A Testing Ground for Measuring Influence of Building Envelope Materials on Energy Efficiency and Indoor Environment

Ilze Dimdiņa[#1*], Andris Jakovičs[#2], Staņislavs Gendelis[#3], Jānis Kļaviņš[#4]

[#]*Laboratory for mathematical modelling of environmental and technological processes, Faculty of physics and mathematics, University of Latvia*
Zellu str. 8, Riga, LV-1002, Latvia

[1]ilze.dimdina@gmail.com

[2]andris.jakovics@lu.lv

[3]stanislavs.gendelis@lu.lv

[4]janis.klavins@lode.lv

[*]*Faculty of Civil Engineering, Riga Technical University*
Azenes str. 16/20, LV-1048, Riga, Latvia

Abstract

We present an ongoing project where five identical experimental constructions with external walls of different composite building materials have been created (the indoor area 9 m^2, the height of ceiling 3 m). All external wall constructions (U=0.16 W/(m^{2}K)) have ventilated façades. Five different insulated materials are used: aerated concrete, ceramic, lightweight concrete, wooden constructions and an innovative composite building material developed in the course of the project. To provide identical thermal performance of the constructions, infrared **(***EN 13187) and fan pressurization (EN 13829) tests will be performed. In all the experimental constructions it is planned to ensure air exchange of 0.6 h^{-1} and indoor air temperature corresponding to category A (EN 15251), while keeping the HVAC system solution identical.*

To analyze the energy efficiency parameters and the quality of indoor environment, outdoor parameters, indoor air quality, and thermal environment parameters will be measured. The monitoring will continue for a whole year, in order to evaluate and analyze the influence of different outdoor parameters in the natural meteorological conditions for Riga, Latvia, which correspond to cold maritime climate. The collected energy efficiency data and the quality of indoor environment parameters will be used to verify a corresponding multi-physical model. The project aim is, by using a multi-physical modelling method, to forecast the influence of different building envelope materials on energy efficiency and the quality of indoor environment.

Keywords - energy efficiency; indoor environment quality; composite building materials; multi-physical modelling; experimental verification

1. Introduction

The aim of the project is to develop a building design based on a multi-physical model of the building's energy efficiency (EE) and indoor environment quality (IEQ) that allows virtually simulating the experimental design of buildings in different climatic conditions. The development of the model will simplify and facilitate new structural solutions and building designs, economically optimal design solutions, building maintenance durability, reduction of environmental impact, improved indoor climate and the corresponding improvement in human health and well-being, which, in turn, should increase labour productivity, and lead to other benefits [1].

This paper presents a current EE and IEQ monitoring project carried out at University of Latvia. It describes the design and engineering solutions of the experimental constructions, the innovative aspects of the building design and the building materials used, and the planned microclimate parameter measurements.

The choice of the building materials for the walls of the five experimental constructions was based on the two main criteria: (a) they should be produced from locally available resources and (b) be high-quality insulation materials. During the project an innovative solution of light building construction was developed, and an experimental composition of a building material was created. The experimental constructions were completed by the beginning of the heating season to ensure the commencement and implementation of monitoring measurements at least within one the calendar year for the duration of the current project. The expected outdoor and indoor air parameters and energy consumption monitoring data will provide an opportunity to analyze the buildings, in which five different construction materials have been used. These data will be employed for verification of a multi-physical model.

Similar studies testing the effects of different building design solutions and materials on energy consumption and indoor climate were performed in Spain, by a group of researchers "GREA Innovació Concurrent" [2]. Complex EE and IEQ studies are mostly done by testing the existing buildings [3], or by modelling, with short-time experimental measurement for the model verification [4].

2. Requirements for the Testing Ground

In the framework of the project, five experimental constructions with different building envelope materials (type A, B, C, D, E) were built, identical in terms of design, geographic location, and engineering solutions.

The building design provides solutions for reduction or elimination of thermal bridges. For all types of exterior wall constructions, the U-value equals 0.16 W/(m^2K), calculated according to the standard (EN ISO 6946).

The indoor environment parameters in typical outdoor climate conditions in the work area must meet the class A for office space requirements (CR 1752, EN 15251): indoor temperature in summer should be 24.5°C ± 1.0°C (at the air velocity 0.18 m/s), in winter -22.0°C ± 1.0°C (at the air velocity 0.15 m/s); relative humidity 30÷70%; noise level ≤30 dB(A); continuous constant exchange of air at a rate of 0.6 h^{-1} must be ensured indoors. It means that for a room of 27 m^3 it is necessary to supply and exhaust 16.2 m^3/h of air.

During the project, measurements of the outdoor air and indoor climate parameters (e.g., temperature, relative humidity, air flow rate, etc.) as well as the energy consumption of each construction will be collected.

The architectural solutions of the experimental constructions provide a simple, easily modelled and symmetrical layout of the interior design and the engineering systems.

3. Constructive Solutions of the Experimental Constructions

The experimental constructions are localized in an urban environment, under natural conditions in Riga, Latvia, characterized by cold, maritime climate (duration of the average heating period of 203 days, the average outdoor air temperature during the heating period is 0.0°C, the coldest five-day average temperature is -20.7°C, the average annual air temperature is 6.2°C, the daily average relative humidity is 79% [5]).

The selected location is the territory of the University Botanical garden. All five experimental constructions are equally placed in terms of their orientation (both in relation to the sun and the surrounding shading objects (such as trees), as shown in Fig. 1).

1) 2)

Fig. 1 The location of experimental constructions: 1) area; 2) orientation

The experimental constructions are designed in a way to minimize differences in output data of energy consumption and indoor climate measurement data analysis and interpretation. Each experimental construction imitates a free-standing building with an interior room (3×3 m

= 9 m^2 floor area, ceiling height of 3 m) with a window and a front door (see Fig. 2). Each building is placed on pillars and has no contact with the ground. To prevent thermal bridges, window and door installations have been taken out to the insulation layer.

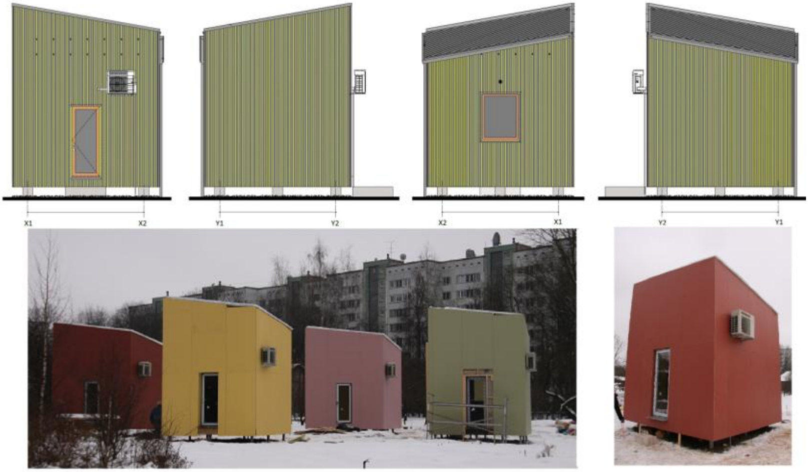

Fig. 2 The experimental constructions design

The basic materials used for the ventilated facade exterior wall construction are (see Figure 3 for the materials and construction process):

1) type A – ceramic blocks (440 mm);
2) type B – aerated concrete blocks (375 mm);
3) type C – experimental insulated birch plywood frame and wood wool slab (296 mm);
4) type D – experimental ceramic blocks with filled cavities (500 mm);
5) type E – glued timber beams (200 mm).

Two innovative solutions were developed and are being experimentally tested during this project:

- type C - plywood frame construction with a mineral wool cladding, the building frame assembly solution of experimental construction, as shown in Fig. 4;
- type D - experimental ceramic blocks with filled cavities (thickness 500 mm). The modelling and analysis of the thermal conductivity of the experimental blocks with a variety of fillings have been implemented earlier in the framework of the project [6].

The layers of different types of building envelopes and the thickness of the layers are summarized in Table 1. The test constructions' design and engineering solutions in cross section are provided in Fig. 5.

Fig. 3 Exterior wall base construction materials and construction process (type A, B, C, D, E)


Fig. 4 Plywood frame structure installation design (type C)

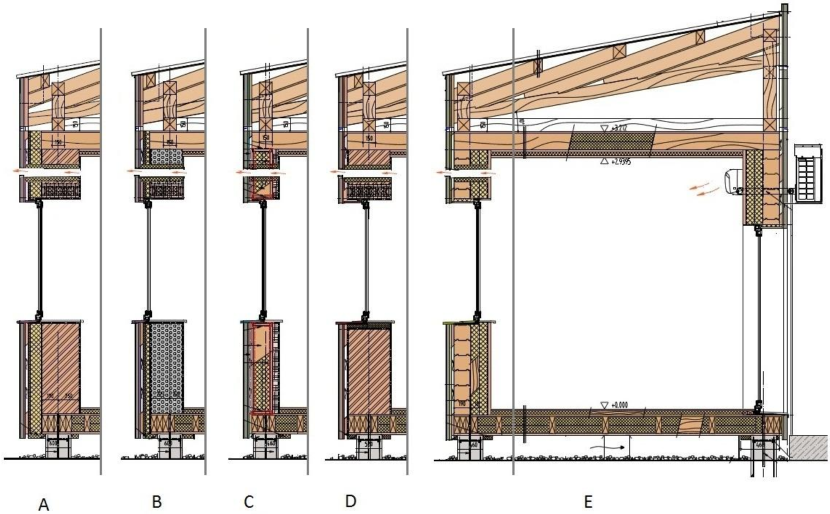

Fig. 5 The experimental construction design and engineering solutions in cross section (type A, B, C, D, E)

Table 1. Exterior wall construction materials and layer thickness (mm)

<table>
<tr><td>Type A (701.5)</td><td>Type B (561.5)</td><td>Type C (387.5)</td><td>Type D (606.5)</td><td>Type E (516.5)</td></tr>
<tr><td colspan="5">Outer finishing - timber siding (40)</td></tr>
<tr><td colspan="5">Plywood covering plate (6.5)</td></tr>
<tr><td colspan="5">Air/ vertical timber lathing (30)</td></tr>
<tr><td colspan="2">Sheathing board (30)</td><td rowspan="5">Plywood frame / insulation (21/(100+100))</td><td rowspan="2">Lime-cement plaster (15)</td><td rowspan="3">Glued timber beams (200)</td></tr>
<tr><td rowspan="2">Insulation / horizontal timber lathing (125)</td><td rowspan="2">Insulation / horizontal timber lathing (50)</td></tr>
<tr><td rowspan="5">Experimental ceramic blocks with filled cavities (500)</td></tr>
<tr><td>Lime-cement plaster (15)</td><td>Lime-cement plaster (15)</td><td>Insulation / horizontal timber lathing (100)</td></tr>
<tr><td rowspan="3">Ceramic blocks (440)</td><td rowspan="3">Aerated concrete blocks (375)</td><td rowspan="2">Insulation / vertical timber lathing (100)</td></tr>
<tr><td rowspan="2">Wood wool slab (75)</td></tr>
<tr><td>Vapour barrier</td></tr>
<tr><td colspan="4">Internal finishing – lime-cement plaster (15)</td><td>Internal finishing – vertical timber siding (40)</td></tr>
</table>

4. Regulation of Indoor Air Quality

To ensure the indoor environment microclimate parameters - temperature, relative humidity and air exchange, every experimental construction has been fitted with an air conditioning unit (heat pump with an additional option to provide fresh and moisturized supply air). The performance characteristics of the device are the following: cooling capacity 2.8 kW; heating capacity 3.6 kW; the continuous outdoor air supply to the room minimum 24 or maximum of 32 m^3/h; the supply air humidification to 400 ml/h (at room temperature 20°CDB, outdoor air temperature 7°CDB/6°CWB, and relative humidity of 87%); supply air purification; the range of outdoor temperatures for cooling -10÷43°CDB, for heating -20÷18°CDB; the sound pressure level of the internal unit nominal cooling mode / heating 33/35 dB(A).

The air conditioning equipment has been installed above the door of each experimental construction. Air leakage from the affected area is designed through overpressure relief via natural ventilation ducts fitted with a gravity louver, located above the window, as shown in Fig. 5.

To ensure the optimal air speed and temperature parameters in the work area of the room, the air conditioning units have been equipped with a moving lattice, directing the flow of air along the ceiling during the cooling period, and directly to the floor during the heating period.

5. Measurements

To examine the performance of the engineering solutions and construction work quality, and to determine the initial parameters of each experimental construction, the tests with infrared method (EN 13187) and fan pressurization method (EN 13829) will be made.

Some examples of the first quality control tests with infrared method during construction are given in Fig.6: a) window corner, construction type E; b) upper corner above the door, construction type D; c) upper corner above the window, construction type C. The first quality control tests reflect the need to prevent thermal bridges.

In all experimental constructions continuous measurements of the temperature and relative humidity (in several places, including the building envelope), pressure and differential pressure, solar radiation, air flow speed and heat flow density throughout the building structures are ensured. In addition, periodic measurements of globe temperature, radiant temperature, lighting, CO and CO_2 concentrations, exposure and brightness are planned. The planned range and accuracy of indoor measuring instruments are following: temperature (-40...60°C, ±0.4°C); relative humidity (0...100%, ±2%); pressure (300...1100 hPa, ±2.5 Pa); pressure difference (0...5 Pa,

±1%); radiation (305...2800 nm, 0...2000 W/m^2, ±1 W/m^2); air flow speed (0.15...5.0 m/s, ±5%).

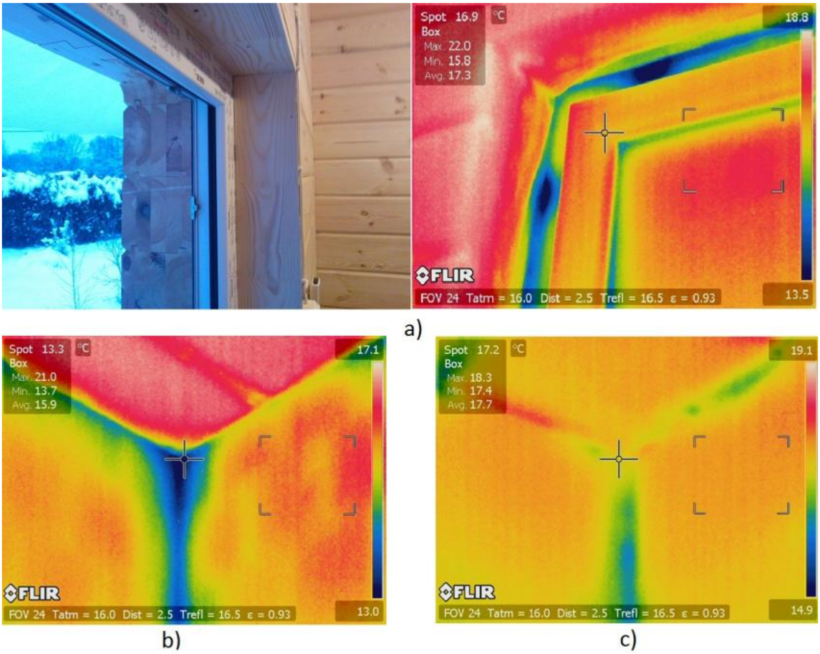

Fig. 6 The construction quality control tests (outdoor temperature -9°C; RH 91%)

The following continuous outdoor measurements of environmental parameters will be implemented: temperature and relative humidity, wind speed and direction, pressure, solar radiation. The planned range and accuracy of outdoor measuring instruments are following: temperature (-50...150°C, ±0.1°C); relative humidity (0...100%, ±0.8%); wind speed (0...60 m/s, ±0.1) and direction (0...360°, ±1°); pressure (600...1100 hPa, ±0.5 hPa); radiation (305...2800 nm, 0...2000 W/m^2, ±1 W/m^2).

The records of the individual energy consumption (electricity) will be kept for each experimental construction (accuracy class 0.2).

6. Numerical Modelling

In the framework of the project:

- a simplified multi-physical model has been designed and the analysis of constructions' thermal inertia impact on the room temperature changes performed [7];

- the modelling and analysis of the thermal conductivity of experimental ceramic block with filled cavities (with models designed for a variety of fillings) has been performed; the results were used to choose the cavity filling of ceramic blocks used for the experimental construction's (type D) exterior wall [6];
- methodology has been explored, and the mathematical analysis of heat and moisture transfer affected by temperature difference in the 5 multi-layer structures has been implemented [8].

The examples of the experimental construction simulation results are provided in Fig. 7, from left: simplyfied 3D geometry; horizontal temperature distibution with corner effects; temperature and airflow distribution in middle cross-section (for 45° inflow angle).

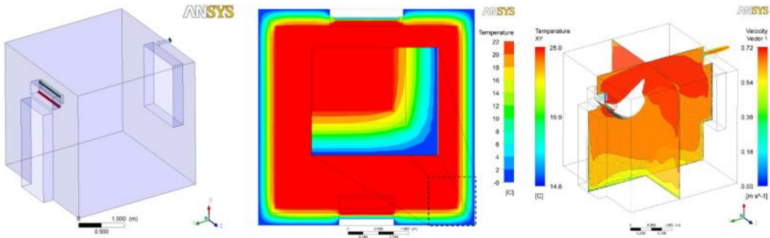

Fig. 7 The experimental construction model

7. Conclusions and Outlook

The design and engineering solutions of the experimental constructions provide an opportunity for further experimental measurements (including moving the experimental constructions to another environment with the necessary minimum requirements for their deployment (supports, electrical outlets, and network connection for data reading from a distance).

Using the developed experimental constructive solutions, it is possible to build experimental constructions from new experimental materials and conduct testing under similar operating conditions, to determine the material characteristics and their effects on EE and IEQ parameters.

The five experimental constructions in future can be used to examine the influence of various heating and air conditioning systems on the EE and IEQ parameters.

Within the current project, measurements of the volatile organic compounds (VOCs) concentration have not been planned. However, the design solution of the experimental constructions is suitable for testing of a variety of interior materials in various operating conditions.

8. Acknowledgment

The current research is performed with financial support of ERAF, project realised by University of Latvia, Nr. 2011/0003/2DP/2.1.1.1.0/10/APIA/VIAA/041.

The authors would like to thank also ceramic block manufacturer *Lode*; log houses manufacturer *Dores Fabrika*; manufacturer *Latvijas Finieris*; HVAC engineering solution developer *Indutek LV* (representative of *Daikin*); insulation manufacturer *Paroc*; dry mortar manufacturer *Sakret* and *Center of Processes´ Analysis and Research* for support by development of testing ground.

9. References

[1] Seppänen O. Indoor environment, productivity in offices and learning in schools. Indoor Climate and Productivity in Offices. REHVA Guidebook no.6 (2006) 1-52.
[2] Cabeza F.L., Castell A., Medrano M., Martorell I., Perez G., Fernandez I. Experimental study on the performance of insulation materials in Mediterranean construction. Energy and Buildings. Vol. 42, Issue 5 (2010) 630-636.
[3] Dimdiņa I., Krūmiņš Ē., Krūmiņš V., Lešinskis A. and Šnīdere L. Results of Living-Room Microclimate Parameter Measures in Multi-Apartment Buildings before Renovation. In: Proceedings of the 7th International Conference on Indoor Climate of Buildings, Trondheim, Norway, 2010.
[4] Zemits J., Borodinecs A. IAQ as a function of air exchaing rate. In: Proceedings of the 6th WSEAS International Conference on Waste Management, Water Pollution, Air Pollution, Indoor Climate (WWAI '12), Porto, Portugal, 2012.
[5] Regulations regarding the Latvian Building Code LBN 003-01 "Construction Climatology". 2001. Latvian Cabinet of Ministers, Riga.
[6] Čertoks S., Gendelis S., Jakovičs A., Kļaviņš J. Mathematical modelling for estimation of heat transfer properties of building materials. In: Proceedings of the 3rd International Conference Advanced Construction, Kaunas, Lithuania, 2012.
[7] Dzenis, T. The study of composite structures influence to the building energy performance (in Latvian). Bachelor's thesis. 2012. University of Latvia, Riga, Latvia.
[8] Ozolinsh A., Jakovich A. Heat and moisture transfer in the multi-layer walls: interaction and influence on the heat loss in the circumstances of changeable external temperature. Latvian journal of physics and technical sciences. Vol. 49 (2012), No. 6.