press. Test	V_{n50}		Air permeability	q_{50}
Air Change Rate at Press. Test	n_{50}	1/h	0,60	0,60	537	m³		0,58	m³/(hm²)

			for Annual Demand:	for Heating Load:
Excess extract air		1/h	0,30	0,30
Infiltration air change rate	$n_{V,Res}$	1/h	0,001	0,005

Ventilation unit / Heat recovery efficiency design

x Sheet Ventilation (Standard design) *(Sheet Ventilation see below)*

☐ Sheet Extended ventilation *(Sheet Additional Vent)*

(Multiple ventilation units, non-residential buildings)

Mean Air exchange	Mean Air Change Rate	Extract air excess (Extract air system)	Effective heat recovery efficiency Unit	Specific power input	Heat recovery efficiency SHX
m³/h	1/h	1/h	[-]	Wh/m³	
161	0,30	0,30		n.s.	0,0%

SHX efficiency η^{*}_{SHX} 0%

Ventilation unit / Heat recovery efficiency design

x Sheet Ventilation (Standard design) *(Sheet Ventilation see below)*

☐ Sheet Extended ventilation *(Sheet Additional Vent)*

(Multiple ventilation units, non-residential buildings)

Mean Air exchange	Mean Air Change Rate	Extract air excess (Extract air system)	Effective heat recovery efficiency Unit	Specific power input	Heat recovery efficiency SHX
m³/h	1/h	1/h	[-]	Wh/m³	
161	0,30	0,30		n.s.	0,0%

SHX efficiency η^{*}_{SHX} 0%

STANDARD INPUT FOR BALANCED VENTILATION

Ventilation dimensioning for systems with one ventilation unit

Occupancy	m²/P	45				
Number of occupants	P	4,0				
Supply air per person	m³/(P*h)	30				
Supply air requirement	m³/h	120				
Extract air rooms		Kitchen	Bathroom	Bathroom (shower only)	WC	
Quantity		1	2	0	0	
Extract air requirement per room	m³/h	60	40	20	20	
Total Extract Air Requirement	m³/h	140				

Design air flow rate (maximum) m³/h 210

Average air change rate calculation

Type of operation	Daily operation duration h/d	Factors referenced to maximum	Air flow rate m³/h	Air change rate 1/h
Maximum		1,00	210	0,39
Standard	24,0	0,77	161	0,30
Basic		0,54	113	0,21
Minimum		0,40	84	0,16
			Average air flow rate (m³/h)	Average air change rate (1/h)
	Average value	0,77	161	0,30

Passive House verification

SPECIFIC ANNUAL HEATING DEMAND

Climate: PL - Strefa II (Poznan/Pila)
Building: Home

Interior Temperature: 20,3 °C
Building Type/Use: Dweelling
Treated Floor Area A_{TFA}: 179,1 m²

Building Element	Temperature Zone	Area		U-Value		Temp. Factor f_t		G_t				per m² Treated Floor Area
		m²		W/(m²K)				kKh/a		kWh/a		
Exterior Wall - Ambient	A	106,2	*	0,272	*	1,00	*	92,9	=	2685		14,99
Exterior Wall - Ground	B		*		*	0,81	*		=			
Roof/Ceiling - Ambient	A	179,1	*	0,209	*	1,00	*	92,9	=	3480		19,43
Floor slab / basement ceiling	B	179,1	*	0,322	*	0,81	*	92,9	=	4329		24,17
	A		*		*	1,00	*		=			
	A		*		*	1,00	*		=			
Garage wall	X	27,5	*	0,266	*	0,50	*	92,9	=	339		1,89
Windows	A	62,3	*	1,420	*	1,00	*	92,9	=	8208		45,82
Exterior Door	A		*		*	1,00	*		=			
Exterior TB (length/m)	A	176,8	*	0,213	*	1,00	*	92,9	=	3491		19,49
Perimeter TB (length/m)	P	78,7	*	0,749	*	0,81	*	92,9	=	4414		24,64
Ground TB (length/m)	B		*		*	0,81	*		=			
Total of All Building Envelope Areas		554,2										kWh/(m²a)
Transmission Heat Losses Q_T										Total 26947		150,4

Ventilation System:

Effective Heat Recovery Efficiency of Heat Recovery η_{eff}: 0%

Efficiency of Subsoil Heat Exchanger η_{SHX}: 0%

	A_{TFA}		Clear Room Height		
	m²		m		m³
Effective Air Volume, V_V	179,1	*	3,00	=	537,4

	$n_{V,system}$		Φ_{HR}		$n_{V,Res}$		
	1/h				1/h		1/h
Energetically Effective Air Exchange n_v	0,300	* (1 -	0,00	) +	0,001	=	0,301

	V_V		n_V		c_{Air}		G_t			
	m³		1/h		Wh/(m³K)		kKh/a		kWh/a	kWh/(m²a)
Ventilation Heat Losses Q_V	537	*	0,301	*	0,33	*	92,9	=	4958	27,7

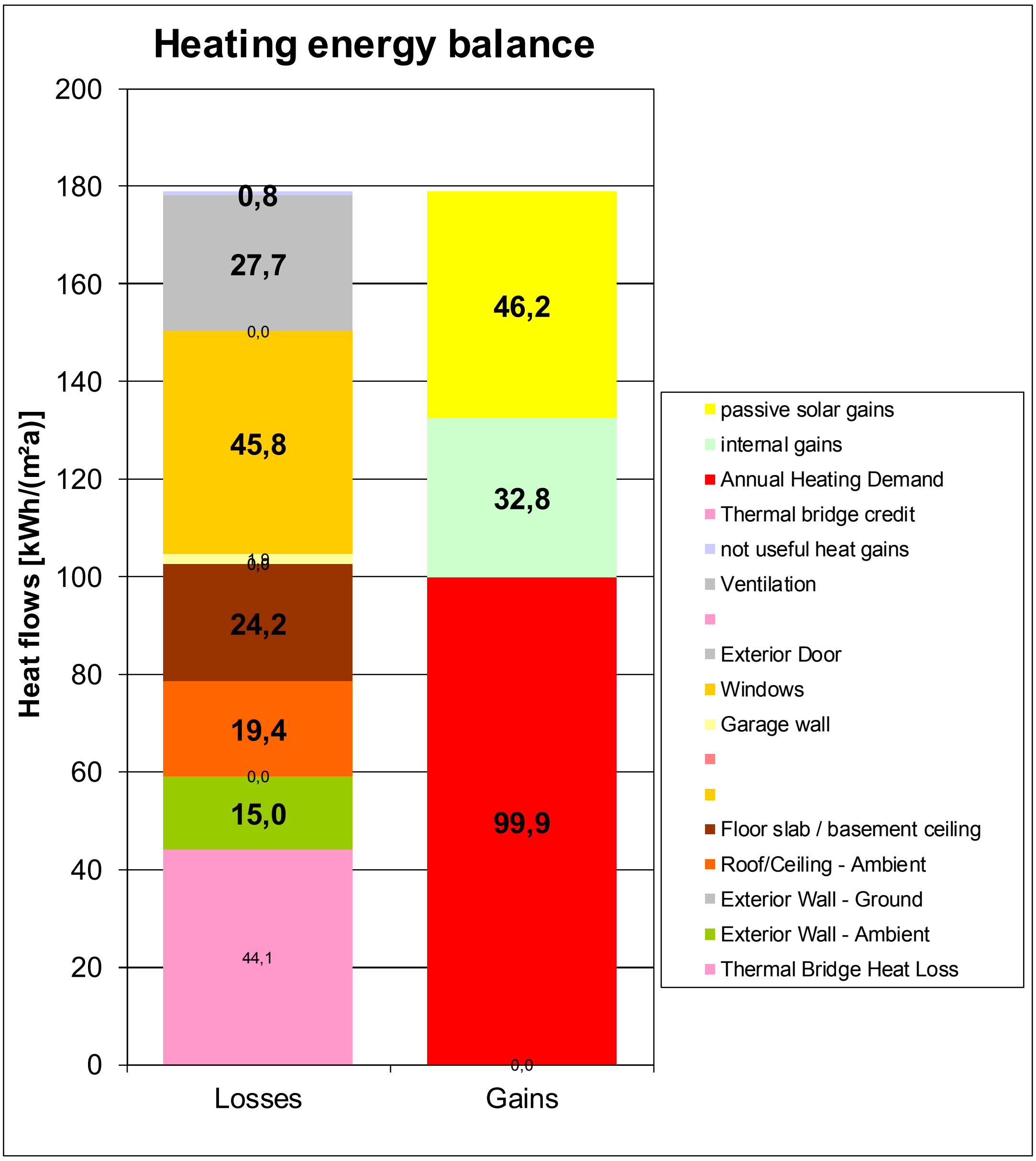
		Q_T		Q_V		Reduction Factor Night/Weekend Saving			
		kWh/a		kWh/a				kWh/a	kWh/(m²a)
Total Heat Losses Q_L	(	26947	+	4958	)	1,0	=	31905	178,1

Orientation of the Area	Reduction Factor See Windows Sheet		g-Value (perp. radiation)		Area		Radiation HP			
					m²		kWh/(m²a)		kWh/a	
1. North	0,55	*	0,70	*	4,50	*	237	=	410	
2. East	0,56	*	0,70	*	6,88	*	293	=	783	
3. South	0,55	*	0,70	*	33,00	*	401	=	5128	
4. West	0,56	*	0,70	*	17,88	*	278	=	1956	
5. Horizontal	0,00	*	0,00	*	0,00	*	344	=	0	
										kWh/(m²a)
Available Solar Heat Gains Q_S								Total	8277	46,2

			Length Heat. Period		Spec. Power q_I		A_{TFA}			
	kh/d		d/a		W/m²		m²		kWh/a	kWh/(m²a)
Internal Heat Gains Q_I	0,024	*	273	*	5,00	*	179,1	=	5869	32,8

			kWh/a	kWh/(m²a)
Free Heat Q_F	Q_S + Q_I	=	14146	79,0
Ratio of Free Heat to Losses	Q_F / Q_L	=	0,44	
Utilisation Factor Heat Gains η_G	$(1 - (Q_F / Q_L)^5) / (1 - (Q_F / Q_L)^6)$	=	99%	
			kWh/a	kWh/(m²a)
Heat Gains Q_G	η_G * Q_F	=	14010	78,2
			kWh/a	kWh/(m²a)
Annual Heating Demand QH	Q_L - Q_G	=	17895	**100**

	kWh/(m²a)		(Yes/No)
Limiting Value	15	**Requirement met?**	**no**


Heating energy balance
Heat flows [kWh/(m²a)]
200
180
160
140
120
100
80
60
40
20
0
Losses
Gains
0,8
27,7
0,0
45,8
1,8
0,0
24,2
19,4
0,0
15,0
44,1
46,2
32,8
99,9
0,0
passive solar gains
internal gains
Annual Heating Demand
Thermal bridge credit
not useful heat gains
Ventilation
Exterior Door
Windows
Garage wall
Floor slab / basement ceiling
Roof/Ceiling - Ambient
Exterior Wall - Ground
Exterior Wall - Ambient
Thermal Bridge Heat Loss

Passive House verification

SPECIFIC ANNUAL HEATING DEMAND
MONTHLY METHOD

(This page displays the sums of the monthly method over the heating period)

Climate:	PL - Strefa II (Poznan/Pila)	Interior Temperature:	20,326 °C
Building:	Home	Building Type/Use:	Dweelling
Spec. Capacity:	204 Wh/(m²K) (Enter in "Summer" worksheet.)	Treated Floor Area A_{TFA}:	179,1 m²

Building Element	Temperature Zone	Area m²		U-Value W/(m²K)		Month. Red. Fac.		G_t kKh/a		kWh/a	per m² Treated Floor Area
Exterior Wall - Ambient	A	106,2	*	0,272	*	1,00	*	104	=	3017	
Exterior Wall - Ground	B		*		*	1,00	*		=		
Roof/Ceiling - Ambient	A	179,1	*	0,209	*	1,00	*	104	=	3911	
Floor slab / basement ceiling	B	179,1	*	0,322	*	1,00	*	78	=	4503	
	A		*		*	1,00	*		=		
	A		*		*	1,00	*		=		
Garage wall	X	27,5	*	0,266	*	0,50	*	104	=	381	
Windows	A	62,3	*	1,420	*	1,00	*	104	=	9224	
Exterior Door	A		*		*	1,00	*		=		
Exterior TB (length/m)	A	176,8	*	0,213	*	1,00	*	104	=	3924	
Perimeter TB (length/m)	P	78,7	*	0,749	*	1,00	*	78	=	4592	
Ground TB (length/m)	B		*		*	1,00	*		=		
											kWh/(m²a)
Transmission Heat Losses Q_T									Total	29552	165,0

		A_{TFA} m²		Clear Room Height m		m³
Effective Air Volume V_{RAX}		179	*	3,00	=	537

	$n_{V,system}$ 1/h		η^*_{SHX}		η_{HR}		$n_{V,Res}$ 1/h		$n_{V,equi,fraction}$ 1/h
Effective Air Change Rate Ambient $n_{V,e}$	0,300	*(1-	0%	)*(1-	0,00	)+	0,001	=	0,301
Effective Air Change Rate Ground $n_{V,g}$	0,300	*	0%	*(1-	0,00	)		=	0,000

	V_{RAX} m³		$n_{V,equi,fraction}$ 1/h		c_{Air} Wh/(m³K)		G_t kKh/a		kWh/a	kWh/(m²a)
Ventilation Losses Ambient Q_V	537	*	0,301	*	0,33	*	104	=	5572	31,1
Ventilation Losses Ground $Q_{V,e}$	537	*	0,000	*	0,33	*	81	=	0	0,0
Ventilation Heat Losses Q_V								Total	5572	31,1

		Q_T kWh/a		Q_V kWh/a		Reduction Factor Night/Weekend Saving		kWh/a	kWh/(m²a)
Total Heat Losses Q_L	(	29552	+	5572	)	1,0	=	35123	196,1

Orientation of the Area	Reduction Factor See Windows worksheet		g-Value (perp. radiation)		Area m²		Global Radiation kWh/(m²a)		kWh/a	kWh/(m²a)
North	0,55	*	0,70	*	4,5	*	477	=	823	
East	0,56	*	0,70	*	6,9	*	593	=	1585	
South	0,55	*	0,70	*	33,0	*	704	=	8990	
West	0,56	*	0,70	*	17,9	*	564	=	3960	
Horizontal	0,00	*	0,00	*	0,0	*	707	=	0	
Sum Opaque Areas									1373	
Available Solar Heat Gains Q_S								Total	16731	93,4

	kh/d		Length Heat. Period d/a		Spec. Power q_I W/m²		A_{TFA} m²		kWh/a	kWh/(m²a)
Internal Heat Gains Q_I	0,024	*	303	*	5,0	*	179,1	=	6514	36,4

				kWh/a	kWh/(m²a)
	Free Heat Q_F	Q_S + Q_I	=	23245	129,8
	Ratio Free Heat to Losses	Q_F / Q_L	=	0,66	
Utilisation Factor Heat Gains η_G			=	78%	
Heat Gains Q_G		η_G * Q_F	=	18113	101,1
Annual Heating Demand QH		Q_L - Q_G	=	17010	**95**

	kWh/(m²a)		(Yes/No)
Limiting Value	15	**Requirement met?**	**no**

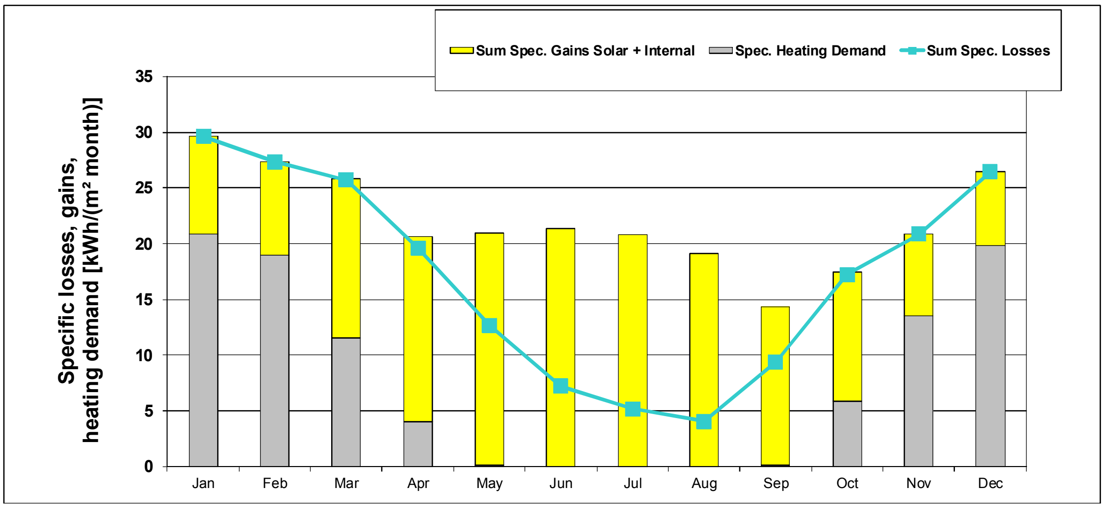
Passive House verification

SPECIFIC ANNUAL HEAT DEMAND MONTHLY METHOD

Climate: PL - Strefa II (Poznan/Pila)
Building: Home

Interior Temperature: 20,326 °C
Building Type/Use: Dweelling
Treated Floor Area A_{TFA}: 179 m²

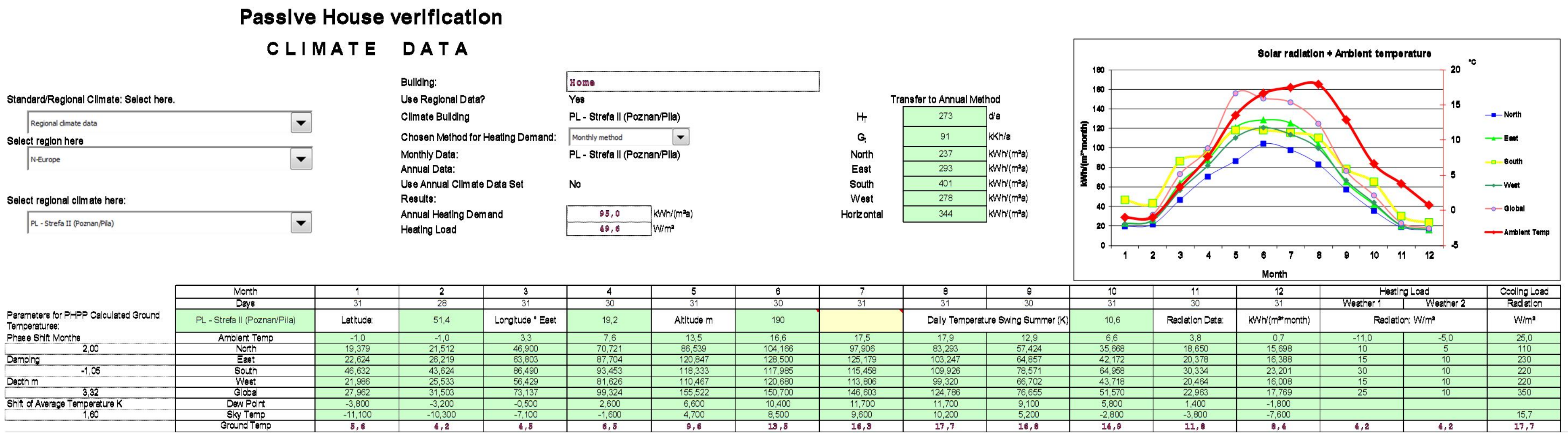
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	
Heating Degree Hours - E	16,2	14,6	13,0	9,4	5,3	2,9	2,3	2,0	5,6	10,5	12,1	14,8	109	kKh
Heating Degree Hours - (	10,9	10,8	11,8	10,0	8,0	4,9	3,0	1,9	2,5	4,1	6,1	8,9	83	kKh
Losses - Exterior	4030	3634	3234	2350	1331	726	582	507	1388	2615	3020	3701	27117	kWh
Losses - Ground	1275	1264	1372	1163	934	570	348	224	293	473	717	1034	9666	kWh
Sum Spec. Losses	29,6	27,3	25,7	19,6	12,6	7,2	5,2	4,1	9,4	17,2	20,9	26,4	205,3	kWh/m²
Solar Gains - North	33	37	81	122	149	180	169	144	99	62	32	27	1135	kWh
Solar Gains - East	60	70	170	234	323	343	334	276	173	113	54	44	2195	kWh
Solar Gains - South	596	557	1105	1194	1512	1508	1475	1405	1004	830	388	296	11870	kWh
Solar Gains - West	154	179	397	574	776	848	800	698	469	307	144	112	5458	kWh
Solar Gains - Horiz.	0	0	0	0	0	0	0	0	0	0	0	0	0	kWh
Solar Gains - Opaque	55	61	141	194	297	295	286	242	150	100	45	35	1900	kWh
Internal Heat Gains	666	602	666	645	666	645	666	666	645	666	645	666	7846	kWh
Sum Spec. Gains Solar +	8,7	8,4	14,3	16,5	20,8	21,3	20,8	19,1	14,2	11,6	7,3	6,6	169,7	kWh/m²
Utilisation Factor	100%	100%	99%	94%	60%	34%	25%	21%	65%	98%	100%	100%	65%	
Annual Heating Demand	3740	3391	2062	730	25	0	0	0	30	1050	2429	3554	17010	kWh
Spec. Heating Demand	**20,9**	**18,9**	**11,5**	**4,1**	**0,1**	**0,0**	**0,0**	**0,0**	**0,2**	**5,9**	**13,6**	**19,8**	**95,0**	kWh/m²



Annual Heating Demand: Comparison

EN 13790 Monthly Method	**17010**	**kWh/a**	**95,0**	**kWh/(m²a) Reference to habitable area**
PHPP, Heating Period Method	**17895**	**kWh/a**	**99,9**	**kWh/(m²a) Reference to habitable area**

Month	1	2	3	4	5	6	7	8	9	10	11	12	Annual Total	Heating Period Method
Days	31	28	31	30	31	30	31	31	30	31	30	31	365	273
Ambient Temp.	-1,00	-1,00	3,30	7,60	13,50	16,60	17,50	17,90	12,90	6,60	3,80	0,70	8,3	6,2
North Radiation	19,4	21,5	46,9	70,7	86,5	104,2	97,9	83,3	57,4	35,7	18,7	15,7	658	237
East Radiation	22,6	26,2	63,8	87,7	120,8	128,5	125,2	103,2	64,9	42,2	20,4	16,4	822	293
South Radiation	46,6	43,6	86,5	93,5	118,3	118,0	115,5	109,9	78,6	65,0	30,3	23,2	929	401
West Radiation	22,0	25,5	56,4	81,6	110,5	120,7	113,8	99,3	66,7	43,7	20,5	16,0	777	278
Hori. Radiation	28,0	31,5	73,1	99,3	155,5	150,7	146,6	124,8	76,7	51,6	23,0	17,8	978	344
Tsky	-11,10	-10,30	-7,10	-1,60	4,70	8,50	9,60	10,20	5,20	-2,80	-3,80	-7,60	-0,5	
Ground Temp	5,63	4,20	4,51	6,47	9,56	13,54	16,32	17,75	16,84	14,88	11,79	8,41	10,9	8,9



Passive House verification

CLIMATE DATA

Standard/Regional Climate: Select here.
Regional climate data ▼

Select region here
N-Europe ▼

Select regional climate here:
PL - Strefa II (Poznan/Pila) ▼

Building: Home
Use Regional Data? Yes
Climate Building PL - Strefa II (Poznan/Pila)
Chosen Method for Heating Demand: Monthly method ▼
Monthly Data: PL - Strefa II (Poznan/Pila)
Annual Data:
Use Annual Climate Data Set No
Results:
Annual Heating Demand 95,0 kWh/(m²a)
Heating Load 49,6 W/m²

Transfer to Annual Method

H_T	273	d/a
G_t	91	kKh/a
North	237	kWh/(m²a)
East	293	kWh/(m²a)
South	401	kWh/(m²a)
West	278	kWh/(m²a)
Horizontal	344	kWh/(m²a)

	Month	1	2	3	4	5	6	7	8	9	10	11	12	Heating Load		Cooling Load
	Days	31	28	31	30	31	30	31	31	30	31	30	31	Weather 1	Weather 2	Radiation
Parameters for PHPP Calculated Ground Temperatures:	PL - Strefa II (Poznan/Pila)	Latitude:	51,4	Longitude ° East	19,2	Altitude m	190		Daily Temperature Swing Summer (K)		10,6	Radiation Data:	kWh/(m²*month)	Radiation: W/m²		W/m²
Phase Shift Months	Ambient Temp	-1,0	-1,0	3,3	7,6	13,5	16,6	17,5	17,9	12,9	6,6	3,8	0,7	-11,0	-5,0	25,0
2,00	North	19,379	21,512	46,900	70,721	86,539	104,166	97,906	83,293	57,424	35,668	18,650	15,698	10	5	110
Damping	East	22,624	26,219	63,803	87,704	120,847	128,500	125,179	103,247	64,857	42,172	20,378	16,388	15	10	230
-1,05	South	46,632	43,624	86,490	93,453	118,333	117,985	115,458	109,926	78,571	64,958	30,334	23,201	30	10	220
Depth m	West	21,986	25,533	56,429	81,626	110,467	120,680	113,806	99,320	66,702	43,718	20,464	16,008	15	10	220
3,32	Global	27,962	31,503	73,137	99,324	155,522	150,700	146,603	124,786	76,655	51,570	22,963	17,769	25	10	350
Shift of Average Temperature K	Dew Point	-3,800	-3,200	-0,500	2,600	6,600	10,400	11,700	11,700	9,100	5,800	1,400	-1,800			
1,60	Sky Temp	-11,100	-10,300	-7,100	-1,600	4,700	8,500	9,600	10,200	5,200	-2,800	-3,800	-7,600			15,7
	Ground Temp	5,6	4,2	4,5	6,5	9,6	13,5	16,3	17,7	16,8	14,9	11,8	8,4	4,2	4,2	17,7

Annex 17

Passive House verification

AREAS DETERMINATION

Building: 　 Heating demand 13 kWh/(m²a)

Group Nr.	Area group	Temp. zone	Area	Unit	Comments	Building element overview	Average U-Value [W/(m²K)]
			Summary				
1	Treated Floor Area		179,14	m²	*Living area or useful area within the thermal envelope*		
2	North Windows	A	4,50	m²	Results are from the Windows worksheet.	North Windows	0,663
3	East Windows	A	6,88	m²		East Windows	0,653
4	South Windows	A	33,00	m²		South Windows	0,616
5	West Windows	A	17,88	m²		West Windows	0,649
6	Horizontal Windows	A	0,00	m²		Horizontal Windows	
7	Exterior Door	A	0,00	m²	*Please subtract area of door from respective building element*	Exterior Door	
8	Exterior Wall - Ambient	A	106,18	m²	*Window areas are subtracted from the individual areas specified in the "Windows" worksheet.*	Exterior Wall - Ambient	0,134
9	Exterior Wall - Ground	B	0,00	m²	*Temperature Zone "A" is ambient air.*	Exterior Wall - Ground	
10	Roof/Ceiling - Ambient	A	179,14	m²	*Temperature zone "B" is the ground.*	Roof/Ceiling - Ambient	0,118
11	Floor slab / basement ceiling	B	179,14	m²		Floor slab / basement ceiling	0,124
12			0,00	m²	*Temperature zones "A", "B","P" and "X" may be used. NOT "I"*		
13			0,00	m²	*Temperature zones "A", "B","P" and "X" may be used. NOT "I"* Factor for X		
14	Garage wall	X	27,49	m²	*Temperature zone "X": Please provide user-defined reduction factor (0 < f_t < 1):* 50%	Garage wall	0,138
						Thermal Bridge Overview	Ψ [W/(m K)]
15	Thermal Bridges Ambient	A	12,00	m	*Units in m*	Thermal Bridges Ambient	0,020
16	Perimeter Thermal Bridges	P	75,66	m	*Units in m; temperature zone "P" is perimeter (see Ground worksheet).*	Perimeter Thermal Bridges	0,001
17	Thermal Bridges Floor Slab	B	0,00	m	*Units in m*	Thermal Bridges Floor Slab	
18	Partition Wall to Neighbour	I	0,00	m²	*No heat losses, only considered for the heating load calculation.*	Partition Wall to Neighbour	
Total thermal envelope			554,20	m²		Average Therm. Envelope	0,183

Area input

Area Nr.	Building element description	Group Nr.	Assigned to group	Quantity	x (	a [m]	x	b [m]	+	User-Determined [m²]	-	User Sub-traction [m²]	-	Subtraction window areas [m²]	) =	Area [m²]	Selection of the corresponding building element assembly	Nr.	U-Value [W/(m²K)]
	Treated Floor Area	1	Treated Floor Area	1	x (		x		+	179,14	-	0,00			) =	179,1			
	North Windows	2	North Windows	Please complete in Windows worksheet only!												4,5	From Windows sheet		0,663
	East Windows	3	East Windows													6,9	From Windows sheet		0,653
	South Windows	4	South Windows													33,0	From Windows sheet		0,616
	West Windows	5	West Windows													17,9	From Windows sheet		0,649
	Horizontal Windows	6	Horizontal Windows													0,0	From Windows sheet		0,000
	Exterior Door	7	Exterior Door		x (		x		+	2,00	-		) -		=		U-Value Exterior Door		0,60
1	Exterior wall south	8	Exterior Wall - Ambient	1	x (		x		+	50,56	-	5,43	) -	33,0	=	12,1	Exterior wall	1	0,130
2	Exterior wall north	8	Exterior Wall - Ambient	1	x (		x		+	39,28	-		) -	4,5	=	34,8	Exterior wall	1	0,130
3	Exterior wall west	8	Exterior Wall - Ambient	1	x (		x		+	41,09	-	2,00	) -	17,9	=	21,2	Exterior wall	1	0,130
4	Exterior wall east	8	Exterior Wall - Ambient	1	x (		x		+	25,30	-		) -	6,9	=	18,4	Exterior wall	1	0,130
5	Roof	10	Roof/Ceiling - Ambient	1	x (		x		+	179,14	-		) -	0,0	=	179,1	Roof	2	0,118
6	Basement floor	11	Floor slab / basement ceiling	1	x (		x		+	179,14	-		) -	0,0	=	179,1	Ground Floor	3	0,124
7	Garage wall thick	14	Garage wall	1	x (	2,45	x	3,88	+		-		) -	0,0	=	9,5	Garage wall south	4	0,128
8	Garage wall thin	14	Garage wall	1	x (	2,45	x	6,00	+		-		) -	0,0	=	14,7	Garage wall west	5	0,141
9	Exterior wall south STB	8	Exterior Wall - Ambient	1	x (		x		+	5,97	-		) -	0,0	=	6,0	Wall substancial thermal bric	6	0,151
10	Exterior wall north STB	8	Exterior Wall - Ambient	1	x (		x		+	4,88	-		) -	0,0	=	4,9	Wall substancial thermal bric	6	0,151
11	Exterior wall west STB	8	Exterior Wall - Ambient	1	x (		x		+	5,11	-		) -	0,0	=	5,1	Wall substancial thermal bric	6	0,151
12	Exterior wall east STB	8	Exterior Wall - Ambient	1	x (		x		+	3,68	-		) -	0,0	=	3,7	Wall substancial thermal bric	6	0,151
13	Garage wall thick STB	14	Garage wall	1	x (	4,18	x	0,25	+	0,74	-		) -	0,0	=	1,8	Wall substancial thermal bric	6	0,151
14	Garage wall thin STB	14	Garage wall	1	x (	6,00	x	0,25	+		-		) -	0,0	=	1,5	Wall substancial thermal bric	6	0,151

Thermal Bridge Inputs

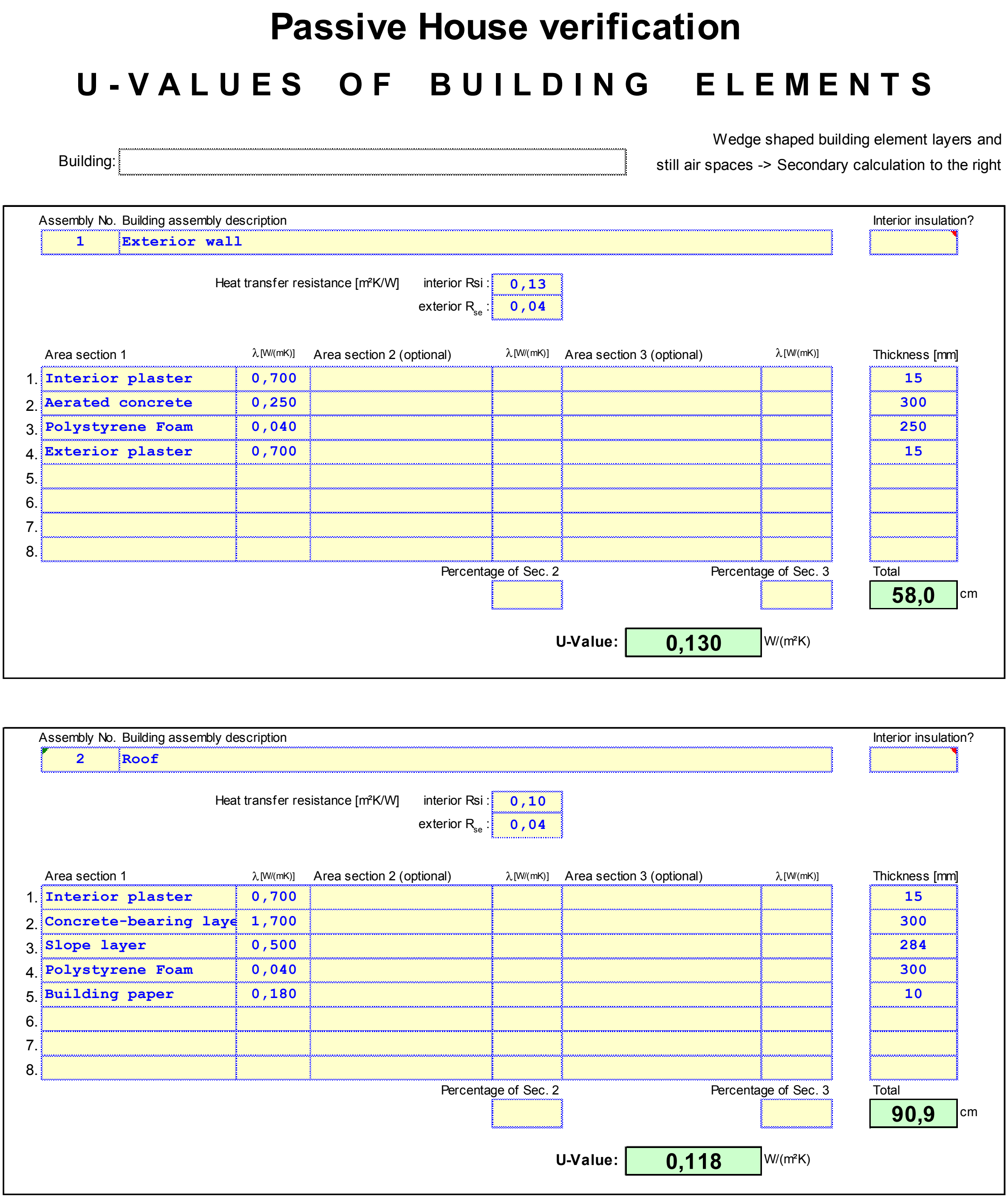
No.	Thermal bridge description	Group Nr.	Assigned to group	Quantity	x (	User determined length [m]	-	Subtraction user-determined length [m]	)=	Length ℓ [m]	Input of thermal bridge heat loss coefficient W/(mK)	Ψ W/(mK)
1					x (		-		) =			
2					x (		-		) =			
3					x (		-		) =			
4					x (		-		) =			
5					x (		-		) =			
6					x (		-		) =			
7	Ext. wall corner	15	Thermal Bridges Ambient	1	x (	12,00	-		) =	12,00	Ext. wall corner	0,020
8					x (		-		) =			
9					x (		-		) =			
10	Corner Ext-Int. Wall- gar	16	Perimeter Thermal Bridges	1	x (	3,00	-		) =	3,00	Corner Ext-Int. Wall- garage	0,020
11	Perimeter bridge to the g	16	Perimeter Thermal Bridges	1	x (	72,66	-		) =	72,66	Perimeter bridge to the ground	0,000

Passive House verification

U - LIST

Compilation of the building elements calculated in the U-Values worksheet and other construction types from databases.

	Type		
Assembly No.	Assembly description	Total thickness	U-Value
		m	W/(m²K)
1	Exterior wall	0,580	0,130
2	Roof	0,909	0,118
3	Ground Floor	0,557	0,124
4	Garage wall south	0,592	0,128
5	Garage wall west	0,414	0,141
6	Wall substancial thermal bridges	0,580	0,151



Passive House verification

U-VALUES OF BUILDING ELEMENTS

Building:

Wedge shaped building element layers and
still air spaces -> Secondary calculation to the right

Assembly No. 1 — Building assembly description: Exterior wall

Interior insulation?

Heat transfer resistance [m²K/W] interior Rsi : 0,13
exterior R_{se} : 0,04

	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Interior plaster	0,700					15
2.	Aerated concrete	0,250					300
3.	Polystyrene Foam	0,040					250
4.	Exterior plaster	0,700					15
5.							
6.							
7.							
8.							

Percentage of Sec. 2:
Percentage of Sec. 3:
Total: 58,0 cm

U-Value: 0,130 W/(m²K)

Assembly No. 2 — Building assembly description: Roof

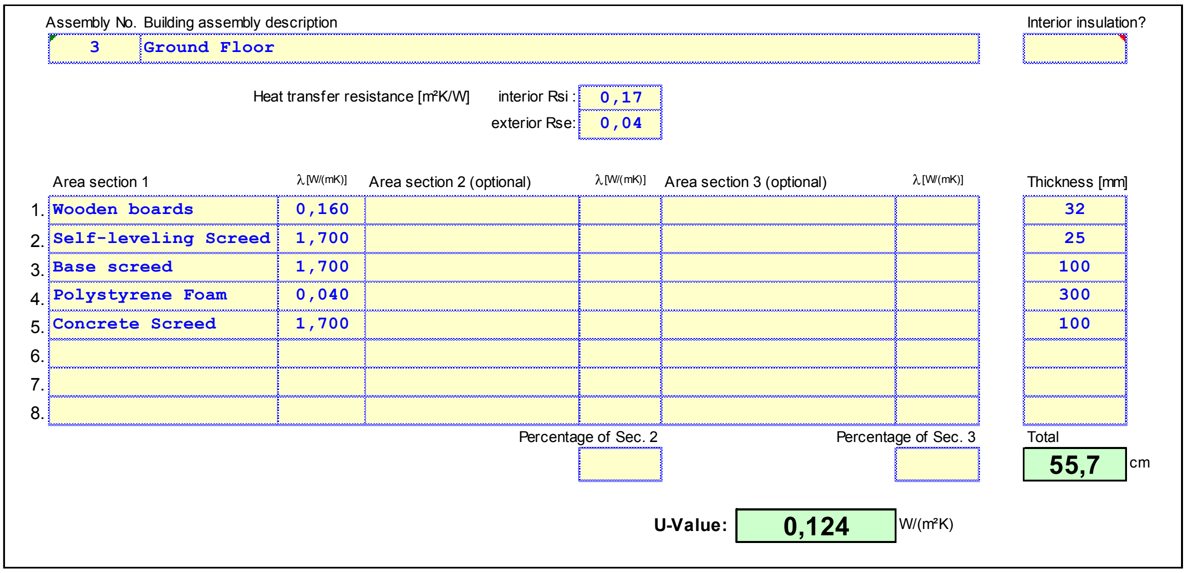
Interior insulation?

Heat transfer resistance [m²K/W] interior Rsi : 0,10
exterior R_{se} : 0,04

	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Interior plaster	0,700					15
2.	Concrete-bearing laye	1,700					300
3.	Slope layer	0,500					284
4.	Polystyrene Foam	0,040					300
5.	Building paper	0,180					10
6.							
7.							
8.							

Percentage of Sec. 2:
Percentage of Sec. 3:
Total: 90,9 cm

U-Value: 0,118 W/(m²K)



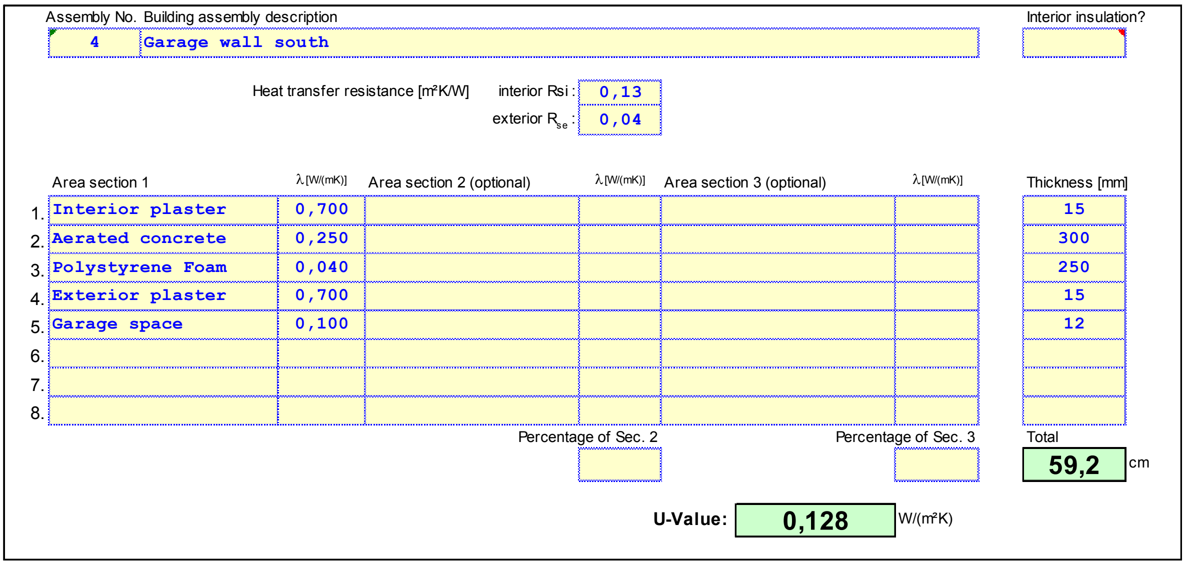
Assembly No.	Building assembly description	Interior insulation?
3	Ground Floor	

Heat transfer resistance [m^2K/W] interior Rsi : 0,17
exterior Rse: 0,04

	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Wooden boards	0,160					32
2.	Self-leveling Screed	1,700					25
3.	Base screed	1,700					100
4.	Polystyrene Foam	0,040					300
5.	Concrete Screed	1,700					100
6.							
7.							
8.							

Percentage of Sec. 2
Percentage of Sec. 3
Total 55,7 cm

U-Value: 0,124 W/(m^2K)



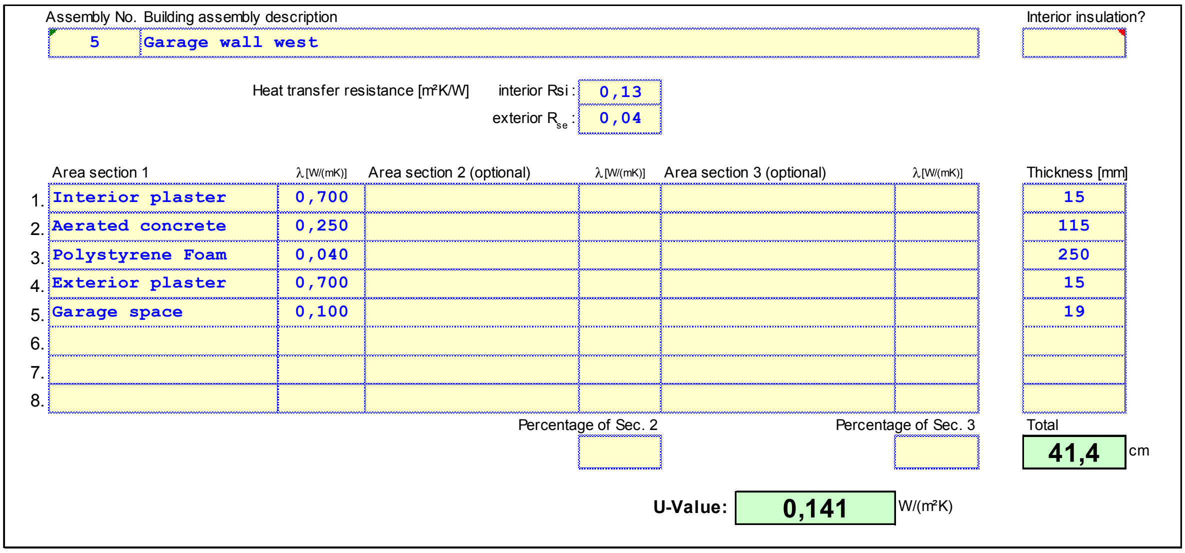
Assembly No.	Building assembly description	Interior insulation?
4	Garage wall south	

Heat transfer resistance [m^2K/W] interior Rsi : 0,13
exterior R_{se} : 0,04

	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Interior plaster	0,700					15
2.	Aerated concrete	0,250					300
3.	Polystyrene Foam	0,040					250
4.	Exterior plaster	0,700					15
5.	Garage space	0,100					12
6.							
7.							
8.							

Percentage of Sec. 2
Percentage of Sec. 3
Total 59,2 cm

U-Value: 0,128 W/(m^2K)



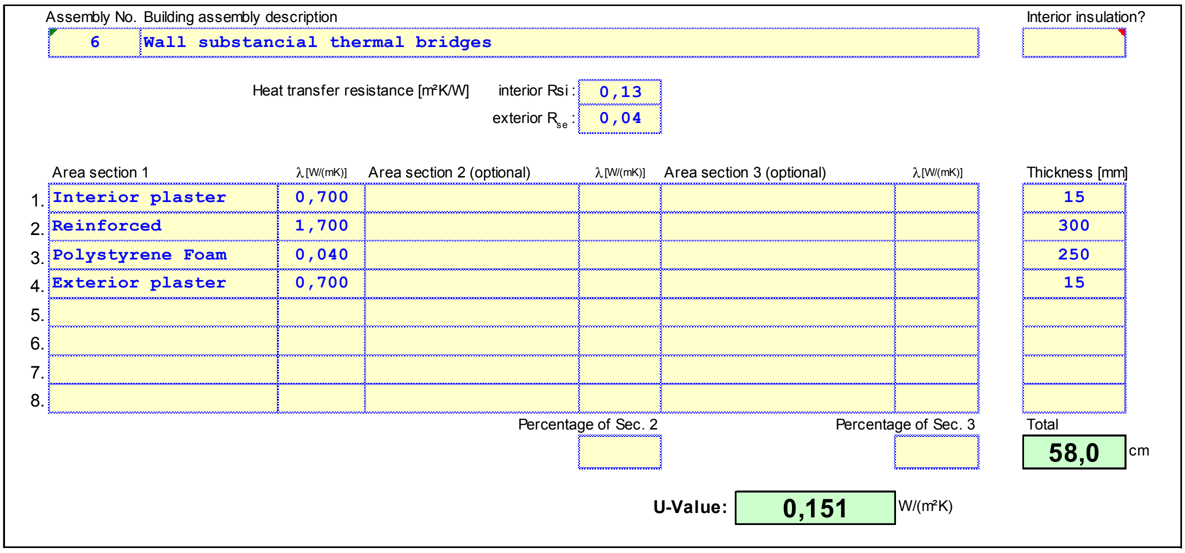
Assembly No.	Building assembly description	Interior insulation?
5	Garage wall west	

Heat transfer resistance [m^2K/W] interior Rsi : 0,13
exterior R_{se} : 0,04

	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Interior plaster	0,700					15
2.	Aerated concrete	0,250					115
3.	Polystyrene Foam	0,040					250
4.	Exterior plaster	0,700					15
5.	Garage space	0,100					19
6.							
7.							
8.							

Percentage of Sec. 2
Percentage of Sec. 3
Total 41,4 cm

U-Value: 0,141 W/(m^2K)



Assembly No.	Building assembly description	Interior insulation?
6	Wall substancial thermal bridges	

Heat transfer resistance [m²K/W] interior Rsi : 0,13

exterior R_{se} : 0,04

	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Interior plaster	0,700					15
2.	Reinforced	1,700					300
3.	Polystyrene Foam	0,040					250
4.	Exterior plaster	0,700					15
5.							
6.							
7.							
8.							

Percentage of Sec. 2 Percentage of Sec. 3

Total 58,0 cm

U-Value: 0,151 W/(m²K)

Passive House verification

HEAT LOSSES VIA THE GROUND

Ground Characteristics							
Thermal Conductivity	λ	2,0	W/(mK)				
Heat Capacity	ρc	2,0	MJ/(m³K)				
Periodic Penetration Depth	δ	3,17	m				

Climate Data			
Av. Indoor Temp. Winter	T_i	20,0	°C
Av. Indoor Temp. Summer	T_i	25,0	°C
Average Ground Surface Temperatur	$T_{g,ave}$	9,3	°C
Amplitude of $T_{g,ave}$	$T_{g,\wedge}$	10,0	°C
Length of the Heating Period	n	7,2	months
Heating Degree Hours - Exterior	G_t	89,3	kKh/a

Building Data							
Floor Slab Area	A	179,1	m²	U-value floor slab/basement ceiling	U_f	0,124	W/(m²K)
Floor Slab Perimeter	P	72,6	m	Thermal bridges floor slab/basement	Ψ_B*l	0,00	W/K
				U-value floor slab/basement ceiling ir	U_f'	0,124	W/(m²K)
Charact. Dimension of Floor Slab	B'	4,93	m	Eq. Thickness Floor	d_t	16,08	m

Floor Slab Type (select only one)			
	Heated Basement or Underground Floor Slab		Unheated basement
x	Slab on Grade		Suspended Floor

Additional Thermal Bridge Heat Losses at Perimeter				Steady-State Fraction	$\Psi_{P,stat}$*l	0,060	W/K
Phase Shift	β		months	Harmonic Fraction	$\Psi_{P,harm}$*l	0,060	W/K

Groundwater Correction							
Depth of the Groundwater Table	z_W	3,0	m	Transm. Belowground El. (w/o Ground)	L_{reg}	22,33	W/K
Groundwater Flow Rate	q_W	0,05	m/d	Relative Insulation Standard	d_t/B'	3,25	-
				Relative Groundwater Depth	z_W/B'	0,61	-
Groundwater Correction Factor	G_W	1,0026792	-	Relative Groundwater Velocity	l/B'	0,17	-

Basement or Underground Floor Slab							
Eq. Thickness Floor Slab	d_t		m	Phase Shift	β		months
U-Value Floor Slab	U_{bf}		W/(m²K)	Exterior Periodic Transmittance	L_{pe}		W/K
Eq. Thickness Basement Wall	d_w		m				
U-Value Wall	U_{bw}		W/(m²K)				
Steady-State Transmittance	L_S		W/K				

Unheated Basement							
Steady-State Transmittance	L_S		W/K	Phase Shift	β		months
				Exterior Periodic Transmittance	L_{pe}		W/K

Slab on Grade							
Heat Transfer Coefficient	U_0	0,11	W/(m²K)	Phase Shift	β	1,42	months
Eq. Ins. Thickness Perimeter Ins.	d'	0,00	m	Exterior Periodic Transmittance	L_{pe}	9,66	W/K
Perimeter Insulation Correction	$\Delta\Psi$		W/(mK)				
Steady-State Transmittance	L_S	19,59	W/K				

Suspended Floor Above a Ventilated Crawl Space (at max. 0.5 m Below Ground)							
Eq. Ins. Thickness Crawl Space	d_g		m	Phase Shift	β		months
U-Value Crawl Space Floor Slab	U_g		W/(m²K)	Exterior Periodic Transmittance	L_{pe}		W/K
U-Value Crawl Space Wall & Vent.	U_X		W/(m²K)				
Steady-State Transmittance	L_S		W/K				

Interim Results							
Phase Shift	β	1,42	months	Steady-State Heat Flow	Φ_{stat}	210,9	W
Steady-State Transmittance	L_S	19,65	W/K	Periodic Heat Flow	Φ_{harm}	36,0	W
Exterior Periodic Transmittance	L_{pe}	9,72	W/K	Heat Losses During Heating Period	Q_{tot}	1298	kWh

Ground reduction factor for "Annual Heating Demand" sheet **0,65**

Monthly Average Ground Temperatures for Monthly Method

Month	1	2	3	4	5	6	7	8	9	10	11	12	Average Value
Winter	7,4	6,3	6,4	7,6	9,6	11,9	13,8	14,8	14,7	13,5	11,5	9,3	10,6
Summer	8,0	6,9	7,0	8,2	10,2	12,5	14,4	15,4	15,3	14,1	12,1	9,9	11,2

Design Ground Temperature for Heating Load Sheet 6,3 **for Cooling Load Sheet** 15,4

Passive House verification

REDUCTION FACTOR SOLAR RADIATION, WINDOW U-VALUE

Building:

Annual heating demand: 13 kWh/(m^{2}a)

Heating degree hours: 89,3

Climate: PL - Strefa II (Poznan/Pila)

Window area orientation	Global radiation (cardinal points)	Shading	Dirt	Non-perpendicular incident radiation	Glazing fraction	g-Value	Reduction factor for solar radiation	Window area	Window U-Value	Glazing area	Average global radiation	Transmission losses	Heat gains solar radiation
maximum:	kWh/(m^{2}a)	0,75	0,95	0,85				m^2	W/(m^{2}K)	m^2	kWh/(m^{2}a)	kWh/a	kWh/a
North	100	0,93	0,95	0,85	0,958	0,50	0,72	4,50	0,66	4,3	100	266	162
East	229	0,88	0,95	0,85	0,963	0,50	0,68	6,88	0,65	6,6	229	401	539
South	427	0,93	0,95	0,85	0,959	0,50	0,72	33,00	0,62	31,7	427	1814	5098
West	229	0,88	0,95	0,85	0,964	0,50	0,69	17,88	0,65	17,2	229	1035	1408
Horizontal	345	1,00	0,95	0,85	0,000	0,00	0,00	0,00	0,00	0,0	345	0	0
	Total or Average Value for All Windows.					0,50	0,71	62,25	0,63	59,8		3516	7207

					Window rough openings		Installed		Glazing		Frame		g-Value	U-Value		Ψ-Spacer	Installation								
Quantity	Description	Deviation from north	Angle of inclination from the horizontal	Orientation	Width	Height	In Area in the Areas worksheet	Nr.	Select glazing from the WinType worksheet	Nr.	Select window from the WinType worksheet	Nr.	Perpendicular Radiation	Glazing	Frames (centre)	Ψ_{spacer} (centre)	Left 1/0	Right 1/0	Bottom 1/0	Top 1/0	$\Psi_{\text{installation}}$ left	$\Psi_{\text{installation}}$ right	$\Psi_{\text{installation}}$ bottom	$\Psi_{\text{installation}}$ top	$\Psi_{\text{installation}}$ Average value
		Degrees	Degrees		m	m	Select:		Select:		Select:		-	W/(m^{2}K)	W/(m^{2}K)	W/(mK)					W/(mK)	W/(mK)	W/(mK)	W/(mK)	W/(mK)
2	South	180	90	South	1,500	2,750	Exterior wall sou ▼	1	INTERPANE - ipl ▼	1	FIX Glas Trösch ▼	1	0,50	0,49	0,58	0,029	1	1	1	1	0,040	0,040	0,040	0,040	0,040
7	South	180	90	South	1,000	2,750	Exterior wall sou ▼	1	INTERPANE - ipl ▼	1	FIX Glas Trösch ▼	1	0,50	0,49	0,58	0,029	0	0	1	1	0,040	0,040	0,040	0,040	0,040
1	East	90	90	East	1,000	2,750	Exterior wall eas ▼	4	INTERPANE - ipl ▼	1	FIX Glas Trösch ▼	1	0,50	0,49	0,58	0,029	1	1	1	1	0,040	0,040	0,040	0,040	0,040
1	East	90	90	East	1,500	2,750	Exterior wall eas ▼	4	INTERPANE - ipl ▼	1	FIX Glas Trösch ▼	1	0,50	0,49	0,58	0,029	1	1	1	1	0,040	0,040	0,040	0,040	0,040
2	West	270	90	West	1,000	2,750	Exterior wall we ▼	3	INTERPANE - ipl ▼	1	FIX Glas Trösch ▼	1	0,50	0,49	0,58	0,029	1	1	1	1	0,040	0,040	0,040	0,040	0,040
3	West	270	90	West	1,500	2,750	Exterior wall we ▼	3	INTERPANE - ipl ▼	1	FIX Glas Trösch ▼	1	0,50	0,49	0,58	0,029	1	1	1	1	0,040	0,040	0,040	0,040	0,040
1	North	0	90	North	1,000	1,500	Exterior wall nor ▼	2	INTERPANE - ipl ▼	1	FIX Glas Trösch ▼	1	0,50	0,49	0,58	0,029	1	1	1	1	0,040	0,040	0,040	0,040	0,040
1	North	0	90	North	2,000	1,500	Exterior wall nor ▼	2	INTERPANE - ipl ▼	1	FIX Glas Trösch ▼	1	0,50	0,49	0,58	0,029	1	0	1	1	0,040	0,040	0,040	0,040	0,040
2	South	180	90	South	1,000	2,750	Exterior wall sou ▼	1	INTERPANE - ipl ▼	1	FIX Glas Trösch ▼	1	0,50	0,49	0,58	0,029	1	0	1	1	0,040	0,040	0,040	0,040	0,040

Results (unhide cells to make U- & Ψ-values from WinType worksheet visible)				Frame-U-values from WinTpye worksheet				Frame measures from WinType worksheet																			Thermal bridges									Installation length	
Window Area	Glazing Area	U-Value Window	Glazed Fraction per Window	Frame left	Frame right	Frame bottom	Frame top	Width - Left	Width - Right	Width - Below	Width - Above	Area left	Area right	Area bottom	Area top	Total area	Glazing edge length left	Glazing edge length right	Glazing edge length bottom	Glazing edge length top	Total glazing edge length	Installation length left	Installation length right	Installation length bottom	Installation length top	Total installation length	$\Psi_{\text{glazing edge}}$ left	$\Psi_{\text{glazing edge}}$ right	$\Psi_{\text{glazing edge}}$ bottom	$\Psi_{\text{glazing edge}}$ top	$\Psi_{\text{installation}}$ left	$\Psi_{\text{installation}}$ right	$\Psi_{\text{installation}}$ bottom	$\Psi_{\text{installation}}$ top	Description	Glazing	Frames
m^2	m^2	W/(m^{2}K)	%	W/(m^{2}K)	W/(m^{2}K)	W/(m^{2}K)	W/(m^{2}K)	m	m	m	m	m^2	m^2	m^2	m^2	m^2	m	m	m	m	m	m	m	m	m	m	W/(mK)	W/(mK)	W/(mK)	W/(mK)	W/(mK)	W/(mK)	W/(mK)	W/(mK)		m	m
8,3	7,98	0,63	97%	0,58	0,58	0,58	0,58	0,02	0,02	0,02	0,02	0,04	0,04	0,02	0,02	0,13	2,72	2,72	1,47	1,47	8,37	2,75	2,75	1,50	1,50	8,50	0,029	0,029	0,029	0,029	0,040	0,040	0,040	0,040	South	16,7	17,0
19,3	18,42	0,60	96%	0,58	0,58	0,58	0,58	0,02	0,02	0,02	0,02	0,04	0,04	0,02	0,02	0,12	2,72	2,72	0,97	0,97	7,37	0,00	0,00	1,00	1,00	2,00	0,029	0,029	0,029	0,029	0,040	0,040	0,040	0,040	South	51,6	14,0
2,8	2,63	0,68	96%	0,58	0,58	0,58	0,58	0,02	0,02	0,02	0,02	0,04	0,04	0,02	0,02	0,12	2,72	2,72	0,97	0,97	7,37	2,75	2,75	1,00	1,00	7,50	0,029	0,029	0,029	0,029	0,040	0,040	0,040	0,040	East	7,4	7,5
4,1	3,99	0,63	97%	0,58	0,58	0,58	0,58	0,02	0,02	0,02	0,02	0,04	0,04	0,02	0,02	0,13	2,72	2,72	1,47	1,47	8,37	2,75	2,75	1,50	1,50	8,50	0,029	0,029	0,029	0,029	0,040	0,040	0,040	0,040	East	8,4	8,5
5,5	5,26	0,68	96%	0,58	0,58	0,58	0,58	0,02	0,02	0,02	0,02	0,04	0,04	0,02	0,02	0,12	2,72	2,72	0,97	0,97	7,37	2,75	2,75	1,00	1,00	7,50	0,029	0,029	0,029	0,029	0,040	0,040	0,040	0,040	West	14,7	15,0
12,4	11,97	0,63	97%	0,58	0,58	0,58	0,58	0,02	0,02	0,02	0,02	0,04	0,04	0,02	0,02	0,13	2,72	2,72	1,47	1,47	8,37	2,75	2,75	1,50	1,50	8,50	0,029	0,029	0,029	0,029	0,040	0,040	0,040	0,040	West	25,1	25,5
1,5	1,42	0,72	95%	0,58	0,58	0,58	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,08	1,47	1,47	0,97	0,97	4,87	1,50	1,50	1,00	1,00	5,00	0,029	0,029	0,029	0,029	0,040	0,040	0,040	0,040	North	4,9	5,0
3,0	2,89	0,63	96%	0,58	0,58	0,58	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,03	0,03	0,11	1,47	1,47	1,97	1,97	6,87	1,50	0,00	2,00	2,00	5,50	0,029	0,029	0,029	0,029	0,040	0,040	0,040	0,040	North	6,9	5,5
5,5	5,26	0,64	96%	0,58	0,58	0,58	0,58	0,02	0,02	0,02	0,02	0,04	0,04	0,02	0,02	0,12	2,72	2,72	0,97	0,97	7,37	2,75	0,00	1,00	1,00	4,75	0,029	0,029	0,029	0,029	0,040	0,040	0,040	0,040	South	14,7	9,5

Passive House verification

GLAZING ACCORDING TO CERTIFICATION

Go to curtain wall facades / window frames from line 99 onwards

	Type		
Assem-bly No.	Glazing	g-Value	U_g-Value
			W/(m²K)
1	INTERPANE - iplus 3CE (4:/12/4/12/:4 Krypton 90%)	0,50	0,49

CURTAIN WALL FACADE / WINDOW FRAME AS PER CERTIFICATE

Go to glazing from line 2 onwards

	Type	U_f-Value				Frame Dimensions				Thermal bridges								
Assem-bly No.	Window frame	Frame left	Frame right	Frame bottom	Frame top	Width - Left	Width - Right	Width - Below	Width - Above	Glazing edge thermal bridge				Installation thermal bridge				Curtain wall facades:
	Curtain wall facade	Post left	Post right	Beam bottom	Beam top	Post left	Post right	Beam bottom	Beam top	$\Psi_{\text{Glazing edge}}$ left	$\Psi_{\text{Glazing edge}}$ right	$\Psi_{\text{Glazing edge}}$ bottom	$\Psi_{\text{Glazing edge}}$ top	$\Psi_{\text{Installation}}$ left	$\Psi_{\text{Installation}}$ right	$\Psi_{\text{Installation}}$ bottom	$\Psi_{\text{Installation}}$ top	χ_{GC} -value Glass carrier
		W/(m²K)	W/(m²K)	W/(m²K)	W/(m²K)	m	m	m	m	W/(mK)	W/(mK)	W/(mK)	W/(mK)	W/(mK)	W/(mK)	W/(mK)	W/(mK)	W/K
1	FIX Glas Trösch - Composite Glazing - Festverglasun	0,58	0,58	0,58	0,58	0,016	0,016	0,016	0,016	0,029	0,029	0,029	0,029	0,040	0,040	0,040	0,040	

Passive House verification

CALCULATING SHADING FACTORS

Orientation	Glazing area	Reduction factor
	m²	r_S
North	4,31	93%
East	6,62	88%
South	31,66	93%
West	17,23	88%
Horizontal	0,00	100%

Quantity	Description	Deviation from North	Angle of Inclination from the Horizontal	Orientation	Glazing width	Glazing height	Glazing area	Height of the shading object	Horizontal distance	Window reveal depth	Distance from glazing edge to reveal	Overhang depth	Distance from upper glazing edge to overhang	Additional shading reduction factor	Horizontal shading reduction factor	Reveal Shading Reduction Factor	Overhang shading reduction factor	Total shading reduction factor
		Degrees	Degrees		m	m		m	m	m	m	m	m	%	%	%	%	%
					w_G	h_G	A_G	h_{Hori}	d_{Hori}	o_{Reveal}	d_{Reveal}	o_{over}	d_{over}	r_{other}	r_H	r_R	r_O	r_S
2	South	180	90	South	1,47	2,72	8,0	0,00	0,00	0,20	0,08	0,00	0,00	1,00	100%	95%	100%	95%
7	South	180	90	South	0,97	2,72	18,4	0,00	0,00	0,20	0,08	0,00	0,00	1,00	100%	93%	100%	93%
1	East	90	90	East	0,97	2,72	2,6	0,00	0,00	0,20	0,08	0,00	0,00	1,00	100%	86%	100%	86%
1	East	90	90	East	1,47	2,72	4,0	0,00	0,00	0,20	0,08	0,00	0,00	1,00	100%	90%	100%	90%
2	West	270	90	West	0,97	2,72	5,3	0,00	0,00	0,20	0,08	0,00	0,00	1,00	100%	86%	100%	86%
3	West	270	90	West	1,47	2,72	12,0	0,00	0,00	0,20	0,08	0,00	0,00	1,00	100%	90%	100%	90%
1	North	0	90	North	0,97	1,47	1,4	0,00	0,00	0,20	0,08	0,00	0,00	1,00	100%	90%	100%	90%
1	North	0	90	North	1,97	1,47	2,9	0,00	0,00	0,20	0,08	0,00	0,00	1,00	100%	95%	100%	95%
2	South	180	90	South	0,97	2,72	5,3	0,00	0,00	0,20	0,08	0,00	0,00	1,00	100%	93%	100%	93%

Passive House verification

VENTILATION DATA

Building:

Treated floor area A_{TFA}		m²	179	*(Areas worksheet)*
Room height h		m	2,5	*(Annual Heating Demand worksheet)*
Room ventilation volume (A_{TFA}*h) =	V_V	m³	448	*(Annual Heating Demand worksheet)*

Type of ventilation system

☒ Balanced PH ventilation *Please Check*
☐ Pure extract air

Infiltration air change rate

Wind protection coefficients e and f		
Coefficient e for screening class	Several sides exposed	One side exposed
No screening	0,10	0,03
Moderate screening	0,07	0,02
High screening	0,04	0,01
Coefficient f	15	20

			for Annual Demand:	for Heating Load:				
Wind protection coefficient, e			0,07	0,18				
Wind protection coefficient, f			15	15	Net Air Volume for Press. Test	V_{n50}	Air permeability	q_{50}
Air Change Rate at Press. Test	n_{50}	1/h	0,60	0,60	448	m³	0,49	m³/(hm²)

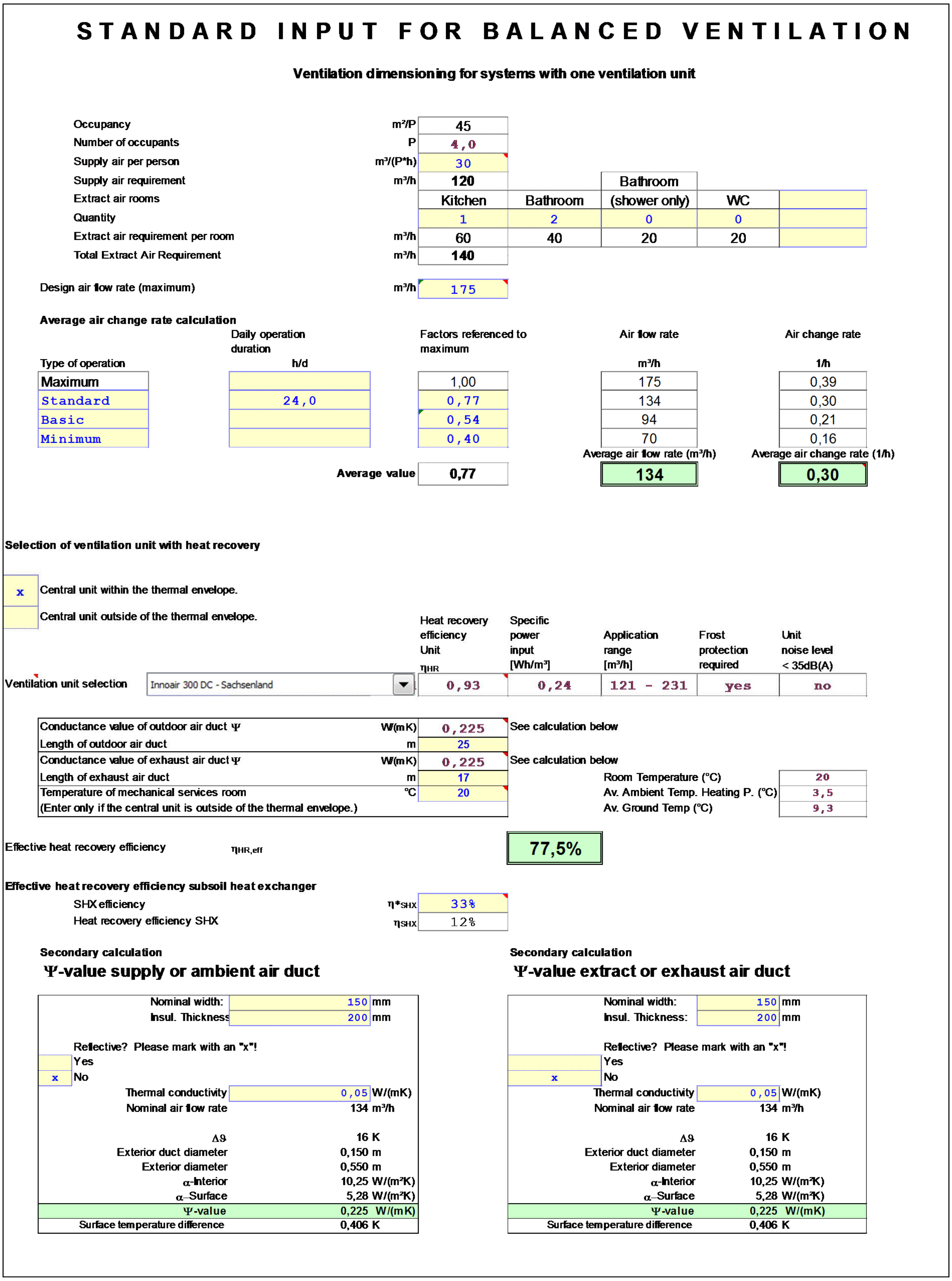
			for Annual Demand:	for Heating Load:
Excess extract air		1/h	0,00	0,00
Infiltration air change rate	$n_{V,Res}$	1/h	0,042	0,105

Ventilation unit / Heat recovery efficiency design

☒ Sheet Ventilation (Standard design) *(Sheet Ventilation see below)*
☐ Sheet Extended ventilation *(Sheet Additional Vent)*
(Multiple ventilation units, non-residential buildings)

Mean Air exchange m³/h	Mean Air Change Rate 1/h	excess (Extract air system) 1/h	recovery efficiency Unit [-]	power input Wh/m³	recovery efficiency SHX
134	0,30	0,00	77,5%	0,24	11,5%

SHX efficiency η^*_{SHX} 33%



STANDARD INPUT FOR BALANCED VENTILATION

Ventilation dimensioning for systems with one ventilation unit

Occupancy	m²/P	45				
Number of occupants	P	4,0				
Supply air per person	m³/(P*h)	30				
Supply air requirement	m³/h	120		Bathroom		
Extract air rooms		Kitchen	Bathroom	(shower only)	WC	
Quantity		1	2	0	0	
Extract air requirement per room	m³/h	60	40	20	20	
Total Extract Air Requirement	m³/h	140				

Design air flow rate (maximum) m³/h 175

Average air change rate calculation

Type of operation	Daily operation duration h/d	Factors referenced to maximum	Air flow rate m³/h	Air change rate 1/h
Maximum		1,00	175	0,39
Standard	24,0	0,77	134	0,30
Basic		0,54	94	0,21
Minimum		0,40	70	0,16
			Average air flow rate (m³/h)	Average air change rate (1/h)
	Average value	0,77	134	0,30

Selection of ventilation unit with heat recovery

x	Central unit within the thermal envelope.
	Central unit outside of the thermal envelope.

	Heat recovery efficiency Unit η_{HR}	Specific power input [Wh/m³]	Application range [m³/h]	Frost protection required	Unit noise level < 35dB(A)
Ventilation unit selection: Innoair 300 DC - Sachsenland	0,93	0,24	121 - 231	yes	no

Conductance value of outdoor air duct Ψ	W/(mK)	0,225	See calculation below
Length of outdoor air duct	m	25	
Conductance value of exhaust air duct Ψ	W/(mK)	0,225	See calculation below
Length of exhaust air duct	m	17	
Temperature of mechanical services room	°C	20	
(Enter only if the central unit is outside of the thermal envelope.)			

Room Temperature (°C)	20
Av. Ambient Temp. Heating P. (°C)	3,5
Av. Ground Temp (°C)	9,3

Effective heat recovery efficiency $\eta_{HR,eff}$ **77,5%**

Effective heat recovery efficiency subsoil heat exchanger

SHX efficiency	η^*_{SHX}	33%
Heat recovery efficiency SHX	η_{SHX}	12%

Secondary calculation

Ψ-value supply or ambient air duct

Nominal width:	150	mm
Insul. Thickness	200	mm
Reflective? Please mark with an "x"!		
Yes		
No	x	
Thermal conductivity	0,05	W/(mK)
Nominal air flow rate	134	m³/h
Δϑ	16	K
Exterior duct diameter	0,150	m
Exterior diameter	0,550	m
α-Interior	10,25	W/(m²K)
α-Surface	5,28	W/(m²K)
Ψ-value	0,225	W/(mK)
Surface temperature difference	0,406	K

Secondary calculation

Ψ-value extract or exhaust air duct

Nominal width:	150	mm
Insul. Thickness:	200	mm
Reflective? Please mark with an "x"!		
Yes		
No	x	
Thermal conductivity	0,05	W/(mK)
Nominal air flow rate	134	m³/h
Δϑ	16	K
Exterior duct diameter	0,150	m
Exterior diameter	0,550	m
α-Interior	10,25	W/(m²K)
α-Surface	5,28	W/(m²K)
Ψ-value	0,225	W/(mK)
Surface temperature difference	0,406	K

Passive House verification

SPECIFIC ANNUAL HEATING DEMAND

Climate:	PL - Strefa II (Poznan/Pila)	Interior Temperature:	20,0	°C
Building:		Building Type/Use:		
		Treated Floor Area A_{TFA}:	179,1	m²

Building Element	Temperature Zone	Area m²		U-Value W/(m²K)		Temp. Factor f_t		G_t kKh/a		kWh/a	per m² Treated Floor Area
Exterior Wall - Ambient	A	106,2	*	0,134	*	1,00	*	89,3	=	1272	7,10
Exterior Wall - Ground	B		*		*	0,65	*		=		
Roof/Ceiling - Ambient	A	179,1	*	0,118	*	1,00	*	89,3	=	1890	10,55
Floor slab / basement ceiling	B	179,1	*	0,124	*	0,65	*	89,3	=	1294	7,22
	A		*		*	1,00	*		=		
	A		*		*	1,00	*		=		
Garage wall	X	27,5	*	0,138	*	0,50	*	89,3	=	169	0,94
Windows	A	62,3	*	0,633	*	1,00	*	89,3	=	3516	19,63
Exterior Door	A		*		*	1,00	*		=		
Exterior TB (length/m)	A	12,0	*	0,020	*	1,00	*	89,3	=	21	0,12
Perimeter TB (length/m)	P	75,7	*	0,001	*	0,65	*	89,3	=	3	0,02
Ground TB (length/m)	B		*		*	0,65	*		=		
	Total of All Building Envelope Areas	554,2									kWh/(m²a)
Transmission Heat Losses Q_T									Total	8167	45,6

		A_{TFA} m²		Clear Room Height m		m³
Ventilation System:	Effective Air Volume, V_V	179,1	*	2,50	=	447,9
Effective Heat Recovery Efficiency of Heat Recovery	η_{eff} 77%					
Efficiency of Subsoil Heat Exchanger	η_{SHX} 12%					

	$n_{V,system}$ 1/h		Φ_{HR}		$n_{V,Res}$ 1/h		1/h
Energetically Effective Air Exchange n_V	0,300	* (1 -	0,80	) +	0,042	=	0,102

	V_V m³		n_V 1/h		c_{Air} Wh/(m³K)		G_t kKh/a		kWh/a	kWh/(m²a)
Ventilation Heat Losses Q_V	448	*	0,102	*	0,33	*	89,3	=	1344	7,5

		Q_T kWh/a		Q_V kWh/a		Reduction Factor Night/Weekend Saving		kWh/a	kWh/(m²a)
Total Heat Losses Q_L	(	8167	+	1344	)	1,0	=	9511	53,1

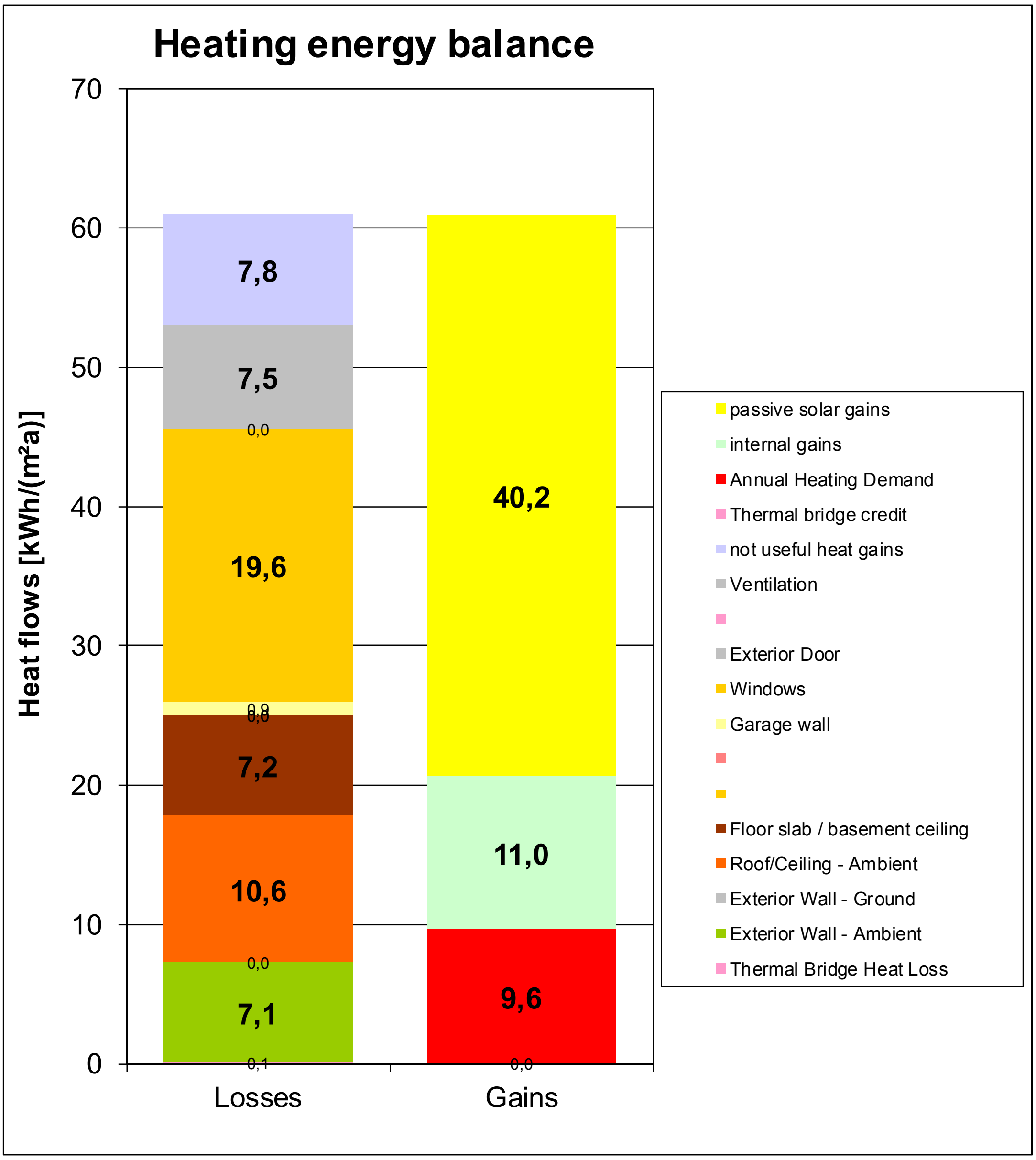
	Orientation of the Area	Reduction Factor See Windows Sheet		g-Value (perp. radiation)		Area m²		Radiation HP kWh/(m²a)		kWh/a
1.	North	0,72	*	0,50	*	4,50	*	100	=	162
2.	East	0,68	*	0,50	*	6,88	*	229	=	539
3.	South	0,72	*	0,50	*	33,00	*	427	=	5098
4.	West	0,69	*	0,50	*	17,88	*	229	=	1408
5.	Horizontal	0,00	*	0,00	*	0,00	*	345	=	0

		kWh/(m²a)
Available Solar Heat Gains Q_S Total	7207	40,2

	kh/d		Length Heat. Period d/a		Spec. Power q_I W/m²		A_{TFA} m²		kWh/a	kWh/(m²a)
Internal Heat Gains Q_I	0,024	*	219	*	2,10	*	179,1	=	1977	11,0

			kWh/a	kWh/(m²a)
Free Heat Q_F	$Q_S + Q_I$	=	9184	51,3
Ratio of Free Heat to Losses	Q_F / Q_L	=	0,97	
Utilisation Factor Heat Gains η_G	$(1 - (Q_F/Q_L)^5) / (1 - (Q_F/Q_L)^6)$	=	85%	
Heat Gains Q_G	$\eta_G * Q_F$	=	7784	43,5
Annual Heating Demand QH	$Q_L - Q_G$	=	1727	**10**

	kWh/(m²a)		(Yes/No)
Limiting Value	15	**Requirement met?**	**yes**


Heating energy balance
Heat flows [kWh/(m²a)]
70
60
50
40
30
20
10
0
7,8
7,5
0,0
19,6
0,8
0,0
7,2
10,6
0,0
7,1
0,1
40,2
11,0
9,6
0,0
Losses
Gains
passive solar gains
internal gains
Annual Heating Demand
Thermal bridge credit
not useful heat gains
Ventilation
Exterior Door
Windows
Garage wall
Floor slab / basement ceiling
Roof/Ceiling - Ambient
Exterior Wall - Ground
Exterior Wall - Ambient
Thermal Bridge Heat Loss

Passive House verification

SPECIFIC ANNUAL HEATING DEMAND
MONTHLY METHOD

(This page displays the sums of the monthly method over the heating period)

Climate:	PL - Strefa II (Poznan/Pila)	Interior Temperature:	20	°C
Building:		Building Type/Use:		
Spec. Capacity:	204 Wh/(m²K) (Enter in "Summer" worksheet.)	Treated Floor Area A_{TFA}:	179,1	m²

Building Element	Temperature Zone	Area m²		U-Value W/(m²K)		Month. Red. Fac.		G_t kKh/a		kWh/a	per m² Treated Floor Area
Exterior Wall - Ambient	A	106,2	*	0,134	*	1,00	*	73	=	1038	
Exterior Wall - Ground	B		*		*	1,00	*		=		
Roof/Ceiling - Ambient	A	179,1	*	0,118	*	1,00	*	73	=	1542	
Floor slab / basement ceiling	B	179,1	*	0,124	*	1,00	*	43	=	954	
	A		*		*	1,00	*		=		
	A		*		*	1,00	*		=		
Garage wall	X	27,5	*	0,138	*	0,50	*	73	=	138	
Windows	A	62,3	*	0,633	*	1,00	*	73	=	2869	
Exterior Door	A		*		*	1,00	*		=		
Exterior TB (length/m)	A	12,0	*	0,020	*	1,00	*	73	=	17	
Perimeter TB (length/m)	P	75,7	*	0,001	*	1,00	*	43	=	3	
Ground TB (length/m)	B		*		*	1,00	*		=		
Transmission Heat Losses Q_T									Total	6560	kWh/(m²a) 36,6

	A_{TFA} m²		Clear Room Height m		m³
Effective Air Volume V_{RAX}	179	*	2,50	=	448

	$n_{V,system}$ 1/h		$\eta*_{SHX}$		η_{HR}		$n_{V,Res}$ 1/h		$n_{V,equi,fraction}$ 1/h
Effective Air Change Rate Ambient $n_{V,e}$	0,300	*(1-	33%	)*(1-	0,77	)+	0,042	=	0,087
Effective Air Change Rate Ground $n_{V,g}$	0,300	*	33%	*(1-	0,77	)		=	0,022

	V_{RAX} m³		$n_{V,equi,fraction}$ 1/h		c_{Air} Wh/(m³K)		G_t kKh/a		kWh/a	kWh/(m²a)
Ventilation Losses Ambient Q_V	448	*	0,087	*	0,33	*	73	=	940	5,2
Ventilation Losses Ground $Q_{V,e}$	448	*	0,022	*	0,33	*	39	=	128	0,7
Ventilation Heat Losses Q_V								Total	1068	6,0

		Q_T kWh/a		Q_V kWh/a		Reduction Factor Night/Weekend Saving		kWh/a	kWh/(m²a)
Total Heat Losses Q_L	(	6560	+	1068	) *	1,0	=	7628	42,6

Orientation of the Area	Reduction Factor See Windows worksheet		g-Value (perp. radiation)		Area m²		Global Radiation kWh/(m²a)		kWh/a	
North	0,72	*	0,50	*	4,5	*	49	=	79	
East	0,68	*	0,50	*	6,9	*	111	=	261	
South	0,72	*	0,50	*	33,0	*	250	=	2983	
West	0,69	*	0,50	*	17,9	*	111	=	683	
Horizontal	0,00	*	0,00	*	0,0	*	162	=	0	
Sum Opaque Areas									168	kWh/(m²a)
Available Solar Heat Gains Q_S								Total	4174	23,3

	kh/d		Length Heat. Period d/a		Spec. Power q_i W/m²		A_{TFA} m²		kWh/a	kWh/(m²a)
Internal Heat Gains Q_I	0,024	*	151	*	2,1	*	179,1	=	1363	7,6

			kWh/a	kWh/(m²a)
Free Heat Q_F	Q_S + Q_I	=	5537	30,9
Ratio Free Heat to Losses	Q_F / Q_L	=	0,73	
Utilisation Factor Heat Gains η_G		=	94%	
Heat Gains Q_G	η_G * Q_F	=	5213	29,1
Annual Heating Demand QH	Q_L - Q_G	=	2415	**13**

	kWh/(m²*a)		(Yes/No)
Limiting Value	15	**Requirement met?**	**yes**

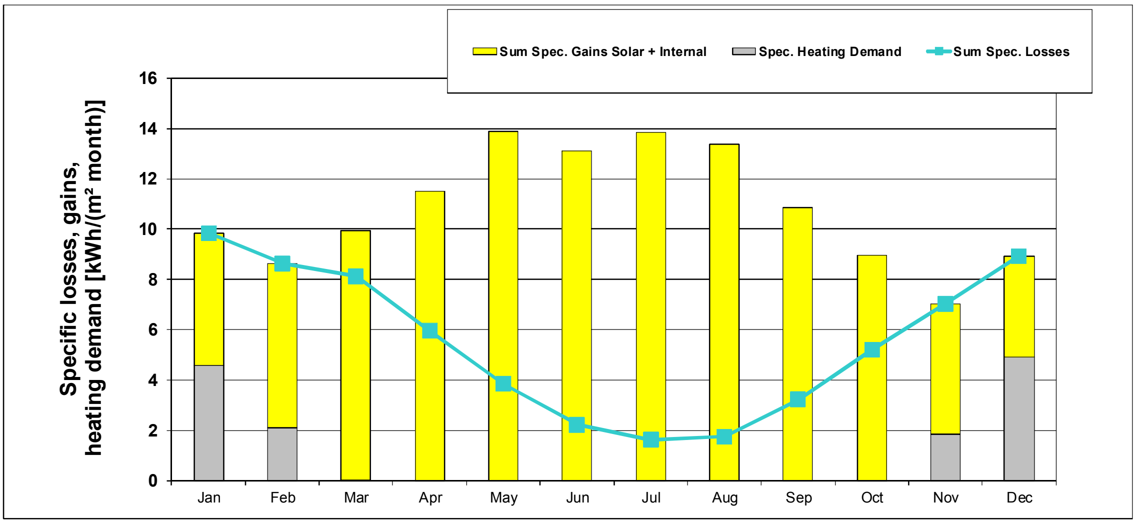
Passive House verification

SPECIFIC ANNUAL HEAT DEMAND
MONTHLY METHOD

Climate: PL - Strefa II (Poznan/Pila)
Building:

Interior Temperature: 20 °C
Building Type/Use:
Treated Floor Area A_{TFA}: 179 m²

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	
Heating Degree Hours - E	17,0	14,7	13,4	9,4	5,5	2,8	1,9	2,4	5,2	8,9	12,2	15,5	109	kKh
Heating Degree Hours - (	9,4	9,2	10,1	8,9	7,7	5,4	4,2	3,4	3,8	4,8	6,1	8,0	81	kKh
Losses - Exterior	1528	1317	1205	844	492	251	172	212	466	798	1098	1395	9780	kWh
Losses - Ground	236	229	252	225	199	147	120	103	110	134	162	205	2122	kWh
Sum Spec. Losses	9,8	8,6	8,1	6,0	3,9	2,2	1,6	1,8	3,2	5,2	7,0	8,9	66,4	kWh/m²
Solar Gains - North	10	18	31	49	70	78	76	58	37	24	13	8	471	kWh
Solar Gains - East	31	56	113	165	228	207	221	191	134	82	38	24	1490	kWh
Solar Gains - South	513	656	990	1050	1193	1050	1145	1193	1074	931	489	334	10619	kWh
Solar Gains - West	92	148	289	418	554	585	591	535	338	234	92	62	3938	kWh
Solar Gains - Horiz.	0	0	0	0	0	0	0	0	0	0	0	0	0	kWh
Solar Gains - Opaque	20	37	73	112	160	160	164	139	88	54	24	14	1044	kWh
Internal Heat Gains	280	253	280	271	280	271	280	280	271	280	271	280	3295	kWh
Sum Spec. Gains Solar +	5,3	6,5	9,9	11,5	13,9	13,1	13,8	13,4	10,8	9,0	5,2	4,0	116,4	kWh/m²
Utilisation Factor	100%	100%	82%	52%	28%	17%	12%	13%	30%	58%	100%	100%	45%	
Annual Heating Demand	819	379	4	0	0	0	0	0	0	0	334	879	2415	kWh
Spec. Heating Demand	**4,6**	**2,1**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**1,9**	**4,9**	**13,5**	kWh/m²



Annual Heating Demand: Comparison

EN 13790 Monthly Method	**2415**	**kWh/a**	**13,5**	**kWh/(m²a) Reference to habitable area**
PHPP, Heating Period Method	**1727**	**kWh/a**	**9,6**	**kWh/(m²a) Reference to habitable area**

Month	1	2	3	4	5	6	7	8	9	10	11	12	Annual Total	Heating Period Method
Days	31	28	31	30	31	30	31	31	30	31	30	31	365	219
Ambient Temp.	-2,00	-1,00	2,70	7,60	13,30	16,70	18,00	17,40	13,40	8,80	3,80	-0,10	8,3	3,0
North Radiation	6,0	11,0	19,0	30,0	43,0	48,0	47,0	36,0	23,0	15,0	8,0	5,0	291	100
East Radiation	13,0	24,0	48,0	70,0	97,0	88,0	94,0	81,0	57,0	35,0	16,0	10,0	633	229
South Radiation	43,0	55,0	83,0	88,0	100,0	88,0	96,0	100,0	90,0	78,0	41,0	28,0	890	427
West Radiation	15,0	24,0	47,0	68,0	90,0	95,0	96,0	87,0	55,0	38,0	15,0	10,0	640	229
Hori. Radiation	19,0	36,0	71,0	109,0	156,0	155,0	160,0	136,0	86,0	52,0	23,0	13,0	1016	345
Tsky	-16,11	-14,50	-9,30	-3,12	2,56	7,16	8,61	8,04	3,41	-3,26	-8,95	-12,84	-3,1	
Ground Temp	7,36	6,31	6,40	7,60	9,60	12,45	14,36	15,41	14,72	13,51	11,52	9,27	10,7	8,9

Passive House verification

SPECIFIC SPACE HEATING LOAD

Building:

Building Type/Use:

Climate (HL): PL - Strefa II (Poznan/Pila)

Treated Floor Area A_{TFA}: 179,1 m²

Interior Temperature: 20 °C

	Design Temperature		Radiation: North	East	South	West	Horizontal	
Weather Condition 1:	-11,0	°C	10	15	30	15	25	W/m²
Weather Condition 2:	-5,0	°C	5	10	10	10	10	W/m²
Ground Design Temp.	6,3	°C						

	Building Element	Temperature Zone	Area m²		U-Value W/(m²K)		Factor Always 1 (except "X")		TempDiff 1 K		TempDiff 2 K		P_T 1 W		P_T 2 W
1.	Exterior Wall - Ambient	A	106,2	*	0,134	*	1,00	*	31,0	or	25,0	=	442	or	356
2.	Exterior Wall - Ground	B		*		*	1,00	*	13,7	or	13,7	=		or	
3.	Roof/Ceiling - Ambient	A	179,1	*	0,118	*	1,00	*	31,0	or	25,0	=	656	or	529
4.	Floor slab / basement ceili	B	179,1	*	0,124	*	1,00	*	13,7	or	13,7	=	305	or	305
5.		A		*		*	1,00	*	31,0	or	25,0	=		or	
6.		A		*		*	1,00	*	31,0	or	25,0	=		or	
7.	Garage wall	X	27,5	*	0,138	*	0,50	*	31,0	or	25,0	=	59	or	47
8.	Windows	A	62,3	*	0,633	*	1,00	*	31,0	or	25,0	=	1221	or	985
9.	Exterior Door	A		*		*	1,00	*	31,0	or	25,0	=		or	
10.	Exterior TB (length/m)	A	12,0	*	0,020	*	1,00	*	31,0	or	25,0	=	7	or	6
11.	Perimeter TB (length/m)	P	75,7	*	0,001	*	1,00	*	13,7	or	13,7	=	1	or	1
12.	Ground TB (length/m)	B		*		*	1,00	*	13,7	or	13,7	=		or	
13.	House/DU Partition Wall	I		*		*	1,00	*	3,0	or	3,0	=		or	

Transmission Heat Losses P_T

Total = 2691 or 2229

Ventilation System:

	A_{TFA} m²		Clear Room Height m		m³
Effective Air Volume, V_V	179,1	*	2,50	=	448

				η_{SHX} 1		η_{SHX} 2
Efficiency of Heat Recovery of the Heat Exchanger η_{HR}	77%	Heat Recovery Efficiency SHX	33%	Efficiency SHX 22%	or	19%

	$n_{V,Res}$ (Heating Load) 1/h		$n_{V,system}$ 1/h		Φ_{HR}		Φ_{HR}		1/h		1/h
Energetically Effective Air Exchange n_V	0,105	+	0,300	*(1-	0,82	or	0,82	) =	0,158	or	0,160

Ventilation Heating Load P_V

V_L m³		n_L 1/h		n_L 1/h		c_{Air} Wh/(m³K)		TempDiff 1 K		TempDiff 2 K		P_V 1 W		P_V 2 W
447,9	*	0,158	or	0,160	*	0,33	*	31,0	or	25,0	=	**724**	or	**591**

Total Heating Load P_L

		P_L 1 W		P_L 2 W
$P_T + P_V$	=	**3415**	or	**2820**

	Orientation the Area	Area m²		g-Value (perp. radiation)		Reduction Factor (see Windows worksheet)		Radiation 1 W/m²		Radiation 2 W/m²		P_S 1 W		P_S 2 W
1.	North	4,5	*	0,5	*	0,7	*	10	or	5	=	16	or	8
2.	East	6,9	*	0,5	*	0,7	*	15	or	10	=	35	or	24
3.	South	33,0	*	0,5	*	0,7	*	30	or	10	=	358	or	119
4.	West	17,9	*	0,5	*	0,7	*	15	or	10	=	92	or	62
5.	Horizontal	0,0	*	0,0	*	0,4	*	25	or	10	=	0	or	0

Solar heating power P_S

Total = **502** or **212**

Internal heating power P_I

Spec. Power W/m²		A_{TFA} m²		P_I 1 W		P_I 2 W
1,6	*	179	=	**287**	or	**287**

Heating power (gains) P_G

		P_G 1 W		P_G 2 W
$P_S + P_I$	=	**788**	or	**499**
$P_L - P_G$	=	**2627**	or	**2321**

Heating Load P_H

= **2627** **W**

Specific Heating Load P_H / A_{TFA}

= **14,7** **W/m²**

Input Max. Supply Air Temperature 52 °C

Max. Supply Air Temperature $\vartheta_{Supply,Max}$ 52 °C

Supply Air Temperature Without Heating $\vartheta_{Supply,Min}$ 14,5 °C 15,4 °C

For Comparison: Heating Load Transportable by Supply Air. $P_{Supply\ Air,Max}$

= **1663** W specific: 9,3 W/m²

Supply Air Heating Sufficient? (Yes/No) **No**

Risk Determination of Group Heating for a Critical Room

Room 3 (living room)	(1= Yes / 0 = No)			
Building Satisfies Passive House Criteria	1			
Room floor area	62	m²	Supply Air per m² Living Area	
Planned ambient air quantity for the room	63	m³/h	1,01	m³/h/m
Planned ambient air quantities for the remaining roon	71	m³/h		

Building Element	Temperature Zone	m²		W/(m²K)		Always 1 (except "X")		K		Room Trans. Loss W
Aboveground Exterior Wall	A	45,1	*	0,13	*	1,00	*	31,0	=	188
Belowground Exterior Wall	B		*		*	1,00	*	13,7	=	
Roof/Ceiling	D	62,0	*	0,12	*	1,00	*	31,0	=	227
Underground Floor Slab	B		*		*	1,00	*	13,7	=	
	A		*		*	1,00	*	31,0	=	
	A		*		*	1,00	*	31,0	=	
	X		*		*	1,00	*	31,0	=	
Windows	A	27,5	*	0,65	*	1,00	*	31,0	=	554
Exterior Door	A		*		*	1,00	*	31,0	=	
Exterior thermal bridges (Length/m)	A		*		*	1,00	*	31,0	=	
Perimeter Thermal Bridges (Length/m)	A		*		*	1,00	*	31,0	=	
Floor Slab Thermal Bridges (Length/m)	A		*		*	1,00	*	31,0	=	
House/DU Partition Wall	I		*		*	1,00	*	3,0	=	
									=	969

	Enter: 1 = Yes 0 = No	$P_{T,Room}$ W	$P_{Supply\ Air}$ W	Ratio	Risk Summand
Transmission Heat Losses		969	665	1,46	**0,46**
Concentrated leakages	0				0,00
Insulation to other rooms, better R = 1.5 m²K/W	0	(2 = no thermal contact except door)			0,00
Room is on the ground floor.	1				0,50
open staircase	0				0,00
TOTAL of the Risk Summands					**0,96**
Interior doors predominantly closed	0			Risk Factor	**1,00**
Total Room Risk					**15,9%**

Appraisal and Advice **normally no problem**

Passive House verification

S U M M E R

Climate: PL - Strefa II (Poznan/Pila)
Building:

Interior Temperature: 20 °C
Building Type/Use:
Treated Floor Area A_{TFA}: 179,1 m²

Spec. Capacity: 204 Wh/K pro m² TFA
Overheating limit: 25 °C

	Building Element	Temperature Zone	Area m²		U-Value W/(m²K)		Red. Factor $f_{T,Summer}$		H_{Summer} Heat Conductance
1.	Exterior Wall - Ambi	A	106,2	*	0,134	*	1,00	=	14,3
2.	Exterior Wall - Grou	B		*		*	1,00	=	
3.	Roof/Ceiling - Ambie	A	179,1	*	0,118	*	1,00	=	21,2
4.	Floor slab / basemen	B	179,1	*	0,124	*	1,00	=	22,3
5.		A		*		*	1,00	=	
6.		A		*		*	1,00	=	
7.	Garage wall	X	27,5	*	0,138	*	0,50	=	1,9
8.	Windows	A	62,3	*	0,633	*	1,00	=	39,4
9.	Exterior Door	A		*		*	1,00	=	
10.	Exterior TB (length/	A	12,0	*	0,020	*	1,00	=	0,2
11.	Perimeter TB (length	P	75,7	*	0,001	*	1,00	=	0,1
12.	Ground TB (length/m)	B		*		*	1,00	=	

Exterior Thermal Transmittance, $H_{T,e}$ 76,9 W/K

Ground Thermal Transmittance, $H_{T,g}$ 22,3 W/K

				A_{TFA} m²		Clear Room Height m		m³
Heat Recovery Efficiency	η_{HR}	77%	Effective Air Volume V_V	179,1	*	2,50	=	448
SHX Efficiency	η^*_{SHX}	33%						

Summer Ventilation continuous ventilation to provide sufficient indoor air quality

Air Change Rate by Natural (Windows & Leakages) or Exhaust-Only Mechanical Ventilation, Summer: 1/h

Mechanical Ventilation Summer: 0,30 1/h ☐ with HR (check if applicable)

	$n_{L,nat}$ 1/h		$n_{V,system}$ 1/h		Φ_{HR}		$n_{V,Rest}$ 1/h		1/h
Energetically Effective Airchange Rate n_V	0,000	+	0,300	* (1 -	0,000	) +	0,042	=	0,342

	V_V m³		$n_{V,equi,fraction}$ 1/h		c_{Air} Wh/(m³K)		
Ventilation Transm. Ambient $H_{V,e}$	448	*	0,243	*	0,33	=	35,9 W/K
Ventilation Transm. Ground $H_{V,g}$	448	*	0,099	*	0,33	=	14,6 W/K

Additional Summer Ventilation for Cooling Temperature amplitude summer 10,6 K

Select: ☒ Window Night Ventilation, Manual
☐ Mechanical, Automatically Controlled Ventilation

Corresponding Air Change Rate 0,43 1/h
(for window ventilation: at 1 K temperature difference indoor - outdoor)

Minimum Acceptable Indoor Temperature 22,0 °C

	Orientation of the Area	Angle Factor Summer		Shading Factor Summer		Dirt		g-Value (perp. radiation)		Area m²		Portion of Glazing		**Aperture** m²
1.	North	0,9	*	0,35	*	0,95	*	0,50	*	4,5	*	96%	=	0,6
2.	East	0,9	*	0,35	*	0,95	*	0,50	*	6,9	*	96%	=	1,0
3.	South	0,9	*	0,34	*	0,95	*	0,50	*	33,0	*	96%	=	4,6
4.	West	0,9	*	0,35	*	0,95	*	0,50	*	17,9	*	96%	=	2,6
5.	Horizontal	0,9	*	1,00	*	0,95	*	0,00	*	0,0	*	0%	=	0,0
6	Sum Opaque Areas													1,2

Solar Aperture Total 10,0 m²/m² 0,06

	Specif. Power q_I W/m²		A_{TFA} m²		W	W/m²
Internal Heat Gains Q_I	2,10	*	179	=	376	2,1

Frequency of Overheating $h_{\vartheta \geq \vartheta_{max}}$ **0,0%** **at the overheating limit ϑ_{max} = 25 °C**

If the "frequency over 25°C" exceeds 10%, additional measures to protect against summer heat waves are necessary.

	Solar Load kWh/d		1/k		Spec. Capacity Wh/(m²K)		A_{TFA} m²		
Daily Temperature Swing due to Solar Load	53,8	*	1000	/ (	204	*	179	) =	**1,5** K

Passive House verification

CALCULATING SUMMER SHADING FACTORS

Summer

Orientation	Glazing area m²	Summer shading factor r_S
North	4,31	35%
East	6,62	35%
South	31,66	34%
West	17,23	35%
Horizontal	0,00	100%

															Summer	Summer			
Quantity	Description:	Deviation from North	Angle of Inclination from the Horizontal	Orientation	Glazing Width	Glazing Height	Glazing Area	Height of the Shading Object	Horizontal Distance	Window Reveal Depth	Distance from Glazing Edge to Reveal	Overhang Depth	Distance from Upper Glazing Edge to Overhang	Additional Shading Reduction Factor (Summer)	Reduction factor z for temporary sun protection	Horizontal Shading Reduction Factor	Reveal Shading Reduction Factor	Overhang Shading Reduction Factor	Total Summer Shading Reduction Factor
		Degrees	Degrees			m		m	m	m	m	m	m	%	%	%	%	%	%
					w_G	h_G	A_G	h_{Hori}	d_{Hori}	o_{Reveal}	d_{Reveal}	o_{over}	d_{over}	r_{other}	z	r_H	r_R	r_O	r_S
2	South	180	90	South	1,47	2,72	8,0	0,00	0,00	0,20	0,08	0,00	0,00	100%	37%	100%	93%	100%	35%
7	South	180	90	South	0,97	2,72	18,4	0,00	0,00	0,20	0,08	0,00	0,00	100%	37%	100%	91%	100%	33%
1	East	90	90	East	0,97	2,72	2,6	0,00	0,00	0,20	0,08	0,00	0,00	100%	37%	100%	94%	100%	35%
1	East	90	90	East	1,47	2,72	4,0	0,00	0,00	0,20	0,08	0,00	0,00	100%	37%	100%	96%	100%	36%
2	West	270	90	West	0,97	2,72	5,3	0,00	0,00	0,20	0,08	0,00	0,00	100%	37%	100%	94%	100%	35%
3	West	270	90	West	1,47	2,72	12,0	0,00	0,00	0,20	0,08	0,00	0,00	100%	37%	100%	96%	100%	36%
1	North	0	90	North	0,97	1,47	1,4	0,00	0,00	0,20	0,08	0,00	0,00	100%	37%	100%	91%	100%	34%
1	North	0	90	North	1,97	1,47	2,9	0,00	0,00	0,20	0,08	0,00	0,00	100%	37%	100%	95%	100%	35%
2	South	180	90	South	0,97	2,72	5,3	0,00	0,00	0,20	0,08	0,00	0,00	100%	37%	100%	91%	100%	33%

Passive House verification

SUMMER VENTILATION

Building:

Building Type/Use:

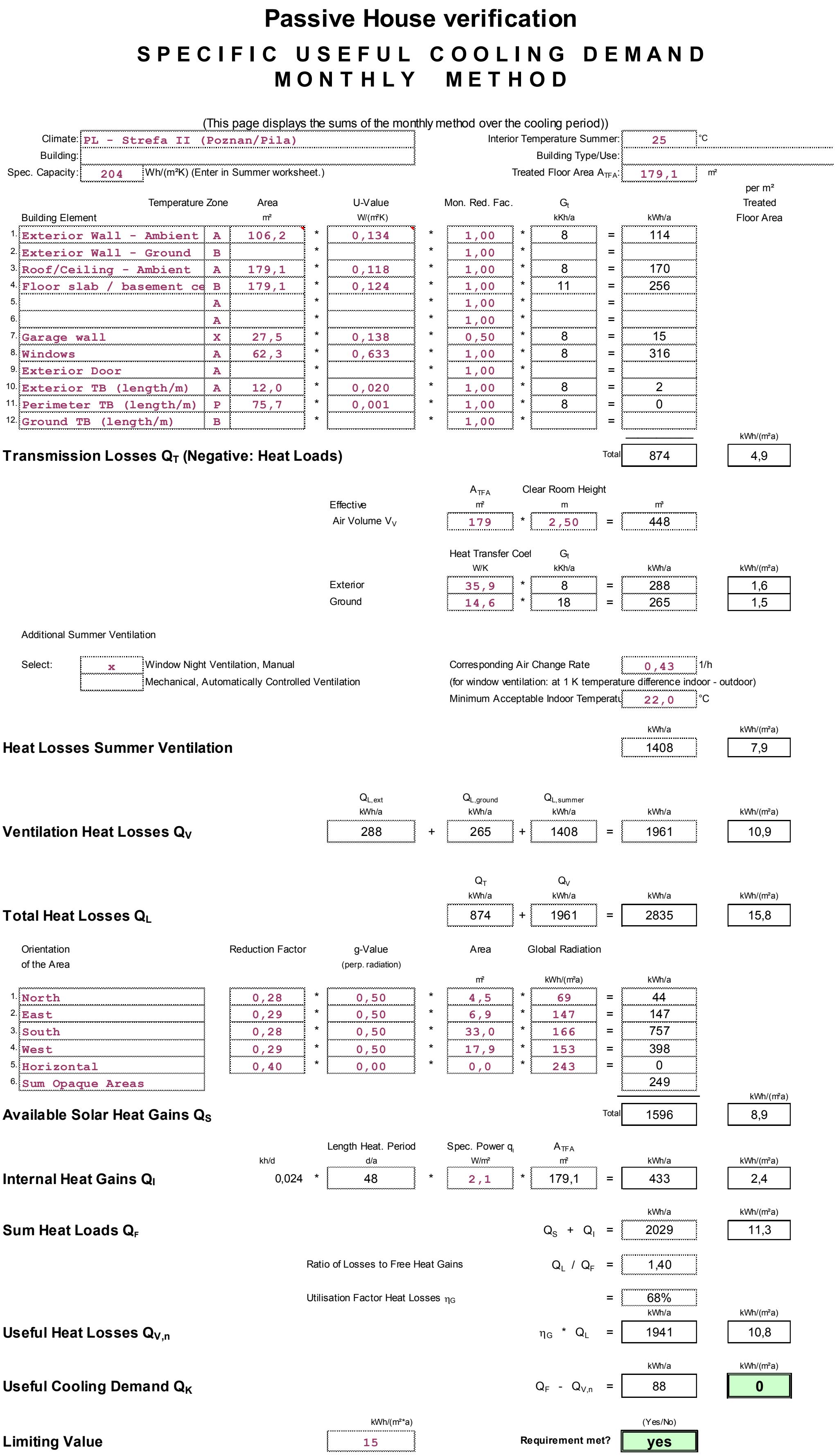
Building Volume: 448 m³

Description	south narrow	south wide		east narrow	east wide		
Fraction of Opening Duration	50%	50%		50%	50%		
Climate Boundary Conditions							
Temperature Diff Interior - Exterior	1	1		1	1		K
Wind Velocity	0	0		0	0		m/s

Note: for summer night ventilation please set a temperature difference of 1 K and a wind velocity of 0 m/s otherwise the cooling effects of the night ventilation will be overestimated!

Window Group 1							
Quantity	8	2					
Clear Width	1,00	1,50					m
Clear Height	2,75	2,75					m
Tilting Windows?	x	x					
Opening Width (for tilting windows)	0,050	0,050					m
Window Group 2 (Cross Ventilation)							
Quantity				2	1		
Clear Width				1,00	1,50		m
Clear Height				2,75	2,75		m
Tilting Windows?				x	x		
Opening Width (for Tilting Windows)				0,050	0,050		m
Difference in Height to Window 1				0,00	0,00		m

Single-Sided Ventilation 1 - Airflow Volume	229	65	0	0	0	0	m³/h
Single-Sided Ventilation 2 - Airflow Volume	0	0	0	57	33	0	m³/h
Cross Ventilation Airflow Volume	229	65	0	57	33	0	m³/h
Contribution to Air Change Rate	0,26	0,07	0,00	0,06	0,04	0,00	1/h



Passive House verification

SPECIFIC USEFUL COOLING DEMAND
MONTHLY METHOD

(This page displays the sums of the monthly method over the cooling period))

Climate: PL - Strefa II (Poznan/Pila)

Building:

Spec. Capacity: 204 Wh/(m²K) (Enter in Summer worksheet.)

Interior Temperature Summer: 25 °C

Building Type/Use:

Treated Floor Area A_{TFA}: 179,1 m²

	Building Element	Temperature Zone	Area m²		U-Value W/(m²K)		Mon. Red. Fac.		G_t kKh/a		kWh/a	per m² Treated Floor Area
1.	Exterior Wall - Ambient	A	106,2	*	0,134	*	1,00	*	8	=	114	
2.	Exterior Wall - Ground	B		*		*	1,00	*		=		
3.	Roof/Ceiling - Ambient	A	179,1	*	0,118	*	1,00	*	8	=	170	
4.	Floor slab / basement ce	B	179,1	*	0,124	*	1,00	*	11	=	256	
5.		A		*		*	1,00	*		=		
6.		A		*		*	1,00	*		=		
7.	Garage wall	X	27,5	*	0,138	*	0,50	*	8	=	15	
8.	Windows	A	62,3	*	0,633	*	1,00	*	8	=	316	
9.	Exterior Door	A		*		*	1,00	*		=		
10.	Exterior TB (length/m)	A	12,0	*	0,020	*	1,00	*	8	=	2	
11.	Perimeter TB (length/m)	P	75,7	*	0,001	*	1,00	*	8	=	0	
12.	Ground TB (length/m)	B		*		*	1,00	*		=		

Transmission Losses Q_T (Negative: Heat Loads) Total 874 kWh/a; 4,9 kWh/(m²a)

	A_{TFA} m²		Clear Room Height m		m³
Effective Air Volume V_V	179	*	2,50	=	448

	Heat Transfer Coel W/K		G_t kKh/a		kWh/a	kWh/(m²a)
Exterior	35,9	*	8	=	288	1,6
Ground	14,6	*	18	=	265	1,5

Additional Summer Ventilation

Select:
- x Window Night Ventilation, Manual
- Mechanical, Automatically Controlled Ventilation

Corresponding Air Change Rate 0,43 1/h
(for window ventilation: at 1 K temperature difference indoor - outdoor)
Minimum Acceptable Indoor Temperatu 22,0 °C

Heat Losses Summer Ventilation 1408 kWh/a; 7,9 kWh/(m²a)

	$Q_{L,ext}$ kWh/a		$Q_{L,ground}$ kWh/a		$Q_{L,summer}$ kWh/a		kWh/a	kWh/(m²a)
Ventilation Heat Losses Q_V	288	+	265	+	1408	=	1961	10,9

	Q_T kWh/a		Q_V kWh/a		kWh/a	kWh/(m²a)
Total Heat Losses Q_L	874	+	1961	=	2835	15,8

	Orientation of the Area	Reduction Factor		g-Value (perp. radiation)		Area m²		Global Radiation kWh/(m²a)		kWh/a
1.	North	0,28	*	0,50	*	4,5	*	69	=	44
2.	East	0,29	*	0,50	*	6,9	*	147	=	147
3.	South	0,28	*	0,50	*	33,0	*	166	=	757
4.	West	0,29	*	0,50	*	17,9	*	153	=	398
5.	Horizontal	0,40	*	0,00	*	0,0	*	243	=	0
6.	Sum Opaque Areas									249

Available Solar Heat Gains Q_S Total 1596 kWh/a; 8,9 kWh/(m²a)

	kh/d		Length Heat. Period d/a		Spec. Power q_I W/m²		A_{TFA} m²		kWh/a	kWh/(m²a)
Internal Heat Gains Q_I	0,024	*	48	*	2,1	*	179,1	=	433	2,4

Sum Heat Loads Q_F $Q_S + Q_I$ = 2029 kWh/a; 11,3 kWh/(m²a)

Ratio of Losses to Free Heat Gains Q_L / Q_F = 1,40

Utilisation Factor Heat Losses η_G = 68%

Useful Heat Losses $Q_{V,n}$ $\eta_G * Q_L$ = 1941 kWh/a; 10,8 kWh/(m²a)

Useful Cooling Demand Q_K $Q_F - Q_{V,n}$ = 88 kWh/a; 0 kWh/(m²a)

Limiting Value 15 kWh/(m²*a)

Requirement met? (Yes/No) yes

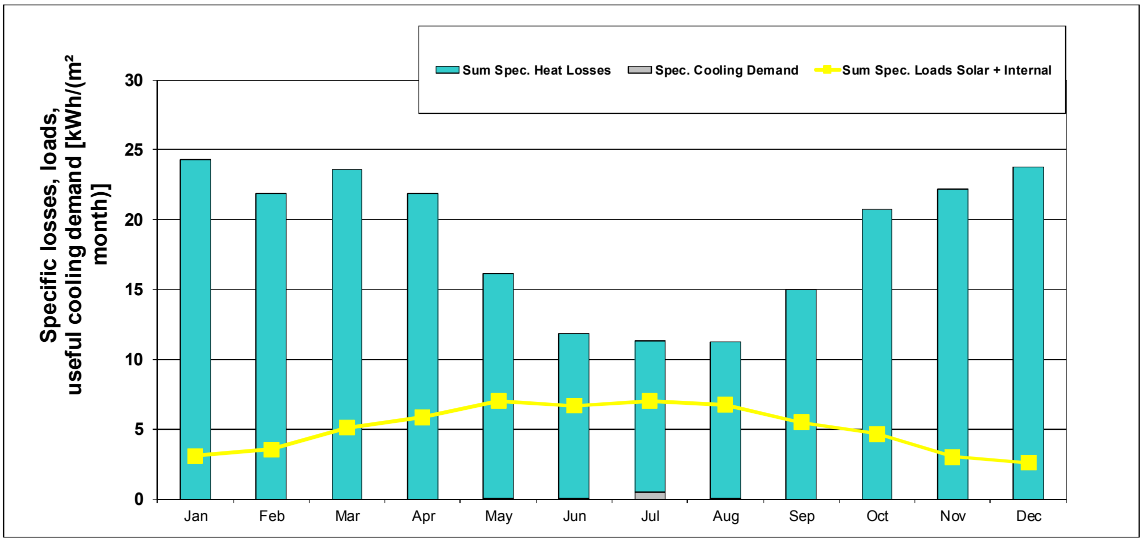
Passive House verification

SPECIFIC USEFUL COOLING DEMAND
MONTHLY METHOD

Climate: PL - Strefa II (Poznan/Pila)
Building:

Interior Temperature: 25 °C
Building Type/Use:
Treated Floor Area A_{TFA}: 179 m²

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	
Heating Degree Hours - E	20,6	17,9	17,0	12,9	9,1	6,3	5,5	6,0	8,7	12,5	15,7	19,1	151	kKh
Heating Degree Hours - (	13,1	12,6	13,8	12,5	11,5	9,0	7,9	7,1	7,4	8,5	9,7	11,7	125	kKh
Losses - Exterior	2325	2022	1922	1457	1027	712	626	677	982	1410	1774	2160	17094	kWh
Losses - Ground	464	434	479	445	426	367	348	330	331	362	382	432	4800	kWh
Losses Summer Ventilati	1563	1461	1819	2018	1436	1046	964	1011	1379	1943	1818	1667	18125	kWh
Sum Spec. Heat Losses	24,3	21,9	23,6	21,9	16,1	11,9	10,8	11,3	15,0	20,7	22,2	23,8	223,3	kWh/m²
Solar Load North	4	7	12	19	27	31	30	23	15	10	5	3	186	kWh
Solar Load East	13	24	48	70	97	88	94	81	57	35	16	10	633	kWh
Solar Load South	196	251	379	402	457	402	439	457	411	356	187	128	4066	kWh
Solar Load West	39	63	123	177	235	248	250	227	143	99	39	26	1668	kWh
Solar Load Horiz.	0	0	0	0	0	0	0	0	0	0	0	0	0	kWh
Solar Load Opaque	20	37	73	112	160	160	164	139	88	54	24	14	1044	kWh
Internal Heat Gains	280	253	280	271	280	271	280	280	271	280	271	280	3295	kWh
Sum Spec. Loads Solar +	3,1	3,5	5,1	5,9	7,0	6,7	7,0	6,7	5,5	4,7	3,0	2,6	60,8	kWh/m²
Utilisation Factor Losses	13%	16%	22%	27%	43%	56%	60%	60%	37%	22%	14%	11%	27%	
Useful Cooling Energy De	0	0	0	0	0	0	88	0	0	0	0	0	88	kWh
Spec. Cooling Demand	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,5**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,5**	kWh/m²



Temperature Amplitude Summer 10,6 K

Month	1	2	3	4	5	6	7	8	9	10	11	12	Annual Total
Days	31	28	31	30	31	30	31	31	30	31	30	31	365
Ambient Temp.	-2,00	-1,00	2,70	7,60	13,30	16,70	18,00	17,40	13,40	8,80	3,80	-0,10	8,3
North Radiation	6,0	11,0	19,0	30,0	43,0	48,0	47,0	36,0	23,0	15,0	8,0	5,0	291
East Radiation	13,0	24,0	48,0	70,0	97,0	88,0	94,0	81,0	57,0	35,0	16,0	10,0	633
South Radiation	43,0	55,0	83,0	88,0	100,0	88,0	96,0	100,0	90,0	78,0	41,0	28,0	890
West Radiation	15,0	24,0	47,0	68,0	90,0	95,0	96,0	87,0	55,0	38,0	15,0	10,0	640
Hori. Radiation	19,0	36,0	71,0	109,0	156,0	155,0	160,0	136,0	86,0	52,0	23,0	13,0	1016
Tsky	-16,11	-14,50	-9,30	-3,12	2,56	7,16	8,61	8,04	3,41	-3,26	-8,95	-12,84	-3,1
Ground Temp	7,36	6,31	6,40	7,60	9,60	12,45	14,36	15,41	14,72	13,51	11,52	9,27	10,7

Passive House verification

COMPRESSOR COOLING UNITS

Climate:	PL - Strefa II (Poznan/Pila)	Interior Temperature Summer:	25	°C
Building:		Building Type/Use:		
		Treated Floor Area A_{TFA}:	179,1	m²

	A_{TFA} m²		Clear Room Height m		m³
Effective Air Volume V_V	179	*	2,50	=	448

	$n_{V,system}$ 1/h		Φ_{HR} Efficiency Humidity Rec.			1/h
Hygrically Effective Mech. Air Change Rate Summer	0,300	* (1 -		)	=	0,300

	$n_{V,nat}$ 1/h		$n_{V,Res}$ 1/h		$n_{Night,Windows}$ 1/h		$n_{Night,mechanical}$ 1/h		
Direct Ambient Air Change Rate Summer	0,000	+	0,042	+	0,800	+	0,000	=	0,842

Ambient Air Change Rate Summer Total 1,14 1/h

☒ **Supply Air Cooling**

check as appropriate

On/Off Mode (check as appropriate)	x	
Minimum Temperature of Cooling Coil Surface	5	°C

☐ **Recirculation Cooling**

check as appropriate

On/Off Mode (check as appropriate)		
Minimum Temperature of Cooling Coil Surface		°C
Volume Flow Rate		m³/h

☐ **Additional Dehumidification**

check as appropriate

Max. Humidity Ratio		g/kg
Humidity Sources		g/(m²h)
Humidity Capacity Building		g/(g/kg)/m²
Humidity at Beginning of Cooling Period	8	g/kg

☐ **Panel Cooling**

check as appropriate

	sensible	latent		Sensible Fraction
Useful Cooling Demand	0,5	0,07		
of which				
Supply Air Cooling	0,5	0,07	kWh/(m²a)	87,4%
Recirculation Cooling			kWh/(m²a)	
Dehumidification			kWh/(m²a)	
Remaining for Panel Cooling			kWh/(m²a)	
Total	**0,5**	**0,07**	kWh/(m²a)	87,4%
Unsatisfied Demand	0,0	0,0	kWh/(m²a)	

Passive House verification

COOLING LOAD

Building:		Building Type/Use:		Interior Temperature:	25 °C
Spec. Capacity:	204 Wh/(m²K) (Enter in "Summer" worksheet.)	Treated Floor Area A_{TFA}:	179,1 m²		
		Climate (Cooling Load):	PL - Strefa II (Poznan/Pila)		

	Ambient Air	Sky	Ground	Radiation:	North	East	South	West	Horizontal	
Design Temperature:	25,0 °C	15,7 °C	15,4 °C		110	230	220	220	350	W/m²

	Building Elements	Temperature Zone	Area m²		U-Value W/(m²K)		Factor Always 1 (except "X")		TempDiff K		W
1.	Exterior Wall - Ambie	A	106,2	*	0,134	*	1,00	*	0,0	=	0
2.	Exterior Wall - Groun	B		*		*	1,00	*	-9,6	=	
3.	Roof/Ceiling - Ambien	A	179,1	*	0,118	*	1,00	*	0,0	=	0
4.	Floor slab / basement	B	179,1	*	0,124	*	1,00	*	-9,6	=	-214
5.		A		*		*	1,00	*	0,0	=	
6.		A		*		*	1,00	*	0,0	=	
7.	Garage wall	X	27,5	*	0,138	*	0,50	*	0,0	=	0
8.	Windows	A	62,3	*	0,633	*	1,00	*	0,0	=	0
9.	Exterior Door	A		*		*	1,00	*	0,0	=	
10.	Exterior TB (length/m)	A	12,0	*	0,020	*	1,00	*	0,0	=	0
11.	Perimeter TB (length/m)	P	75,7	*	0,001	*	1,00	*	-9,6	=	-1
12.	Ground TB (length/m)	B		*		*	1,00	*	-9,6	=	
13.	House/DU Partition Wall	I		*		*	1,00	*	3,0	=	

		$L_{ambient}$ W/K		TempDiff K		L_{Sky} W/K		TempDiff K		
14.	Radiation Correction	-5,6	*	0,0	+	5,5	*	-9,3	=	-52

Transmission Heat Losses P_T Total = **-266**

Ventilation System:

	A_{TFA} m²		Clear Room Height m		m³
Effective Air Volume, V_V	179,1	*	2,50	=	448

	Vent. Transm. W/K		TempDiff K		W
Exterior	35,9	*	0,0	=	0
Ground	14,6	*	-9,6	=	-140

Additional Summer Ventilation:

☒ Window Night Ventilation, Manual — Corresponding Air Change Rate 0,43 1/h

☐ Mechanical, Automatically Controlled Ventilation — Minimum Indoor Temperature 22,0 °C

		kWh/d		kh/d		W
Heat Removal Cooling Design Day	Window Ventilation	-11,2	/	0,024	=	-467
(from Cooling worksheet)	Automatic Night Ventilation	0,0	/	0,024	=	0

Ventilation Heat Load P_V Total = W **-608**

	Orientation of the Area	Area m²		g-Value (perp. radiation)		Reduction Factor		Radiation W/m²		P_S W
1.	North	4,5	*	0,5	*	0,28	*	110	=	70
2.	East	6,9	*	0,5	*	0,29	*	230	=	230
3.	South	33,0	*	0,5	*	0,28	*	220	=	1005
4.	West	17,9	*	0,5	*	0,29	*	220	=	573
5.	Horizontal	0,0	*	0,0	*	0,40	*	350	=	0
6.	Sum Opaque Areas									361

Heat Gain - Solar Heat Load, P_S Total = **2240**

	Spec. Power W/m²		A_{TFA} m²		P_I W
Internal Heat Load P_I	3,1	*	179	=	**555**

Cooling Load P_C $P_T + P_V + P_S + P_I$ = **1922** **W**

Specific Maximum Cooling Load P_C / A_{EB} = **10,7** **W/m²**

Minimal supply air temperature 8 °C — Supply air temperature without cooling $\vartheta_{Supply,Min}$ 21,8 °C

Cooling capacity that is transportable through the supply air $P_{SupplyAir;Max}$ = **615** W

specific = 3,4 W/m²

Air conditioning over the supply air possible? (yes/no) **no**

	Solar Load W		Time h/d		Spec. Capacity Wh/(m²K)		A_{TFA} m²			
Daily Temperature Swing due to Solar Load	2239,9	*	24	/ (	204	*	179	) =	**1,5**	**K**

Passive House verification

HEAT DISTRIBUTION AND DHW SYSTEM

Building:		
Interior Temperature:	20	°C
Building Type/Use:		
Treated Floor Area A_{TFA}:	179	m²
Occupancy:	4,0	Pers
Number of Residences:	1	
Annual Heating Demand qHeating	2415	kWh/a
Length of Heating Period:	219	d
Average heating load Pave:	0,5	kW
Marginal Utilisability of Additional Heat Gains:	45%	

Space Heat Distribution

				Parts: Warm Region	Parts: Cold Region		Total		
				1	2	3			
Length of Distribution Pipes	L_H	(Project)		25,00				m	
Heat Loss Coefficient per m Pipe	Ψ	(Project)		0,172				W/(mK)	
Temperature of the Room Through Which the Pipes	ϑ_X	Mechanical Room		20				°C	
Design Flow Temperature	ϑ_{dist}	Flow, Design Value		55,0				°C	
Design System heating load	$P_{heating}$	(exist./calc.)		2,0				kW	
Flow Temperature Control (check)				x					
Design Return Temperature	ϑ_R		$=0.714*(\vartheta_{dist}-20)+20$	45,0				°C	
Annual Heat Emission per m of Plumbing	q^*_{HL}		$= \Psi (\vartheta_m - \vartheta_X) t_{Heating}*0.0$	9			Total 1,2,3	kWh/(m·a)	
Possible Utilization Factor of Released Heat	η_G			45%				-	
Annual Losses	Q_{HL}		$= L_H \cdot q^*_{HL} \cdot (1-\eta_G)$	124	0	0	124	kWh/a	
Specif. Losses	q_{HL}		$= \Sigma Q_{HL} / A_{TFA}$					kWh/(m²a)	0,7
'Performance ratio of heat distribution	$e_{a,HL}$		$= (q_H + q_{HL}) / q_H$				105%	-	

DHW: Standard Useful Heat

				Total		
DHW Consumption per Person and Day (60 °C)	V_{DHW}	(Project or Average Value 25 Litres/P/d)		25,0	Litre/Person/d	
Average Cold Water Temperature of the Supply	ϑ_{DW}	Temperature of Drinking Water (10°)		9,3	°C	
DHW Non-Electric Wash and Dish		(Electricity worksheet)		0	kWh/a	
Useful Heat - DHW	Q_{DHW}			2148	kWh/a	
Specif. Useful Heat - DHW	q_{DHW}		$= Q_{DHW} / A_{TFA}$		kWh/(m²a)	12,0

DHW Distribution and Storage

				Warm Region	Cold Region		Total		
Length of Circulation Pipes (Flow + Return)	L_{HS}	(Project)		25,0	1,5			m	
Heat Loss Coefficient per m Pipe	Ψ	(Project)		0,193	0,193			W/m/K	
Temperature of the Room Through Which the Pipes	ϑ_X	Mechanical Room		20	9,2			°C	
Design Flow Temperature	ϑ_{dist}	Flow, Design Value		60,0	60,0			°C	
Daily circulation period of operation.	td_{Circ}	(Project)		18,0	18,0			h/d	
Design Return Temperature	ϑ_R		$=0.875*(\vartheta_{dist}-20)+20$	55	55			°C	
Circulation period of operation per year	t_{Circ}		$= 365\ td_{Circ}$	6570	6570			h/a	
Annual Heat Released per m of Pipe	q^*_Z		$= \Psi (\vartheta_m - \vartheta_X) t_{Circ}$	48	61			kWh/m/a	
Possible Utilization Factor of Released Heat	η_{GDHW}		$=t_{heating}/365d * \eta_G$	27%	0%			-	
Annual Heat Loss from Circulation Lines	Q_Z		$= L_{HS} \cdot q^*_Z \cdot (1-\eta_{GDHW})$	867	92		959	kWh/a	
Total Length of Individual Pipes	L_U	(Project)		28,00				m	
Exterior Pipe Diameter	d_{U_Pipe}	(Project)		0,016				m	
Heat loss per tap opening	$q_{Individual}$		$=(c_{pH2O} V_{H2O} + c_{pMat} V_{Mat})(\vartheta_{dist}-$	0,1954				kWh/tap opening	
Amount of tap openings per year	n_{Tap}		$= n_{Pers} . 3 . 365 / n_{LU}$	4380				Tap openings per year	
Annual Heat Loss	q_U		$= n_{Tap} \cdot q_{Individual}$	856				kWh/a	
Possible Utilization Factor of Released Heat	η_{G_U}		$=t_{heating}/8760*\eta_G$	27%				-	
Annual Heat Loss of Individual Pipes	Q_U		$= q_U \cdot (1-\eta_{G\_U})$	624			624	kWh/a	
							Total 1,2,3		
Average Heat Released From Storage	P_S			104	104			W	
Possible Utilization Factor of Released Heat	η_{G_S}		$=t_{heating}/8760*\eta_G$	27%	0%				
Annual Heat Losses from Storage	Q_S		$= P_S \cdot 8.760\ kh \cdot (1-\eta_{G\_S})$	665	911		1576	kWh/a	
							Total 1,2,3		
Total Heat Losses of the DHW System	Q_{WL}		$= Q_Z+Q_U+Q_S$				3159	kWh/a	
Specif. Losses of the DHW System	q_{WL}		$= Q_{WL} / A_{TFA}$					kWh/(m²a)	17,6
Performance ratio DHW-distribution + storage	$e_{a,WL}$		$= (q_{TWW} + q_{WV}) / q_{TWW}$				247,1%	-	
Total Heating Demand of DHW system	Q_{gDHW}		$= Q_{DHW}+Q_{WL}$				5307	kWh/a	
Total Spec. Heating Demand of DHW System	q_{gDHW}		$= Q_{gDHW} / A_{TFA}$					kWh/(m²a)	29,6

Passive House verification

SOLAR HOT WATER GENERATION

Building:		**Building Type/Use:**	
		Treated Floor Area A_{TFA}:	179,1 m²

Solar Fraction with DHW demand including washing and dish-washing

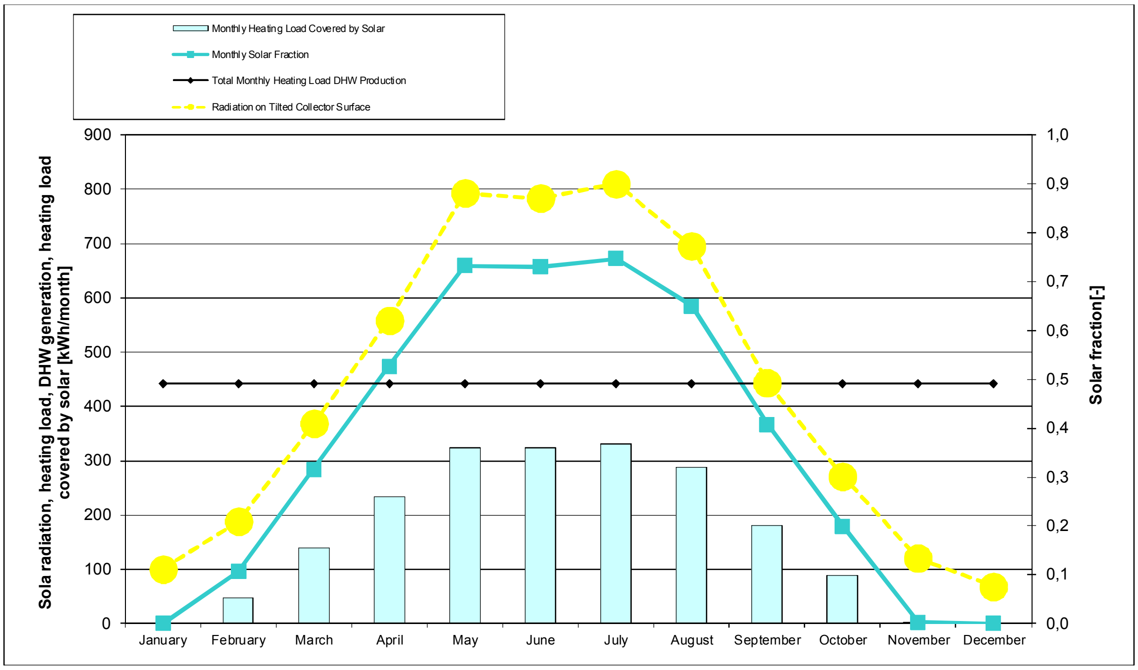
Heating Demand DHW	q_{gDHW}	5307	kWh/a	from DHW+Distribution worksheet
Latitude:		51,4	°	from Climate Data worksheet
Selection of collector from list (see below):		7	Selection:	7 Improved Flat Plate Collector
Solar Collector Area		5,00	m²	
Deviation from North		180	°	
Angle of Inclination from the Horizontal		3	°	
Height of the Collector Field		1	m	
Height of Horizon	h_{Hori}	0,40	m	
Horizontal Distance	a_{Hori}	6,00	m	
Additional Reduction Factor Shading	r_{other}	100%	%	

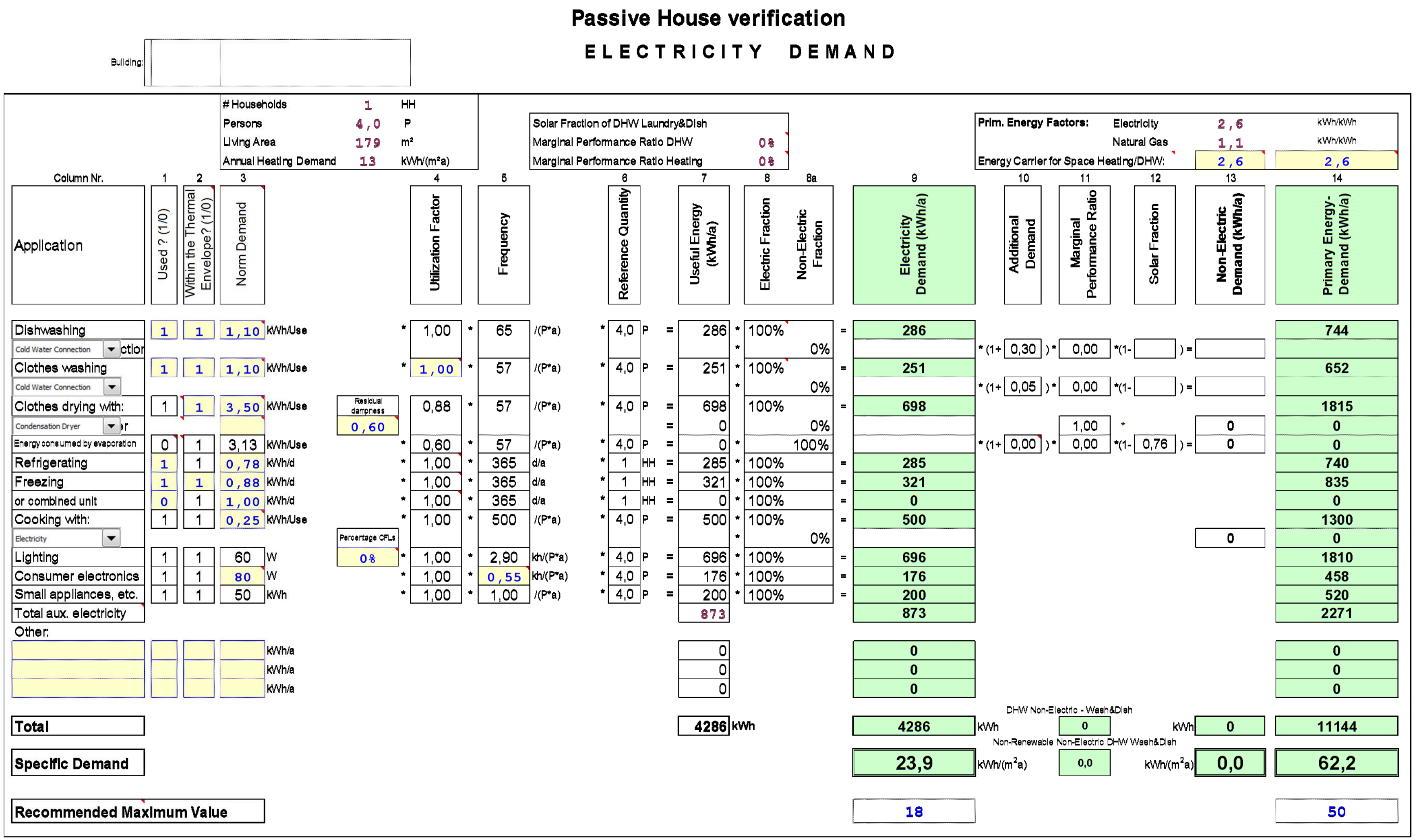
Occupancy	4,0	Persons
Specific Collector Area	1,3	m²/Pers

Estimated Solar Fraction of DHW Production	37%			
Solar Contribution to Useful Heat	1956	kWh/a	11	kWh/(m²a)

Secondary Calculation of Storage Losses

Selection of DHW storage from list (see below):	10	Selection:	10 Stratified Solar Storage
Total Storage Volume	313	litre	
Volume Standby Part (above)	94	litre	
Volume Solar Part (below)	219	litre	
Specific Heat Losses Storage (total)	2,6	W/K	
Typical Temperature DHW	60	°C	
Room Temperature	20	°C	
Storage Heat Losses (Standby Part Only)	26	W	
Total Storage Heat Losses	104	W	





Passive House verification

ELECTRICITY DEMAND

Building:

# Households	1	HH
Persons	4,0	P
Living Area	179	m²
Annual Heating Demand	13	kWh/(m²a)

Solar Fraction of DHW Laundry&Dish	
Marginal Performance Ratio DHW	0%
Marginal Performance Ratio Heating	0%

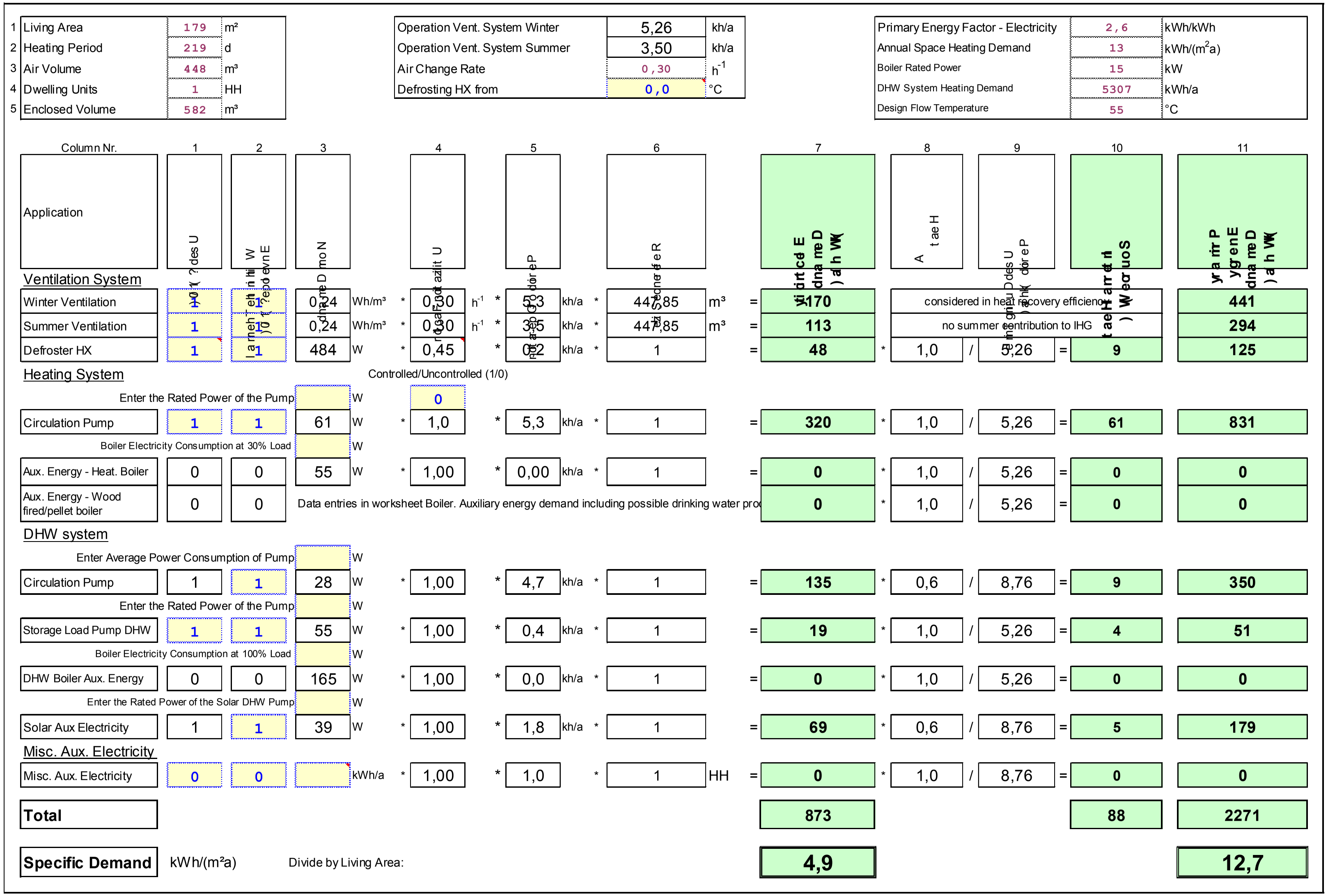
Prim. Energy Factors:			
Electricity	2,6		kWh/kWh
Natural Gas	1,1		kWh/kWh
Energy Carrier for Space Heating/DHW:	2,6	2,6	

Column Nr.	1	2	3		4	5	6	7	8	8a	9	10	11	12	13	14
Application	Used ? (1/0)	Within the Thermal Envelope? (1/0)	Norm Demand		Utilization Factor	Frequency	Reference Quantity	Useful Energy (kWh/a)	Electric Fraction	Non-Electric Fraction	Electricity Demand (kWh/a)	Additional Demand	Marginal Performance Ratio	Solar Fraction	Non-Electric Demand (kWh/a)	Primary Energy-Demand (kWh/a)
Dishwashing	1	1	1,10 kWh/Use		1,00	65 /(P*a)	4,0 P	286	100%		286					744
Cold Water Connection ▼ ction										0%		0,30	0,00			
Clothes washing	1	1	1,10 kWh/Use		1,00	57 /(P*a)	4,0 P	251	100%		251					652
Cold Water Connection ▼										0%		0,05	0,00			
Clothes drying with:	1	1	3,50 kWh/Use	Residual dampness	0,88	57 /(P*a)	4,0 P	698	100%		698					1815
Condensation Dryer ▼ r				0,60				0		0%			1,00		0	0
Energy consumed by evaporation	0	1	3,13 kWh/Use		0,60	57 /(P*a)	4,0 P	0		100%		0,00	0,00	0,76	0	0
Refrigerating	1	1	0,78 kWh/d		1,00	365 d/a	1 HH	285	100%		285					740
Freezing	1	1	0,88 kWh/d		1,00	365 d/a	1 HH	321	100%		321					835
or combined unit	0	1	1,00 kWh/d		1,00	365 d/a	1 HH	0	100%		0					0
Cooking with:	1	1	0,25 kWh/Use		1,00	500 /(P*a)	4,0 P	500	100%		500					1300
Electricity ▼				Percentage CFLs						0%					0	0
Lighting	1	1	60 W	0%	1,00	2,90 kh/(P*a)	4,0 P	696	100%		696					1810
Consumer electronics	1	1	80 W		1,00	0,55 kh/(P*a)	4,0 P	176	100%		176					458
Small appliances, etc.	1	1	50 kWh		1,00	1,00 /(P*a)	4,0 P	200	100%		200					520
Total aux. electricity								873			873					2271
Other:																
			kWh/a					0			0					0
			kWh/a					0			0					0
			kWh/a					0			0					0
Total								4286 kWh			4286 kWh	DHW Non-Electric - Wash&Dish	0	kWh	0	11144
Specific Demand											23,9 kWh/(m²a)	Non-Renewable Non-Electric DHW Wash&Dish	0,0	kWh/(m²a)	0,0	62,2
Recommended Maximum Value											18					50

Passive House verification

AUXILIARY ELECTRICITY

Building:



1	Living Area	179	m³
2	Heating Period	219	d
3	Air Volume	448	m³
4	Dwelling Units	1	HH
5	Enclosed Volume	582	m³

Operation Vent. System Winter	5,26	kh/a
Operation Vent. System Summer	3,50	kh/a
Air Change Rate	0,30	h^{-1}
Defrosting HX from	0,0	°C

Primary Energy Factor - Electricity	2,6	kWh/kWh
Annual Space Heating Demand	13	kWh/(m²a)
Boiler Rated Power	15	kW
DHW System Heating Demand	5307	kWh/a
Design Flow Temperature	55	°C

Column Nr.	1	2	3		4		5		6		7	8	9	10	11
Application															
Ventilation System															
Winter Ventilation	1	1	0,24	Wh/m³	* 0,30	h^{-1}	* 5,3	kh/a	* 447,85	m³	= 170	considered in heat recovery efficiency			441
Summer Ventilation	1	1	0,24	Wh/m³	* 0,30	h^{-1}	* 3,5	kh/a	* 447,85	m³	= 113	no summer contribution to IHG			294
Defroster HX	1	1	484	W	* 0,45		* 0,2	kh/a	* 1		= 48	* 1,0	/ 5,26	= 9	125
Heating System					Controlled/Uncontrolled (1/0)										
Enter the Rated Power of the Pump				W	0										
Circulation Pump	1	1	61	W	* 1,0		* 5,3	kh/a	* 1		= 320	* 1,0	/ 5,26	= 61	831
Boiler Electricity Consumption at 30% Load				W											
Aux. Energy - Heat. Boiler	0	0	55	W	* 1,00		* 0,00	kh/a	* 1		= 0	* 1,0	/ 5,26	= 0	0
Aux. Energy - Wood fired/pellet boiler	0	0	Data entries in worksheet Boiler. Auxiliary energy demand including possible drinking water pro								0	* 1,0	/ 5,26	= 0	0
DHW system															
Enter Average Power Consumption of Pump				W											
Circulation Pump	1	1	28	W	* 1,00		* 4,7	kh/a	* 1		= 135	* 0,6	/ 8,76	= 9	350
Enter the Rated Power of the Pump				W											
Storage Load Pump DHW	1	1	55	W	* 1,00		* 0,4	kh/a	* 1		= 19	* 1,0	/ 5,26	= 4	51
Boiler Electricity Consumption at 100% Load				W											
DHW Boiler Aux. Energy	0	0	165	W	* 1,00		* 0,0	kh/a	* 1		= 0	* 1,0	/ 5,26	= 0	0
Enter the Rated Power of the Solar DHW Pump				W											
Solar Aux Electricity	1	1	39	W	* 1,00		* 1,8	kh/a	* 1		= 69	* 0,6	/ 8,76	= 5	179
Misc. Aux. Electricity															
Misc. Aux. Electricity	0	0		kWh/a	* 1,00		* 1,0		* 1	HH	= 0	* 1,0	/ 8,76	= 0	0
Total											873			88	2271
Specific Demand	kWh/(m²a)		Divide by Living Area:								**4,9**				**12,7**

Passive House verification

PRIMARY ENERGY VALUE

Building:		Building Type/Use:	
		Treated Floor Area A_{TFA}:	179	m^2
		Space Heating Demand incl. Distribution	14	kWh/(m^{2}a)
		Useful Cooling Demand:	1	kWh/(m^{2}a)

			Final Energy kWh/(m^{2}a)	Primary Energy kWh/(m^{2}a)	Emissions CO_2-Equivalent kg/(m^{2}a)
Electricity Demand (without Heat Pump)				PE Value	CO_2-Emissions Factor (CO_2-Equivalent)
Covered Fraction of Space Heating Demand		*(Project)*	0%	kWh/kWh	g/kWh
Covered Fraction of DHW Demand		*(Project)*	0%	2,6	680
Direct Electric Heating	$Q_{H,de}$		0,0	0,0	0,0
DHW Production, Direct Electric (without Wash&Dish)	$Q_{DHW,de}$	*(DHW+Distribution, SolarDHW)*	0,0	0,0	0,0
Electric Post heating DHW Wash&Dish		*(Electricity, SolarDHW)*	0,0	0,0	0,0
Strombedarf Haushaltsgeräte	Q_{EHH}	*(Electricity worksheet)*	19,1	49,5	13,0
Electricity Demand - Auxiliary Electricity			4,9	12,7	3,3
Total Electricity Demand (without Heat Pump)			**23,9**	**62,2**	**16,3**
Heat Pump				PE Value	CO_2-Emission Factor (CO_2-Equivalent)
Covered Fraction of Space Heating Demand		*(Project)*	0%	kWh/kWh	g/kWh
Covered Fraction of DHW Demand		*(Project)*	0%	2,6	680
Energy Carrier - Supplementary Heating			Electricity	2,6	680
Annual Coefficient of Performance - Heat Pump		Separate Calculation	1,00		
Total System Performance Ratio of Heat Generator		Separate Calculation	1,20		
Electricity Demand Heat Pump (without DHW Wash&Dish)	Q_{HP}		0,0	0,0	0,0
Non-Electric Demand, DHW Wash&Dish		*(Electricity worksheet)*	0,0	0,0	0,0
Total Electricity Demand Heat Pump			**0,0**	**0,0**	**0,0**
Compact Heat Pump Unit				PE Value	CO_2-Emission Factor (CO_2-Equivalent)
Covered Fraction of Space Heating Demand		*(Project)*	0%	kWh/kWh	g/kWh
Covered Fraction of DHW Demand		*(Project)*	0%	2,6	680
Energy Carrier - Supplementary Heating			Electricity	2,6	680
COP Heat Pump Heating		*(Compact worksheet)*	0,0		
COP Heat Pump DHW		*(Compact worksheet)*	0,0		
Performance Ratio of Heat Generator (Verification)		*(Compact worksheet)*			
Performance Ratio of Heat Generator (Planning)		*(Compact worksheet)*			
Electricity Demand Heat Pump (without DHW Wash&Dish)	Q_{HP}	*(Compact worksheet)*	0,0	0,0	0,0
Non-Electric Demand, DHW Wash&Dish			0,0	0,0	0,0
Total Compact Unit		*(Compact worksheet)*	**0,0**	**0,0**	**0,0**
HP Combination: 2 independent HP for heating and WW	**see "HP Combi" worksheet**			PE Value	CO_2-Emission Factor (CO_2-Equivalent)
Covered Fraction of Space Heating Demand		*(Project)*	100%	kWh/kWh	g/kWh
Covered Fraction of DHW Demand		*(Project)*	100%	2,6	680
Energy Carrier - Supplementary Heating			Electricity	2,6	680
COP Heat Pump for Heating		*(Compact worksheet)*	2,9		
COP Heat Pump for DHW		*(Compact worksheet)*	3,8		
Performance Ratio of Heat Generator (Verification)		*(Compact worksheet)*	0,37		
Performance Ratio of Heat Generator (Planning)		*(Compact worksheet)*	0,37		
Electricity Demand Heat Pump (without DHW Wash&Dish)	Q_{HP}	*(Compact worksheet)*	12,0	31,3	8,2
Non-Electric Demand, DHW Wash&Dish			0,0	0,0	0,0
Total Combined HP		*(Compact worksheet)*	**12,0**	**31,3**	**8,2**
Boiler				PE Value	CO_2-Emission Factor (CO_2-Equivalent)
Covered Fraction of Space Heating Demand		*(Project)*	0%	kWh/kWh	g/kWh
Covered Fraction of DHW Demand		*(Project)*	0%		
Boiler Type		*(Boiler worksheet)*			
Performance Ratio of Heat Generator		*(Boiler worksheet)*	0%		
Annual Energy Demand (without DHW Wash&Dish)		*(Boiler worksheet)*	0,0	0,0	0,0
Non-Electric Demand, DHW Wash&Dish		*(Electricity worksheet)*	0,0	0,0	0,0
Total Heating Oil/Gas/Wood			**0,0**	**0,0**	**0,0**
District Heat				PE Value	CO_2-Emission Factor (CO_2-Equivalent)
Covered Fraction of Space Heating Demand		*(Project)*	0%	kWh/kWh	g/kWh
Covered Fraction of DHW Demand		*(Project)*	0%	0,0	0
Heat Source		*(District Heat worksheet)*			
Performance Ratio of Heat Generator		*(District Heat worksheet)*	0%		
Heating Demand District Heat (without DHW Wash&Dish)		*(District Heat worksheet)*	0,0	0,0	0,0
Non-Electric Demand, DHW Wash&Dish		*(Blatt Strom)*	0,0	0,0	0,0
Total District Heat			**0,0**	**0,0**	**0,0**

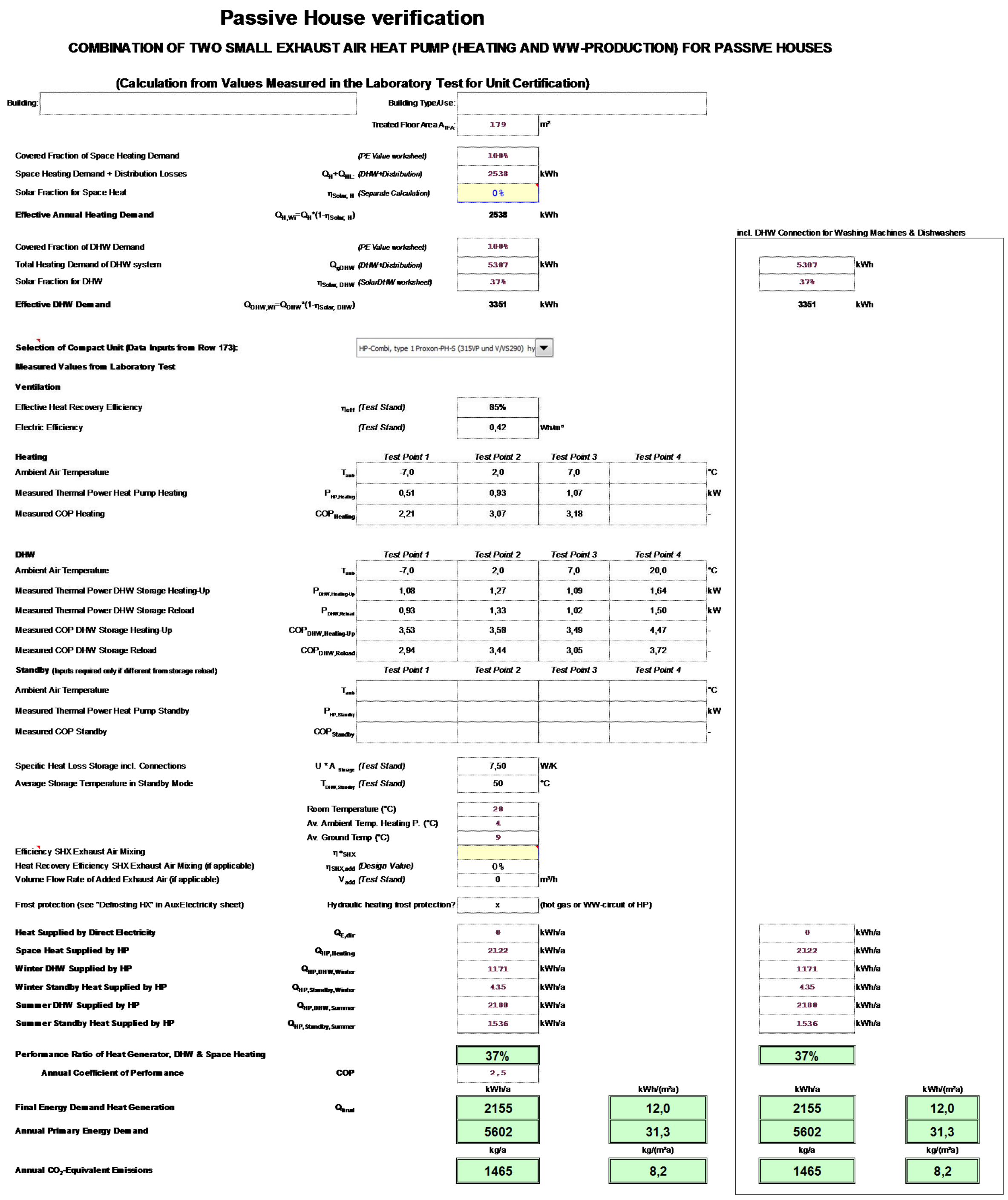
Other			PE Value	CO_2-Emission Factor (CO_2-Equivalent)
Covered Fraction of Space Heating Demand	*(Project)*	0%	kWh/kWh	g/kWh
Covered Fraction of DHW Demand	*(Project)*	0%	0,2	55
Heat Source	*(Project)*	Wood		
Performance Ratio of Heat Generator	*(Project)*			
Annual Energy Demand, Space Heating		0,0	0,0	0,0
Annual Energy Demand, DHW (without DHW Wash&Dish)		0,0	0,0	0,0
Non-Electric Demand, DHW Wash&Dish	*(Blatt Strom)*	0,0	0,0	0,0
Non-Electric Demand Cooking/Drying (Gas)	*(Blatt Strom)*	0,0	0,0	0,0
Total - Other		**0,0**	**0,0**	**0,0**

Cooling with Electric Heat Pump			PE Value	CO_2-Emission Factor (CO_2-Equivalent)
			kWh/kWh	g/kWh
Covered Fraction of Cooling Demand	*(Project)*	100%	2,6	680
Heat Source		Electricity		
Annual coefficient of performance cooling		3,2		
Energy Demand Space Cooling		**0,2**	**0,5**	**0,1**

Heating, Cooling, DHW, Auxiliary and Household Electricity		**36,1**	**93,9**	**24,6**
Total PE Value	**93,9**	kWh/(m²a)		
Total Emissions CO_2-Equivalent	**24,6**	kg/(m²a)		(Yes/No)
Primary Energy Requirement		120	kWh/(m²a)	**yes**

Heating, DHW, Auxiliary Electricity (No Household Applications)		**16,9**	**43,9**	**11,5**
Specific PE Demand - Mechanical System	**43,9**	kWh/(m²a)		
Total Emissions CO_2-Equivalent	**11,5**	kg/(m²a)		

Solar Electricity		kWh/a	PE Value (Savings)	CO_2-Emission Factor
Planned Annual Electricity Generation	*Separate Calculation*	0	kWh/kWh	g/kWh
			0,7	250
Specific Demand		**0,0**	**0,0**	**0,0**
PE Value: Conservation by Solar Electricity	**0,0**	kWh/(m²a)		
Saved CO_2 emissions through solar electricity	**0,0**	kg/(m²a)		



Passive House verification

COMBINATION OF TWO SMALL EXHAUST AIR HEAT PUMP (HEATING AND WW-PRODUCTION) FOR PASSIVE HOUSES

(Calculation from Values Measured in the Laboratory Test for Unit Certification)

Building:
Building Type/Use:
Treated Floor Area A_{TFA}: 179 m²

					incl. DHW Connection for Washing Machines & Dishwashers	
Covered Fraction of Space Heating Demand		(PE Value worksheet)	100%			
Space Heating Demand + Distribution Losses	Q_H+Q_{HL}:	(DHW+Distribution)	2538	kWh		
Solar Fraction for Space Heat	$\eta_{Solar,\,H}$	(Separate Calculation)	0%			
Effective Annual Heating Demand	$Q_{H,WI}=Q_H*(1-\eta_{Solar,\,H})$		2538	kWh		
Covered Fraction of DHW Demand		(PE Value worksheet)	100%			
Total Heating Demand of DHW system	Q_{gDHW}	(DHW+Distribution)	5307	kWh	5307	kWh
Solar Fraction for DHW	$\eta_{Solar,\,DHW}$	(SolarDHW worksheet)	37%		37%	
Effective DHW Demand	$Q_{DHW,WI}=Q_{DHW}*(1-\eta_{Solar,\,DHW})$		3351	kWh	3351	kWh

Selection of Compact Unit (Data Inputs from Row 173): HP-Combi, type 1 Proxon-PH-S (315VP und V/VS290) hy

Measured Values from Laboratory Test

Ventilation

Effective Heat Recovery Efficiency	η_{eff}	(Test Stand)	85%	
Electric Efficiency		(Test Stand)	0,42	Wh/m³

Heating		Test Point 1	Test Point 2	Test Point 3	Test Point 4	
Ambient Air Temperature	T_{amb}	-7,0	2,0	7,0		°C
Measured Thermal Power Heat Pump Heating	$P_{HP,Heating}$	0,51	0,93	1,07		kW
Measured COP Heating	$COP_{Heating}$	2,21	3,07	3,18		-

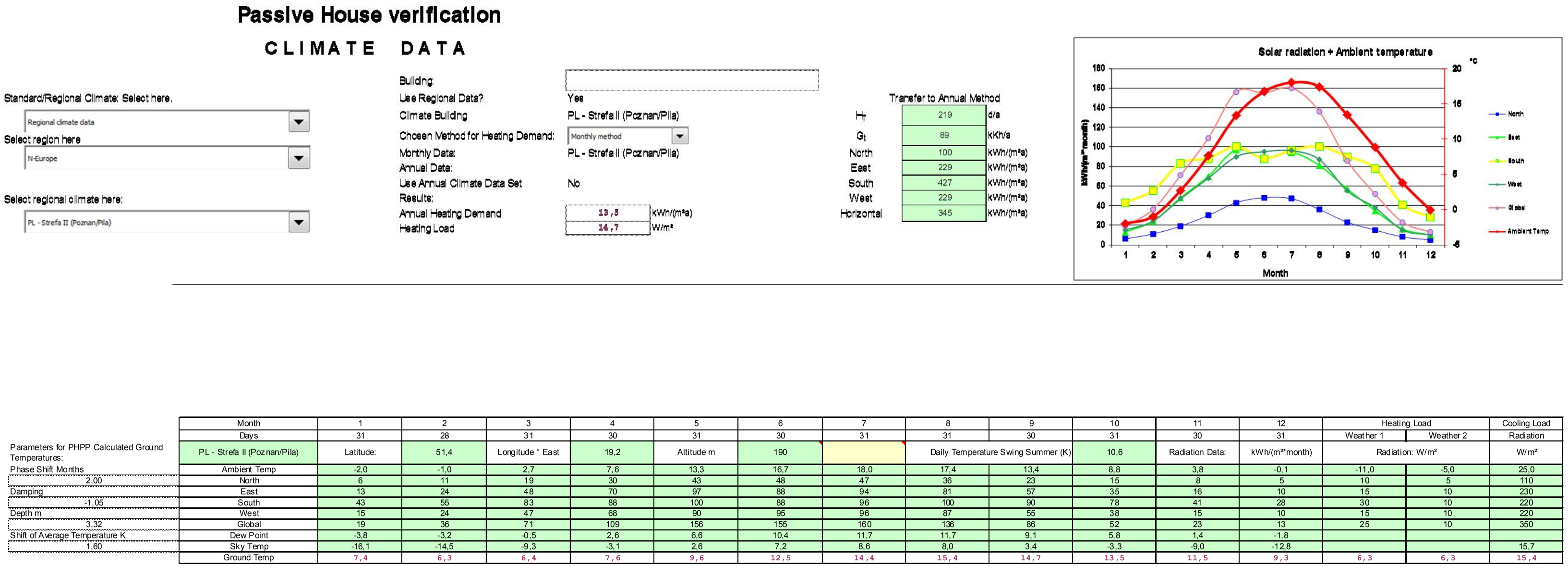
DHW		Test Point 1	Test Point 2	Test Point 3	Test Point 4	
Ambient Air Temperature	T_{amb}	-7,0	2,0	7,0	20,0	°C
Measured Thermal Power DHW Storage Heating-Up	$P_{DHW,Heating-Up}$	1,08	1,27	1,09	1,64	kW
Measured Thermal Power DHW Storage Reload	$P_{DHW,Reload}$	0,93	1,33	1,02	1,50	kW
Measured COP DHW Storage Heating-Up	$COP_{DHW,Heating-Up}$	3,53	3,58	3,49	4,47	-
Measured COP DHW Storage Reload	$COP_{DHW,Reload}$	2,94	3,44	3,05	3,72	-

Standby (Inputs required only if different from storage reload)		Test Point 1	Test Point 2	Test Point 3	Test Point 4	
Ambient Air Temperature	T_{amb}					°C
Measured Thermal Power Heat Pump Standby	$P_{HP,Standby}$					kW
Measured COP Standby	$COP_{Standby}$					-

Specific Heat Loss Storage incl. Connections	$U*A_{Storage}$	(Test Stand)	7,50	W/K
Average Storage Temperature in Standby Mode	$T_{DHW,Standby}$	(Test Stand)	50	°C
	Room Temperature (°C)		20	
	Av. Ambient Temp. Heating P. (°C)		4	
	Av. Ground Temp (°C)		9	
Efficiency SHX Exhaust Air Mixing	$\eta*_{SHX}$			
Heat Recovery Efficiency SHX Exhaust Air Mixing (if applicable)	$\eta_{SHX,add}$	(Design Value)	0%	
Volume Flow Rate of Added Exhaust Air (if applicable)	V_{add}	(Test Stand)	0	m³/h
Frost protection (see "Defrosting HX" in AuxElectricity sheet)	Hydraulic heating frost protection?		x	(hot gas or WW-circuit of HP)

Heat Supplied by Direct Electricity	$Q_{E,dir}$	0	kWh/a	0	kWh/a
Space Heat Supplied by HP	$Q_{HP,Heating}$	2122	kWh/a	2122	kWh/a
Winter DHW Supplied by HP	$Q_{HP,DHW,Winter}$	1171	kWh/a	1171	kWh/a
Winter Standby Heat Supplied by HP	$Q_{HP,Standby,Winter}$	435	kWh/a	435	kWh/a
Summer DHW Supplied by HP	$Q_{HP,DHW,Summer}$	2180	kWh/a	2180	kWh/a
Summer Standby Heat Supplied by HP	$Q_{HP,Standby,Summer}$	1536	kWh/a	1536	kWh/a

Performance Ratio of Heat Generator, DHW & Space Heating		37%		37%	
Annual Coefficient of Performance	COP	2,5			
		kWh/a	kWh/(m²a)	kWh/a	kWh/(m²a)
Final Energy Demand Heat Generation	Q_{final}	2155	12,0	2155	12,0
Annual Primary Energy Demand		5602	31,3	5602	31,3
		kg/a	kg/(m²a)	kg/a	kg/(m²a)
Annual CO_2-Equivalent Emissions		1465	8,2	1465	8,2



Passive House verification

CLIMATE DATA

Standard/Regional Climate: Select here.
Regional climate data
Select region here
N-Europe

Select regional climate here:
PL - Strefa II (Poznan/Pila)

Building:		
Use Regional Data?	Yes	
Climate Building	PL - Strefa II (Poznan/Pila)	
Chosen Method for Heating Demand:	Monthly method	
Monthly Data:	PL - Strefa II (Poznan/Pila)	
Annual Data:		
Use Annual Climate Data Set	No	
Results:		
Annual Heating Demand	13,5	kWh/(m²a)
Heating Load	14,7	W/m²

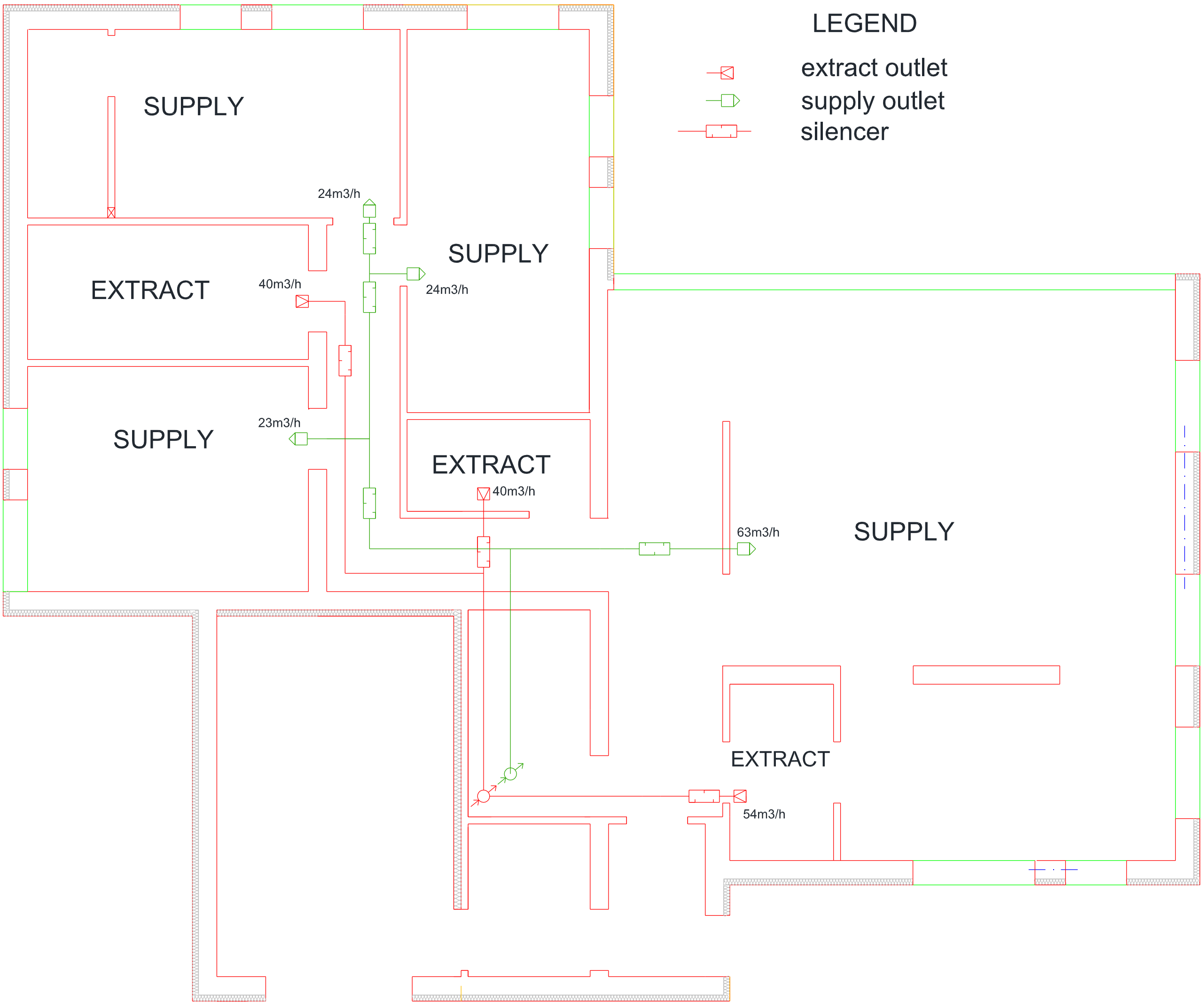
Transfer to Annual Method

H_T	219	d/a
G_t	89	kKh/a
North	100	kWh/(m²a)
East	229	kWh/(m²a)
South	427	kWh/(m²a)
West	229	kWh/(m²a)
Horizontal	345	kWh/(m²a)

	Month	1	2	3	4	5	6	7	8	9	10	11	12	Heating Load		Cooling Load
	Days	31	28	31	30	31	30	31	31	30	31	30	31	Weather 1	Weather 2	Radiation
Parameters for PHPP Calculated Ground Temperatures:	PL - Strefa II (Poznan/Pila)	Latitude:	51,4	Longitude ° East	19,2	Altitude m	190		Daily Temperature Swing Summer (K)		10,6	Radiation Data:	kWh/(m²*month)	Radiation: W/m²		W/m²
Phase Shift Months	Ambient Temp	-2,0	-1,0	2,7	7,6	13,3	16,7	18,0	17,4	13,4	8,8	3,8	-0,1	-11,0	-5,0	25,0
2,00	North	6	11	19	30	43	48	47	36	23	15	8	5	10	5	110
Damping	East	13	24	48	70	97	88	94	81	57	35	16	10	15	10	230
-1,05	South	43	55	83	88	100	88	96	100	90	78	41	28	30	10	220
Depth m	West	15	24	47	68	90	95	96	87	55	38	15	10	15	10	220
3,32	Global	19	36	71	109	156	155	160	136	86	52	23	13	25	10	350
Shift of Average Temperature K	Dew Point	-3,8	-3,2	-0,5	2,6	6,6	10,4	11,7	11,7	9,1	5,8	1,4	-1,8			
1,60	Sky Temp	-16,1	-14,5	-9,3	-3,1	2,6	7,2	8,6	8,0	3,4	-3,3	-9,0	-12,8			15,7
	Ground Temp	7,4	6,3	6,4	7,6	9,6	12,5	14,4	15,4	14,7	13,5	11,5	9,3	6,3	6,3	15,4

Annex 18


SUPPLY
EXTRACT
SUPPLY
SUPPLY
EXTRACT
TRANSFER
SUPPLY
EXTRACT


LEGEND
extract outlet
supply outlet
silencer
SUPPLY
24m3/h
SUPPLY
24m3/h
EXTRACT
40m3/h
SUPPLY
23m3/h
EXTRACT
40m3/h
63m3/h
SUPPLY
EXTRACT
54m3/h