

Modeling with finite element the convective heat transfer in civil building EPS insulated walls

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Abstract: - In this paper we present the analysis of convective heat transfer in the walls of a house insulated with polystyrene. In the first part we make an evaluation of the insulation that is currently used in the houses. We start the simulation using a real model of a house and then we make the model in Solidworks 2009. We run the model in Solidworks Thermal study after we insert the initial conditions. We notice that the obtained results indicate a problem which occurs inside the brick, the dew-point appearance. Further investigations must be made to solve this problem.

Key-Words: - convective heat transfer, dew-point, finite element, polystyrene insulation.

1 Introduction

Thermal insulation in buildings is an important factor to achieving thermal comfort for its occupants. Insulation reduces unwanted heat loss or gain and can decrease the energy demands of heating and cooling systems. It does not necessarily deal with issues of adequate ventilation and may or may not affect the level of sound insulation. In a narrow sense insulation can just refer to the insulation materials employed to slow heat loss, such as: cellulose, glass wool, rock wool, polystyrene, urethane foam, vermiculite and earth or

soil. But it can also involve a range of designs and techniques addressed to the main modes of heat transfer - conduction, radiation and convection materials.

Construction quality issues include inadequate vapour barriers and problems with draft-proofing. In addition, the properties and density of the insulation material itself is critical. The use of building walls and roof thermal insulation does not only contribute in reducing the required air-conditioning system size, but also in reducing the annual energy cost. Additionally, it helps in extending the periods of thermal comfort without reliance on mechanical air-conditioning

especially during inter seasons periods. Therefore, proper use of thermal insulation in buildings enhances thermal comfort at less operating cost. However, the magnitude of energy savings as a result of using thermal insulation vary according to the building type, the climatic conditions at which the building is located as well as the type, thickness and location of the used insulating material. The question now is no longer if insulation should be used but rather which type and how much [1]. The purpose of buildings thermal insulation is to maintain a comfortable and hygienic indoor climate at low ambient temperatures. A minimal amount of thermal insulation is required to protect the constructional elements against thermal impact and moisture related damage. The main aim of thermal insulation in winter is energy conservation leading to a decrease in heating demand and hence the protection of the environment. This aim has to be considered in new buildings as well as in renovating the building stock. Strategies to reach this aim are the use of building materials with low thermal conductivity values and the installation of windows with low U-values on the one side and the avoidance of thermal bridges and uncontrolled infiltration on the other side. Besides the above mentioned purpose, thermal insulation plays a major role in preventing summertime overheating of buildings through reducing the transmission of solar radiation, absorbed on the buildings exterior surfaces, to the interior. The lowest λ values of non-evacuated elements achievable are the one of motionless air. Hence the basic principle in developing insulation materials is to enclose as much non-moving air into the structure of the material as possible and still satisfy the required structural stability. In cold conditions, the main aim is to reduce heat flow out of the building. The components of the building envelope - windows, doors, roofs, walls and air infiltration barriers are all important sources of heat loss; in an otherwise well insulated home, windows will then become an important source of heat transfer. The resistance to conducted heat loss for standard glazing corresponds to an R-value of about $0.17\text{W}/\text{m}^2/\text{K}^\circ$ (compared to $2\text{-}4\text{W}/\text{m}^2/\text{K}^\circ$ for glass wool bats). Losses can be reduced by good weatherization, bulk insulation and minimizing the amount of non-isolative (particularly non-solar facing) glazing. Indoor thermal radiation can also be retarded with spectrally selective (low-e, low-emissivity) glazing. Some insulated glazing systems can double to triple R values.

2 Parameters related to building physic

The thermal properties of structural elements are characterized by the mass density ρ , the λ -values of the building elements layers and the heat transfer

coefficients α at the surfaces. The heat transmission through an element is defined by the air to air heat transmission coefficient U. Reducing the λ -value of a material or increasing the thickness of the insulation layer results in an decreasing U-value. The heat transfer coefficients are composed of a convective and a radiative part [2].

3 Types of thermal insulation

Thermal insulation is implemented as opaque or transparent constructional elements depending on the requirements. Opaque constructions can consist of evacuated or non-evacuated insulating elements. In the vacuum, the heat transfer mechanisms are restricted to the transport of energy through radiation. It is therefore possible to achieve better U-values in relation to the insulation layers thickness. The λ -value of an evacuated panel is five to six times smaller than that of non-evacuated insulation materials. Because of their high production cost, the use of evacuated panels is very limited.

Depending on the ambient temperatures, the heated up exterior surface of the wall leads to a reduced transmission loss or even to a transmission gain through the wall. In both cases the heating energy demand is reduced by the use of the transparent insulation construction. The gain energy per year and square meter area of transparent insulation amounts to 30-120 kWh.

4 Implementation types

Basically there are three possibilities for the positioning of the insulation layer within a structural element. These are external, internal and core thermal insulation. The external one is the most favorable one. The whole building is enclosed within a gapless thermal skin. Thermal bridging and the under-cooling of the buildings structures are avoided. A special form of external insulation is the perimeter insulation which encloses all structural elements having soil contact. The perimeter insulation is positioned vertically at the basement walls and horizontally under the basements floor outside the buildings sealing layer. It has to meet structural stability criteria and long-term endurance to moisture exposition. An example for external insulation is the integrated insulation systems, which are also called a thermal skin. It consists of an insulation layer, a reinforced layer and a final coating. The reinforced layer and the final coating protect the insulation material against mechanical stress and effects of weather [3].

The core insulation is positioned in the cavity of a wall. The cavity is either completely or partially filled

with the insulation material, leaving space for an air gap, which can be used as an additional insulating layer or to ventilate the cavity and hence quickens the drying of the insulation material. Disadvantages of this placement are that the building construction is under-cooled in winter and the hardly controllable difficulties related to thermal bridges. Furthermore, the summer overheating problem is increased by the reduction of the thermal capacity on the interior surfaces.

5 Material requirements

Insulation materials have to keep their shape durable and resistant against mould and parasites. The moisture balance of the construction has to be positive, i.e. the water accumulating inside the construction during the thawing period (winter) has to be removed to the exterior during the evaporating period (summer). The placement of a wind tight layer at the outer surface and an airtight on the inner surface prevent the insulation material from being perused with humid and warm room air from the inside or cold ambient air from the outside. Depending on the field of use, the insulation material has to suffice the safety requirements for fire protection.

Polystyrene insulation is a type of rigid foam insulation which is commonly used in residential and commercial settings. It has an exceptional ability to insulate against noise and extreme temperatures. It is also waterproof and long-lasting. These qualities combine to make polystyrene insulation an exceptionally useful product. Two types of polystyrene are used for insulation: expanded and extruded polystyrene. Expanded polystyrene, also called bead board, has a lower density than the extruded type and is less expensive, but also has slightly less insulating power. This is because of its coarse cells and the fact that they contain only air. Extruded polystyrene, due to the way in which it is made, has other qualities that make it a superior choice for insulation. It begins in the form of solid polystyrene crystals, which are combined with special additives and melted. In an extruder, the temperature and pressure are tightly controlled to convert the crystals into a thick plastic fluid. This liquid is then forced into a mold or dies. These interlocking foam formations are often made with hollow regions that can be filled with concrete which creates a grid of columns and beams when dry.

The materials for polystyrene insulation [4] are often quite expensive and can add approximately five to ten percent onto the cost of building a house. However, the savings on heating and cooling can allow the homeowner to recoup the extra cost over the structure life. The concrete grid in the insulation offers its own benefits apart from the polystyrene. These include being

impervious to many pests such as termites that can cause structural damage to an ordinary wood frame home if left unchecked.

As with any alternative building material, polystyrene insulation does have some disadvantages. Apart from the increased cost, it is also flammable and requires a fire-protective coating. It can also slightly degrade if exposed to sunlight or temperatures above 165 degrees Fahrenheit (74 degrees C). However, considering that most home insulation is never exposed to that type of temperature, it presents little practical risk. Expanded Polystyrene, or EPS for short, is a lightweight, rigid, plastic foam insulation material produced from solid beads of polystyrene (with a diameter of 0,2 to 0,3 mm). Expansion is achieved by virtue of small amounts of pentane gas dissolved into the polystyrene base material during production. The gas expands under the action of heat [5], applied as steam, to form perfectly closed cells of EPS. These cells occupy up to 50 times the volume of the original polystyrene bead. The EPS beads are then molded into appropriate forms suited to their application.

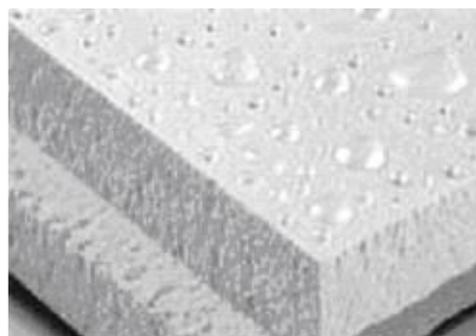


Fig. 1 Expanded Polystyrene (EPS)

There are 5 manufacturing stages:

1. Pre-expansion: polystyrene granules are expanded by free exposure to steam to form larger beads, each consisting of a series of non-interconnecting cells.
2. Conditioning: after expansion, the beads still contain small quantities of both condensed steam and pentane gas. As they cool, air gradually diffuses into the pores, replacing, in part, the other components.
3. Molding: the beads are molded to form boards, blocks or customized products. During molding, the steam causes fusion of each bead to its neighbors, thus forming a homogeneous product.
4. Shaping: following a short cooling period, the molded block is removed from the machine and after further conditioning, may be cut or shaped as required using hot wire elements or other appropriate techniques.
5. Post-production processing: the finished product can be laminated with foils, plastics, roofing felt, fiberboard or other facings such as roof or wall cladding

material.

Expanded polystyrene foam (EPS) is usually white. Some new innovative EPS products are grey due to the inclusion of graphite, which substantially increases the insulation performance. EPS is safe, non-toxic and inert.

6 The house walls modelling with finite element

As physical model for finite element analysis we use the window of residential house from Craiova, Romania. The real conditions of building wall execution were used as input data for heat transfer analysis.

Tab. 1 present the main dimensions for the layers made by different materials – external plaster including decorative paint, expanded polystyrene, Porotherm brick and interior plaster including paint.

Tab. 2 presents the material properties for all type of layers and Tab. 3 presents the temperature for inside of the wall and in exterior and the convection coefficient.



Fig. 2 The residential house used as real model

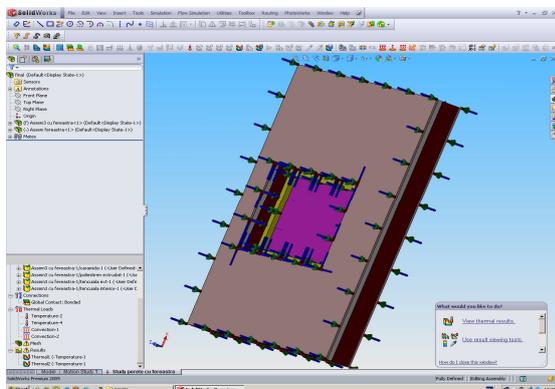


Fig. 3 The building wall modeled in SOLIDWORKS 2009 environment

Table 1 Dimensions for layers

No.	Type of layers	Width [mm]	Height [mm]
1	External Plaster	3000	2500
2	Polystyrene expanded EPS 20	3000	2500
3	Porotherm Brick	3000	2500
4	Interior Plaster	3000	2500
5	Glass 1	1360	860
6	Glass 2	1360	860
7	Air	1360	860
8	PVC	1500	1000

Table 2 Materials' properties

No.	Materials	Thermal conductivity [W/mK]	Thick-ness [m]	Mass Density kg/m ³	Specifi c heat [J/kgK]
1	Plaster exterior	0,93	0,02	1800	840
2	Polystyrene expanded EPS 20	0,029	0,05	30	1460
3	Brick Porotherm	0,8	0,2	1300	870
4	Plaster interior	0,93	0,02	1800	840
5	Glass	0,74976	0,004	2457,6	834,61
6	Air	0,027	0,004	1,1	1000
7	PVC	0,147	0,07	1300	1355

Table 3 Temperatures and convection coefficients

Interior Temperature [°C]	External Temperature [°C]	Interior Convection Coefficient α_i [W/m ² K]	Exterior Convection Coefficient α_e [W/m ² K]
20	-15	7	17
20	-15	7	17

7 Experimental data

Using SOLIDWORKS 2009, the thermal results are presented in the following figures.

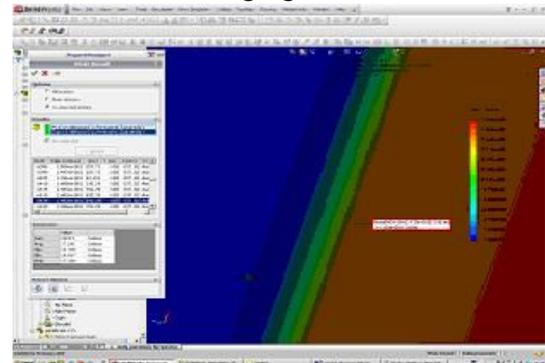


Fig. 4 The dew-point appears in interior of the brick in node 6424 (x=642.29, y=-1083, z=-337.82)

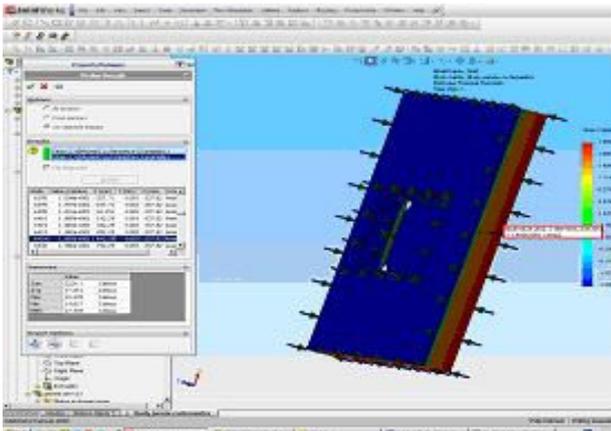


Fig. 5 The temperature map in all the layers of the wall

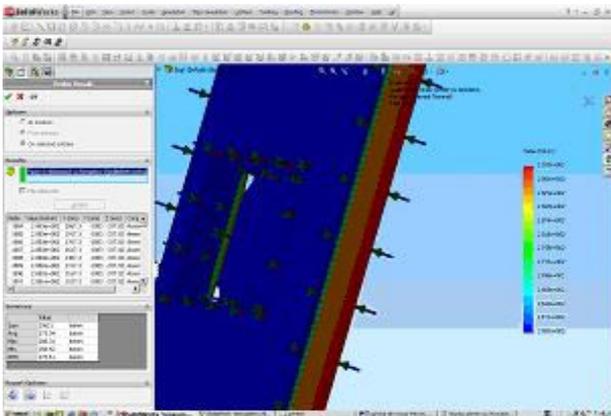


Fig. 6 The temperature of 14°C is obtained for the 1884-1891 nodes ($z=-333.82$)

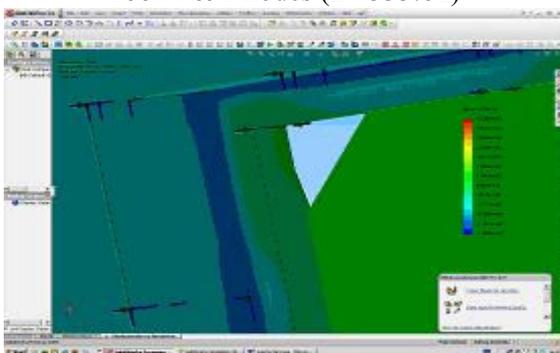


Fig. 7 The thermal bridge around the windows

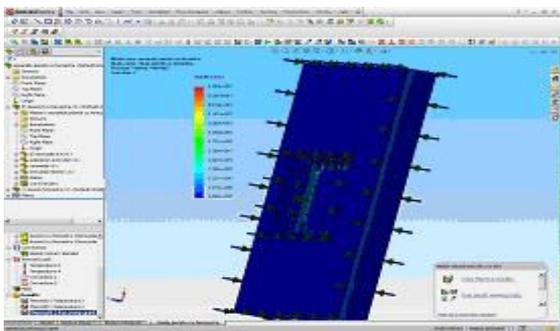


Fig. 8 The resultant gradient of temperature map

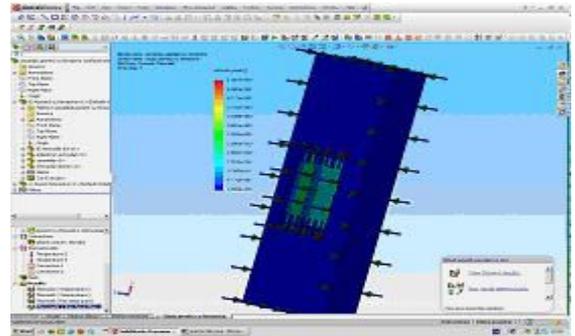


Fig. 9 The resulting heat flux on z axis

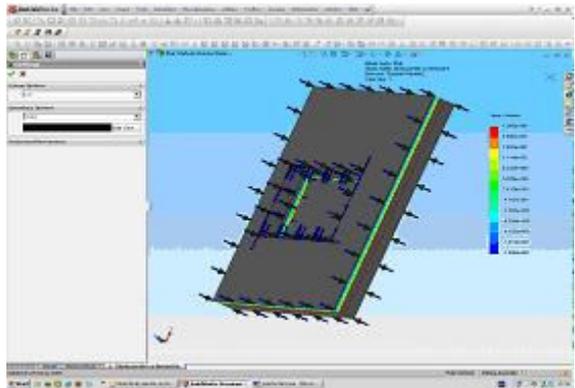


Fig. 10 The separation line between the layers from the wall and the distribution of the temperature in the exterior

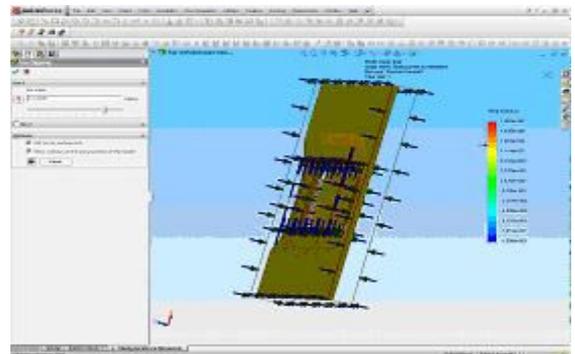


Fig. 11 The transversal plane where the dew-point occurs (interior of the brick)

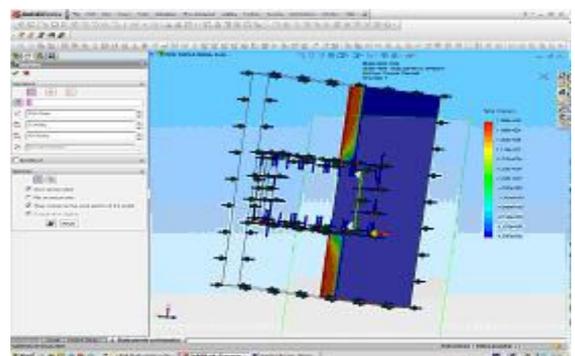


Fig. 12 The transversal section through the wall (wall-window)

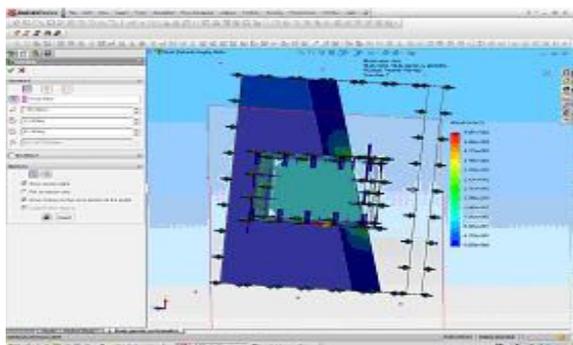


Fig. 13 The resultant heat flux in the plane
(-150.00, 14°, 57°)

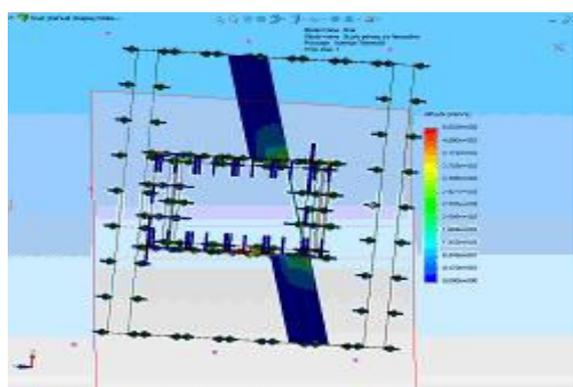


Fig. 14 Section with the resulting heat flux

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8 Results' interpretation

The dew-point, the temperature at which water vapor condenses, is located inside the brick layer, which leads to the possibility that condensation will collect in the walls, possibly freezing and causing damage.

The dew-point in brick cladding is typically in the interior of the cladding, increasing the chance that moisture will condense within the wall, possibly freezing and causing damage.

The thermal bridges occur around the windows due the bad insulation with EPS in those areas.

9 Conclusion

The important conclusion is that the EPS insulation has to be more than 5 cm, at least 8 cm for the dew-point migration from exterior of the brick to inside EPS cladding for better execution and exploitation.

For a winter in Southern East Europe such in Craiova, Romania, where the medium temperature is -10°, the negative influence of the dew-point occurring in the brick wall is maintained for 4 months annually. Even the quality of the Porotherm brick is very good as humidity resistance, in time the negative effects will appear.