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Energy Efficiency and Sustainability of Different Building Structures in Latvian Climate

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Abstract. Five experimental test buildings have been built in Riga, Latvia. They are identical except external walls for which different mainly regional building materials are used. Calculated *U*-values of the other walls, floor and ceiling are the same for each test building. Initial moisture influences the relative humidity of indoor air, which can be higher in the initial time period; as a result, heat transmittances are also very different and cause different heating/cooling energy consumption. Overheating risk in summer exists for test buildings with the smallest thermal inertia. Both summer and heating seasons have been analysed and differences between five test houses have been discussed in details.

1. Introduction

This article presents selected results of the test building monitoring project. The choice of building material for five different walls of experimental constructions was determined by the objective to find the best possible application of high-quality insulation materials produced from the local resources. The expected outdoor and indoor air parameters and energy consumption monitoring data allow analyzing the buildings in which five different construction materials have been used. Similar studies were performed on a variety of building design solutions and material effect on energy consumption and indoor climate also in other countries, e.g. in Finland, Spain [1, 2].

Five test buildings have been built with different wall materials, identical in terms of design, geographic location and engineering solutions (figure 1). For all types of exterior walls with ventilated facade, the calculated *U*-value is 0.16 W/(m^{2}K). Constant air exchange rate of 0.45 h^{-1} is provided by the air-air heat pump, which is used also for heating and cooling. More detailed information about project is summarized in [3]. The basic materials used for the walls are as follows (see figure 2):

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Figure 1. Experimental buildings.

- perforated ceramic blocks (440 mm) with stone wool insulation outside (type CER);
- aerated concrete blocks (375 mm) with stone wool layer outside (type AER);
- plywood panels with stone wool filling (200 mm) and fibrolite (70 mm) inside (type PLY);
- perforated ceramic blocks (500 mm) filled with insulating granules (type EXP);
- laminated beams (200 mm) with stone wool insulation layer and wood panelling (type LOG).

To provide the same set temperature and air exchange, every building is equipped with an air-air heat pump with outdoor air intake option. All test stands are equipped with the same set of sensors. 40 different sensors include temperature and humidity (T/H) sensors, air velocity flow sensors, solar radiation sensors, energy meters, heat flow sensors. The locations of the main air temperature and humidity sensors are shown in figure 3 as black dots. The data logger collects all sensor data including data from the electric energy meter. To collect meteorological data, a weather station is installed on the top of a test stand with the separate data logger. Details of the developed measuring system can be found in [3].

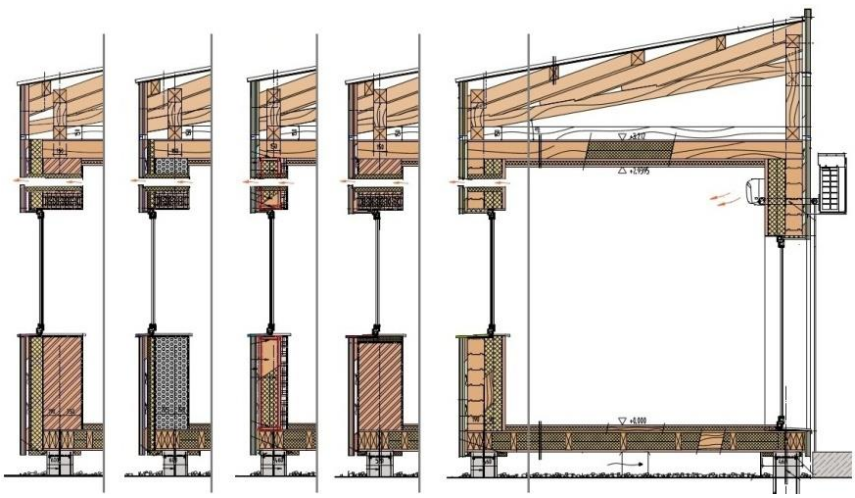

Figure 2. Cross-section of the buildings.

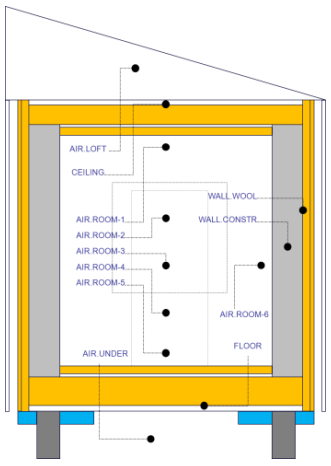

Figure 3. The location of T/H sensors.

2. Air exchange rate measurements

The main aim of the project is to determine and analyse energy consumption for all test buildings, therefore it is very important to evaluate all the heat losses. One of them is convection heat loss through ventilation opening and construction joints, which can be characterized by the air exchange rate in the room. Tracer gas method and special measuring system including multipoint sampler/doser and photo acoustic gas monitor are used for this purpose.

Table 1. Measured air exchange rate *n*.

Test building	*n* (1/h)
LOG	0.45±0.03
LOG[a]	0.03±0.01
EXP	0.48±0.02
AER	0.50±0.03
CER	0.43±0.04
PLY	0.44±0.01

[a] with sealed ventilation opening.

Experimental studies of actual air change were made in all test buildings at least for 24 hours for every building. The obtained results (table 1) show that the actual air exchange rate with switched on ventilation system in all test buildings is within the range of 0.43…0.50 (1/h). An additional measurement was carried out with the switched off ventilation system and sealed ventilation opening; this study shows that air change in this case is very close to zero (see [5]). The general finding of this experiment is that test buildings are very air-tight and the actual air exchange rates *n* with the switched on ventilation system are very close, which means that more than 90% of actual air exchange is a result of mechanical ventilation system operation.

3. *U*-value measurements

The measurements of heat transmittance U (W/m2K) are made for constructions in all test buildings just after manufacturing of the test buildings and during operation period (figure 4). Measurements are carried out using long-term monitoring of heat flux density and temperature difference. The variation in the determined *U*-values is mainly caused by different humidity conditions of a building structure (see next chapter).

The resulting value range is a result of several measurement cycles (up to 5 for each construction). Comparing experimental results with the calculated (designed), it is seen that walls in PLY building, as well floors and ceilings in all buildings are very close. The measured *U*-value for walls in LOG building is lower than the calculated value; this can be explained by low moisture content in timber constructions just after manufacturing, which is slightly increasing. Very high values of heat transmittance obtained for EXP building can be explained by mistakes in the manufacturing process of ceramic blocks, resulting in the highest volume of ceramics and the highest thermal conductivity.

Based on the experimental result obtained, it is estimated that the *U*-values for all the masonry constructions (especially for the aerated concrete) in the first year of operation are very closely linked to the moister content in the structures. In the next years, heat transmittance was decreasing, this

means also reduction in conduction heat losses from the buildings. Slight changes in heat transmittance due to variable moisture content in autumn and spring periods have also been observed.

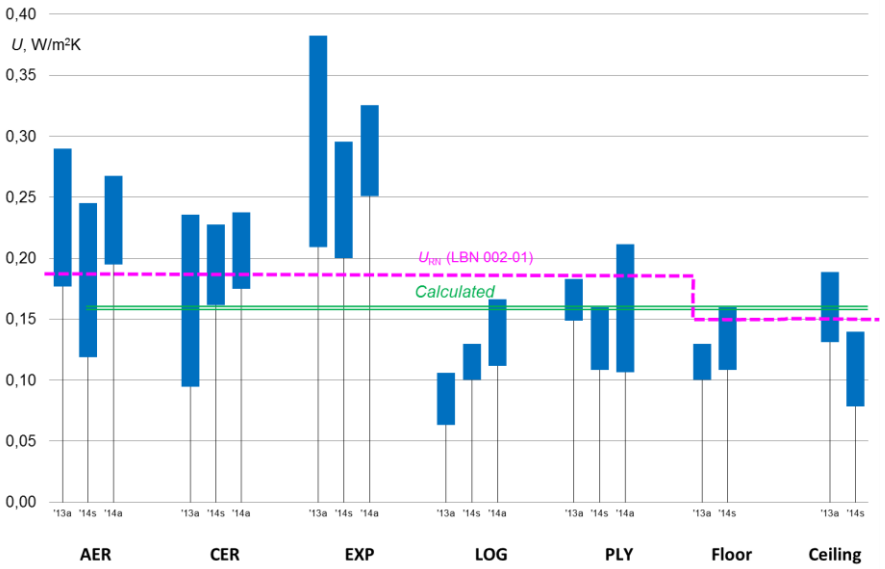

Figure 4. Measured *U*-values for different constructions (*a* – autumn, *s* – spring periods).

4. Air humidity measurements

Temperature and relative air humidity (RH) in different places of the test buildings (in the air as well as in the building structures) are controlled by several sensors (figure 3). Characteristic values of air humidity in all buildings (the data from sensor located in the middle of a room) for all monitored period are displayed in figure 5. The highest relative air humidity values (by 10-15%) are observed for AER type building built from aerated concrete after one year operation under set ventilation conditions. This difference decreases in time and after two heating seasons it becomes very close to other buildings due to relatively slow drying of the construction.

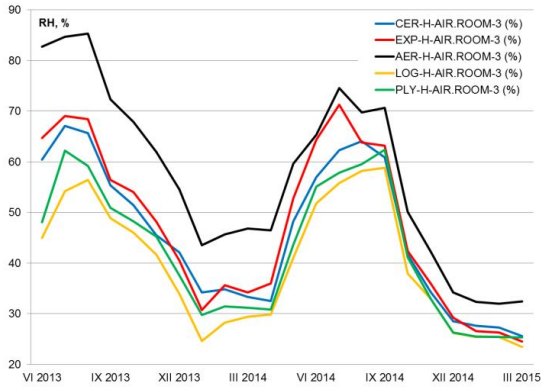

Figure 5. Measured relative air humidity RH (%) in the middle of the room.

As the test buildings are well ventilated, the measured air humidity depends mainly on moisture content in the building structures. However, humidity measurements in the structures or near their surfaces are also very important, e.g. the data from humidity sensors located under the window sill and between mineral wool layer and the main material (figures 6, 7) allows to better understand the drying processes and moisture transport in building constructions [6]. As seen from the graphs, the relative air humidity in AER and EXP buildings is very high and reaches even 100% in autumns under the window sill. The measured relative humidity near mineral wool layer for AER, LOG and PLY buildings (figure 7) is very high throughout the year (more than 65%); seasonal changes are clearly seen for LOG and PLY buildings.

Moisture has a significant negative influence on building structures, not only in terms of increasing of thermal transmittance, but also condensation and mould growing. More information about mathematical modelling and analysis of the condensation risk and mould growth in test buildings is summarised in [6, 7].

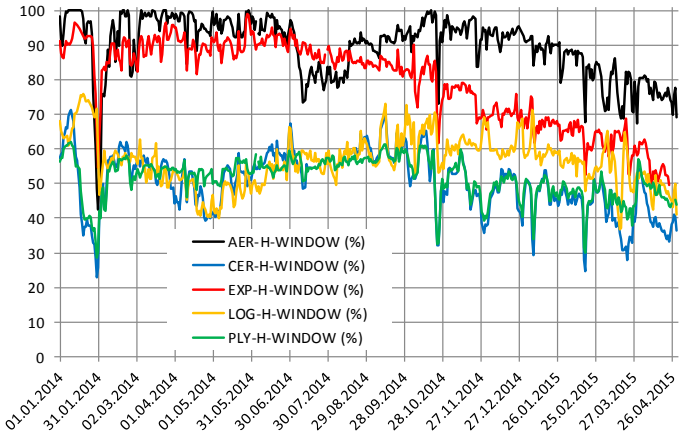

Figure 6. Measured RH (%) under the window sill.

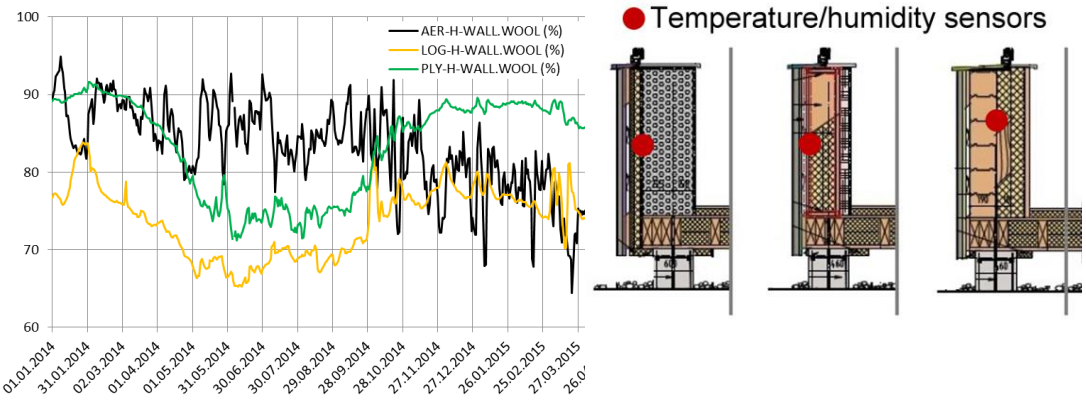

Figure 7. Measured RH (%) near mineral wool layer.

5. Energy consumption measurements

After two years of project running, huge amount of data from all types of sensors has been collected. It is possible to get the most interesting and representative results by analysing the heating and cooling energy consumption for different test buildings.

At the beginning of heating season, couple of months after the test buildings were built, energy consumption in buildings AER and EXP was higher than in another three buildings with practically the same consumption. Graphs in figure 8 show the increase of difference in heating energy consumption for all test buildings during one heating month. The main reason is the increased conduction heat losses through walls in AER building due to higher moisture content. Increasing of *U*-value for walls also in EXP building has an effect on heating energy consumption, which is 25% higher.

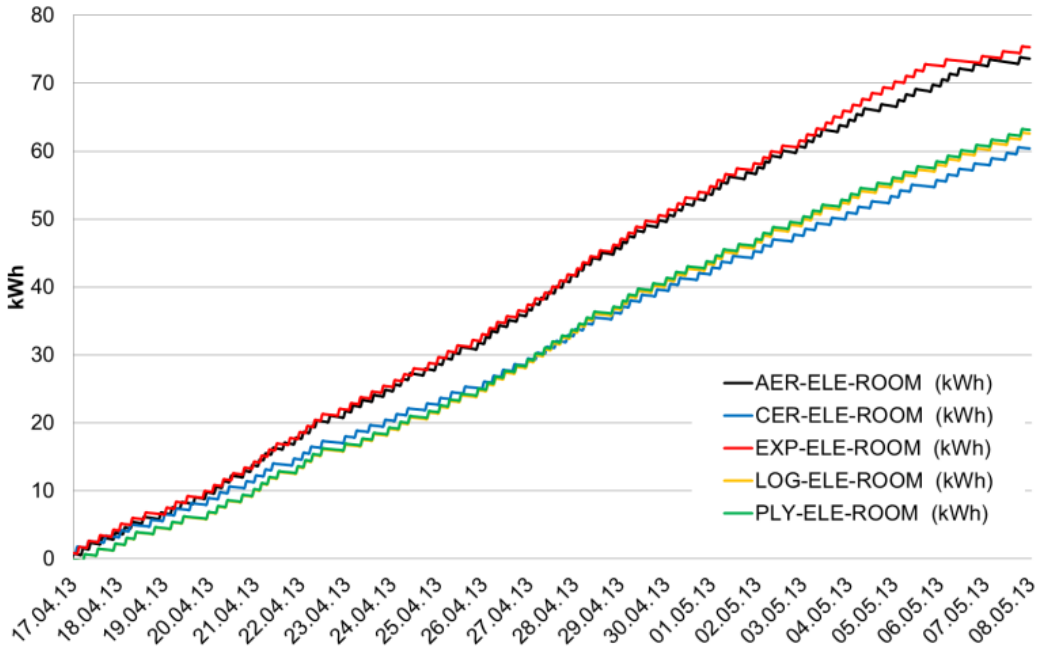

Figure 8. Heating energy consumption in different test buildings (indoor temperature T_{in}=19°C, n=0.45 h^{-1}).

At the same time, cooling energy consumption in hot summer days shows than the buildings which consumed more heating energy (AER and EXP) are very energy efficient. It can be explained by two factors:

- highest thermal transmittance for those buildings (see figure 4), which means more intense heat transmittance from the room;
- drying of relatively humid structures (see figure 6), which requires additional energy for evaporation.

6. Overheating analysis

The role of heat capacity is very important to reduce peaks of temperature fluctuation, especially in summer days when solar radiation influences the indoor temperature very significantly. The effect of rapid increase of indoor temperature during direct solar radiation is also called "overheating"; an example of this process is shown in figure 9, where temperature in the test buildings is not controlled, only ventilation system is on. As it is seen, the maximum temperature inside LOG building is 5°C higher than in AER building.

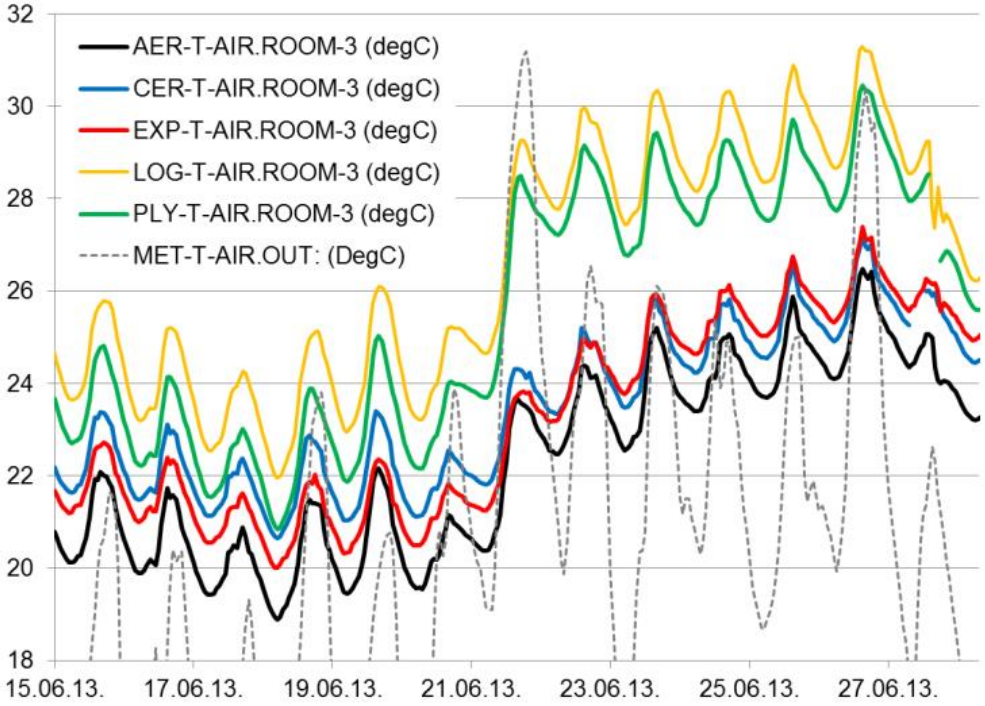

Figure 9. Indoor temperature (°C) demonstrated overheating of light-weight test buildings (LOG and PLY) without cooling.

7. Conclusion

Long-term monitoring of various physical parameters in 5 different low energy test buildings in the Latvian climate shows that:

- The calculated and measured heat transmittance for building structures may vary mainly due to different moisture content, which means also increased heating energy consumption.
- After two years of operation, wet constructions dry out and room's air humidity decreases; it means decreasing in heating energy consumption for the next heating seasons.
- Thermal mass of a building structure is a very important factor, which affects increasing of indoor temperature in the buildings without cooling systems in summer time.

More information about actual research results including thermal comfort analysis, estimation of actual energy efficiency for different heating systems (heat pumps) and indoor air quality may be found in publication [8-11] or at the project's web site *www.eem.lv* (in Latvian).

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Acknowledgments

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