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INVESTIGATION OF PSYCHROMETRIC CONDITION WITHIN THE UNINHABITED ATTIC - EXPERIMENT VS. SIMULATION

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Streszczenie: W artykule przedstawiono analizę pomiarów parametrów powietrza wewnątrz poddasza nieużytkowego. Szczegółowo przeanalizowano wilgotność powietrza, co pozwoliło na badanie zmian transportu masy przez przegrodę dachową ze szczególnym uwzględnieniem wpływu warstwy powietrza na intensywność procesu. Wyniki pomiarów zostały porównane z rezultatami symulacji wykonanej w programie WUFI-Pro.

Słowa kluczowe: indoor relative humidity, moisture transport, uninhabited attic

1. INTRODUCTION

The attic used to play a role of a thermal buffer for the top building floor. Nowadays with modern insulating materials we try to use the whole volume of the building, including the attic. The roofs with usable attic need to be ventilated (a ventilated air gap) in order to carry away the moisture penetrating from the attic (moisture from people, devices, cooking, washing) into the roof construction. A ventilated air gap is useful in summer allowing to carry away the excessive heat gains from sun while in the winter it allows maintaining a homogenous temperature under the roof surface which prevents from snow melting on warmer parts or snow storing on colder parts of the roof. The influence of air gap (in this case ventilated uninhabited attic) should be considered with a special attention. The most important question is the required thickness of air gap or required intensity of ventilation of air gap. This problem is rather solved by best practice experience. In other hand the thickness of air gap is often reduced to save the space below the roof.

This paper presents psychrometric condition within the air layer. Possibility of simulation the moisture and temperature transport through the air layer was also investigated.
The paper present the investigation of moisture and temperature distribution within the roof and consisted of two stages: 1) an experimental campaign and results analysis, 2) numerical simulations with WUFI software.
The experimental campaign was carried out at two periods: one week with winter conditions and one with a summer ones. The measurements were done at a pitched roof in Wesoła – a district of Warsaw.
During the measurements the unexpected correlation between temperature and moisture content within the attic was appeared. This phenomena was not sufficiently explained after simulations. The most probably explanation is moisture accumulation in insulation material, however this process runs rather too fast, comparing the properties of material.

2. MEASUREMENTS

2.1. Building and roof description

The objective of the experimental campaign was to investigate moisture and temperature distribution within roof and to compare measured data with simulation results obtained with WUFI software.
The experimental site was located in Wesoła – a residential district of Warsaw. The measurements were carried out in a typical single-family building (Fig. 1). A pitched roof with non-usable attic was investigated (Fig. 2).

Fig. 1. The investigated building.

Fig. 2. Investigated pitched roof with non-usable attic.

Table 1 and Fig. 3 present roof construction with layers layout, width and building materials used.

Table 1. Roof construction.

#	Layer	Width [mm]
1	Tin plate	2
2	Wooden boarding	12
3	Attic (air)	500-1500
4	Thermal insulation (mineral wool)	100
5	Wooden boarding	12
6	Plaster	20

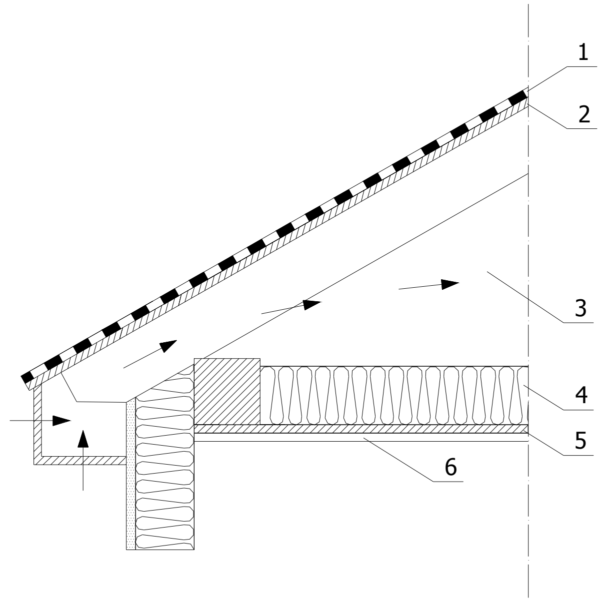


Fig. 3. Roof construction.

The experimental campaign took place in 2007. Four temperature and relative air humidity data loggers were mounted at the site:

- inside the building in the bedroom at first floor,
- inside the building at the bottom of the attic on the insulation layer,
- inside the building at the top of the attic sealed to the roof surface,
- outside the building at the balcony at first floor.

a)

b)

Fig. 4. Sensors mounted at the site: at the insulation layer (a), and at the roof surface (b).

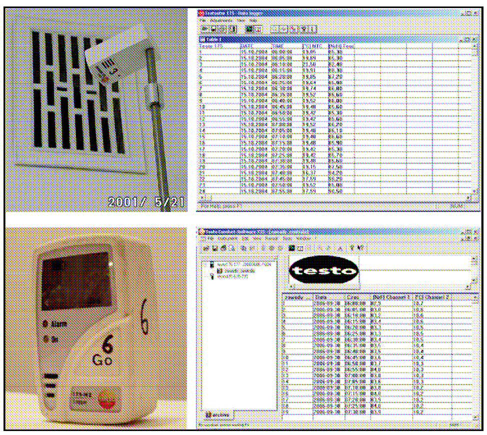


Fig. 5. Dataloggers (TESTO 175-2 and TESTO 175-H2) and software used for measurements and data recording.

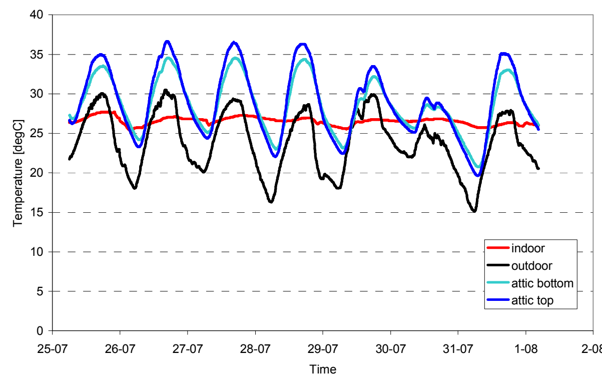
2.2. Results - summer

The graphs below present weekly variations of air temperature, moisture content and relative humidity measured during summer period. The temperature inside the building is quite constant, around 26°C, while the external ambient air temperature varies from around 16°C up to 30°C daily. Notice that the maximum temperature values are registered in the afternoon (around 18:00). This is caused by the fact that the sensors were placed on the western side of the building. Air temperature in the attic is very high reaching 36°C in the afternoon. The temperature amplitude is little higher at the top of the attic (roof surface).

The moisture content was higher inside the building than outdoors. The moisture gains related with building exploitation (gains from people, cooking, washing, etc.) can be seen at the graphs, especially during first four days (a shift between indoor and outdoor moisture content). The trend of moisture content variations is descending in the first part of the measurements and then increasing towards the end. This suggests that the measurements started after a period of rainfall, then raining stopped and started again in the end of the analysed period. This also explains the relevant temperature drop the 30th July.

The moisture content variations in the attic follow strictly the temperature values, mount very high in the afternoon and descend at night and in the morning and are very similar in the upper and lower part of the attic. This indicates that the moisture evaporates as the insulation and the deck are being dried at high air temperatures and then is accumulated again within the roof construction materials. This results show that the roof might be insufficiently ventilated.

a)



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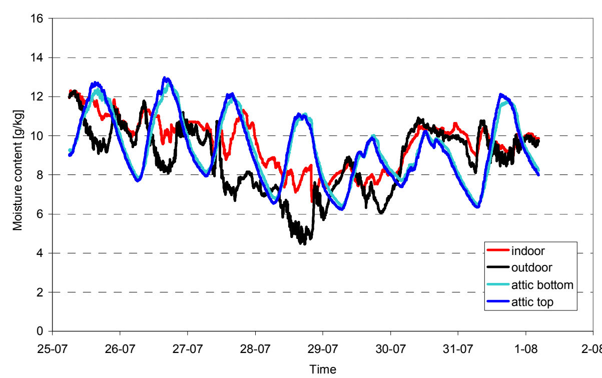
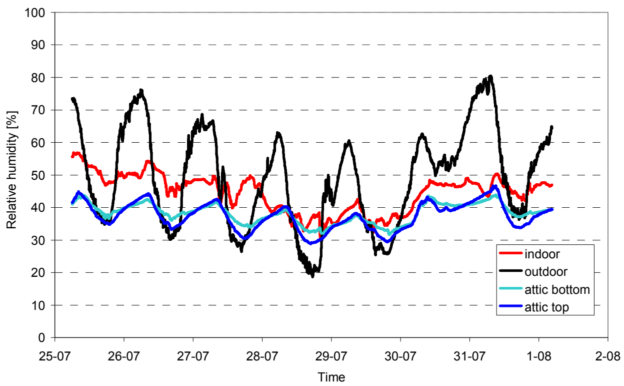


Fig. 6. Weekly air temperature (a) and moisture content (b) variations during summer.

a)



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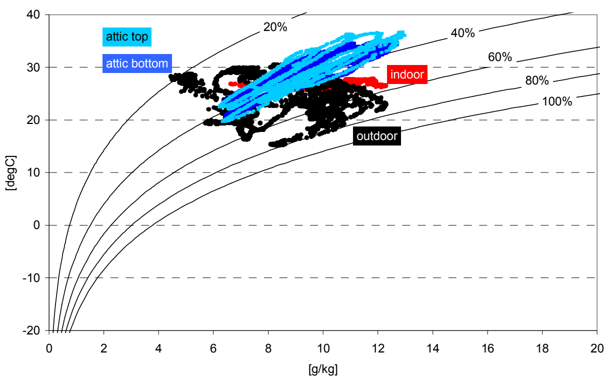


Fig. 7. Weekly relative air humidity variations (a) and the measurements results at psychrometric graph (b).

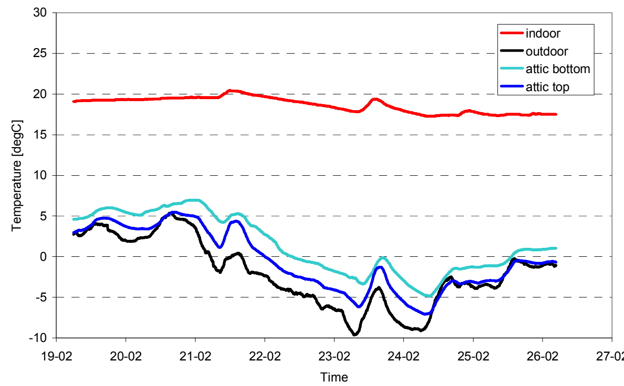
2.3. Results winter

The graphs below present weekly variations of air temperature, moisture content and relative humidity measured during winter period. The external ambient air temperature varies from 5°C down to -10°C. The temperature inside the building is constant around 18-20°C. The temperature in the attic is quite low and follows the pattern of external ambient air temperature variations. The temperature at the attic bottom is about 2K higher than at the top. Such temperature stratification was not the case in the summer. This effect is related with high temperature gradient between indoor and outdoor air (up to 25K, while only 10K in summer). Low peaks of the temperature values during the day indicate that solar radiation intensity was very low during the analysed period.

The moisture content of the external air dropped suddenly from around 4 g/kg to 2 g/kg. This decline is related with external ambient air temperature decrease below 0°C – the moisture from the air condensed. The moisture content in the attic air successively followed the decline, so did the moisture content in the indoor air. The moisture content of the air inside the building is much higher (up to 5 g/kg) which is related with moisture gains from building exploitation.

We can see that once again the moisture content of the air within the attic follows the pattern of temperature variations. Probably explanation of this phenomena is that with the air temperature increase the moisture evaporates and accumulates back within roof construction materials as the air temperature drops.

a)



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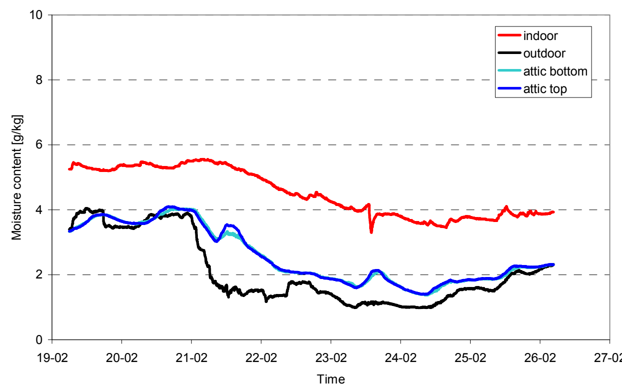


Fig. 8. Weekly air temperature (a) and moisture content (b) variations during winter.

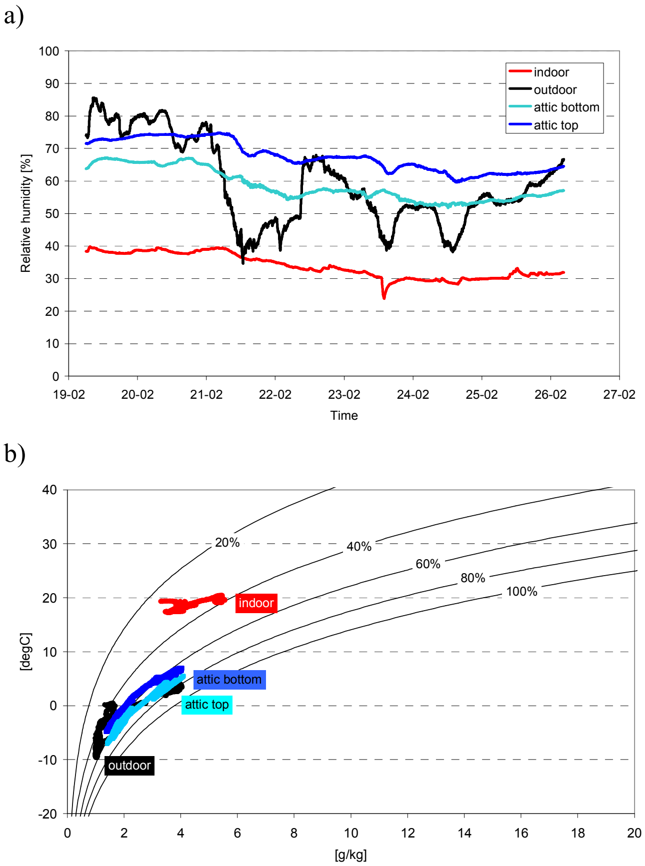


Fig. 9. Weekly relative air humidity variations (a) and the measurements results at psychrometric graph (b).

The moisture content in the attic air is very low during winter. The relative air humidity is reaching 75% maximum. The moisture gains from living space are not very high and are easily carried away by building ventilation system. There is no condensation risk.

Surprisingly, the moisture content in the attic air is relatively high in summer, especially after a period of rainfall. With air temperature increase in the attic, forced with intensive solar radiation, the roof construction materials are being dried but the moisture is not carried away. It seems that the roof ventilation is less efficient in summer.

3. SIMULATIONS

3.1. Simulation software

Numerical simulations were carried out with WUFI software. WUFI is a Windows-based programme for hygrothermal analysis of building envelope constructions developed at Frauenhofer Institute in Germany. The examined roof construction was investigated. The materials data used in calculations were taken according to WUFI libraries. The calculations were carried out for both weeks periods in the summer and in the winter. The measured indoor and outdoor air temperature and relative humidity values were the boundary conditions for the simulations. The solar radiation data were applied according to reference meteorological data for Warsaw. The rainfall was not included in the analysis.

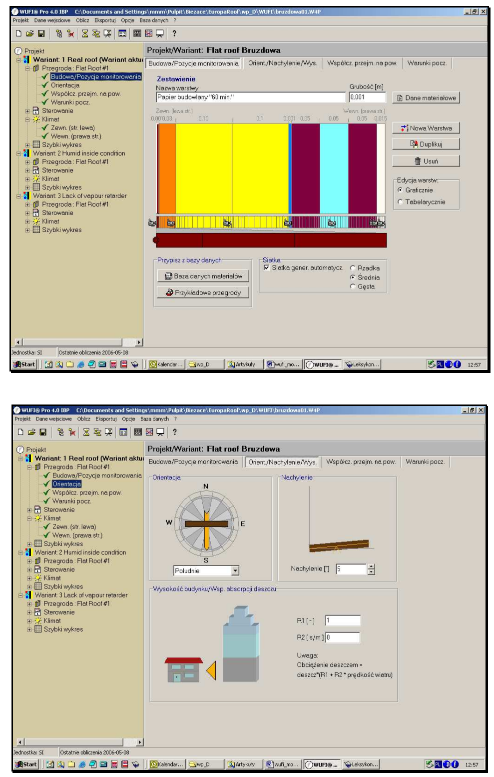


Fig. 10. Defining of building component in the WUFI ORNL/OBP model

3.2. Results

For each examined case (summer and winter), the air temperature, moisture content and relative humidity courses were traced at the points where measurements were carried out (bottom and top of the attic). The results were correlated with the measurements. The time step was one hour.

The comparisons presented on Fig. 11 to Fig. 18 show that the agreement between the results and simulations is adequate. Simulated values follow the measurements, however the absolute values differ significantly. For the summer period the temperature drop at night is overestimated, while for winter period the underestimations occur not only at night. The differences reach up to 5K. Simulated moisture content values give satisfactory agreement with the measurements. Nevertheless in summer the peaks are significantly overestimated, while in winter underestimation in the first part (especially relevant at the attic bottom) and overestimation in the final part of analysed period occurred. Simulated relative humidity values give poor agreement. In summer they follow variations of the measurements, while the absolute values differ considerably. Simulation results for winter do not represent measured fluctuations and remain quite constant. There is a sudden relative humidity drop from the initial value at the bottom of the attic, at the very start of simulations, not reported by the measurements.

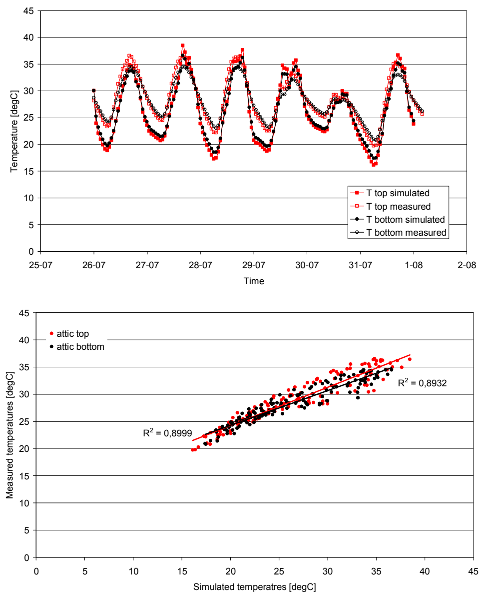


Fig. 11. Comparisons between measurements and simulations of air temperature in the attic in summer

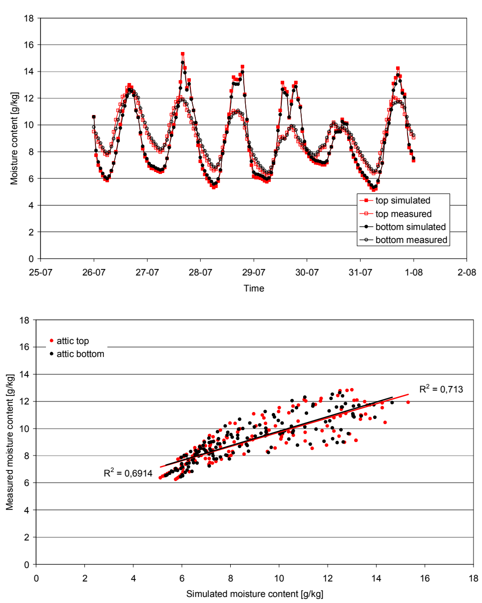


Fig. 12. Comparisons between measurements and simulations of moisture content in the attic in summer.

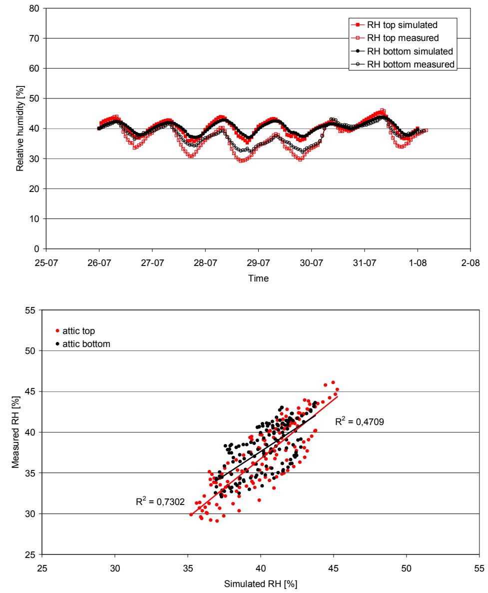


Fig. 13. Comparisons between measurements and simulations of relative air humidity in the attic in summer

An overview on the Fig. 14 and 19 presenting average air temperature in the attic compared to ambient air temperature shows that attic air temperature is certainly correlated with ambient air temperature, but remains up to 8K higher. This indicates that the attic ventilation rate is low enough to allow the air to warm up significantly.

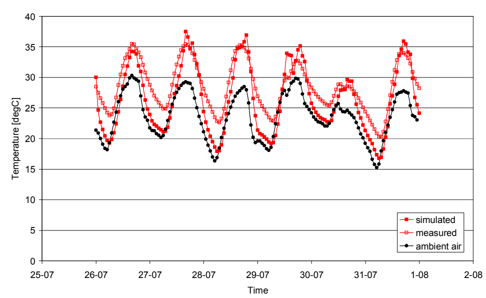
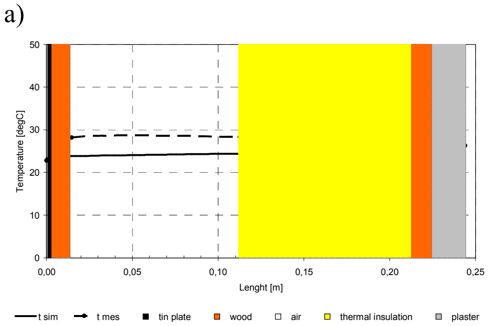


Fig. 14. Comparisons between average measured and simulated air temperature in the attic in summer with ambient air temperature

a)



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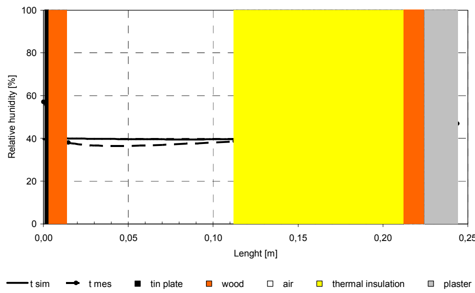


Fig. 15. Temperature (a) and relative humidity (b) simulated versus measured profiles at the end of summer period

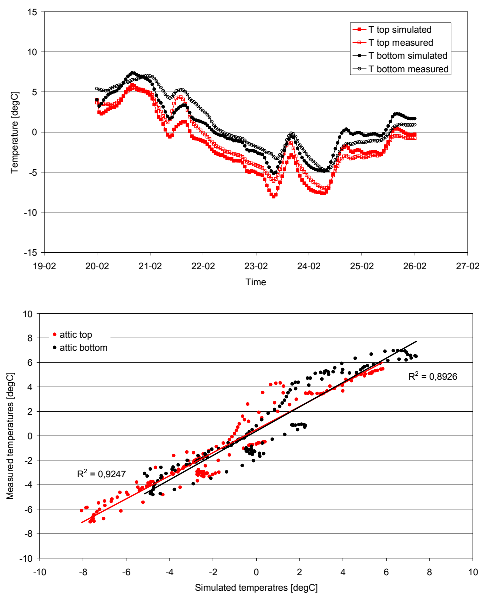


Fig. 16. Comparisons between measurements and simulations of air temperature in the attic in winter

Fig. 15 and Fig. 20 present temperature and relative humidity profiles across the roof. The profiles are presented at the end of summer (July 31) and winter (February 25) periods. The line presenting simulated values can be compared with measured profiles. The agreement is adequate however temperature values in summer show certain disagreement. The disagreement of humidity values in winter is caused by the fact that measured profiles are based upon four points only, which is insufficient to represent precisely humidity changes across the roof.

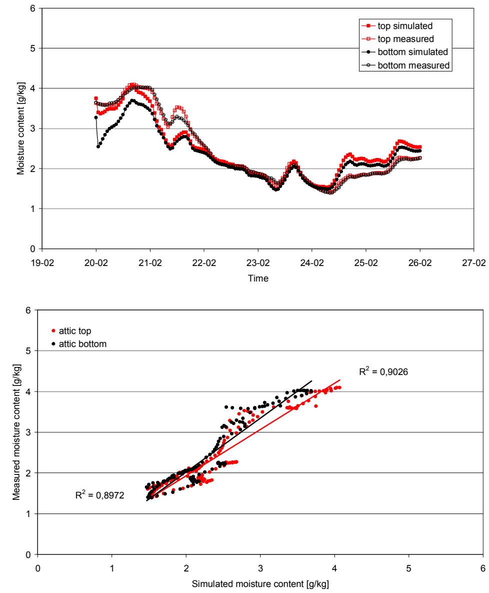


Fig. 17. Comparisons between measurements and simulations of moisture content in the attic in winter

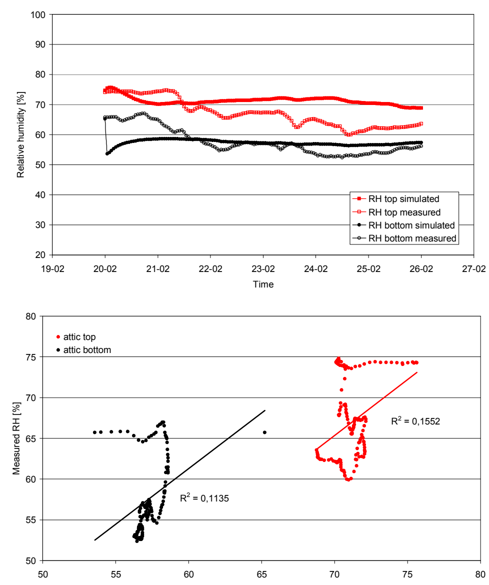


Fig. 18. Comparisons between measurements and simulations of relative air humidity in the attic in winter

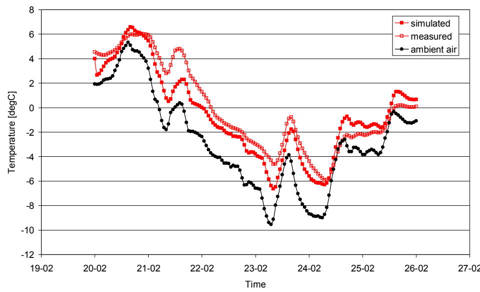
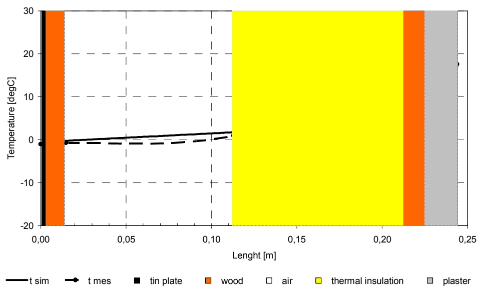


Fig. 19. Comparisons between average measured and simulated air temperature in the attic in winter with ambient air temperature

a)



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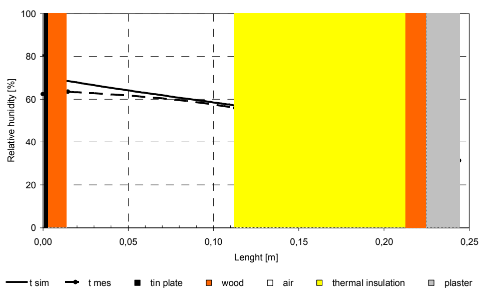

Fig. 20. Temperature (a) and relative humidity (b) simulated versus measured profiles at the end of winter period

4. CONCLUSION

The experimental campaign gives a decent overview on the hygrothermal processes taking place within roofs. However it has to be stated that available database is insufficient for complete analysis of the moisture and heat fluxes. The measurement campaign lacked detailed solar radiation data. The relative humidity within roof construction in summer turned out to be higher than in the winter. This is mostly related to the fact that the ambient air moisture content in the summer is much higher than in the winter, while insulation layer temperatures remain similar during both seasons. The measurements and simulations indicate that condensation does not occur.

WUFI software gives quite good demonstration of hygrothermal processes taking place within roof constructions. The model is best suited for full roofs (no ventilation). Unfortunately the model is unable to adequately represent roof ventilation: air gaps or attics. It is especially difficult in 1-dimension mass and heat transfer models. Other reason for imperfect agreement between the measurements and simulations is the lack of proper input data for simulations (i.e. solar irradiation data). Applied data may have differed from the real values. Finally the materials properties might have been inappropriately applied which of course could have impact on the results.

5. ACKNOWLEDGMENTS

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