

Woodhouse Energy Consumption Measurement System for Diagnostics of Thermal and Technical Properties of Buildings Envelope

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Abstract – To reduce the construction costs and to increase energy savings and the indoor environmental quality in a woodhouse, an energy consumption measuring system for diagnostics of thermal and technical properties of buildings envelope is introduced. At present, the vast majority of calculations for the thermal and technical characteristics of buildings are based on simple mathematical models of building envelope behaviour derived primarily from the thermal conductivity of individual materials. However, the thermal conductivity is measured in a stable laboratory environment. Therefore, the measured values may not match the real behaviour of materials in continually changing climatic conditions. The Energy Consumption Measuring System has been installed to eight woodhouses in different climatic areas to diagnose the thermal and technical properties of buildings envelope. The power consumption, temperature, and humidity of the air and of the wood, CO₂ concentration, temperature of the individual layers of the envelope sandwich structure and wind speed and direction are measured. Thanks to the sets of real measurements of the thermal and technical behaviour, the actual dependence of the indoor environment quality on the outdoor climatic conditions are obtained.

Keywords – *Measuring system, Thermal propagation, Woodhouse measurement, Indoor environment quality*

I. INTRODUCTION

The paper is introducing a building energy consumption monitoring system for the determination of a heat transfer through the individual parts of woodhouse envelope for diagnostics of the thermal and technical properties of buildings.

At present, there is no binding uniform methodology for diagnostics of wooden house sandwich structure system. These characteristics have been tested in the accredited laboratories in laboratory conditions where real climatic changes are only simulated. Due to the fact, that

only the surface temperature of the tested object (envelope sandwich structure) is measured and the other quantities such as heat flux density or heat transfer coefficient are explicitly calculated, these results do not correspond to actual real conditions. Besides, the subjective and objective causes of the use of woodhouse are omitted. In newly built or reconstructed residential buildings it leads to excessive usage in over-dimensioned thickness of insulation systems (200 mm, 250 mm, etc.). The energy saving in such an over-dimensioned buildings is already negligible, and hygienic comfort of a user is clearly deteriorating [1–3].

The proposed technical solution could eliminate the shortcomings of currently available solutions in the area of energy consumption of wooden houses. In order to introduce a binding uniform methodology based on woodhouses diagnostic of its thermal and technical properties a set of different quantities monitoring indoor and outdoor environment have to be analysed. The system should also include a set of sensors for monitoring the thermal propagation through the individual layers of the building envelope. Moreover, sensors monitoring temperature and humidity of the wood inside the building's structure would be desirable. [4 - 6]

With increasing share number of the wooden houses on the total building constructed (e.g. in Scandinavia, Japan or the USA more than 70% of a newly constructed building is wooden houses), there is also a need to monitor the relative humidity, humidity of the wood to prevent the increase of humidity [7]. There is also need to Monitor CO₂ concentration and temperature in order to increase the indoor environment comfort.

The paper introduces a complete measuring system that can monitor and measure the indoor environment quality and diagnose thermal and technical properties of buildings envelope related to the outdoor weather conditions. The proposed system also includes a developed application for collecting and processing all measured data. If enough data will be collected from wood houses build in different relevant climatic areas the binding uniform methodology can be to reduce the construction costs, increase the energy

savings and to increase the indoor environment quality of the woodhouses.

The paper is organized as follows. In Section II, The Energy Consumption Measuring System for Diagnostics together with the developed software is introduced and described. In Section III, the example of measured real data through one year is presented. The conclusion and future work are presented in section IV.

II. METHODS

In cooperation with a construction company RD Rymarov s. r. o., seven different one-floor or two-floor residential woodhouses was selected. The buildings are located in the Czech Republic in four different climatic areas. To collect a sufficient number of data, the measurement is performed for a three-year period.

Additionally, a measurement system was constructed in a laboratory for comparison with measurements from the real buildings. The laboratory model is able to simulate a wide range of climatic conditions. The model includes the same measurement system setup as a one-floor wooden house.

The system has been designed in order to fulfill all the mentioned criteria to measure the outdoor and indoor environment and thermal propagation through the envelope of the residential woodhouse. The system has to monitor the object for at least three years, and most of the sensors are placed into a structural system, where cannot be reached. Therefore, it was not preferable to use the wireless connection of individual sensors to the central unit since the loss of the data (e.g., loss of power, disturbance of a wireless transmission) could seriously affect the experiment.

The proposed measuring system consists of monitoring the weather: wind speed and its direction together with outside temperature and humidity; power consumption of building heating units; indoor temperature and relative humidity of the air and CO₂ concentration; wood temperature and moisture. To monitor the thermal propagation through the sandwich structure of the envelope of the wooden house, the temperature in three different layers of the structure is also monitored.

Each wooden house sandwich envelope consists of Fermacell gypsum fibreboard (1), wooden frame filled with heat insulation (2), Vapour barrier (3), wooden frame filled with heat insulation (4), Fermacell gypsum fibreboard (5) and thermo-façade (6) as shown on Fig. 1.

The system also includes all necessary communication units collecting data within a monitored object. The data from all monitored buildings are measured in real time and wirelessly sent to a remote server. There are processed and stored for further diagnostic. Moreover, measured data are supplemented by the local weather forecast.

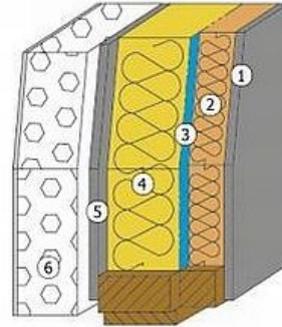


Fig. 1. The scheme of the standard wall of the wooden house [8]

The typical example positioning the individual sensors for a two-floor woodhouse is shown in Fig. 2.

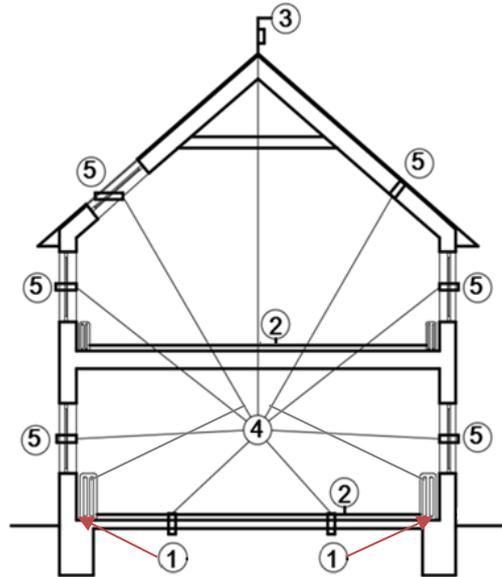


Fig. 2. The positioning the measuring sensors

The outdoor environment is measured by the set of temperature and relative humidity sensors (Fig. 2 - 5). Ethernet anemometer placed at the rooftop (Fig. 2 - 3) measures wind speed and its direction. The temperature and relative humidity sensors are placed at the outer part of the envelope sandwich structure (thermo-façade (Fig. 1 - 6) at each cardinal direction in a distance about 1.5 m above the base level of each floor including the roof (Fig. 2 - 5) as shown in Fig. 2. All the spots are measured using intelligent sensor communicating via RS485. The accuracy class of the sensor is $\pm (0.3 + 0.005 |v|)$, where v is the measured temperature in °C. Since the RS 485 standard allows the maximum number of 32 connected devices, Ethernet concentrators are used to extend the maximum number of devices/intelligent sensor. Together with temperature measured in thermo-façade, two more layers are measured.

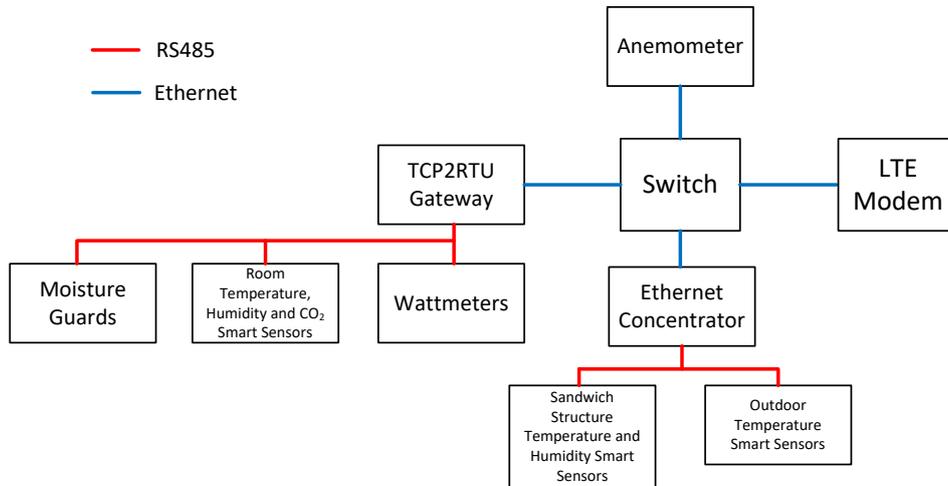


Fig. 3. The block diagram of the Measurement system

Temperature and humidity inside the envelope in a wooden frame filled with heat insulation (Fig. 1 - 4) and in fermacell gypsum fibreboard (Fig. 1 - 1) specifically. In this way, the thermal propagation/heat flux through the sandwich structure is monitored on each floor of the building including the roof and at the same time from all sides of the object. All the intelligent sensors use the same Ethernet concentrator to collect the data to the central unit.

To collect the data from the indoor environment quality the temperature and humidity of the air and CO₂ concentration smart sensors (Fig. 2 - 2) are installed in each room of the woodhouse. CO₂ concentration sensors help to monitor the movement of the residents around of the object. The accuracy of the sensor is $\pm (50\text{ppm} + 2\%$ from reading) and measuring range from 0 to 2000 ppm. Power meters to monitor the watt consumption for heating of individual rooms and the total energy consumption of the residential wooden house are also present. Intelligent sensors for monitoring indoor environment quality also communicate via RS485 and uses TCP2RTU gateway to connect to the central unit. Besides the measurement of temperature and humidity of the air in the sandwich structure, the temperature and humidity of the wooden structure are also measured. Four Moisture Guard intelligent sensors [7, 9] are located in a place where the structural system of the woodhouse meets the baseplate (Fig. 2 -1). Moisture guard is connected via RS485 to TCP2RTU gateway.

The Ethernet concentrator and TCP2RTU gateway are then connected to the Ethernet switch and to the communication unit which sends the measured data to the remote server using the LTE standard. The block diagram of the whole system is in Fig. 3. As written above, communication within one monitored object is done using the RS-485 Fieldbus, mainly due to its high resistance to disturbance. To ensure compatibility between individual sensors, data transmission from sensors or measuring transducers is done using the Modbus RTU protocol. Due to the requirement to send measured data real-time to a

remote server, the TCP2RTU gateway is added to the measured chain. Modbus TCP uses a standard Ethernet cable as a physical layer and allows remote access to all sensors or measuring transducers using the Internet. All TCP2RTU gateways are connected to an industrial switch, which is connected to an LTE modem. LTE modem sends data over a mobile 3G network to a remote server.

The transmission of measured data is performed using a client-server network architecture, where each of the monitored objects is a client sending data to a remote server. A relational database is located on the server, which stores aggregated information about monitored objects, installed sensors and measured data from all the sensors. The overall number of used sensors depends on the number of floors and number of rooms. The average number of sensors per one house is approx. 60. All data is collected continuously with sample frequency $f_s = 0.0011$ Hz, i.e., four samples per hour. By this way of measuring more than 80 000 measured samples is collected per one day. The principle of all the measured data from monitored residential wooden houses and the laboratory model is shown in Fig. 4.

As a part of the system custom software has been developed. The software package consists of several applications. The first of the applications provides continuous collection of data from each monitored object and stores the data in a relational database. The data contain measured quantity and also includes the time stamp and the location of the sensor. The second application is used to export measured data from the database. In this application, the user can select one particular monitored object and then specify the required data from specific sensors and the time interval. Selected data is then exported from the database to an MS Excel spreadsheet. The other two applications are used to set communication parameters of intelligent sensors before installation into the monitored objects and to control communication during installation of all sensors into the monitored objects

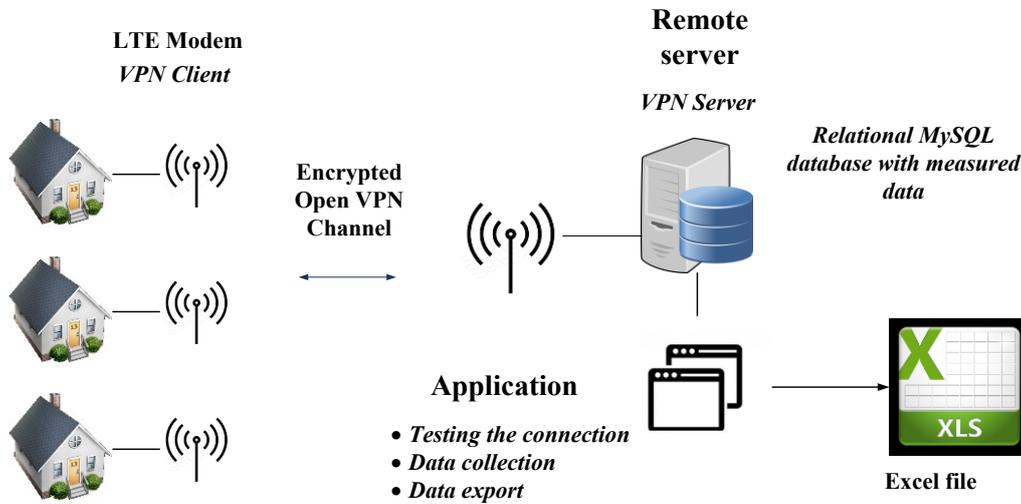


Fig. 4. The data collection block diagram

III. RESULTS

The data have been already collected through the first year of the measurement. All the demonstrated data have been measured on the same monitored residential woodhouse located in the highland in the eastern part of Czechia. The presented data are CO₂ concentration, change of the humidity of the wood and temperature in the envelope sandwich structure.

The example of CO₂ concentration measured in master bedroom through fourteen days is shown in Fig. 5.

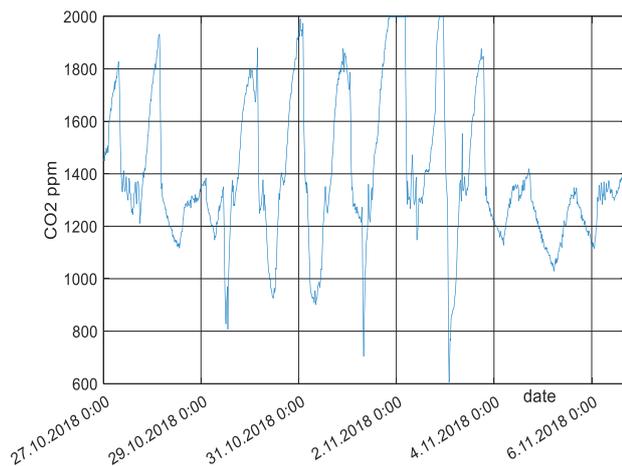


Fig. 5. CO₂ concentration in master bedroom

From the measured data, the resident's habits and movement around the house can be revealed. Data clearly shows the presence of the persons as well as times of the ventilation or when the residents leave the object. Therefore, it helps to understand the connection between

the movement of the residents and indoor temperature and ventilation.

Measured data in Fig. 6. shows how the humidity of the wood is changing with the time. Data are collected from all cardinal directions of the monitored object over the nine-month period.

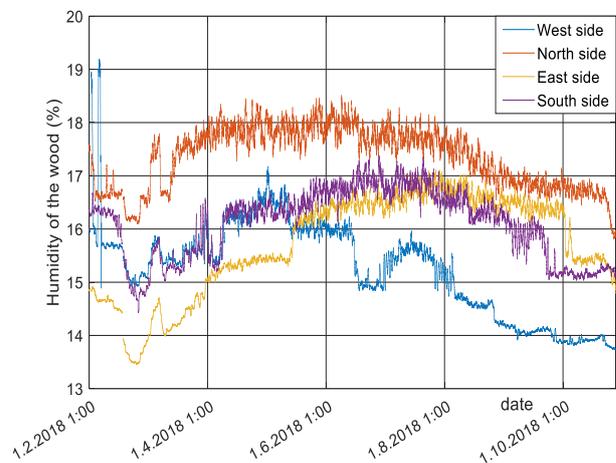


Fig. 6. Change of the humidity of the wood

The data shows the wooden humidity in the measured period is changing in a range no greater than 3%. Also, these data can be used to early detect moisture in the building's structure.

Fig. 7 shows the change of the temperature through the individual layers of the envelope sandwich structure in the north side of the monitored object over a month period. Using these data a thermal propagation/heat flux can be calculated [2, 10]. The data are already collected for one year. However, two more years have to be collected to get a sufficient amount of data.

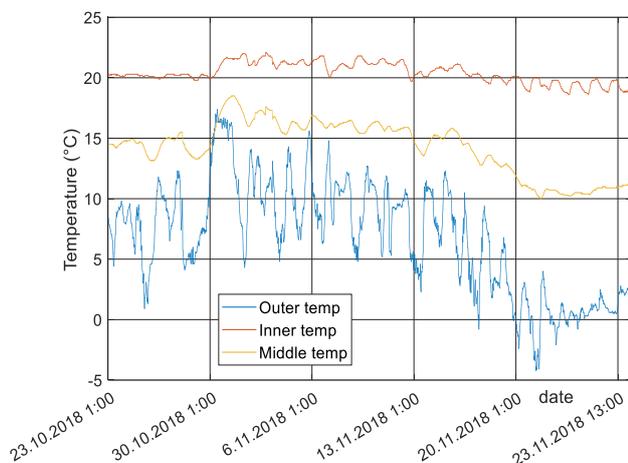


Fig. 7. The temperature in the individual layers of the envelope sandwich structure

Based on three years measurement, a binding uniform methodology for diagnostics of wooden house sandwich structure system will be proposed. In future, the system can be used for commercial use to monitor and to diagnose of any wooden structure. Based on the measurement, the control of the ventilation, heating or cooling systems, can be done. Furthermore, the proposed system can also monitor the humidity of the wooden structure, and it will be able to early detect moisture in a building's structure.

IV. CONCLUSIONS

In the article, The Energy Consumption Measuring System for Diagnostics has been introduced. The solution consists in the design of a universal measuring system for monitoring the thermal and technical properties of individual parts of the wooden house envelope, energy consumption for heating or cooling and the total energy consumption of the building depending on real climatic conditions to which the building is exposed.

The Energy Consumption Measuring System for Diagnostics has an innovative contribution due to the well-designed measuring methodology and its evaluating. The measurements correspond to actual climatic changes in combination with indoor environmental conditions. Based on the measurement, the individual parts of a woodhouse envelope can be revised to save the construction costs, energy savings, impact on the environment, and to increase

the indoor environment quality of the woodhouses. The measurement is already taken for one year, but two more years have to be measured to get enough data for a diagnostic.

V. ACKNOWLEDGMENT

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REFERENCES

- [1] Šála, J., Keim, L., Svoboda, Z., Tywoniak, Z., *Thermal protection of buildings*, IC CKAIT s.r.o., ISBN: 978-80-87093-30-6, 2008.
- [2] Kloiber, M., Drdácý, M., *Diagnostics of wooden constructions*, IC CKAIT s.r.o., ISBN: 978-80-87438-64-0 2016.
- [3] ČSN 73 0540-3 Thermal protection of buildings, Czech Standards Institute, 2005.
- [4] Blazek, J.; Mucka, M.; Trgala, K.; Cost and thermal - Technical optimization of wooden construction in the passive standard, *Wood Research*, 61, 663-672, 2016/
- [5] United States Department of Agriculture, *Wood Handbook – Wood as an Engineering Material*, U.S. Forrest Service, General Technical Report FPLGTR190, 2010.
- [6] Onysko D., Schumacher Ch., Garrahan P., *Field Measurements of Moisture in Building Materials and Assemblies: Pitfalls and Error Assessment*, DMO Associates, Building Science Corporation, FPInnovations, Forintek Division, 2008.
- [7] Včelák, J., Vodička, A., Maška, M., Mrňa, J., *Smart building monitoring from structure to indoor environment*, 2017 Smart City Symposium Prague (SCSP), Prague, 2017, pp. 1-5.
- [8] RD Rymarov s. r. o., 2018, Available at <https://www.rdrymarov.cz/en/scheme-of-walls-and-ceilings>
- [9] Vodička, A., Maška, M., Včelák, J., Mlejnek, P., *Sensor system for continuous moisture monitoring in wooden buildings and structures*, World conference on timber engineering 2016, Vienna, Austria, 2016.
- [10] Bosnic, J.A., Petrovic, G., Malaric, R., *Estimation of the wall thermal properties through comparison of experimental and simulated heat flux*, 21st IMEKO TC-4 International Symposium on Understanding the World through Electrical and Electronic Measurement, pp. 11-15, 2016.