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NUMERICAL SIMULATION OF HEAT AND MASS TRANSFER IN PERFORMANCE ASSESSMENT OF BUILDING ENVELOPE

BY

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Abstract. Energy performance of buildings is directly influenced by building envelope efficiency, that is on its turn affected by thermal bridging. World wide there are different appliances used for assessment of energy performance of buildings, that take into consideration thermal bridge effect by different degrees of accuracy, in order to obtain more realistic results.

This paper presents a detailed analysis of Energy Performance of Building Directive integration in Romanian National Building Codes and Legislation, with regards to thermal bridging. Furthermore, there are described study possibilities of heat and mass transfer by means of numerical simulation tools. Analysing the influence of using these numerical programs in thermal bridge assessment, and its share in the final results for energy efficiency, allows us to lay down some useful conclusions concerning the building energy certification and regulation activity and in pointing out future research directions.

Key words: energy performance of buildings (EPBD); energy efficiency; thermal bridge; numerical simulation tools.

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1. Introduction

Under the aspect of health and comfort a thermal bridge introduces an area with lower interior surface temperature, where the condensation of indoor moisture causes a high relative humidity, and furthermore the risk of mould growth (Gudum, 2008). A high energy efficiency of a building envelope becomes more difficult to achieve in situations where exterior insulation is not effective, resulting in increased heat flow at various locations, and therefore causing additional transmission losses (Erhorn *et al.*, 2010).

2. Thermal Bridges in the Energy Performance of Building Directive (EPBD) Context

2.1. EPBD

The main legislative instrument affecting energy performance in the EU building sector, EPB Directive has the objective to promote the improvement of the energy performance of buildings, taking into account outdoor climatic and local conditions, as well as indoor climate requirements and cost-effectiveness (EU, 2010).

The recast, approved May 19, 2010, improves the original directive by expanding its scope where the main potential lies, which is in existing buildings (ECEEE, 2010).

2.2. Thermal Bridges in EU Member States Regulations

In EU Member States, thermal bridges are taken into consideration in the energy performance assessment of new buildings, and also in the assessment of existing buildings that undergo major renovation.

European standards cover the calculation of thermal losses transmission; the multidimensional thermal transmission through thermal bridges is particularly covered by EN ISO 10211 with detailed calculations and EN ISO 14683 with simplified methods (Vandermarcke, 2006).

Although, according to European Committee for Standardization (CEN), CEN standards will be used as national standards, they are not mandatory and therefore the actually energy performance requirements come from the national building codes (Arkesteijn & Dijk, 2008).

There are a few methods to deal with the maximum value for thermal bridges in regulations. Specific requirements concerning the quality of building junctions are used in Germany for the dimensionless temperature factor, f_{Rsi}, in Denmark and Czech Republic, as a $\psi_{\max}$ value depending on the type of junction and in France, as a $\psi_{\max}$ value depending on the type of building (Citterio, 2008).

The quality control of details and the execution of building junctions are verified in some countries during the design phase of the building and on the construction site.

2.3. Integration of EPBD in Romanian National Building Codes

The leading measure in implementing the directive into national regulations is the energy certificate, compulsory for buildings when are constructed, sold or rented.

For this purpose the calculation procedures are defined in the "Thermal regulations" (C107-2005) and in the "Methodology of Calculation of the Energy Performance of Buildings Mc 001/part 1, 2, 3 – 2006" taking into account all CEN standards available and Romanian research activity results, both for new and existing buildings and also for residential and non-residential buildings (Dumitrescu, 2008).

Furthermore, for facilitating qualified experts activity in elaborating certificates, two national regulations will come in help: a "Catalogue of Thermal Bridges in Buildings" which comprises precalculated values of linear and punctual thermal transmittances for a very large number of details from new and existing buildings that undergo retrofitting processes, and a technical regulation will offer solutions for higher energy efficiency in what concerns the thermal insulating level of envelope.

3. Thermal Bridge Assessment by Numerical Simulation

3.1. Hygrothermal Performance Predictions on Building Envelope

The knowledge of the physical processes that define hygrothermal behaviour allows the prediction of a building response to climatic solicitation and the selection of envelope solutions that will lead to required feasibility (Ramos *et al.*, 2010).

In the field of building physics, software tools have been developed for evaluating building energy efficiency. The hygrothermal models included use of best available methods of analysis to simulate a particular physical process or building system.

Regarding the heat transfer through building enclosure there are some aspects that should be handled by using complex calculation methods: the multidimensional phenomenon, the transient behaviour and the moisture conditions (Santos & Mendes, 2006).

The three-dimensional simulation provides better prediction of envelope thermal transmittance than two-dimensional simulation by taking into consideration the effect of punctual thermal bridges, its use being recommended in order to obtain more accurate results in the study of multidimensional models.

The dynamic thermal behaviour of building components is generally neglected (Martin *et al.*, 2011). Though, since steady state conditions will currently be a rough approximation to reality, it is necessary to introduce into calculation the inertia of thermal bridges, by transient heat loads and variations of material properties with temperature, moisture content and age.

As for the third aspect, the moisture in the building envelope implies an additional mechanism of transport, absorbing or releasing latent heat of vaporization, that leads to poor thermal performance of the building enclosure, degradation of organic materials, structure deterioration and health risks (Qin *et al.*, 2006). Therefore, the investigation of the coupled transport processes of heat and mass in building envelope is important in order to determine where and when condensation occurs.

3.2 Numerical Simulation of a Three-dimensional Building Element for Heat Transfer

The following study analyses the growing impact of thermal bridges related to the improved energy performance of a building envelope. The main purpose of this analysis is to underline the influence of three-dimensional heat transfer in the building enclosure on its thermal transmittance and it is carried out by means of a steady-state simulation, performed by modelling with ANSYS 12 program.

In addition, the effects of thermal bridges are assessed in connection with the energy performance of the envelope.

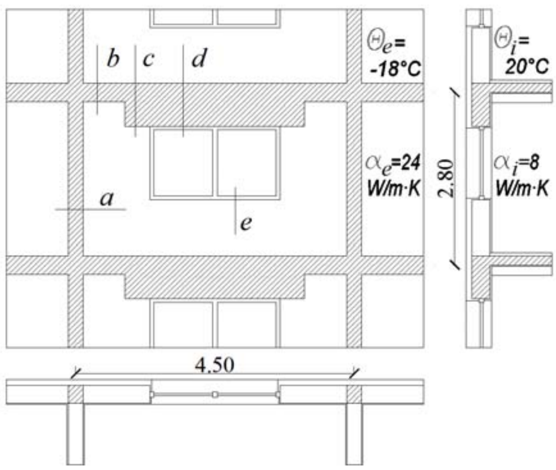

Fig. 1 – Three-dimensional element analysed by numerical simulation.

The model used for this study is a section of an external brick wall delimited by two intermediate floors and two interior walls.

Initially, the wall is protected on both sides only by renderings, and subsequently is retrofitted by applying exterior layers of extruded polystyrene with thicknesses from 2 to 20 cm. As a solution for thermal insulated window reveals, a 3 cm layer of insulation is used in all retrofitting situations, since the application of a higher performance thermal insulation could bring only small differences on linear thermal transmittances and interior surface temperatures (Willems & Schild, 2008).

Fig. 1 shows the physical domain of the analysed façade and the internal and external boundary conditions used in this application.

3.3. Results and Discussion

Towards an improvement of the buildings energy performance, the demands that must be attained are the satisfaction of required reference values and the optimization between alternative solutions.

The graph in Fig. 2 presents the variations of linear thermal transmittances for each of linear thermal bridges in the model analysed, as functions of insulation thickness. While thermal bridges at junctions of exterior wall with interior walls and floors (marked with *a*, *b*, *c*) become insignificant for maximum insulating level, the ones at window reveal area (marked with *d*, *e*) remain almost constant for more than 6 cm of insulation.

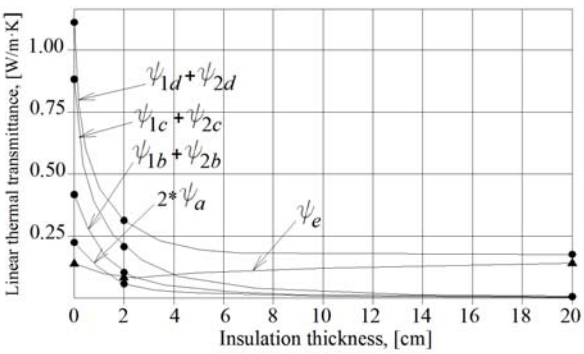

Fig. 2 – Linear thermal transmittance variation *vs.* insulation thickness.

The overall thermal transmittance of the envelope element, calculated with relation

$$U' = U + \sum \frac{\psi_i l_i}{A} + \sum \frac{\chi_j}{A}, \quad (1)$$

is illustrated in Fig. 3, where: U is the thermal transmittance of the wall for unidirectional heat flux, [W/m^2·K]; ψ_i – the linear thermal transmittance; χ_j – the punctual thermal transmittance; l_i – the length of linear thermal bridge; A – the area of the wall.

Regarding linear thermal bridges, their share on the overall thermal transmittance varies from 23% in the non-retrofitted case, to 36% in the highest energy efficiency case. It must be mentioned that those values are mostly on account of thermal bridges *b*, *c* and *d* in the first situation, respectively of thermal bridges d and e in the last situation.

The sinergetic effect of at least two linear thermal bridges by their junction in a punctual thermal bridge derives from the superposition of their thermal fields. In this case, the three-dimensional thermal transmittance, obtained from eq. (1) reaches an insignificant fraction from the *U'*-value, since for the area of a punctual thermal bridge are already considered the effects for each of the two linear thermal bridges.

A model of a similar wall, without window, changes the additional heat loss rate due to linear thermal bridges, from 10%, in the non-retrofitted case, to 1% in the highest energy efficiency case (Fig.4).

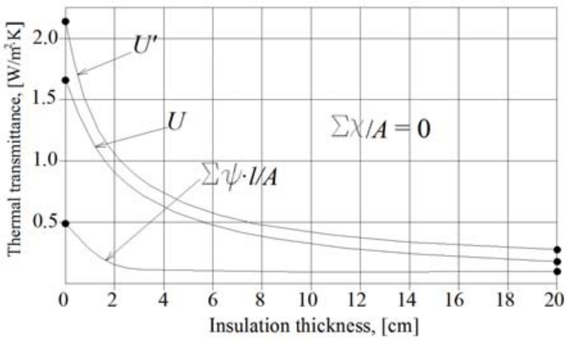

Fig. 3 – Thermal transmittance variation *vs.* insulation thickness (wall with window).

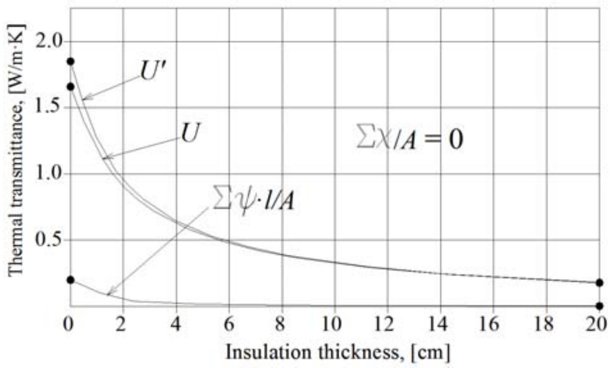

Fig. 4 – Thermal transmittance variation *vs.* insulation thickness (wall without window).

In order to evaluate the errors that a two-dimensional simulation inserts into calculation, in what concerns the interior surface temperatures, the temperature factor, f_{Rsi} , is determined for junction of exterior wall with floor, as shown in Fig. 5. The three-dimensional simulation reveals differences between f_{Rsi}^{2D} and f_{Rsi}^{3D} up to 12%.

Condensation problems are highlighted by comparing the dew point with surface temperature. From reasons of interior air quality there was established a lower limit of 30% and an upper limit of 70% relative air humidity. Following the graphic, the two temperature factor curves are recommending different minimum insulation thicknesses in order to prevent surface temperature to reach the dew point.

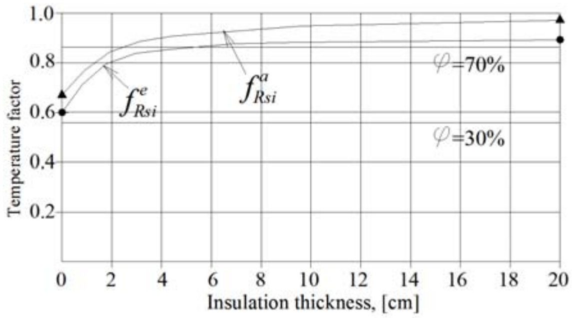

Fig. 5 – Temperature factor variation at a floor junction *vs.* insulation thickness.

Another set of limitations is obtained for relative air humidity at window reveal area. For a specific retrofitting solution Fig. 6 indicates the maximum allowable air humidity for preventing the dew point on interior window reveal area.

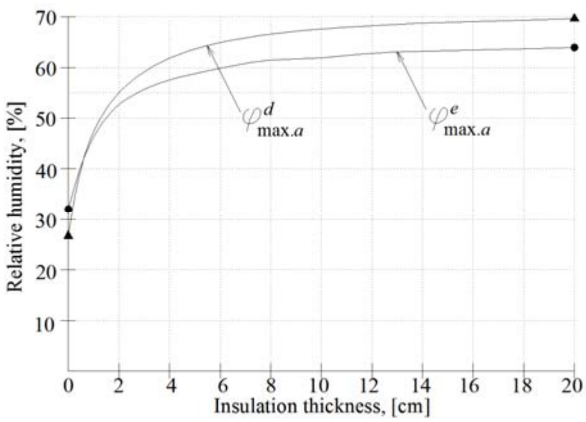

Fig. 6 – Maximum allowable air humidity *vs.* insulation thickness.

In the non-retrofitted situation there is a high probability of surface condensation in a common interior climate, but for more than 4 cm of insulation the dew point can be foreclosed if it is respected a more safe recommendation on thermal and respiratory comfort, which sets the upper limit of relative air humidity to 55%.

4. Conclusions

The approximations that are usually made in practice in the study of hygrothermal performance of building envelope imply the insertion of errors in calculation. However, the difficulty of assessing a thermal bridge by numerical simulation of a model, reproducing with precision the detail and the climate conditions from reality, makes this a time-consuming activity. Therefore, it might be motivated the use of a simplified model. To conclude, some recommendations are addressed for further work towards evaluating those errors and assuming them in calculation procedures.

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REFERENCES

Arkesteijn K., Dijk D., *Overview of the Practical Use of the CEN Standards (EPBD)*. Project Document, IEE CENSE, September 2008.

Citterio M., Cocco M., Erhorn-Kluttig H., *Thermal Bridges in the EPBD Context: Overview on MS Approaches in Regulations*. IEE ASIEPI Project, Information Paper P64, www.asiepi.eu.

Dumitrescu L., Simion A., Cocora O., *Implementation of the EPBD in Romania: Status and Planning – May 2008*. Country Reports, 2008, European Communities, Brussels, 175-181.

Erhorn H., Erhorn-Kluttig H., Citterio M., *An Effective Handling of Thermal Bridges in the EPBD Context*. Final Report of the IEE ASIEPI Work on Thermal Bridges, March 31, 2010.

Gudum C., *Evaluation of Thermal Bridges by Means of Numerical Simulation*. Nordic Symp. on Build. Phys. 2008, Copenhagen, Denmark, June 16-18, 2008.

Martin K., Erkoreka A., Flores I., Odriozola M., Sala J.M., *Problems in the Calculation of Thermal Bridges in Dynamic Conditions*. Energy and Buildings, **43**, 529-535 (2001).

Qin M., Belarbi R., Ait-Mokhtar A., Seigneurin A., *An Analytical Method to Calculate the Coupled Heat and Moisture Transfer in Building Materials*. Internat. Commun. in Heat and Mass Transfer, **33**, 39-48 (2006).

Ramos N.M.M., Delgado J.M.P.Q., Barriera E., Freitas V.P., *Hygrothermal Numerical Simulation: Application in Moisture Damage Prevention*. In: *Numerical Simulations – Examples and Applications in Computational Fluid Dynamics*, Angermann L., (Ed.), Intech, Rijeka, Croatia, 97-122.

Santos G.H., Mendes N., *Simultaneous Heat and Moisture Transfer in Soils Combined with Building Simulation*. Energy a. Build., **38**, 303-314 (2006).
Vandermarcke B., Schietecat J., Houvenaghel G., Orshoven D., Roels S., Janssens A., *Handling Thermal Bridges in the Context of the EPBD: Description of the Approach Developed in Belgium*. Proc. EPIC 2006 AIVC-Conf.: "Technologies and Sustainable Policies for a Radical Decrease of the Energy Consumption of Buildings", Lyon, France, November 20-22, 2006.
Willems W.M., Schild K., *Where to Use Vacuum Insulation ... and where not!*. Nordic Symp. on Building Phys., Copenhagen, Denmark, June 16-18, 2008.
* * * *Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the Energy Performance of Buildings*. The European Parliament and the Council of the European Union, Official Journal of the European Union, May 2010.
* * * *The Energy Performance of Buildings Directive (2010/131/EU)*. European Council for an Energy Efficient Economy, October 2010, www.eceee.org.

SIMULAREA NUMERICĂ A TRANSFERULUI TERMIC ŞI DE MASĂ ÎN EVALUAREA PERFORMANŢEI ANVELOPEI CLĂDIRILOR

(Rezumat)

Performanța energetică a clădirilor este direct influențată de eficiența anvelopei, care este la rândul ei afectată de prezența punților termice. La nivel mondial există numeroase instrumente de evaluare a performanței energetice a clădirilor, care iau in considerare efectele punților termice cu diferite grade de precizie, cu scopul de a obține rezultate cât mai realiste.

Această lucrare prezintă o analiză detaliată a integrării Directivei Performanței Energetice în Construcții în legislația şi normativele româneşti, cu privire la punțile termice. Mai mult, sunt descrise posibilități de studiu al transferului termic şi de masă cu ajutorul simulării numerice. Analiza influenței utilizării acestor programe numerice în evaluarea punților termice şi ponderea lor în rezultatele finale ale eficienței energetice permit formularea unor concluzii utile în activitatea de certificare energetică şi reglementare în domeniul construcțiilor şi pentru dezvoltarea unor noi direcții de cercetare.