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Exterior thermal insulation systems for AAC building envelopes: Computational analysis aimed at increasing service life

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ABSTRACT

A computational analysis aimed at increasing service life of exterior thermal insulation systems suitable for building envelopes based on autoclaved aerated concrete (AAC) in the climatic conditions of Central Europe is presented. In the first step, a sensitivity analysis of the effect of hygric parameters of materials involved in thermal insulation systems on the hygrothermal performance of AAC envelopes is accomplished, in order to identify appropriate ranges of their values. Computational simulations of temperature and moisture fields in AAC building envelopes are then performed, using proper combinations of properties of exterior layers. The results are evaluated from the point of view of frost resistance of the whole building envelope, and the appropriate values of hygric properties of thermal insulation layer and exterior plaster are identified. Finally, prospective types of materials suitable for the investigated thermal insulation system are proposed.

1. Introduction

Besides the load bearing capability which, obviously, will always remain the most important factor in construction design, the thermal insulation solutions present nowadays one of the key factors for assessment of material composition of building envelopes [1,2]. One of the main design objectives is thus to reach thermal insulation properties as good as possible. This can easily be accomplished using thermal insulation layer whereas the most important decision is to choose a proper insulation material. Thickness of thermal insulation layer is then calculated according to appropriate standards.

However, taking into account also other points of view such as hygric properties or hygrothermal performance, one can notice that a designed envelope may not be as perfect as it seemed before. Inappropriate material combination can lead to accumulation of moisture inside the material and water condensation consequently. If the moisture-related problems are combined with the effects of temperature, such as water freezing/thawing in the pore system, the end result can be early destruction of some materials or at least significant decrease of durability of building envelope.

One of the current trends in building industry is to use new materials with better thermal insulating properties which make possible to avoid thermal insulation layers in building envelope and reach financial savings in that way. A typical material of this kind is autoclaved aerated concrete (AAC) [3,4]. Despite the current availability of many advanced AAC products on the European market [5], an extensive research is still in progress, aimed at the improvement of thermal, hygric and mechanical parameters of AAC. The innovations in AAC composition are being sought for instance by using hydrophobic agents [6], natural zeolites [7], or various waste materials such as bottom ash [8,9], silica fume [10], gasification residues [11], clayey waste [12], and fly ash from cellulose industry [13].

The valid Czech standard ČSN EN 73 0540-2 [14] requires for vertical walls the overall heat transfer coefficient (*U*-value) of 0.38 W/m^2 K but recommends 0.25 W/m^2 K. Nowadays, many current AAC materials available on the European market in the dry state safely meet this requirement, so that they are allowed to be used in single-layer masonry without thermal insulation. Some AAC products meet in the dry state even the recommended *U* value. However, the requirements of European standards on thermal protection of buildings are steadily increasing during the last years. For instance, last updating of British Approved document L1A [15] requires the *U*-value of 0.25 W/m^2 K. The proposal of updated ČSN EN 73 0540-2 which is to be issued before the end of 2011 decreases the required *U* value for vertical walls to 0.30 W/m^2 K and specifies the target *U* values for passive houses within 0.18–0.12 W/m^2 K. While the more stringent requirements on vertical walls of common buildings can still be met using the current assortment of AAC products, perhaps with some slight adjustments, the very low *U* values recommended for passive houses make the application of single-layer AAC masonry in this particular segment of building market rather difficult.

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Thermal insulation systems are currently not applied for AAC-based building envelopes, mainly because their use is not supported by major AAC producers. However, taking into account the increasing demand for reducing thermal loss of buildings, which persists in Europe at least since the energy crisis in 1970s, a situation may arise in a not very distant future when for AAC walls the recommended *U*-values might be achievable only with unrealistic masonry thickness. Therefore, a study of the applicability of thermal insulation systems in AAC-based building envelopes seems to be timely at present. An additional argument for such an analysis is the still unresolved problem of the hygric behavior of AAC walls, which the current standards do not take into account, and the related problem of their real service life.

2. Previous work on the service life assessment of AAC-based building envelopes

Precise analyses of hygrothermal performance of AAC-based building envelopes based on sound scientific knowledge were not performed very frequently to date. The experimental work presented in [3,16] and computational analyses reported in [17–20] belong to the few exceptions. As showed by the results reported in [17], the service life of simple AAC wall without any finishes was relatively short because of exposition to high moisture straining and freezing of condensed water which in the conditions of Central Europe could be realized as much as 19 times per a reference year. The first signs of material damage could then occur already after 2 years. So, it was confirmed necessary to provide AAC block with a suitable external finish in order to eliminate the amount of incoming moisture. However, with respect to very specific hygric behavior of AAC the common plasters could not be used, because service life of that building envelope would be very limited. For instance, hygrothermal simulation of AAC masonry provided with common lime plaster showed even higher accumulation of moisture inside the wall and the higher number of freezing cycles in AAC than in unplastered wall. The first sign of damage would occur before the second year. Apparently, it was this fact that led in the past years to the development of specific plasters designed especially for AAC. For example, hygrothermal performance of AAC masonry provided with MVR Uni, which is specific plaster developed for AAC by Baumit Ltd., was entirely sufficient and there were not any freezing cycles in whole envelope during a reference year in Central Europe. Common thermal insulation systems improved thermal properties of envelope and protected well AAC against the effect of climatic conditions [17] but the exterior plaster was found to be exposed to abnormal straining. Its service life was then limited to 6 or 7 years.

In this paper we present a computational analysis aimed at the identification of appropriate properties of thermal insulation material and exterior plaster which are supposed to be used in AAC-based building envelopes. Based on the results of this analysis, a new AAC-specific thermal insulation system can be developed. Thanks to that, reliable protection of AAC against the effect of climatic straining can be accomplished and simultaneously the service life of exterior plaster can be extended.

3. Methods of computational analysis

Building envelopes always behave as systems. Therefore, the properties of the parts of the system, of the particular materials, have to be compatible. It is not sufficient to develop and employ one excellent material, but it is necessary to develop a working multi-layered systems consisting of different materials. This is the most important feature of any computational design of a building envelope from the point of view of building physics. In

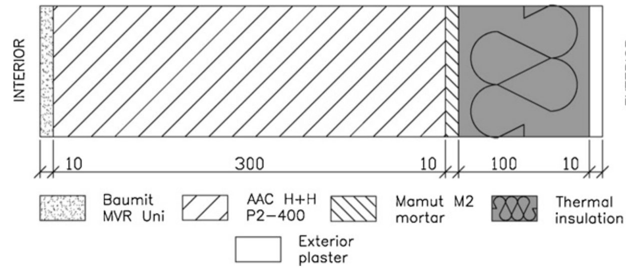

Fig. 1. Scheme of investigated building envelope.

the particular case solved in this paper, we considered a system consisting of internal plaster, load-bearing structure, connecting layer, thermal insulation layer, and external plaster. The studied system is composed of a fundamental part, which is supposed to be fixed in the computational analysis, and a free part, whose properties are subject of variations within chosen limits. In our case, the fundamental part consisted of an AAC layer (P2-400 produced by H+H was chosen as a typical representative of AAC blocks currently used in Europe), internal plaster (Baumit MVR Uni as a material known to perform reasonably in the previous studies) and connecting layer (Mamut M2 mortar, also known from previous analyses); thermal insulation layer and external plaster formed the free part (Fig. 1). The envelope is oriented to the south.

The hygric, thermal and basic physical properties of materials presented in Fig. 1 are shown in Table 1, where the following symbols are used: ρ – bulk density (kg/m^3), ψ – porosity (%), c – specific heat capacity (J/kg K), μ – water vapor diffusion resistance factor (–), λ_{dry} – thermal conductivity in dry state (W/m K), λ_{sat} – thermal conductivity in water saturated state (W/m K), κ_{av} – average value of moisture diffusivity (m^2/s), w_{hyg} – maximum hygroscopic moisture content by volume (m^3/m^3). For AAC, interior plaster and connecting layer, the data of hygric, thermal and basic physical properties were taken from [5]. The properties of thermal insulation layer and external plaster were subject of computational analysis. Some of these properties were prescribed in advance. For the bulk density, open porosity, and specific heat capacity the values characteristic for thermal insulation materials and plasters were chosen. The thermal conductivity was supposed to conform to the common requirements for the analyzed types of materials. The main hygric parameters of the thermal insulation layer and external plaster, namely the water vapor diffusion resistance factor, moisture diffusivity and maximum hygroscopic moisture content were considered free parameters in the computational analysis. The reason for this choice was the principal role of hygric parameters of both thermal insulation material and exterior plaster in the service life of exterior plasters which was revealed in the previous analysis reported in [17].

The computer simulation tool HEMOT [21] was used in the calculations, which was developed at the Department of Materials Engineering and Chemistry, Faculty of Civil Engineering, Czech Technical University in Prague and can be used to solve 1D or 2D transport problems. In this paper, the investigated building envelope was solved as 1D model. The construction of the code is based on the application of the general finite element computer simulation tool SIFEL (SImple Finite ELements) [22]. The moisture and heat balance equations were formulated in the simplified form proposed by Kuenzel [23]. This model has already been verified and successfully applied in many hygrothermal simulations before [5,24,25].

In service-life aimed analyses, the calculations should be done for the conditions as close as possible to the real conditions on building site. Therefore, hourly values of meteorological data in the form of a reference year for Prague, Czech Republic, were used as