Thermal comfort in summer in low energy buildings

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SUMMARY:
The aim of this work is to analyse thermal comfort and overheating risks under Latvian climate conditions. Two cases were inspected: no cooling and heating applied indoors (temperature fluctuates due to free floating conditions) and cooling applied indoors. Results for 3 test houses significantly differ, despite the similar projected U-value for each external wall. Differences are analysed in detail. It is shown that the initial moisture on the external wall can significantly influence the thermal comfort in the room. Despite the temperate climate in Riga, Latvia, both the experiments and the calculations show that overheating risks are high in summer.

1. Introduction

By December 31, 2020, all the newly constructed buildings are to become the "nearly zero energy consumption buildings" according to (Directive of the European parliament and of the council 2010/31/EU). However, overheating risks can be observed for passive houses, especially in summer. A high indoor temperature combined with a higher relative humidity can influence the living conditions negatively, affecting human health. Therefore a comprehensive study of thermal comfort in passive houses is strongly recommended. Living conditions in summer have been widely researched. 207 across the England were chosen and summertime temperatures were analysed (Beizaee & Lomas 2013). A single Slovenian passive house was analysed and overheating risks in summer have been investigated in (Mlakar & Strancar 2011). In (Bravo & Gonzalez, 2013) thermal comfort in hot-humid climate has been analysed. (Brun & Wurtz & Hollmuller, 2013) applied a new free-cooling system in experimental houses with the aim to analyse summer comfort.

FIG 1. On the left: The test stands of houses. On the right: A cross-section of one test stand

Despite the countless researches dedicated to the thermal comfort in houses at the summertime, the research of houses having the same parameters (net volume, roof, floor, orientation, projected U-value of external walls), the only difference among the houses being materials used in external walls, has not yet been published.. Such experiments have been done in Riga, Latvia, where five test houses have been built (see Fig. 1). Thermal comfort conditions in the three test houses were analysed in

(Ozolins & Jakovics & Ratnieks & Gendelis 2013). However, that publication focussed on the heat and moisture transfer on the walls as well as on the temperature distribution in the room. Moreover, at the time the experiments were not started yet in the houses placed in Riga (see Fig. 1). The experimental results obtained from the test stands were discussed in (Ozolins & Jakovics & Ratnieks 2013). However, this paper focussed on moisture risks on the walls. Small test houses were created in (Mlakar & Strancar 2013). However, in this case the net volume was significantly lower, projected U-values of external walls were not equal and the aim of the given paper was completely different. INCAS platform with several test houses was described in (Spitz & Mora & Wurtz & Jay, 2012).

The aim of this work is to analyse thermal comfort and overheating risks under Latvian climate conditions.

2. Short description of test houses and measurements

This section provides a brief description of external walls of five test stands built in Riga, Latvia (see Fig. 1). Project homepage (EEM, 2011) provides a comprehensive image gallery of test stands as well as a detailed material description.

TABLE 1. Description of building construction's walls

AER house, 165 kg/m^2 $U_{projected}$=0.153 W/(m^{2}K) from outside to inside		CER house, 363 kg/m^2 $U_{projected}$=0.151 W/(m^{2}K) from outside to inside		PLY house, 79 kg/m^2 $U_{projected}$=0.154 W/(m^{2}K) from outside to inside	
Material	Thermal conductivity [W/mK], μ [-], c_p×ρ [J/(m^{3}K)]	Material	Thermal conductivity [W/mK], μ [-], c_p×ρ [J/(m^{3}K)]	Material	thermal conductivity [W/mK], μ [-], c_p×ρ [J/(m^{3}K)]
Wind protection slab, 0.03 m	0.034, 1, 59500	Wind protection slab, 0.03 m	0.034, 1, 59500	Plywood, 0.02 m	0.17, 700, 750000
Stone wool, 0.02 m	0.036, 1, 33200	Stone wool, 0.125 m	0.043, 1, 33200	Stone wool, 0.2 m	0.041, 1, 33200
Lime plaster, 0.015 m	0.7, 7, 1344000	Lime plaster, 0.015 m	0.7, 7, 1344000	Plywood, 0.02 m	0.17, 700, 750000
Aerated concrete, 0.375 m	0.072, 4, 255000	Aerated clay bricks, 0.44 m	0.175, 7, 595000	Fibrolite, 0.075 m	0.068, 2, 756000
Lime plaster, 0.015 m	0.7, 7, 1344000	Lime plaster, 0.015 m	0.7, 7, 1344000	Lime plaster, 0.015 m	0.7, 7, 1344000

In Table 1, the multi-layered external walls of each test house are characterized. For layers consisting of the stone wool effective λ is chosen taking into account the wood frame. Wood siding in front of walls for each test house was used to protect the walls from rain and solar radiation. Ventilated air layer with a thickness of 2 cm is located between the wood siding and the wall. The roof, floor, windows and doors of all test stands are similar. Triple-glazed window with solar heat gain coefficient 0.5 is built into the south-facing wall of each test stand. U-value is 0.72 W/m^{2}K for the window and width, height and height above floor are 1.2 m, 1.5 m and 1 m, respectively. It can be noted that the inner loads due to the measuring equipment were approximately 3 W/m^2 for each of the test stands. More information about test stands and materials used for each of the test houses is available in (EEM, 2011).

3. Results and discussions

The current section consists of 2 parts:

- thermal comfort analysis based on the measurements in the test houses;
- analysis of the long term overheating risks based on the numerical calculations.

Numerical simulation has been implemented by using software WUFI PLUS: room climate model for calculation of the inner climate conditions.

3.1 Thermal comfort under different exploitation conditions

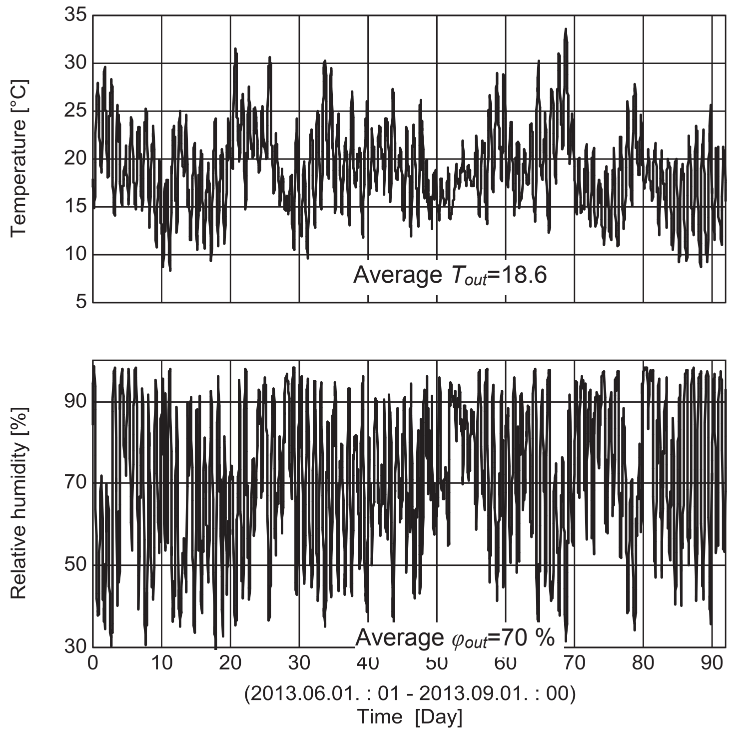

FIG 2. Outdoor temperature and relative humidity from June 1 to August 31

Measurements were implemented in test houses with the aim to estimate the room comfort under different conditions: no heating and cooling applied indoors in June, i.e. T_{in} and T_{out} fluctuated by free floating conditions. In July maximal T_{in} was set as +24 °C, i.e. cooling was ensured if indoor temperature rose beyond 24 °C. In August neither heating nor cooling were applied. However, the difference between the interior conditions in August and June was created by covering the windows from outside in August with the aim to observe the role of the solar radiation through the window. Air exchange coefficient was approximately 0.5 1/h and the indoor relative humidity fluctuated by free floating conditions for all time period. The outdoor climate conditions are shown in Fig. 2. The data has been obtained from the meteorological station created in the test polygon. The maximal outdoor temperature was observed on August 8, when maximum of T_{out} rose up to 33.6 °C. The average T_{out}

was 19.2 °C, 19.1 °C and 18.2 °C in June, July and August respectively. The average φ_{out} was 67 %, 71 % and 74 % in June, July and August respectively.

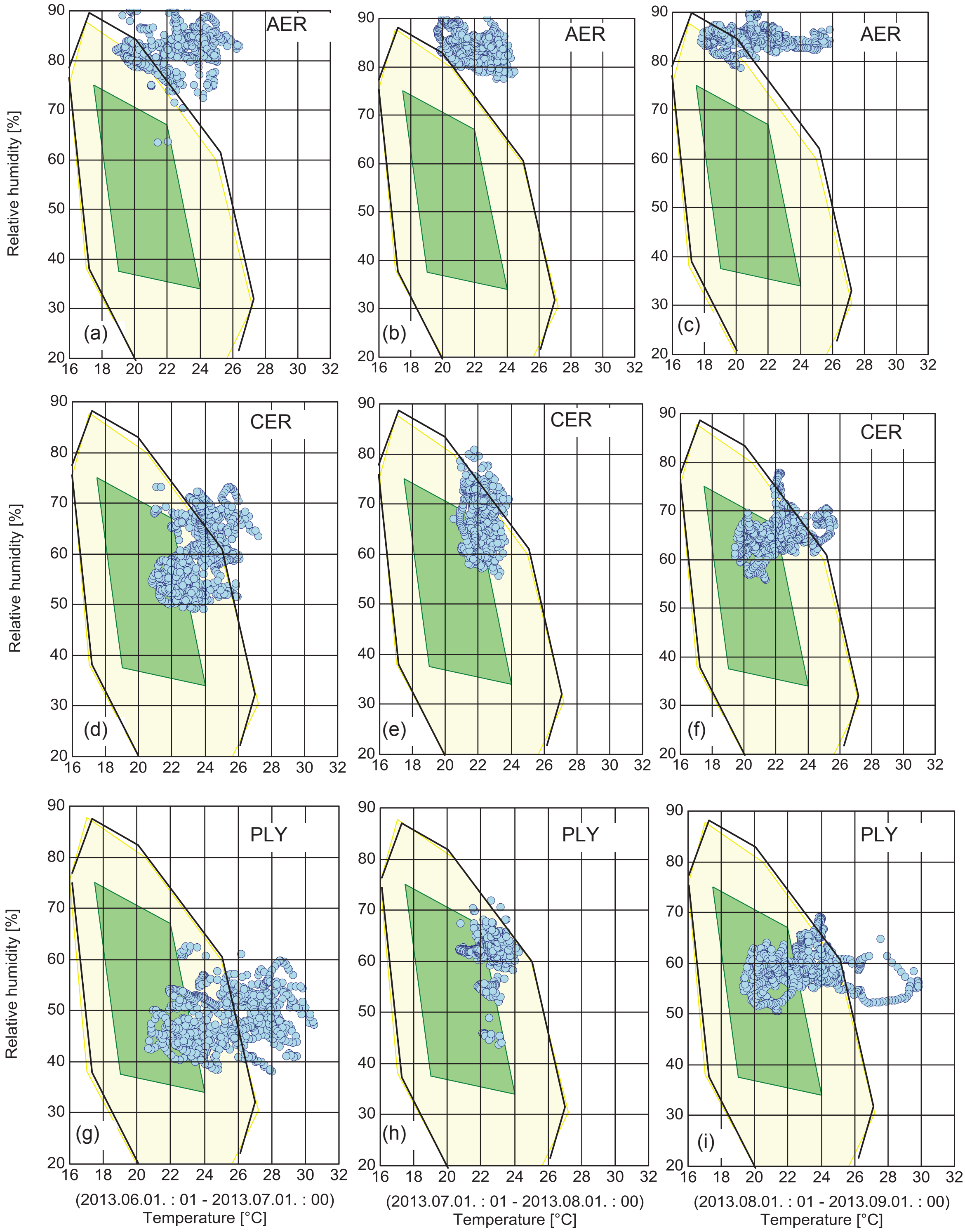

FIG 3. The measured indoor relative humidity compared to indoor temperature for 3 different test houses. Bounded regions are thermal comfort charts according to (ASHRAE Standard 55). Smaller region: comfortable. Larger region: still comfortable. On the left: room conditions in June when no heating and cooling was applied indoors. In the middle: room conditions in July when maximal T_{in}

was set at +24 °C. On the right: windows were covered in August, no cooling or heating applied indoors.

As it is shown in Fig. 3a, b, c, a high indoor relative humidity has been observed in case of the test stand of AER that can negatively influence human health. An explanation of high humidity is the high initial moisture for the aerated concrete that significantly influences the room conditions. The situation was not improved when the cooling was applied indoors. In the test stand of CER the room climate was significantly better (see Fig. 3d, e, f). For some time periods, the optimal thermal comfort was not ensured and circles slightly go out of optimal thermal comfort region due to the higher relative humidity (see Fig. 3e). When the windows were covered from the outside, the optimal comfort was also ensured almost throughout all days in August (see Fig. 3f). In case of the test house of PLY, a significantly lower relative humidity in the room (see Fig. 3g,h,i) was observed. However, a higher overheating was also observed, especially in June (Fig. 3g), when T_{in} fluctuates by free floating conditions and solar influence through the windows was observed. The problem is solved when cooling is applied indoors (see Fig. 3h). When windows were covered, the optimal comfort climate was also observed (see Fig. 3i), except during some warmer days that can be seen in Fig. 2. It can also be concluded that a significant impact of different building components used on the external walls to the thermal comfort has been demonstrated. The amplitude of T_{in} fluctuations was the lowest in case of the test stand of CER (Fig. 3d compared to Fig. 3g, Fig. 3f compared to Fig. 3i). It can be explained by higher volumetric heat capacity of aerated clay bricks incorporated in the external wall of CER that does not allow the heat to quickly transfer through the wall.

TABLE 1. Average outdoor and indoor temperatures for 3 test houses

	T_{out}	AER; T_{in}	CER; T_{in}	PLY; T_{in}
June	19.5	22.5	23.4	25.4
August	18.2	20.9	21.8	22.4

If we compare Fig. 3a to Fig. 3c, Fig. 3d to 3f, Fig. 3g to 3i, it can be seen that the average T_{in} between the months of June and August does not differ as much as it can be expected. More precisely, in June the average T_{in} was 3 °C, 3.9 °C and 5.9 °C higher than the average T_{out} for the test stands of AER, CER and PLY respectively (Table 2). The difference between T_{out} and T_{in} is explained with the inner sources and solar radiation through the window. In August average T_{in} was 2.7 °C, 3.6 °C and 4.2 °C higher than the average T_{out} for the test stands of AER, CER and PLY respectively (Table 2). It can thereby be concluded that a covered window only partially decreases the overheating risks.

3.2 Overheating risks in a long term

Measurements for estimating overheating risks in different building constructions were described in a previous subsection. However, only one summer was inspected, and the outdoor climate conditions can differ during other years. Therefore it is required to analyse the overheating risks in low energy houses during a long term. At first, WUFI PLUS model will be verified and the results compared with the experimental data obtained.

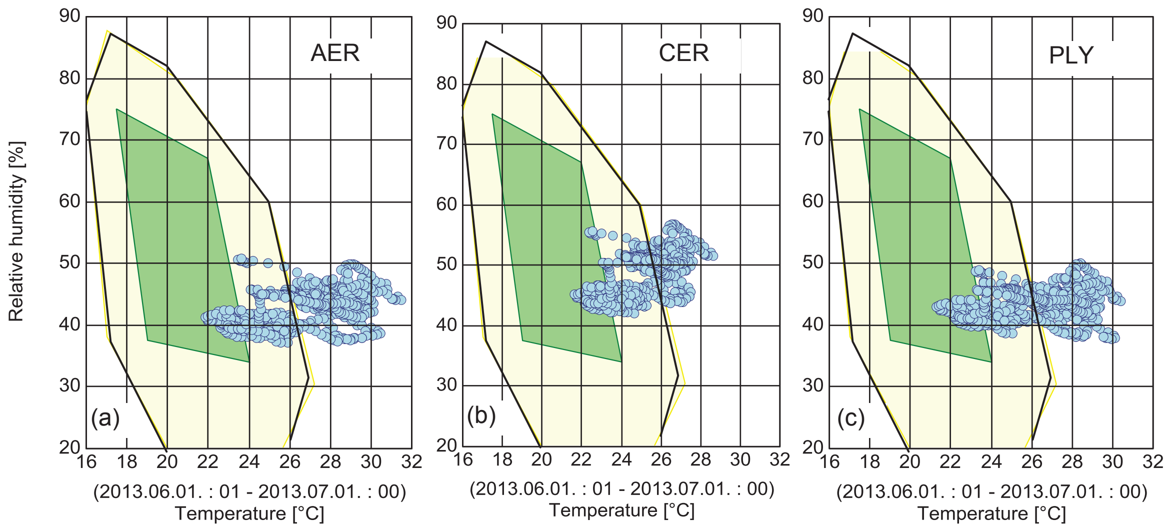

FIG 4. Calculated indoor relative humidity against indoor temperature for 3 different test houses.

It is shown that the numerical results (Fig. 4) significantly differ from the measurements (Fig. 3a, d, g). The differences in case of the test house of AER (Fig. 3a compared to Fig. 4a) are explained with a high initial moisture in aerated concrete that was not taken into account in numerical simulations. This moisture on the external wall promotes a higher indoor relative humidity, higher U-value and therefore lower indoor temperature. For the test stand of CER, the differences from measurements are lower (Fig. 3d compared to Fig. 4b). because the initial moisture for aerated clay bricks is not as high as for aerated concrete. For the test stand of PLY the range of T_{in} is similar both for measurements and numerical model (Fig. 3g compared to Fig. 4c). However, the measured range of φ_{in} is from 40-60 % despite the range of 40-50 % for numerical model.

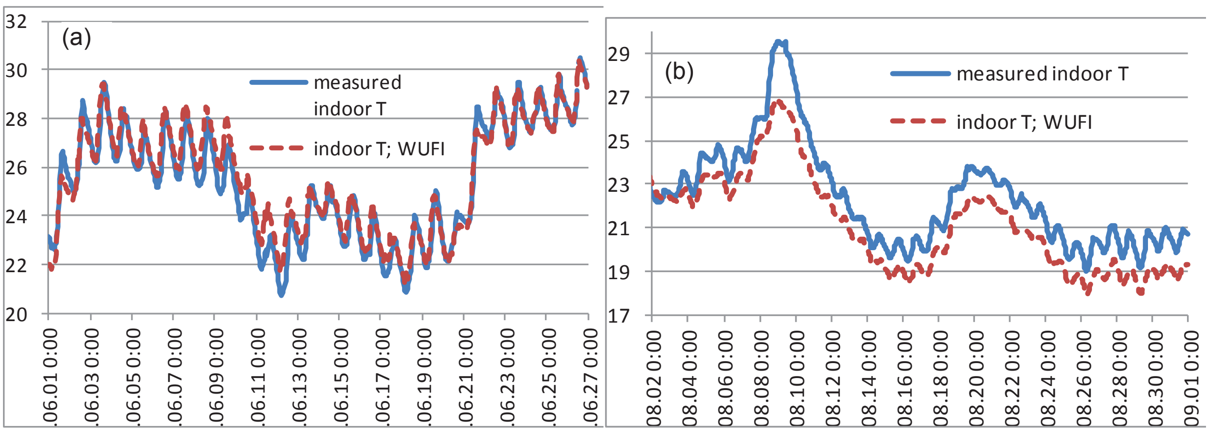

FIG 5. Experimental results (solid line) against numerical results (dashed line). Windows were: (a) uncovered; (b) covered

In Fig. 5 the dynamics of measured T_{in} are shown to verify the numerical model used in software WUFI PLUS. In June the numerical model is well fitted with measurements (Fig. 5a). However, measured T_{in} is for approximately 1-1.5 °C higher than the one obtained by numerical model in August (Fig. 5b). One explanation of this displacement is the overheating on the loft that can influence the room temperature more significantly, when the solar influence through the window is negligible

Since the numerical model shows reliable results for estimating room temperature for the test stand of PLY, a detailed analysis of overheating risks will be made in a long term, using the climate data from

2006 to2012 in Riga. It will be assumed that no heating and cooling is applied indoors in summer and solar influence through the window will be negligible.

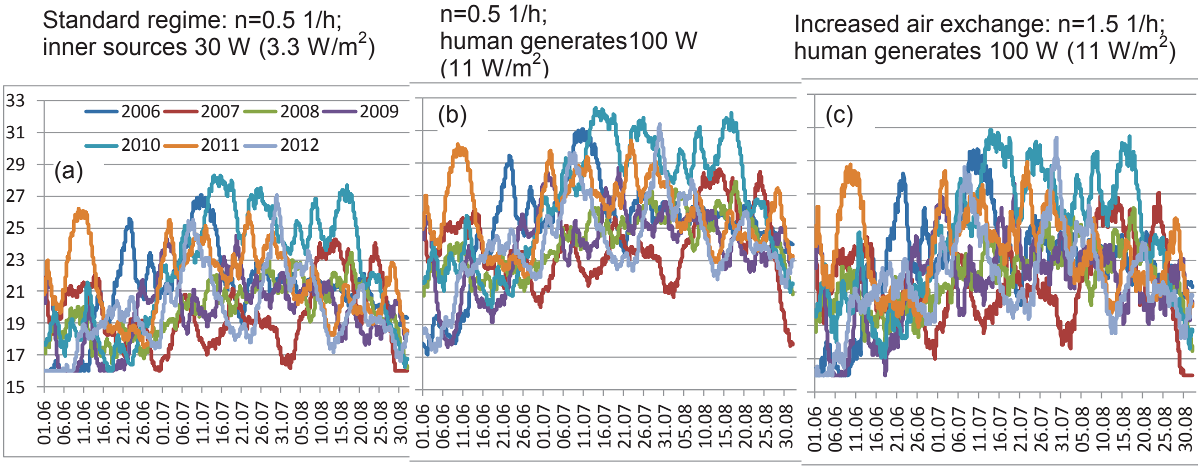

FIG 6. Calculated indoor temperatures for the test stand of PLY in a long term (2006-2012), solar influence through the window is negligible. (a) Standard room conditions that were applied on the real test house. (b) Inner loads 100 W due to the human activity. (c) Inner loads 100 W and increased air exchange from 0.5 to 1.5 1/h

Numerical calculations show that room temperature could increase above +25 °C in August only in 2010 (see Fig. 6a). It means that the situation, when T_{in} increases up to +29 °C (see measurement in Fig. 5b), is a rare phenomena at the given room conditions. However, T_{in} can increase above +25 °C several times during the 7 year period that can cause uncomfortable room living conditions. In a real situation, humans can produce additional heat or inner source. For the sake of simplicity it has been assumed that the inner loads are constant 100 W. The results obtained based on this assumption show a completely different situation (see Fig. 6b). Rooms can overheat for a longer time periods in several summers. Even T_{in}>30 °C can be reached. An assumption about an increased air exchange up to 1.5 1/h improves the thermal comfort (see Fig. 6c). However, the overheating risks remain and uncomfortable room conditions are often a case during the time period of 2006-2012. A better solution could be the night ventilation.

4. Conclusions

In the current paper three test stands of houses were compared and the experimental measurements of room living conditions for different cases (no heating and cooling applied indoors, covered windows, cooling) were obtained. The experiments show that the thermal comfort was not ensured for the house with external wall mainly consisting of the aerated concrete blocks and insulation materials. The living conditions were absolutely uncomfortable due to the high indoor humidity. The reason was a high initial moisture in the aerated concrete and very slow drying process. Thermal comfort also was not achieved in the test stands with the external walls mainly consisting of wooden materials and insulation layer. However, cooling or covering of the window significantly improves the situation. The best interior living conditions were observed in the test stand mainly consisting of aerated clay bricks and insulation materials.

Long term simulations based on the “light” test stand mainly consisting of plywood and stone wool shows that overheating risks could be observed for several time periods and for several summers despite the assumption about the window covered from the outside.

Since the initial moisture significantly influences the thermal comfort in case of one test house, it presents an interesting challenge to observe, how much the interior living conditions will improve for several subsequent summers. Such measurements will continue.

5. Acknowledgements

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