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Thermal comfort in a passive solar building

W Sobczyk^{1,*}, E J Sobczyk²

¹ AGH University of Science and Technology, Faculty of Mining & Geoengineering, Krakow, Poland

² Mineral Energy and Economy Research Institute of the Polish Academy of Sciences, Krakow, Poland

E-mail: sobczyk@agh.edu.pl

Abstract. The paper offers a description of possibilities of reducing energy consumption in modern passive solar buildings. The research was carried out based on the analysis of regulatory documents (EU directives, Polish legislation, analyses of reports and publications of the US Department of Energy – National Energy Technology Laboratory). The applied methods comprised the modelling and design method, as well as the analytical method. Heat balance was calculated using Herz OZC, version 3.0 © computer software 1994-2007. The heat demand of the passive building has been calculated considering the heat recovery from ventilation and the efficiency of the recuperator. The average annual cost of heating of the energy-efficient building is PLN 4,715, while of the traditional building – PLN 14,115, i.e. three times as much. The solutions proposed in the article significantly reduce the heat load on a traditional building, so they are a good way to reduce heating expenditures. Building a passive solar house is a green investment offering tangible environmental and economic benefits. Construction of passive buildings contributes to lower consumption of fossil fuels, the resources of which are shrinking with the ever-increasing demand for energy.

1. Introduction

The development of innovative technologies reduces the negative impact of man on the environment. The construction sector is the largest source of final energy consumption. For many years, research has been conducted to improve the strength of the buildings' structure, enhance the aesthetic qualities, improve the insulation of the partitions and minimize the need for heating energy.

Passive solar systems use building elements (e.g. glazing) to accumulate heat. No intermediate medium for transport and heat transfer is used. Sunlight in the form of visible and infrared waves penetrates into the rooms, accumulates in the walls, floors and ceilings. These elements heat up and then emit heat radiation, causing a greenhouse effect [1].

Passive heating methods are effective only for buildings with small unitary energy requirements for heating purposes. They can also be a good source of heat in traditional construction [2, 3]. In passive buildings, the improvement in heat balance can be achieved through glass heat exchangers, shutters or energy-saving roller shutters. The shape of the building should be straight, compact, limiting heat loss through the outer walls (figure 1).





Figure 1. Improperly designed new building. a. northern façade – fully glazed, b. south-western façade without glazing [by EJ Sobczyk].

In the north of Spain, in Pamplona a "zero emission" building has been created. This name signifies the use of renewable sources of heat to achieve an environmentally neutral carbon dioxide balance. The facility, with a total usable area of 3400 m² (built-up area of 881 m²), annually consumes 28 kWh·m⁻² of energy (traditional building 247 kWh·m⁻²). Drastic reduction of heat demand was made possible by the use of carefully selected building materials and a compact building block [4].

2. Methods

Research was carried out based on analysing reports and regulatory documents (EU directives, Polish legislation, strategies, strategic documents of the Ministry of Economy and the Ministry of Environment in Poland (DOE – NETL, US Department of Energy – National Energy Technology Laboratory, International Energy Agency/Committee for Energy Research and Technology).

The following scientific methods were used in the study: modelling and design method, analytical method (calculation method). Heat balance was calculated using HerzCHD (calculation of heat demand), version 3.0 © computer software 1994-2007).

3. Installations of thermal comfort of the building

The designed building is a continuation of the experiment conducted in 2013 [3]. Several new solutions have been added to the proposed installation. The following were used: flat plate collector, installation of the hydrostatic release unit (HRU) - recuperator, domestic hot water (DHW), building envelope tight and hermetic floor, as well as thermal protection of external walls.

4. Ensuring a building envelope tight

An airtight building envelope is – along with the ventilation system – the most important change that needs to be implemented when a building is converted into a passive one. The key criterion is maintaining the adequate heat transfer coefficient U , i.e. 0.15 W·(m²·Kelvin) for passive buildings.

Ensuring building airtightness is necessary to minimize uncontrollable heat loss and to secure the structure from the damaging effects of moisture which condensates inside the external walls (its source is the air escaping from the inside of a building to the outside). Passive building airtightness is determined with the following formula:

$$n_{50} \leq 0.6 \cdot h^{-1} \quad (1)$$

This means that the amount of air that leaks out through cracks in the structure may not exceed 0.6 of the internal cubic volume of a building per one hour, assuming that the difference in air pressure between inside of the building and outside is 50 Pa. The airtightness level is checked by conducting an airtightness test using special tools (e.g. infrared camera). In practice, the values of n_{50} range from 0.2 to 0.6.

5. Thermal protection of external walls

Average charges for heating a poorly insulated building may be as high as 40% of total operating costs. Heat transfer through insufficiently insulated walls causes a heat loss of approx. 25%. To improve insulation of external walls, a decision was made to use top quality polystyrene plates PLATINUM PLUS –façade (EPS EN 13163) [5]. Their thermal conductivity coefficient, λ_D , is $0.031 \text{ W} \cdot (\text{m}^2 \cdot \text{Kelvin})$ at 10°C .

The plates are designed to provide thermal insulation of walls and facades, and can also be applied during modernization work on existing buildings. The plates are manufactured of NEOPOR® material, previously enhanced with graphite, added to the pellets in the course of polystyrene production. The system improves the insulating properties of plates, so it is possible to use thinner pieces with the same insulation effects. It is worth mentioning that Poland's first passive house, which was granted the German Passivhaus of Darmstadt certificate, was insulated with PLATINUM PLUS Styrofoam (EPS EN 13163). This brand of panels ranges in thickness from 1 centimeter to 20 centimeters. However, a system of two plates (2 x 10 cm) laid alternately was used in the design so that thermal bridges could be reduced to the minimum.

Concrete aprons and drainage films are used in hydro-insulation of building ground sections. Their function is to prevent (partially or entirely) water penetration and/or ingress, which can be caused by soil moist (capillary water), water which does not cause hydrostatic pressure (percolating water), or water under pressure (subsoil water or groundwater). Hydro-insulation is meant to protect the building against aggressive chemical compounds that can be found in soil (as a result of plant decaying processes or chemical processes), which can be destructive whilst percolating [6].

In this case, the apron system installed in a traditional building will be moved due to the increased insulation thickness of external and foundation walls. A 7 cm thick layer of styrodur laid by the foundation wall will be made thicker by another 5 cm of the same material. In addition, the apron will be made of sodium bentonite. This sealing material increases its volume from 12 to 15 times in contact with water, forming a gel coating blocking water infiltration.

To avoid superfluous thermal bridges, balconies on the elevations facing north and west will be eliminated.

6. Hermetic floor

An air-tight envelope is not limited to external walls only, but it also includes floors and roofing. Because of that, the insulating properties of the substrate must be improved. The heat transfer coefficient of the partition – the floor laid on the ground in zone 1 (namely by external walls) - in (average) moist conditions goes up to $0.451 \text{ W} \cdot (\text{m}^2 \cdot \text{Kelvin})$. To reduce this coefficient new layers with improved insulating parameters should be applied. It was, therefore, decided to use highly insulating partitions over the entire surface, consisting of the following: a leveling sand layer (10 cm), a number of protective and damp-proof films, thermal insulation of the foundation plate (30 cm, or preferably 20 cm, of polystyrene resistant to mechanical damage), a heating plate (15 cm thick ECOTHERM plate), a reinforced concrete foundation slab (15 cm) and the heating plate itself. The decision to use a floor heating solution stems from its positive impact on human thermal comfort. Moreover, such solution is more economical, brings about significant improvement in aesthetic terms, and has beneficial effects on human health.

Floor heating eliminates the circulation of dust caused by the operation of convection heaters, which is a better option especially for allergy sufferers. It is worth mentioning that when air comes in contact with the metal surfaces of heaters, positive ions that have an adverse impact predominate, causing shortness of breath and dryness of the respiratory tract in humans [7]. The most important argument is, however, appropriate distribution of temperature in the room. Thermal comfort is established for the average temperature of air and walls in the room, reaching 20°C , at normal humidity (50%) and with still air (flow rate below $0.15 \text{ m} \cdot \text{s}^{-1}$). In such conditions, a casually dressed adult performing minor works should not experience any thermal sensations.

Low temperature heating systems include: planar heating (floor, wall, ceiling), air heating and convection heating, along with an increased surface area of heat exchangers in comparison to traditional solutions. The floor heating slab will be required in rooms where the air temperature should be at least 20°C. In garages, utility rooms and entrance vestibules no such installation is needed, so any design heat loss will be distributed among other rooms. Corridors and circulation spaces also have a minimum temperature of 20°C, but heat loss in them is so low that it can be distributed among other rooms.

When building a new house, the MEGATHERM foundation heating plate as well as a heating floor/ceiling assembly would be the best solution. These investments are much more advantageous, cheaper and faster to implement. A properly installed foundation plate ensures stability of the whole structure and adequate insulation; moreover, it is an excellent solution in the areas with difficult soil and water conditions. The MEGATHERM plate technology is a combination of anhydrite and hot foundation plate with floor heating. The ready plate features all the necessary wiring and systems. By installing MEGATHERM plates proper accumulation and inertia of heat are obtained, along with optimum building insulation from the ground while maintaining economic benefits.

7. Installation of the recuperator

To ensure trouble-free and economical operation, you should install a recuperator, for example the AERIS 350 LUXE VV HRU. It is a top-class counter flow heat exchanger, which offer a 95% efficiency. The built-in filters guarantee clean air, while the polypropylene insulation inside the machine ensures silent operation. By installing an auxiliary heater, the supplied air temperature can be controlled. Another advantage of the AERIS HRU is the possibility to connect the controller to the rapid ventilation in the bathroom, kitchen and toilet. The HRU can be programmed according to weekly or hourly options/modes. It can cooperate with the ARTIC cooling system [8]. Before the HRU can be installed, the route of the main cable should be determined, the volume of air should be correctly calculated, the diameter and insulation of ducts should be carefully selected, while the pressure should be equalized. An important element is to ensure an adequate level of humidity in the rooms, especially during the heating season. Moisture and CO₂ sensors which can be connected to the HRU are well worth investing in. In addition to that, all components of the system should be carefully selected: ducts, diffusers, silencers, etc. The HRU must have a low power heater to support heat recovery in the periods when the outside air is very cold [2].

The design also takes the distribution of air supply and exhaust devices into consideration. The former will be installed in least polluted spaces, i.e. bedrooms, living rooms and guest rooms, while the latter – in the kitchen, bathrooms, hall, garage, i.e. spaces where air can be contaminated or too humid. The air flow rate should not exceed 0.2 m·s⁻¹. The air supply devices should be spaced away from the places of human occupancy (e.g. over beds, armchairs or desks) and their number should match the cubic volume and throughput of the spaces.

Condensation of the water vapour contained in the cooled air takes place in the exchanger; it is then directed to the vents, and then discharged into drains.

8. Installation of a heat pump with a ground heat exchanger

According to the building construction plan, the Vitocal 343–G heat pump is also to be installed. Its bottom source of heat is a horizontal ground heat exchanger. It is a high-capacity, energy-efficient, DC-powered electronic pump of the brine-to-water type. It has been equipped with the user-friendly Vitotronic controller displaying text notifications and is capable of quiet operation [9]. The heat pump is integrated with floor heating in the rooms and it supports the HDW heating system (which in the summer is mainly supplied by the solar collector).

The Viessmann heat pump is very compact, taking up little space. In order for the pump to operate properly, horizontal collectors of proper length should be selected so that the desired efficiency of the equipment is achieved.

9. Calculation of the energy balance

According to calculations carried out in previous years [2], the effect of the airtight building envelope can be achieved with special attention paid to the minimization of thermal bridges. With the maximum demand for heating power (which should not be more than $10 \text{ W} \cdot \text{m}^{-2}$) this calculations is $27.3 \text{ W} \cdot \text{m}^{-2}$ and is represented by the symbol Q_f . Taking into account the heat recovery from ventilation (71%) and the efficiency of the recuperator (95%), the heat demand Q_c is calculated using the formula:

$$Q_c = Q_o - (Q_{\text{went.}} \times 0,95) [W] \quad (2)$$

where:

Q_c - heat demand

Q_o - heat demand along with heat loss through ventilation (calculation of heat demand:

$Q_o = 6244 \text{ W}$)

$Q_{\text{went.}}$ - heat demand for ventilation (heat demand: $Q_{\text{went.}} = 2954 \text{ W}$).

Substituting the formula:

$$Q_c = 6244 \text{ W} - (2954 \text{ W} \times 0,95) = 6244 \text{ W} - 2806,3 \text{ W} = 3438 \text{ W} \quad (3)$$

$$3438 \text{ W} : 230 \text{ m}^2 = 14,9 \text{ W} \cdot \text{m}^{-2} \quad (4)$$

For a single-family house with an area of 230 m^2 the power demand per 1 m^2 of heated surface is about 15 W .

For comparison, the heat load Q_c of a traditional building is equal to 10296 W , so the E_A indicator is $122.7 \text{ kWh} \cdot (\text{m}^2 \cdot \text{year})$ and it is a value complying with the Polish Standard.

The energy intensity of residential buildings was estimated using the seasonal demand for heating ratio - E_A [9]. Knowing the unit price of energy and the area of the apartment, the average heating costs calculated for the year were determined. Calculations were made by multiplying the unit price of energy by the value of the E_A ratio and by the area of the apartment. Annual heating costs were calculated according to the formula:

$$Rk = E_A \times Ce \times Fm [PLN \cdot kWh^{-1} \times m^2] \quad (5)$$

where:

E_A - seasonal demand for heat ratio [$kWh \cdot (\text{m}^2 \cdot \text{year})$],

Ce - energy price taking into account the efficiency of the heating system [$PLN \times kWh^{-1}$]
(current price in Poland in 2017 is $0.50 \text{ PLN} \times kWh^{-1}$)

Fm - area of the apartment [m^2].

At an energy efficient home:

$$Rk = E_A \times Ce \times Fm [PLN \cdot kWh^{-1} \times m^2] = 41 \text{ kWh} \cdot \text{m}^{-2} \times 0,50 \text{ PLN} \cdot kWh^{-1} \times 230 \text{ m}^2 = 4715 \text{ PLN} \quad (6)$$

In a standard building:

$$Rk = E_A \times Ce \times Fm [PLN \cdot kWh^{-1} \times m^2] = 122,7 \text{ kWh} \cdot \text{m}^{-2} \times 0,50 \text{ PLN} \cdot kWh^{-1} \times 230 \text{ m}^2 = 14115 \text{ PLN} \quad (7)$$

10. Discussion and conclusions

The result of $15 \text{ W} \cdot \text{m}^{-2}$, obtained from the calculation of the demand for 1 m^2 of heated surface, is satisfactory given the value for a traditional building: $41.9 \text{ W} \cdot \text{m}^{-2}$, but still not suitable for the standard of a passive building: $\leq 10 \text{ W} \cdot \text{m}^{-2}$.

In the case of a seasonal heat demand ratio (in $kWh \cdot (\text{m}^2 \cdot \text{year})$) it is also too high:

$$(15 \text{ W} \cdot \text{m}^{-2} \times 1000) : 365 \text{ days} = 41 \text{ kWh} \cdot (\text{m}^2 \cdot \text{year}) \quad (8)$$

This result includes the heat recovery from ventilation due to the installed recuperator.

In a standard house, which is outside the energy efficiency classifications and is built in accordance with the Polish Standard, the designed thermal load Q_c is equal to 10296 W , so the seasonal heat demand ratio E_A is $122.7 \text{ kWh} \cdot (\text{m}^2 \cdot \text{year})$:

$$10296 \text{ W} : 230 \text{ m}^2 = 44,8 \text{ W}\cdot\text{m}^{-2} \quad (9)$$

$$(44,8 \text{ W}\cdot\text{m}^{-2} \times 1000) : 365 \text{ days} = 122,7 \text{ kWh}\cdot(\text{m}^{-2}\cdot\text{year}) \quad (10)$$

The average annual heating costs for an energy efficient building are 4715 PLN, while for a traditional building are equal to 14115 PLN, which is three times more. The solutions proposed in the present work significantly reduce the heat load of a traditional building, so they are a good way to reduce the financial expenses for heating.

In passive buildings proper thermal comfort should be achieved at the lowest possible energy consumption. Therefore low temperature heating systems are more advantageous. A lower temperature inside a building results in less heat loss to the environment, which entails lower heating costs. In systems with heat pumps, lower temperatures of the heating medium improve device performance and increase its efficiency. The designed supply temperature in low-temperature systems does not exceed 55°C.

The demand for primary energy is aimed to meet all of the energy needs required by the house (heating, HDW preparation, ventilation, air conditioning, lighting, cooking). Energy-efficient appliances (dishwashers, washing machines, dryers) are therefore also required to reduce demand to a minimum.

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