IMPROVING CALCULATIONS OF BUILDING ENERGY CONSUMPTION BASED ON TEN YEAR MEASURED DATA

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Abstract. Research in energy consumption and efficiency of buildings is very topical, urgent and rapidly developing. A great amount of models and building energy simulation programs have been developed. Despite of these efforts the accurate input data for the programs are still scarce in the literature. Ten-year measured data have been gathered at the Department of Civil Engineering at the Tampere University of Technology (RTEK/TUT). Data acquisition was performed from six identical-sized test buildings with different construction materials applied in the external wall structure. The following parameters were recorded: indoor-outdoor temperatures; temperatures at various depths within the northern, southern, eastern, and western walls; indoor-outdoor relative humidity, heating energy, wind speed and direction, air tightness, infiltration, and horizontal global radiation. A computer system was applied to monitor, check, calculate, and integrate the data from approximately 520 sensors in each test building. Measurements were taken with a time interval of 20 s. The 20 s values were then integrated over a time interval of 30 min and the minimum, maximum, and mean values were subsequently stored to a computer database. Partners are welcome to further utilize the available data through collaboration work.

Keywords: test buildings, external walls, energy consumption.

Introduction

The building industry and the built environment are one of the largest contributors to energy and material use worldwide. Buildings account for about 40 % of the total energy use in Europe, and for about 36 % of the EU total CO_2 emissions [1]. Even though energy saving measures at the building level have been proposed, the net energy use is still increasing. With rising energy prices and greater focus on energy efficiency the building sector offers the single largest potential for energy savings. Energy performance of buildings is a key to achieve the EU Climate & Energy objectives for the year 2020 [2]. The main legislative instrument towards the objectives is the Energy Performance of Building Directive (EPBD) [3; 4].

Research concerning the energy need and efficiency of buildings is very topical, urgent and rapidly developing. A great amount of models and simulations on the energy consumption in buildings have been developed and improved. Some review of the current status in research is provided by the following papers. The accuracy of energy analysis and for modern, well-insulated Nordic buildings in Nordic climate has been studied [5]. Calculations by seven researchers and by seven different calculation programs were compared. Six of these programs were simulation programs (Consolis Energy, IDA-ICE, SciaQPro, TASE, VIP, VTT House model) and one monthly energy balance method (Maxit energy) based on the predecessor of the standard EN ISO 13790. The study showed that the differences in the input data cause often greater differences in the calculation results than the differences between various calculation and simulation methods [5]. The Round Robin Test [6] was performed to compare, test and validate the several existing typologies of building energy simulation tools, provided that the same data input and typology of the calculation model are given. The Round Robin Test included all modern energy calculation methods. The results of the Round Robin Test show the relationship between thoroughness of data input and energy evaluation accuracy. The more the input data are affected by uncertainty, the less precise the energy efficiency calculation is [6]. It has been stated in the conclusions of [7] that since all building simulation programs require hourly meteorological input data for their thermal comfort and energy evaluations, the provision of suitable weather data becomes critical.

In order to summarize the previous paragraph, the research review by [5] and [6] conclude that inaccurate input data lead to inaccurate results in calculation of energy consumption of buildings. Another reference [7] has notified that the provision of suitable weather data (input) becomes critical in building simulation programs. Therefore, the following experimental study solves an urgent scientific demand for: a) accurate measured data and b) appropriate input for building energy simulation programs.

The Department of Civil Engineering at the Tampere University of Technology (RTEK/TUT) has gathered ten-year (Sept. 1997 to Aug. 2007) long measured data from six test buildings. Six-year (Apr. 2001 to Aug. 2007) data from additional two test buildings are also available. The data were collected from identical-sized test buildings, having different commonly used exterior wall structures in Finland. A computer system (data logger) was used to monitor, check, calculate, integrate, and save the data acquired from approximately 520 sensors in each building that were applied in data recording. Measurements were taken with a time interval of 20 seconds. The 20 second values were then integrated over a time interval of 30 minutes and the minimum, maximum, and mean values were subsequently stored to a computer database.

Materials and methods

Six test buildings are constructed in a moderately exposed parking area within the compound of the Tampere University of Technology (Fig. 1). Later on two more test buildings were constructed. The test buildings shield one another from the outdoor winds.

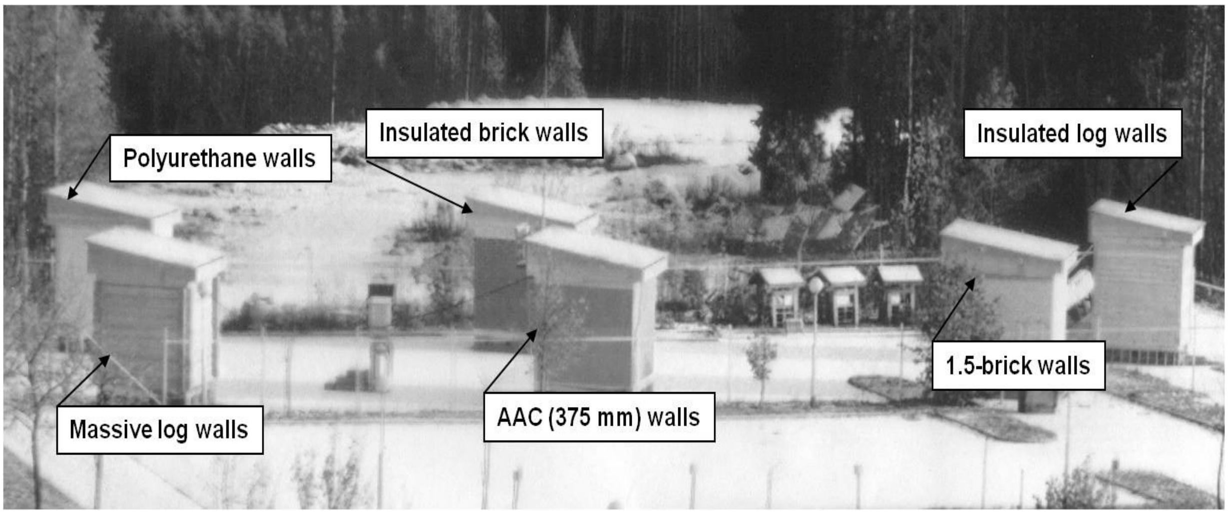

Fig. 1. **Test buildings at RTEK/TUT**

The external walls of the test buildings were constructed of different building materials that include: polyurethane insulated wooden frame wall (T-B 1), insulated cavity brick wall (T-B 2), insulated log wall (T-B 3), plastered massive brick wall (T-B 4), autoclaved aerated concrete (AAC) block wall (T-B 5), and log wall (T-B 6). Deliberately, those external wall structural solutions were chosen, since they are rather common in Finland. External doors of all of the test buildings are installed within the eastern wall and the test buildings have no windows. The floor area of each test building is 2.4 m × 2.4 m and the free floor to ceiling height is 2.6 m. All test buildings are heated with a 1500 W electric radiator (1248 mm × 400 mm heat panel) except for the massive brick wall test building, which is heated by two 1200 W electric radiators (1008 mm × 400 mm heat panels). Fig. 2 shows the details of the external wall structures of the test buildings.

The ceilings and floors of all test buildings are composed of two layers of foamed polyurethane elements with an overall thickness of 200 mm. The joints between the polyurethane elements are sealed with polyurethane foam and ventilation tapes. During the heating season the indoor air temperature inside the test buildings was constantly maintained at 20 ºC. The test buildings number 1, 3, and 5 were ventilated by balanced mechanical ventilation systems with heat recovery. The test buildings number 2, 4, and 6 were ventilated by the exhaust mechanical ventilation system. The air change rate in all test buildings was 0.5 h^{-1}. For occupancy simulation, (2 $g \cdot m^{-3}$) moisture content was constantly added to the indoor air. The additional moisture content was provided by continuously heating water that was kept into plastic containers inside each test building.

A weather observation station was constructed at the test building site that measures the outdoor temperatures, wind speed, and direction, and the relative humidity of the air. The intensity of solar radiation was also measured on-site by a pyranometer (solar meter) that was fixed on the eaves level of the test building number 5. The pyranometer measures the global solar radiation to the building surface, which is composed of the direct, and the diffused solar radiation. The wind speed and direction were measured 10 m high from the ground using an anemometer that was fixed to a steel mast at the test building number 5. A three-cup anemometer was used to measure the wind speed whilst a wind streamer monitored the wind direction.

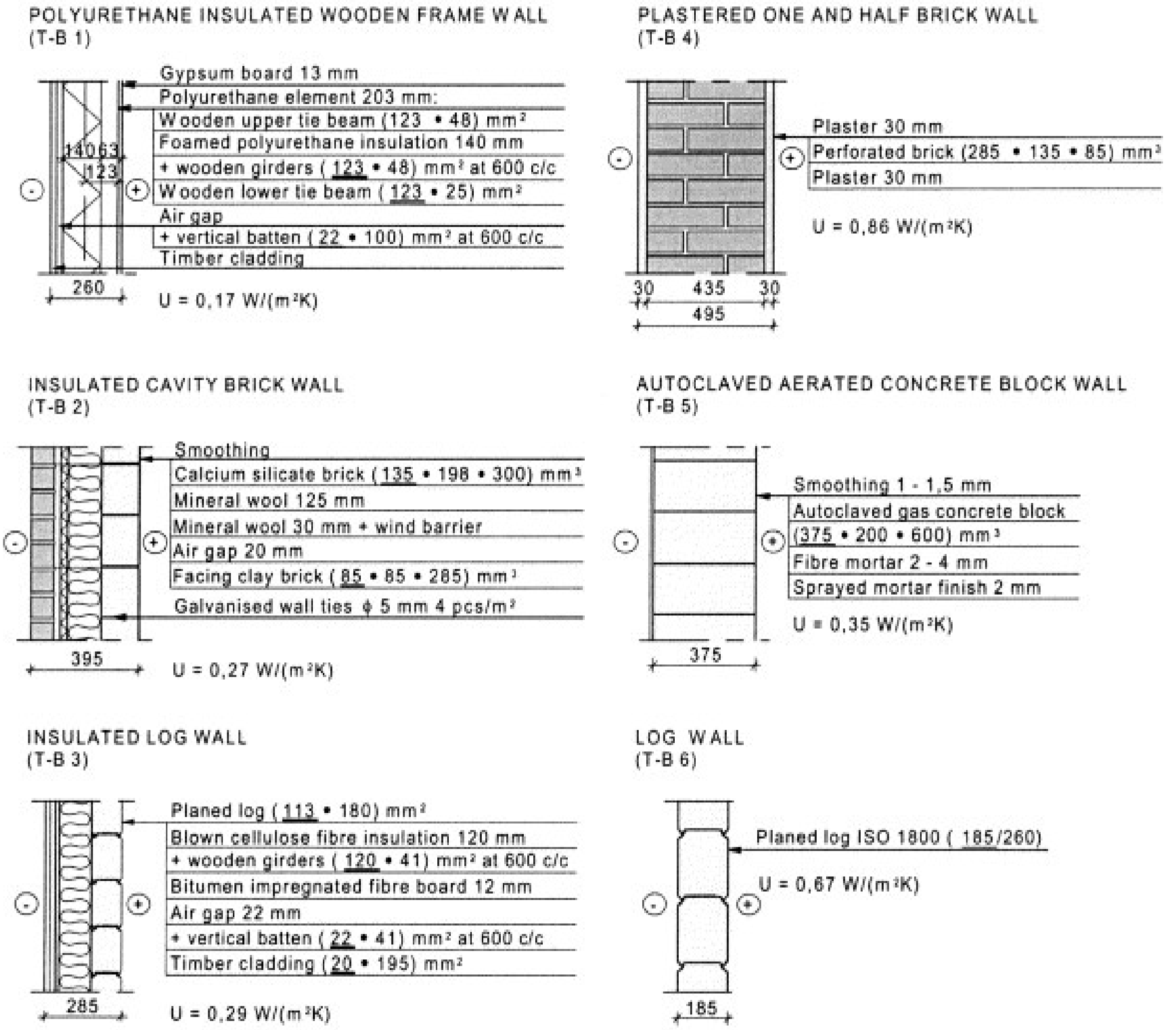

Fig. 2. **Details of the external wall structures of the test buildings**

The indoor air temperature was monitored at three heights (near the floor, at the middle, and near the ceiling). Temperatures above the ceiling and in the crawling spaces were monitored at several places. In addition, temperatures inside the wall structures were monitored at different depths in order to determine the temperature distribution in the walls during the day. The airflow rates and temperatures of the supply and exhaust air were continuously monitored. The temperatures were measured with calibrated semiconductor sensors and copper–constantan thermocouples. The indoor relative humidity was monitored with two humidity sensors. The number of semiconductor sensors and thermocouples was about 350 and 170, respectively. The measurement control system is shown in Fig. 3.

Multiplexers were used to collect the data from the sensors so that the readings from each channel were recorded to a computer after every 20 s. Analog-to-Digital and Digital-to-Analog (ADDA) cards were used for data collection and conversion. The minimum, maximum, and average values from the 20 s measured values were saved to a computer hard disc after every 30 min. The relative humidity inside the wall structures of the northern and southern facades were measured to determine the moisture content of the wall materials and the rate of drying after construction. The air tightness of the test buildings was measured by the pressurization test method at 50 Pa pressure difference while infiltration was measured using tracer gas.

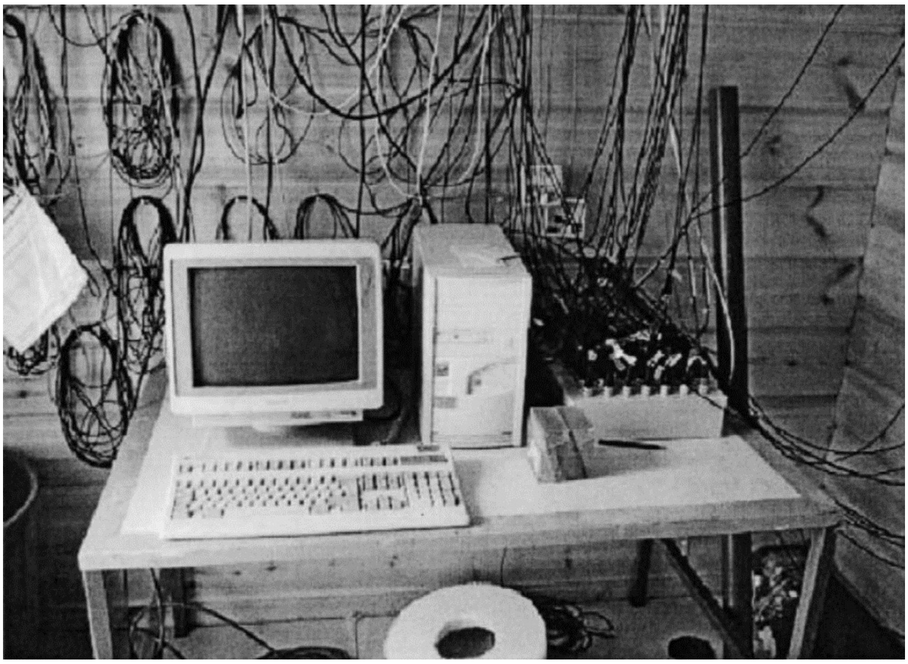

Fig. 2. **Measurement control system**

Results and discussion

Through the analyzed period from September 1998 to May 1999 the measured (light grey bars) heat losses through the external walls of the test buildings were up to 50 % smaller than calculated (light grey + dark grey bars; Fig. 3) [8; 9].

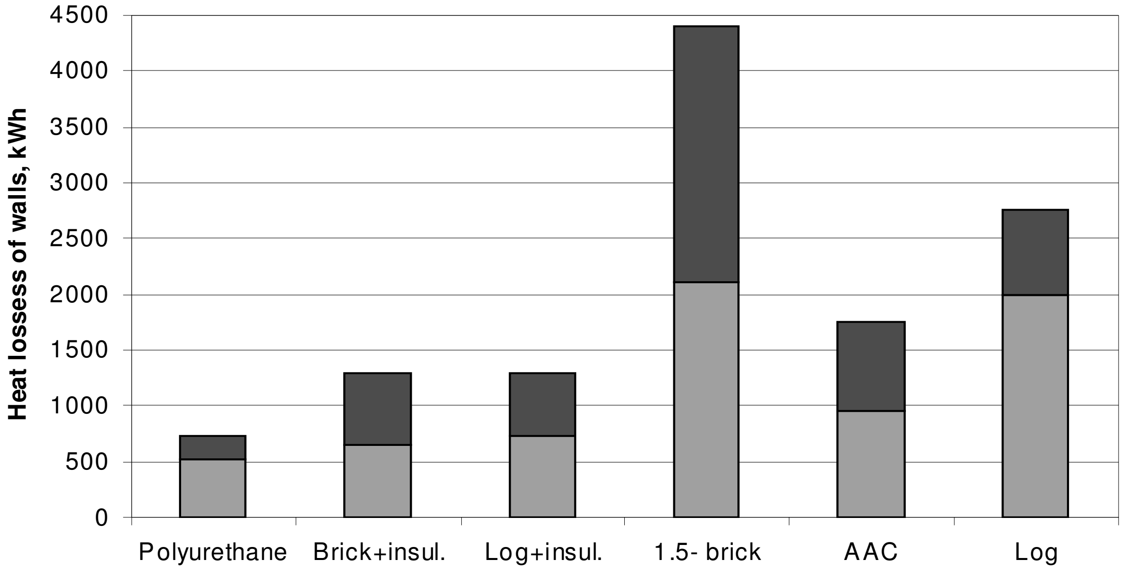

Fig. 3. **Measured (light grey bars) and calculated (light grey + dark grey bars) heat losses of the walls of the test buildings at TUT from Sept. 1998 to May 1999 [9]**

These results confirm the information from the previously referred literature sources, that inaccurate source data lead to inaccurate calculation results. Even more, it is highly possible (in all six test buildings) that the calculated energy consumptions over-estimate considerably the real situation. Based on these rather short-term results, perhaps the buildings are not responsible for as much of energy consumption as assumed in the Energy Performance of Buildings Directive.

It is clear that the data from the test buildings need more analysis. The following research aims for the future research could be raised:

- Establish appropriate boundary conditions for calculating the energy need of external walls of buildings in Finland, based on already measured 10-year data. Validated measured data can be applied as boundary conditions or input for building simulation programs. That will lead to accurately found heat losses of walls of buildings.
- Compare the measured and calculated heat losses, based on a long-term measurement period of 10 years (6 test buildings) and 6 years (2 test buildings). Also, find the main causes for discrepancy of the measured and calculated heat losses.
- Understand the time-dependent temperature distribution within the external wall structures under real climatic conditions. Tentative hypotheses could lead to a novel knowledge in the field of building physics.
- Propose recommendations for calculation of energy need of buildings in order to have an impact on standardization in Finland and EU.

Conclusion

With the growing concern towards environmental protection and achieving sustainable development, the design of energy efficient buildings is increasingly gaining attention. A great amount of building simulations and models have been developed and will be developed further. Despite of these efforts, a lack of accurate input data exists for the simulation programs. Several literature sources have shown that inaccurate input data lead to inaccurate results in calculation of energy consumption of buildings.

Ten-year long coherent measured data have been gathered at the Department of Civil Engineering at the Tampere University of Technology. The level of detail (520 sensors in each), amount (after each 20 seconds), long-term (measuring period of six and ten years) and coherency (measured at the same time at the same conditions) makes the data unique in Finland as well as in Europe. Therefore, a proper input for building energy simulation software is available. For the time being these data are largely underutilized. Interested parties are encouraged to come forth and make use of the available data through collaboration work.

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