Abstract: Computational analysis of hygrothermal performance of several building envelopes based on autoclaved aerated concrete (AAC) is presented in the paper. Based on the knowledge of thermal and hygric conditions inside the building envelope, the energy balance calculations assuming the effect of moisture content are accomplished. All the material parameters necessary for the calculations are measured within the experimental analysis preceding the computations. As boundary conditions, climatic data in form of reference year are used. The obtained results are compared and conclusions are drawn.

Key-Words: AAC, building envelope, hygrothermal performance, heat and moisture transport, energy balance, mineral wool

1 Introduction
Calculations of energy balance of building envelopes or their parts can be performed in many ways. The accuracy of obtained results depends on quality and quantity of input parameters and methods of their processing. For instance standard procedure presented in Czech thermal standard [1-2] should provide simple calculation in order to be easily used by designers. However, the simplifications have side effect in form of inaccuracies, because only simple Glaser’s model is used and thus whole liquid moisture intake and transport is neglected. It is generally known that thermal conductivity is highly dependent on moisture content [3], especially when thermal insulations are under consideration [4-5]. Although this standard obtains design values of thermal conductivity assuming certain moisture content, under real conditions this amount can be much higher as well as subsequent heat losses. It is important to perform the calculations precisely in order to get as accurate results as possible. That means that a complete set of thermal and hygric material parameters should be used, as well as realistic boundary conditions in form of climatic data.

Besides mechanical parameters of building materials, also their thermal insulating properties play currently very important role. The reason is very simple, because energy prices are very high and exhaustibility of nonrenewable energy resources threatens the society. That explains present efforts to achieve energy savings in building industry, which is one of the largest energy consumers in EU [6]. It can be achieved using modern building materials with better thermal insulating skills such as autoclaved aerated concrete (AAC). Combination of this material with common thermal insulations will create building envelopes with excellent thermal insulating capabilities and helps to reach required energy savings, because substantial share of energy is consumed by heating [7]. However, it is important to pay attention to their hygrothermal performance, so insulating materials have to be chosen wisely [8] and mineral wool seems to be the most appropriate solution.

The main objective of this paper is to assess energy balance of AAC based building envelope provided from exterior and interior with several types of mineral wools according to the results of numerical simulation assuming presence and transport of liquid moisture under real climatic conditions.

2 Computational Analysis
The computational analysis was performed using computer code HEMOT [9-10], which was developed at Department of Materials Engineering and Chemistry, Faculty of Civil Engineering, Czech Technical University in Prague. This code is an extension of program package SIFEL [11] and allows a user to utilize its user-friendly interface to define all the necessary input parameters, such as mathematical model, scheme of analyzed
construction detail, initial and boundary conditions or time specification of calculations. Within the framework of this paper, Künzel’s mathematical model for coupled heat and moisture transport [12] was used. This model was successfully verified [13] and used in the previous researches [14-15].

2.1 Scheme of construction details

As load bearing material, AAC P2-350 in a thickness of 450 mm was assumed. This wall was provided with external and internal thermal insulating system consisting of 100 mm thick layer of hydrophobic/hydrophilic mineral wool connected using 10 mm thick adhesive layer. As external and internal finishes, MVR Uni plaster (10 mm) was used. This plaster was developed especially for AAC-based constructions. As reference building envelope, only AAC wall with MVR Uni plaster was defined. All the variations of building envelope are captured in Fig. 1.

![Fig. 1: Scheme of analyzed building envelopes](image)

2.2 Material parameters

All the parameters of materials which are involved in analyzed building envelopes were measured in the laboratories of the Department of Materials Engineering and Chemistry, Faculty of Civil Engineering, Czech Technical University in Prague [16-19]. These parameters are summarized in Tables 1-2, where following symbols are used: \( \rho \) – bulk density \([\text{kg/m}^3]\), \( \psi \) – porosity \([\%]\), \( c \) – specific heat capacity \([\text{J/(kg K)}]\), \( \mu \) – water vapor diffusion resistance factor \([-]\), \( \lambda_{\text{dry}} \) – thermal conductivity in dry state \([\text{W/(m K)}]\), \( \lambda_{\text{sat}} \) – thermal conductivity in water saturated state \([\text{W/(m K)}]\), \( \kappa_{\text{app}} \) – apparent moisture diffusivity \([\text{m}^2/\text{s}]\), \( w_{\text{hyg}} \) – hygroscopic moisture content \([\text{m}^3/\text{m}^3]\).

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2.3 Initial and boundary conditions

Initial and boundary conditions should be as realistic as possible in order to achieve the most accurate results. For this reason, climatic data for Prague was used on exterior side of analyzed building envelope in the form of reference year. Reference climatic year contains averaged long-term hourly values of temperature, relative humidity, wind direction and velocity, rainfalls and several kinds of sun radiation. It was generated using METEONORM software [20]. On the interior
side, constant temperature 21 °C and relative humidity 55 % was used. These data are prescribed in Czech thermal standard CSN 73 0540-3 Thermal protection of buildings – Design value quantities [2].

2.4 Methodology of energy balance calculations

Energy balance of analyzed building envelopes was calculated on the basis of computational results. The results were obtained in form of hourly values of temperature and moisture content in any point of construction. In the first step, heat flux through the envelope was calculated according to

\[ q = \lambda(w) \frac{dT}{dx} \]  \hspace{1cm} (1)

where \( q \) is heat flux [W/m²], \( \lambda(w) \) is thermal conductivity depending on moisture content [W/(m K)], \( dT \) is temperature difference between two nodal values [K] and \( dx \) is distance of these nodes [m]. The nodes were chosen on interior side, because the simulations were not performed in steady state and values of temperature and moisture content near the interior side of building envelope were much stable because of constant boundary conditions on this side.

After hourly values of heat flux were calculated, integration of time function of heat flux (Eq. 2) provided the energy balance per one square meter of envelope and chosen time period, one year for instance,

\[ Q = \int q(t) \, dt, \]  \hspace{1cm} (2)

where \( Q \) is energy balance per certain time period [kWh/m²], \( q(t) \) is time function of heat flux [W/m²] and \( t \) is time [h].

3 Computational Results and Discussion

All the results are related to the third year of computational simulation. Plus sign of heat flux denotes heat loss, minus sign denotes heat gain. In the presented figures and tables the following shortcuts are used: HFOBext - hydrophobic mineral wool applied on exterior side, HFOBint – hydrophobic mineral wool applied on interior side, HFILext – hydrophilic mineral wool applied on exterior side, HFILint – hydrophilic mineral wool applied on interior side and REF – reference building envelope without thermal insulating system.

Comparison of time functions of heat fluxes of building envelopes with external insulation systems is shown in Fig. 2. Also time function of heat flux of reference building envelope without thermal insulation is included.

![Fig. 2: Time function of heat flux – external thermal insulating system](image)

It is obvious from Fig. 2 that the highest heat flux is obtained when thermal insulation is missing. Building envelope provided with hydrophilic mineral wool has not as good thermal insulating properties as building envelope with hydrophobic mineral wool, because the heat flux is much higher. Main reason of this fact is easy moisture acceptance of hydrophilic mineral wool and subsequent quick moisture transport (\( \kappa = 2.07 \times 10^7 \text{ m}^2/\text{s} \)) which leads to worsening of its thermal conductivity (see \( \lambda_{dry} \) and \( \lambda_{sat} \) in Table 2). Thanks to hydrophobic agents contained in hydrophobic mineral wool, this material is kept in relatively dry state all the time, which ensures preservation of its excellent thermal insulating capabilities.

Annual and monthly energy balance of AAC-based building envelopes provided from exterior with different types of mineral wool is shown in Fig. 3. While hydrophobic mineral wool improves monthly energy balance of AAC-based building envelope approximately by 26-39 %, hydrophilic mineral wool does not provide such good results. In warm summer months, July and August, energy balance of building envelope with hydrophilic mineral wool was even worse by 34 and 54 %,
respectively, than reference envelope. It is caused by number of rainfalls characteristic for this period of year, which significantly decreases thermal insulating capability of hydrophilic mineral wool.

Based on results presented in Fig. 3 one can realize that hydrophilic mineral wool in not suitable for application in exterior or it has to be carefully protected against moisture intake.

Protection against moisture is also effective, when internal thermal insulating systems are used. In Fig. 4, time functions of heat fluxes of building envelopes with this type of thermal insulation system are presented together with reference building envelope. Heat fluxes of both provided building envelopes are very similar, but hydrophobic mineral wool gives slightly better results. Similarly to the previous case, presence of hydrophobic agents plays a significant role here.

Thermal performance of building envelope with hydrophilic mineral wool is much better in this case and leads to the improvement of energy balance approximately by 29 %. However, better energy balance is achieved again, when hydrophobic mineral wool is assumed (37 %). Complete monthly energy balance of building envelopes with internal thermal insulating system is shown in Fig. 5.

Comparison of annual energy balances of all investigated variations of building envelopes is shown in Fig. 6 and Table 3. According to the results, best energy balance is achieved when hydrophobic mineral wool is assumed and it does not matter whether on external or internal side of building envelope. Presence of hydrophobic agents protects mineral wool against liquid moisture intake, thus only water vapor, which does not have significant influence on thermal properties, is transported mainly. Slightly better energy balance is even achieved when internal thermal insulating system is assumed. It can be explained by combination of especially developed MVR Uni plaster with AAC, which was already confirmed before [21] and which effectively works together when exposed to weather conditions.
While position of hydrophobic mineral wool in composition of building envelope is not decisive, the right placement of hydrophilic mineral wool is crucial factor of its correct function. When it is exposed to effects of weather conditions - that means on exterior side - it is necessary to protect it against increased moisture intake, for instance using special plasters with low moisture diffusivity and low water vapor diffusion resistance factor allowing fast water evaporation. More advantageous application of hydrophilic mineral wool seems to be as internal thermal insulating system. Even if this type of insulation is not as common as external, its application is also possible and has been already studied and verified [22-24].

4 Conclusions

Energy balance of several types of AAC-based building envelopes based on results of computational analysis was performed. Unlike standard procedure of energy balance calculations, application of computational analysis gives more precise results because a broader set of input parameters is used and in particular, liquid water intake and transport is not neglected. As a disadvantage of this method, one can consider the demanding experimental analysis which requires experimental equipment and takes lot of time. However, the more accurate results which are obtained are sufficient counterbalance.

Energy balance of five variations of building envelopes was compared, namely AAC provided with external and internal thermal insulating system based on hydrophobic and hydrophilic mineral wool and reference building envelope without any thermal insulation.

Better energy performance was achieved when hydrophobic mineral wool was assumed. From the point of view of energy balance, application of hydrophilic mineral wool cannot be recommended on exterior side of building envelope, unless proper protection against moisture is done. In other case, this type of mineral wool should be used on interior side, where provides better thermal insulating function.

It is also important to mention, energy balance is not only single decisive factor during a design of building envelope. It is necessary to focus on several other properties concurrently, such as proper hygrothermal behavior, mechanical properties or economical aspects.

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References:


