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Outer wall with thermal barrier. Impact of the barrier on heat losses and CO_2 emissions

Key words: thermo-active-wall-barrier, CO_2 impact, heat loss, energy consumption

Introduction

The building sector's large contribution to the total energy use in the EU, estimated to be 40% (Directive 2010/31/ /UE) simultaneously creates a potential for reducing its power consumption as well as the emission of greenhouse gasses by implementing pertinent solutions. Current Polish and EU research confirms, that efforts to improve the energy efficiency of the building sector have led to a significant impact on the reduction of greenhouse gas emissions and are consequently mitigating the effects of climate change (Report COM(2017) 56). They also decrease the low-stack emissions, which pose significant harm to the public and the environment. The requirements and laws to reduce the energy consumption and to up the share of renewable energy sources employed in buildings are becoming stricter, which forces the inception of new, innovative technologies. One of them is a thermal barrier in the exterior wall creating a nonstandard thermal insulation (Xu, Wang, Wanga & Xiao, 2010). Buildings with an active thermal barrier are categorized as thermo-active building systems (TABS). A thermal barrier is achieved by maintaining a constant flow of a low temperature medium, most commonly a solar fluid, through a conduit properly spaced out within the layer of the exterior wall. During the heating period this medium has a lower temperature compared to the conditions inside the building, but a higher temperature compared to conditions inside the same wall layer had the pipes not been installed. This way heat loss due to transmission is minimized. Energy supplied this way to the outer wall interior is most commonly derived from solar and geothermal energy accumulated in a special thermal energy storage. The active thermal barrier can be used not only for heating, but also for the cooling of the building. In such a case, the temperature of the medium is lower compared to the temperature of the same wall interior layer had the pipes not been installed.

Such an application of a relatively low-temperature medium is intended to limit heat loss due to transmission in new buildings as well as thermo-modernised buildings using one of various systems, including: ISOMAX, ISOACTIVE-3D, BT&SONS Kft system.

Active thermal insulation

Walls with active thermal insulation can have different constructions. However, they always have coils that generate a thermal barrier for heat transfer through the wall. One of the first systems using this solution was the ISOMAX system. In this system an external wall is built from 12.5 cm foamed polystyrene board connected by means of patented concrete fins to another 12.5 cm foamed polystyrene board. Between them PP pipes in form of meanders are placed. The space between these foamed polystyrene boards is filled with BIO-POR concrete. The construction of such a wall is based on a core in which a constant temperature is maintained, and which is thermally well insulated on both sides. A thermal barrier is achieved by providing a constant flow of a low-parameter medium through pipes appropriately placed in the core. The application of a partition with a thermal barrier prevents vapour from escaping and significantly reduces the loss of heat by transmission from a building interior by creating blockades preventing heat flow from the areas of higher energy levels into the lower ones. Figure 1 presents the scheme of such a partition.

Walls with active thermal insulation of slightly different construction are used in Hungary. In ISOACTIVE-3D technology, the external wall is made of foamed polystyrene board: 5 cm thick (external) and 15 cm connected by means of a special metal mesh embedded in lightweight concrete. The PP pipes are placed in the outer layer of the concrete. Similar to the ISOMAX system, the thermal barrier is achieved due to the constant flow of a low-temperature medium through the coils. The scheme of such a partition is

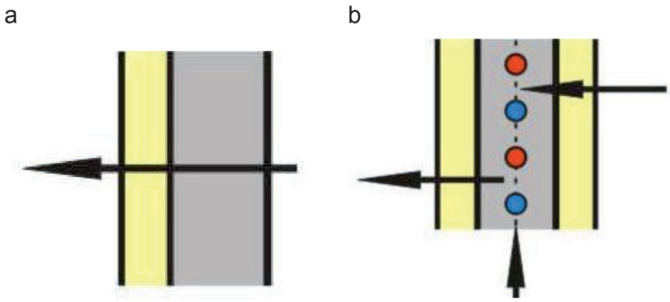


FIGURE 1. The scheme of an insulated external partition: a – traditional; b – with a thermal barrier in the ISOMAX system (12.5 cm of foamed polystyrene, 15 cm of BIO-POR – concrete with PP pipes, 12.5 cm of foamed polystyrene)

shown in Figure 2. Walls with active thermal insulation from BT&SONSKft have different constructions shown in Figure 3.

As observed the coils can be located in different layers of the wall cross-section. The effectiveness of the coil's operation as a thermal barrier depends largely

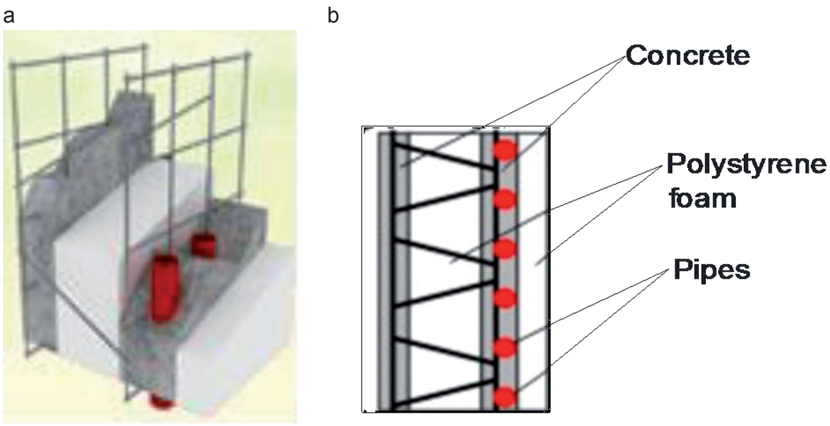


FIGURE 2. The view and the scheme of the external partition with a thermal barrier in the ISOACTIVE-3D system (5 cm of foamed polystyrene from the outside, lightweight concrete with PP pipes, 15 cm of foamed polystyrene, lightweight concrete, all connected with a metal mesh embedded in concrete)

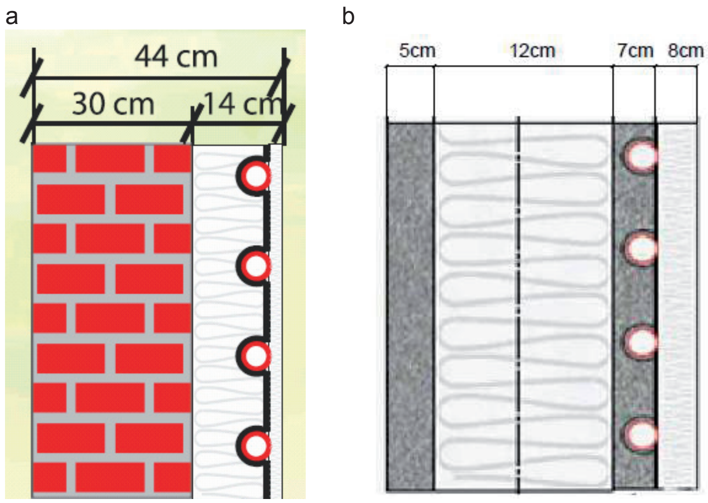


FIGURE 3. The scheme of the external partition with an active thermal insulation BT&SONS Kft: a – a partition made of 30 cm Porotherm, insulated with 14 cm thick foamed polystyrene with PE pipes with a low parameter measure on the outside; b – a partition made of 5 cm Porotherm, 12 cm of foamed polystyrene, 7 cm of Porotherm with PE pipes on the outside and external layer of 8 cm foamed polystyrene

FIGURE 4. The external partition with an active thermal insulation (photo by BT&SONS Kft, 15 April 2017)

on its position as well as on the temperature level of the medium that supplies it.

The building's heating in the above-mentioned technologies using an active thermal insulation is realised through a combination of passive solar energy use within the roof and outer walls as well as geothermal energy. There is a solar absorber in the building's roof. It consists of a system of thin polypropylene or polyethylene pipes located directly under the roof, but above the insulation layer of the roof structure (between roofing and

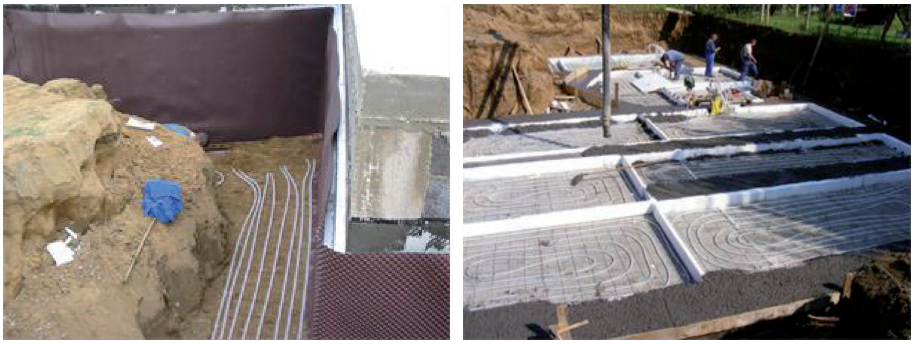


FIGURE 5. Heat storage under the foundation plate and outside the building (photo by BT&SONS Kft, 15 April 2017)

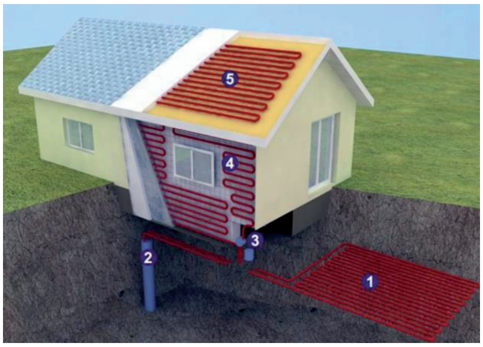


FIGURE 6. The scheme of the building with an active thermal insulation in external partitions (illustration by BT&SONS Kft system, 15 April 2017): 1, 2 – heat storage under the foundation plate or next to the building; 3 – circulating pump; 4 – coils in external walls; 5 – roof absorber

roof insulation). The system of polypropylene pipes is also in the core of the external walls (Fig. 4). Under the building there is a foundation – a floor plate. It also has a polypropylene pipe system insulated with foamed polystyrene and it performs the function of an underground heat storage system (energy reservoir) – Figure 5. The principle of the system's operation is as follows (Fig. 6).

Solar energy is absorbed by the solar absorber below the roof and is transmitted to the external walls. The excess of energy, which is not used for the building's heating is accumulated in the underground storage system. As the needs arise this energy is consumed. Energy obtained from the sun, stored under the foundation plate is returned to the wall's core from cellular concrete and it also indirectly heats the soil under the building. For the sake of high air tightness of the building the mechanical ventilation with heat recovery is used additionally.

The influence of thermal barrier position on its effectiveness

The outer walls with a thermal barrier limit heat transmission losses from heated rooms. In the ISOMAX system polypropylene pipes with heating medium are located exactly in the centre of the wall's core. In reality they can be in any place inside the wall. In the partitions used in Hungary, the coils are located on the outside of the wall. Therefore, the following section shows how the location of the pipes influences heat transmission losses from heated rooms. For this purpose, the model of an outer wall with thermal barrier presented in earlier works was used (Leciej-Pirczewska & Szaflik, 2006, 2010). It is based on the balance of energy supplied and discharged from the partition. Based on this the heat fluxes $\dot{Q}_1$, $\dot{Q}_2$ and $\dot{Q}_3$ were determined (Fig. 7).

The heat fluxes $\dot{Q}_1$, $\dot{Q}_2$ and $\dot{Q}_3$ were made dependent on R_1 – the thermal resistance of the internal courses of the external wall (these which are between pipes and the room), in order to better display this problem.

The calculations were conducted for the walls made of the same materials as presented in the above section about active thermal insulation. The results of calculations for a partition in the ISOMAX system are introduced in Figure 7 for three different locations of thermal barrier and for the wall without this barrier. The following data was used in the calculations:

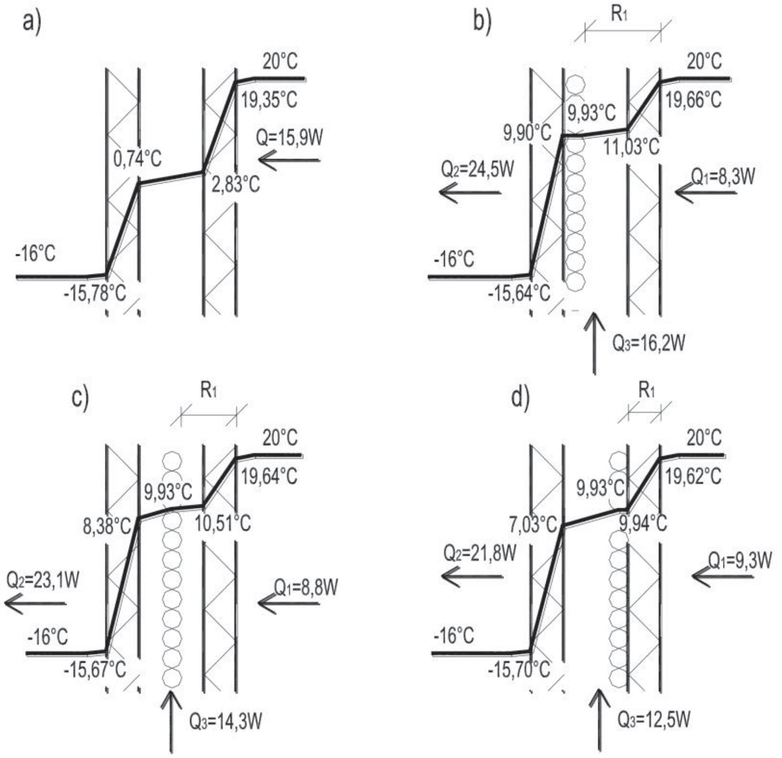
- internal temperature $T_i = 20°C$,
- external temperature $T_e = -16°C$,
- initial medium temperature $T_p = 10°C$,
- medium thermal capacity $W = 104.8\ W \cdot K^{-1}$.

Heat fluxes $\dot{Q}_1 / \dot{Q}$, $\dot{Q}_2 / \dot{Q}$ and $\dot{Q}_3 / \dot{Q}$ relative as a function of thermal resistance R_1 established for such conditions are introduced in Figure 8.

The heat flux transmission from the room $\dot{Q}_1$ decreases when the thermal barrier moves along the outside. The heat flux transmission outside the building $\dot{Q}_2$ and the heat flux given out during medium flow $\dot{Q}_3$ grows when the thermal barrier moves along outside.

The use of a thermal barrier considerably limits the heat losses from the room. The heat flux transmitted from the inside when the outer wall has a thermal barrier decreased compared with the wall without thermal barrier by:

- 41.09% for the outer wall in IZOMAX system with thermal barrier located inside the core,
- 44.75% for the outer wall in IZOMAX system with thermal barrier located in the centre of the core,
- 47.32% for the outer wall in IZOMAX system with thermal barrier located outside the core,
- 57.32% for the outer wall in BT&SONS Kft system with thermal barrier on the outside (Fig. 3b),
- 59.22% for the outer wall in BT&SONS Kft system with thermal barrier on the outside (Fig. 3a).



$\dot{Q}_1$ – heat flux penetrated from the room, $\dot{Q}_2$ – heat flux penetrated outside, $\dot{Q}_3$ – heat flux given up during medium flow, $\dot{Q}$ – heat flux penetrated from the room with traditional wall without thermal barrier.

FIGURE 7. Possible solutions of outer wall and wall's temperature distribution: a – traditional, highly--insulated outer wall without thermal barrier; b – outer wall with thermal barrier – PP pipes are close to outside the core; c – outer wall with thermal barrier – PP pipes are in the centre of the wall's core; d – outer wall with thermal barrier – PP pipes are close to inside the core

Resulting from this analysis, the highest reduction of heat losses is achieved with the thermal barrier positioned on the outside of the core. Such a position of the thermal barrier inside the wall is usually encountered in newly thermo-renovated buildings. This instance of the barrier placement has been thus assumed for further energy analysis below.

Thermal barrier influence on the energy performance of a typical single-family house and CO_2 emission

It is interesting, to what degree the thermal barrier can contribute to improvement of the building's energy

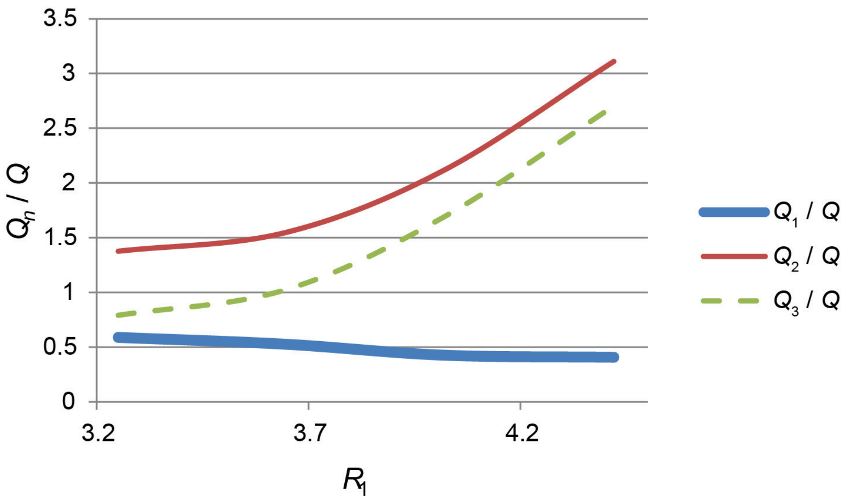


FIGURE 8. Diagram of relative heat fluxes $\dot{Q}_1 / \dot{Q}$, $\dot{Q}_2 / \dot{Q}$ and $\dot{Q}_3 / \dot{Q}$ depending on thermal resistance of the internal courses of the external wall R_1 [$m^2 \cdot K \cdot W^{-1}$]

performance and the reduction of CO_2 emissions. To arrive at an answer to this question an analysis of the influence of the energy consumption on a typical single-family building after thermo-modernisation was conducted. It was important to determine the following quantities for the selected building:

– the index of annual demand for final energy (EK),
– the index of annual energy needs (EU).

Methodology of research

Calculations were performed using current procedures for evaluating building energy performance, using the monthly method, according to 2016 Regulation of the Minister of Infrastructure and Construction methodology. The general calculations of the energy demand for heating, cooling and ventilation are based on methods from CEN standards (ISO 13790:2008). The energy demand for heating and ventilation in the building has been determined, excluding heating of domestic hot water. The general calculations are based on methods from CEN standards (ISO 13790:2008). Emission factors for electricity are taken from the report of the Polish National Centre for Emissions Management (KOBiZE, 2018). On that basis, CO_2 emissions were calculated.

Case study

The target building for this case study is a typical single-family household. It is a semi-detached building with three floors, a garage and a complete basement. The attic is not utilized. The basement, porch and attic are regarded as non-heated spaces.

The buildings parameters are:

– total surface area 170.8 m^2,
– utility surface area 92.6 m^2,
– ceiling height 2.8 m.

The thermal barrier is assumed to be constructed on the outer side of the core of the exterior wall analogous to the proposed thermo-modernisation solution of the ISOMAX system. A barrier temperature of 10°C was assumed.

Compared variants:

– before modernisation,
– after thermo-modernisation with the use of an active thermal barrier on the exterior side of the wall directly behind a 12 cm thick layer of insulation.

When it comes to the construction of the walls, the two variants differ from each other only on the basis, that after modernisation cement lime plaster to embed the wall barrier PP pipes has been added to the wall.

In the variant before thermo-modernisation the central heating installation is equipped with floor heating elements. The building possesses a mechanical ventilation unit with heat recovery of $\varphi = 80\%$. The source of heat is a brine/water heat pump ($SCOP = 4.0$).

In the variant after thermo-modernisation, the foundation slab serves as a heat storage unit as a result of the renovation of the basement. The accumulated thermal energy is provided to the thermal barrier made from PP pipes. The installation is equipped also with floor heating elements as before thermo-modernisation. The same conditions were assumed for ventilation and the heat source as for the building before renovation. Figure 9 presents the calculated values for the EU and EK index of annual demand for useable and final energy for heating and ventilation.

TABLE 1. The multilayer wall construction with thermal barrier for building after thermo-modernisation

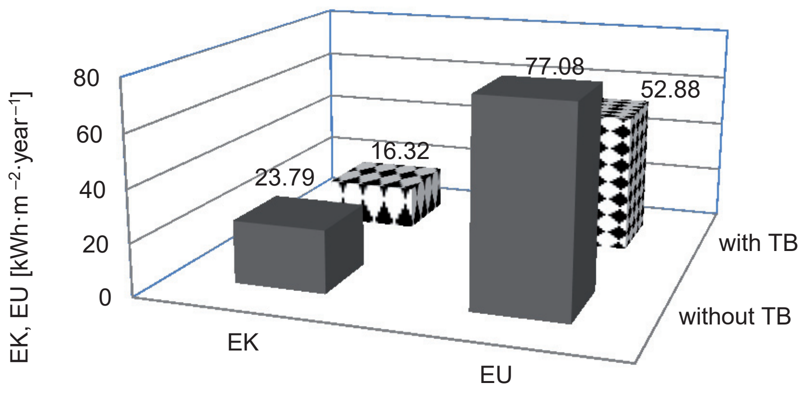
Envelope element	Material	s	λ	R	ΣR	Rsi	Rse	R_1
		m	$W \cdot m^{-1} \cdot K^{-1}$	$m^2 \cdot K \cdot W^{-1}$				
Exterior wall	porous ceramic bricks Porotherm 38 P+W	0.38	–	2.690	2.73	0.13	–	2.86
	gypsum plaster	0.015	0.35	0.043				

R_1 – the thermal resistance of the internal courses of the external wall (those between pipes and the room).

TABLE 2. The multilayer wall construction with thermal barrier (TB)

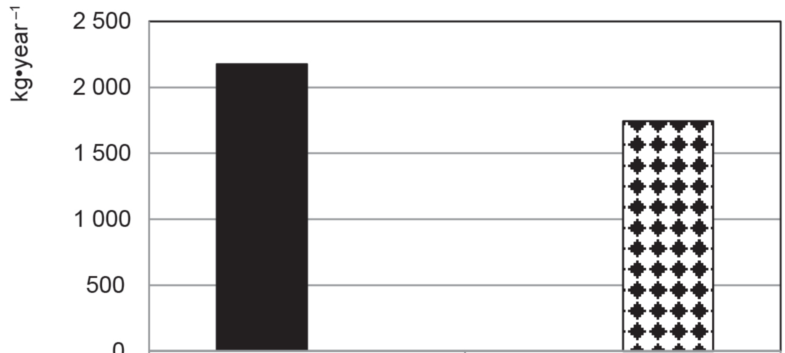
Envelope element	Material	s	λ	R	ΣR	Rsi	Rse	R_2
		m	$W \cdot m^{-1} \cdot K^{-1}$	$m^2 \cdot K \cdot W^{-1}$				
Exterior wall	gypsum plaster	0.01	0.35	0.029	3.06	–	0.04	3.10
	polystyrene EPS 70-040 12 cm thickness	0.12	0.04	3.000				
	cement-lime plaster coat to embed the wall barrier PP pipes	0.025	0.82	0.030				

R_2 – the thermal resistance of the external courses of the external wall (those between pipes and the outdoor air).



	EK	EU
without TB	23.79	77.08
with TB	16.32	52.88

FIGURE 9. Value o indexes EU, EK before (without thermal barrier TB) and after thermorenovation (with TB)



	kg•year⁻¹	kg•year⁻¹
before renovation	2 176	
after renovation		1 743

FIGURE 10. CO_2 emission in the analyzed building before (without TB) and after thermorenovation (with TB)

Results

The improvement of the energy performance due to the renovation concerning the application of a thermal barrier results in a reduction of about 31% of the building's energy demand referring to both final and usable energy for heating and ventilation in the modernised building. It was calculated by KOBiZE (2018), that the average CO_2 emissions for electricity in Poland are approximately 778 g of CO_2 per 1 kWh. Using this specific CO_2-factor for electricity needed to operate the heat pump and auxillary equipment in the analyzed building, savings from the thermal barrier installation amount to 433 kg of CO_2 annually (Fig. 10).

Conclusions

From the example of a typical single--family house it can be concluded, that the energy performance and CO_2 emission responsible for global warming can be significantly improved by using a thermo active barrier in the external wall. The application of a thermal barrier results in a reduction of the heat lost from the inside. A barrier placement near to the outside is beneficial, and installing it during thermorenovation can yield significant energetic improvements and be more enviromentally friendly. Even though in the article the values of energy demand and CO_2 emission relate only to the analysed building and our assumptions, it can be expected, that the results generalize further.

References

BT&SONS Kft system (2017-04-15). Retrieved from: www.btandsons.hu [access 15.04.2017].

Directive 2010/31/UE of the European Parliament and the Council of 19 May 2010 on the energy performance of buildings (recast). OJ L 153 of 18.06.2010.

ISO 13790:2008. Energy performance of buildings. Calculation of energy use for space heating and cooling.

ISOACTIVE-3D system (2019). *ISOACTIVE-3D system*. Retrieved from: www.isoactive-3d.hu [access 09.09.2019].

ISOMAX system (2019a). *ISOMAX system*. Retrieved from: http://isomax.isodom.pl/budownictwo,abc_systemu_isomax.html [access 09.09.2019].

ISOMAX system (2019b). *ISOMAX system*. Retrieved from: http://www.isomaxterrasol.eu/technologie.html [access 09.09.2019].

Krajowy Ośrodek Bilansowania i Zarządzania Emisjami [KOBiZE] (2018). *Wskaźniki emisyjności CO_2, SO_2, NO_x, CO i pyłu całkowitego dla energii elektrycznej na podstawie informacji zawartych w Krajowej bazie o emisjach gazów cieplarnianych i innych substancji za 2017 rok* [*Emission factors of CO_2, SO_2, NO_x, CO and TSP for electricity on the basis of information contained in the National Base on Emissions greenhouse gases and other substances for 2017*]. Warszawa: KOBiZE.

Krzaczek, M., Florczuk, J. & Tejchman J. (2019). Improved energy management technique in pipe-embedded wall heating/cooling system in residential buildings. *Applied Energy*, *254*, 113711-113738.

Leciej-Pirczewska, D. & Szaflik, W. (2006). Uses of outer wall with permanent thermal barrier in building engineering. In *XI International Symposium on heat transfer and renewable sources of energy*. Międzyzdroje 2006 (pp. 321-328). Szczecin: Wydawnictwo Uczelniane Politechniki Szczecińskiej.

Leciej-Pirczewska, D. & Szaflik, W. (2010). Wykorzystanie niskotemperaturowego czynnika w ogrzewaniu ściennym [Application of low-temperature medium in wall heating]. *Ciepłownictwo, Ogrzewnictwo, Wentylacja*, *41*(5), 168-172.

Report from the Commission to the European Parliament and the Council. 2016 assessment of the progress made by Member States in 2014 towards the national energy efficiency targets for 2020 and towards the implementation of the Energy Efficiency Directive 2012/27/EU as required by Article 24 (3) of the Energy Efficiency Directive 2012/27/EU. COM(2017) 56 final of 01.02.2017. Brussels: European Commission.

Rozporządzenie Ministra Infrastruktury i Budownictwa z dnia 20 grudnia 2016 r. zmieniające Rozporządzenie w sprawie metodologii wyznaczania charakterystyki energetycznej budynku lub części budynku oraz świadectw charakterystyki energetycznej. Dz.U. 2017, poz. 22 [Regulation of the Minister of Infrastructure and Construction of 20 December 2016 on the methodology of determining the energy performance of a building or part of a building and energy performance certificates. Journal of Laws 2017, item 22].

Xu, Xh., Wang, S., Wanga, J. & Xiao, F. (2010). Active pipe-embedded structures in buildings for utilizing low-grade energy sources: a review. *Energy and Buildings*, *42*(10), 1567-1581.

Summary

Outer wall with thermal barrier. Impact of the barrier on heat losses and CO_2 emissions. New demands for lowering energy consumption of buildings lead to many new solutions including, amongst others, the introduction of an outer wall thermal barrier for both heating and cooling effect. The analysed thermo-active-wall-barrier is a water-based system, where the pipes are embedded in the wall construction. It enables the use of a low-temperature barrier medium for space heating, thereby increasing the efficiency of all potential energy supply systems using renewable energy sources. The pipes form an active thermal barrier for heat transfer between the outer and the heated space. There are many possibilities to place the pipes in the wall for example in the case of energetic thermo-modernisation. Our research and calculations have shown that thermo-active-wall-barrier is sensitive to the location of pipes. The following paper also provides a study of the impact of thermal barrier on a building's energy performance. The analysis was conducted for a single-family house in a temperate climate based on parameters taken from one of the Polish meteorological data-bases. Calculations using current procedure of evaluating building energy performance show, that the thermal barrier can contribute to significant reduction of transmission energy loss thus lowering the environmental impact.

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