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THE ENERGY PERFORMANCE OF ADAPTIVE INSULATION APPLIED TO AN OFFICE BUILDING

BY

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Abstract. The paper aims at evaluating the energy performance of an average office building characterized by very high glazing ratio, with adaptable envelope solution, *i.e*. adaptive insulation for the opaque area. Using the PHPP programme, three cases were analysed and compared: exterior walls and roof with i) conventional thermal insulation and with adaptive insulation having ii) minimum thermal transmittance (insulating state) and respectively iii) maximum thermal transmittance (conducting state). Considering the monthly energy demand for cooling and the potential of the adaptive insulation to eliminate excess heat at night, the energy savings were calculated at 134.9 kWh/m^{2}year, representing 59.19% of the annual cooling demand. Moreover, when the opaque façade area is in insulating state, characterized by minimum thermal transmittance, the heating energy demand decreases by 18%, respectively from 117 kWh/m^{2}year to 96 kWh/m^{2}year.

Keywords: energy efficiency; adaptive insulation; adaptable envelope; fibreglass insulated panel; thermodynamic simulation.

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1. Introduction

The envelope is the main building subsystem that influences the energy performance. By responding directly to the indoor and outdoor dynamic conditions, the adaptable envelope systems lead to low energy demand.

The paper focuses on assessing the energy performance of an envelope with adaptive insulation (AI) using calculations based on the simulation of this system integrated in an office building, proposed to be researched for finding the impact on the energy demand for heating and cooling and defining the optimal performance parameters.

Adaptive thermal insulation (AI) is based on vacuum insulation techniques; the thermal conductivity λ of a flat steel panel, filled in with evacuated glass fiber, is ranging from 0.002 W/mK to 0.17 W/mK by adding hydrogen under 100 mbar pressure. The hydrogen is released by heating a metal hydride getter, a process that requires the application of an electric current up to 5 W for 1 m^2 panel surface. When the metal hydride getter cools down again to the room temperature, hydrogen is reabsorbed and the thermal conductivity drops.

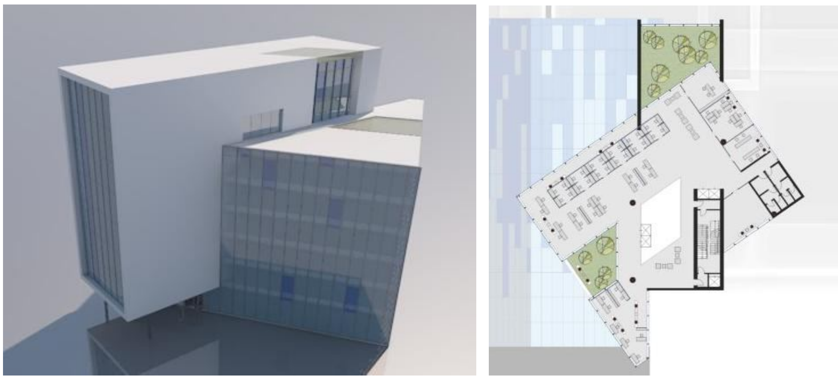
Through this reaction, controlled by a sensor activated by the outside temperature variation, the insulating panels will change their thermal transmittance. By increasing the panel thermal resistance, heat is kept inside by night or during cloudy days. Depending on the nature of the façade on which the panels are installed, a heat transfer coefficient of 0.2 W/m^2K can be obtained for the case of insulating state of the panels and respectively 10 W/m^2K when conductivity is high.

The profitability in using adaptive insulation panels is investigated focusing on the effect on energy efficiency and thermal comfort according to the building characteristics, orientation and climate. The potential energy savings for heating and cooling offer the possibility of improving indoor thermal comfort without air conditioning supply. Therefore, the proposed office building using adaptive thermal insulation was analyzed by taking into account two hypotheses: with minimum and respectively with maximum thermal transmittance for the opaque area of exterior walls and the building roof.

2. Parameters and Starting Points

In order to generate accurate results, as close to reality as possible, a 3D model of an office building was designed in the modelling programme Archicad. The defined properties of the component elements, the specific interior space functionality and the occupancy schedule are introduced into the thermodynamic simulation programme PHPP. The chosen location, which is the city of Iasi, Romania, provides the climatic parameters.

The office building of average dimensions is characterised by an opaque-transparent ratio in favour of transparency (Fig.1), for the best highlight of the problems generated by the high glazing ratio and of the possibilities for optimizing this category of buildings. For the given value of the glazing ratio (60.9%), the office building enrols into the category of buildings with maximum energy performance: no operable windows and with centralized air conditioning.



a *b*

Fig. 1 – *a* – 3D representation of the office building; *b* – current floor.

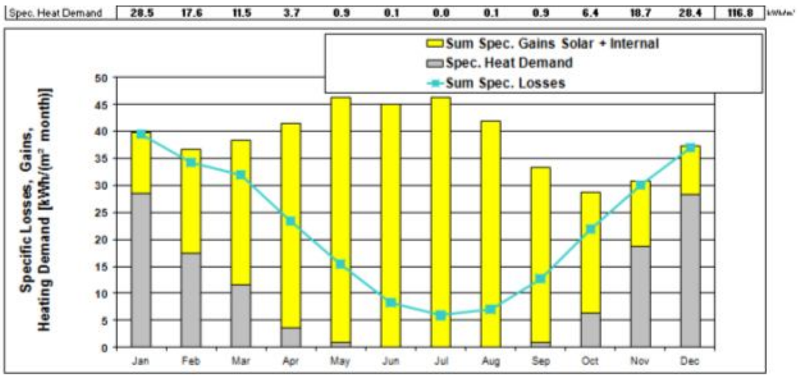
In terms of floor number and height, the building fits in the average buildings typology for Europe, USA and China, with 8 levels and 30 m high. The structure of the exterior walls consists of an inside layer with high thermal mass (brick or reinforced concrete) and an outer layer of adaptive thermal insulation. The construction details of the envelope elements are designed to achieve low thermal transmittance values. Some relevant data are given below:

- volume = 16,960 m^3;
- area of floor on the ground = 858.43 m^2;
- exterior opaque walls = 1,430.38 m^2;
- glazed surface = 2,227.88 m^2;
- level height = 3.50 m;
- floor dimensions: 30 m × 33 m;
- triple-layer curtain wall g = 0.47, Ug = 0.49 W/m^2K;
- Uf = 0.63 W/m^2K, ϕ_{spacer} = 0.043 W, $\phi_{installation}$ = 0.040 W;
- global thermal insulation coefficient G = 0.474 W/m^2K;
- climatic data – afferent to Iaşi, Romania;
- U values for walls, roof, floor on the ground - calculated in PHPP;
- U values for curtain walls – selected from the PHPP database.

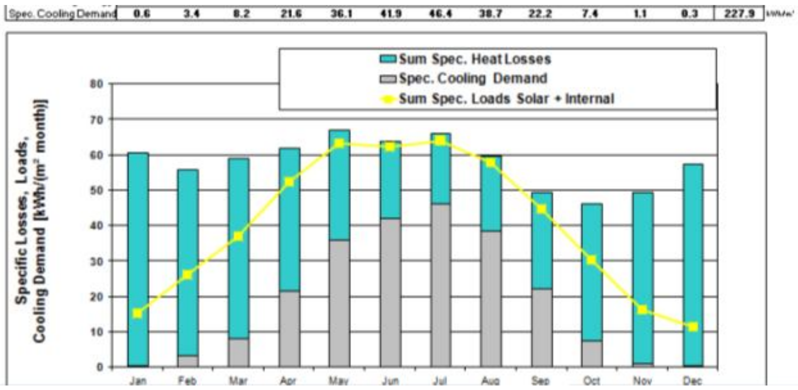
3. Case Study

In order to evaluate the performance of an adaptive insulation system, the case study, aiming at the evaluation of the building energy performance, has been developed in three hypotheses concerning the thermal insulation of the opaque area of exterior walls and the building roof: **A** – with conventional thermal insulation; B – with adaptable insulation in insulating state (minimum thermal transmittance) and C – with adaptive insulation in conducting state (maximum thermal transmittance obtained by releasing hydrogen into the glass fibre panel following the electric current generation). Therefore, in the PHPP programme the comparison of cooling and heating energy demand for different values of thermal transmittance is performed:

A. Simulation for *conventional thermal insulation* ($\lambda_{conv.ins.}$ = 0.04 W/mK)



a.



b.

Fig. 2 – Monthly and annual energy demand for: *a* – cooling; *b* – heating.

For the envelope with conventional thermal insulation, the simulation provides the following results: 117 kWh/m^{2}year for heating energy demand and 228 kWh/m^{2}year for cooling energy demand.

B. Simulation for adaptive insulation: *minimum thermal transmittance* of external walls and terrace roof (λ_{AI} = 0.002 W/mK) (*insulating state*)

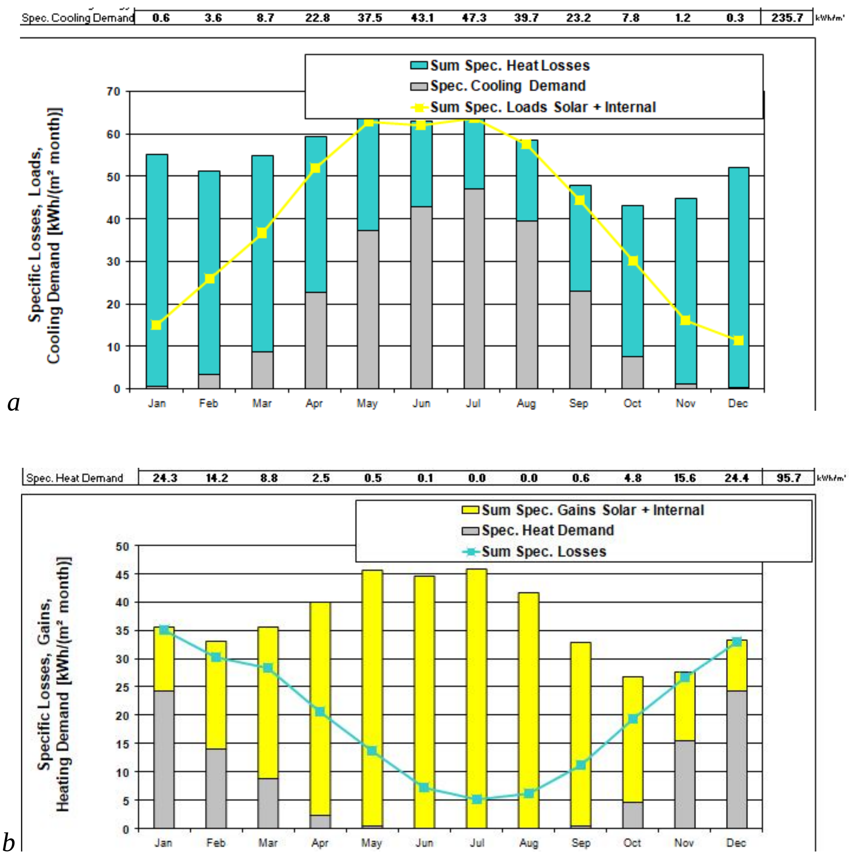


Fig. 3 – Monthly and annual energy demand for: *a* – cooling; *b* – heating.

The results in Fig. 3 show a slow increase of cooling energy demand from 228 kWh/m^{2}year to 235.7 kWh/m^{2}year (*i.e.* 3.4%) because the excess heat inside the building is not eliminated. Instead, by replacing the original thermal insulation with more efficient adaptive insulation, the energy demand for heating decreases by 18%, from 117 kWh /m^{2}year to 96 kWh/m^{2}year.

C. Simulation for adaptive insulation: *maximum thermal transmittance* of external walls and terrace roof (λ_{AI} = 0.17 W/mK) (*conducting state*)

Results in Fig. 4 show that if used in the conducting state, in one year the cooling energy demand decreases by 31% (from 228 kWh/m^{2}year to 135.2k Wh/m^{2}year). However this solution implies significant increase in energy consumption for heating (+176.9%).

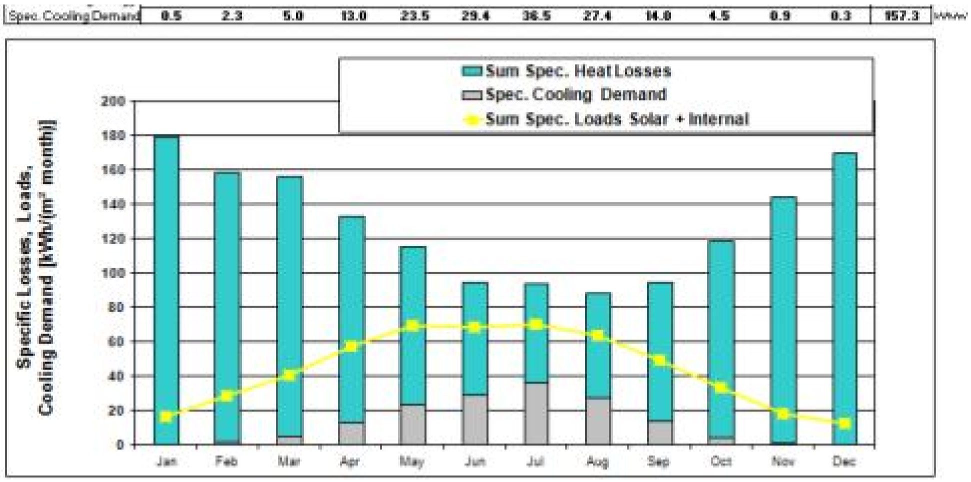


Fig. 3 – Monthly energy demand for cooling.

Table 1 shows the heat losses for the case studies presented above: the envelope with conventional insulation (A), with adaptive insulation in insulating state (B) and respectively in conducting state (C).

By comparing the cooling energy demand without adaptive insulation and the heat losses with minimum thermal resistance of the outer walls and terrace roof, the energy savings can be determined in order to evaluate the improvement of the envelope's energy performance (Fig. 4). This calculation also highlights the annual periods when the AI system has a high contribution to reducing energy demand: May, June, July, August and September.

The annual energy demand for cooling decreases by 59.2% (–134.9 kWh/m^{2}year). The calculation is approximate, because generating a dynamic simulation with parameters changing over a day is not possible. Thus, the performance of the adaptive insulation is actually higher, but the results are influenced by the significant heat flow entering the building during the day, due to the high thermal transmittance of the envelope elements.

Table 1
Table 1 Reduction of Energy Demand by Using Adaptive Insulation

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Tot.
Specific heat losses - max. thermal insulation, [kWh/m^2] **(B)**	60.0	52.4	50.8	40.2	31.0	22.0	19.6	20.8	27.4	38.8	48.2	57.1	
Specific heat losses -min. thermal insulation, [kWh/m^2] **(C)**	106.7	93.3	90.3	71.6	54.9	39.0	34.5	36.7	48.2	68.6	85.5	101.3	
Additional heat losses – case C compared to case B, [kWh/m2] **(C-B)**	46.7	40.9	39.5	31.4	23.9	17.0	14.9	15.9	20.8	29.8	37.3	44.2	
Cooling energy demand – conventional thermal Insulation, [kWh/m2] **(A)**	0.6	3.4	8.2	21.6	36.1	41.9	46.4	38.7	22.2	7.4	1.1	0.3	227.9
Energy savings in specific cooling energy demand with AI, [kWh/m2]	0.6	3.4	8.2	31.4	23.9	17.0	14.9	15.9	20.8	7.4	1.1	0.3	134.9
Cooling energy demand –AI, [kWh/m2]	0.0	0.0	0.0	9.8	12.2	24.9	31.5	22.8	1.4	0.0	0.0	0.0	92.8

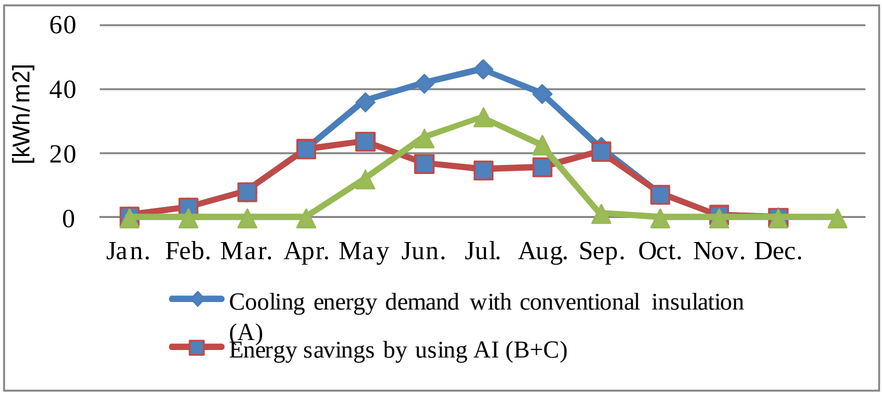


Fig. 4 – Cooling energy demand and savings.

Therefore, the reduction in cooling energy demand through the integration of the AI system is significant, especially for the period of April to September when the cooling energy demand is reduced to 0, except for the period of June-August (Fig.4).

4. Conclusions

The study demonstrates a considerable impact upon the building's energy performance and the indoor thermal comfort by replacing the conventional thermal insulation of the façade's opaque area with insulating panels that switch from insulating state to conducting state according to interior and exterior parameters. The adaptable envelope proves to be a right solution to the overheating and significant heat loss problems specific to buildings with high glazing ratio. Due to continuous development of this field and mass production, these types of panels will become more and more efficient and cheaper. Taking this into account together with the significant energy savings and an office building lifespan, the return on investment will shorten.

This technology contributes to achieve the objective of designing buildings with minimal impact on energy resources, thus demonstrating that the limitations of the existing facades' solutions can be overcome only by passing on from static systems to adaptable dynamic systems that respond continuously to changes in the indoor and outdoor environment parameters.

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PERFORMANȚA ENERGETICĂ A IZOLAȚIEI TERMICE ADAPTABILE APLICATE UNEI CLĂDIRI DE BIROURI

(Rezumat)

Prezenta lucrare propune evaluarea performanței energetice a unei clădiri de bioruri de dimensiuni medii, cu o suprafață vitrată semnificativă, care integrează o soluție de anvelopă adaptabilă, anume izolație termică adaptabilă pentru partea opacă. Au fot analizate şi comparate trei cazuri, utilizând programul de calcul PHPP: pereți exteriori şi acoperiş terasă cu izolație termică convențională (A), izolație termică adaptabilă cu transmitanță termică minim (B) (starea izolatoare) şi respectiv maxim (C) (starea conductivă). Rezultatele arată o economie de energie de 134.9 kWh/m^{2}an, reprezentând 59.19% din consumul anual de energie pentru răcire, ca rezultat al potențialului izolației termice adaptabile în stare izolatoare de a elimina căldura în excess în timpul nopții. Mai mult decât atât, consumul de energie pentru încălzire scade cu 18%, respectiv de la 117 kWh/m^{2}an la 96 kWh/m^{2}an, atunci când suprafața opacă a anvelopei prezintă o trasmitanță termică minimă.