INTEGRATED SIMULATION OF HEAT DEMAND AND AIR EXCHANGE IN A MULTIFAMILY BUILDING

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ABSTRACT

The paper presents the results of the measurements and integrated simulation of the energy demand and air exchange in one of the flats located in a 5-storey building located in urban area. The experiment was carried out during 3 weeks of March. The total energy consumption necessary for flat heating was measured continuously (at a 2 sec time step). After measurements were finished the energy demand and ventilating air flows were calculated assuming the same weather data variation as measured during the experiment, using the ESP-r software. The own author's program Multiven was also used for the air infiltration simulation, giving more detailed results about the ventilation air flows within the building.

Keywords: Simulation, energy consumption, ventilating air flows

1. INTRODUCTION

Prediction of heat demand in dwellings is important in designing and also during a life-cycle of buildings. In the past years, computer methods applied to the thermal building simulation were developed very rapidly, being more and more often used not only by researchers but also by designers, architects etc. [1].

The main aim of the work was the validation of simulation methods of heat demand and air exchange in dwellings and the software calibration.

There is no doubt that the inside structure of multifamily buildings is very complicated and it is impossible, in practice, fully reproduce it in a numerical model in all respects. In addition, the knowledge of operating characteristics of a given object is usually poor therefore being a source of great uncertainties in simulation results [2].

The empirical validation of simulation gives the possibility of checking the simulation results and – if needed – to calibrate the software. Additionally, thanks to the measurements performed unknown values of data and operating characteristics necessary for the simulation can be determined.

In the work presented, a scope of the experiment was limited to the single flat located in the existing, inhabited multifamily building. The direct measurement of the heat supplied by the central heating was very difficult due to vertical location of main supplied pipes in the whole building. It was decided that all heaters in the flat were closed, supply pipes well insulated and the heating was realized by the electric heaters. In this case, the electric energy consumption could be fully measured and recorded. The advantage of such solution in relation to the simulation procedure lay in that that the measurement included also energy used by electrical appliances and light in the flat, thus creating the additional heat gains. The meteorological conditions during the experiment were one of the most important data for simulation reliability. The compact weather monitoring station located on the roof of the building was used for measurements and it recorded all necessary data with a 5-minute time step.

2. EXPERIMENT PREPARATION AND MEASUREMENTS PERFORMED

For the experimental and simulation purposes a block of flats located in the urban area was chosen (Figure 1). It represented a stand-alone, 5-storey dwelling house with four apartments on each floor. All apartments were ventilated by the gravitational ventilating system by means of individual ventilating ducts connecting each flat with the outlets on the roof. As the object of investigation, the small apartment located on the ground floor of the building was selected. It consists of a living room, bedroom, kitchen and bathroom connected by a small hall. In Figure 2 a plan of the ground floor is shown and the flat of interest is marked by a dashed line.

When the measurement and simulation had been planned it was assumed that the whole flat would be treated as one zone. Such assumption is quite realistic from the occupant point of view, when the doors between rooms are opened as usual. In this case, the resistance of heat and mass transfer between particular parts of the flat can be neglected, especially when a constant air temperature in the flat was kept.

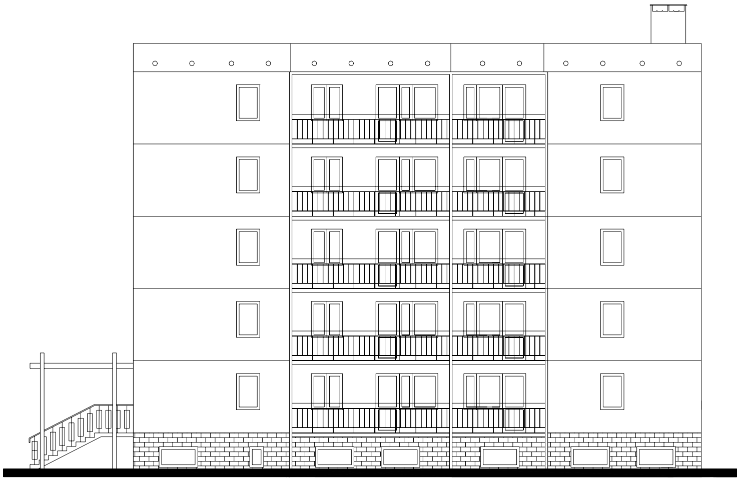

Figure 1 Back facade of the chosen building

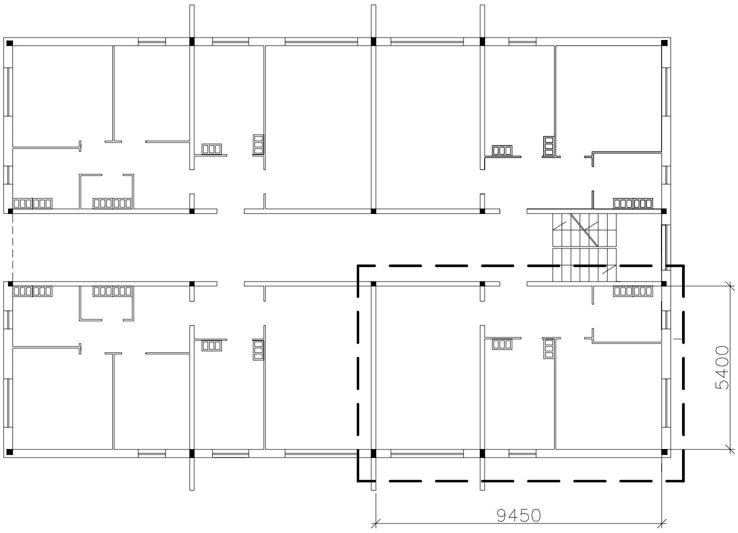

Figure 2 Floor plane

2.1. Energy consumption and indoor temperature measurement

The main experiment was carried out continuously during 3 weeks of March. It consisted of the energy consumption and indoor air temperature measurement in the flat, recordings the meteorological data and determination of windows air tightness. The dwelling house in which the measurements were carried out was centrally heated. The heaters installed in the flat were replaced with electric heaters. A system of four independently working electric heaters was used for heating the flat (2 kW of power in the rooms and in the kitchen and 1.5 kW in the bathroom). The temperature inside the rooms was maintained at the level of 21 ^{o}C with the accuracy of ± 0,3 ^{o}C by means of the electronic temperature controller. The controller was connected in series with electric heaters switches and with thermistor sensors. The sensors were placed at 1.2 m above the floor on stands situated in the central points of each room (Figure 3).

Power measurement was carried out by means of the power meter connected to the computer recording system. The measurements were performed round the clock with a time step equal to 2 sec, and recorded into a text file by means of the software supplied together with the power meter. The indoor temperature was measured in each room of the flat by means of copper-constantan thermocouples, placed in a central place of each room. The same sensors were also located in the flat surrounding of (next flat, staircase, cellar below and upper flat). Registration of the parameters was carried out by means of a precise 30-channel thermometer. It was possible to register the temperature automatically at the time step equal to 5 minutes with the accuracy of 0.3 ^{o}C. Then the values registered were exported to a computer and processed in a calculation sheet.

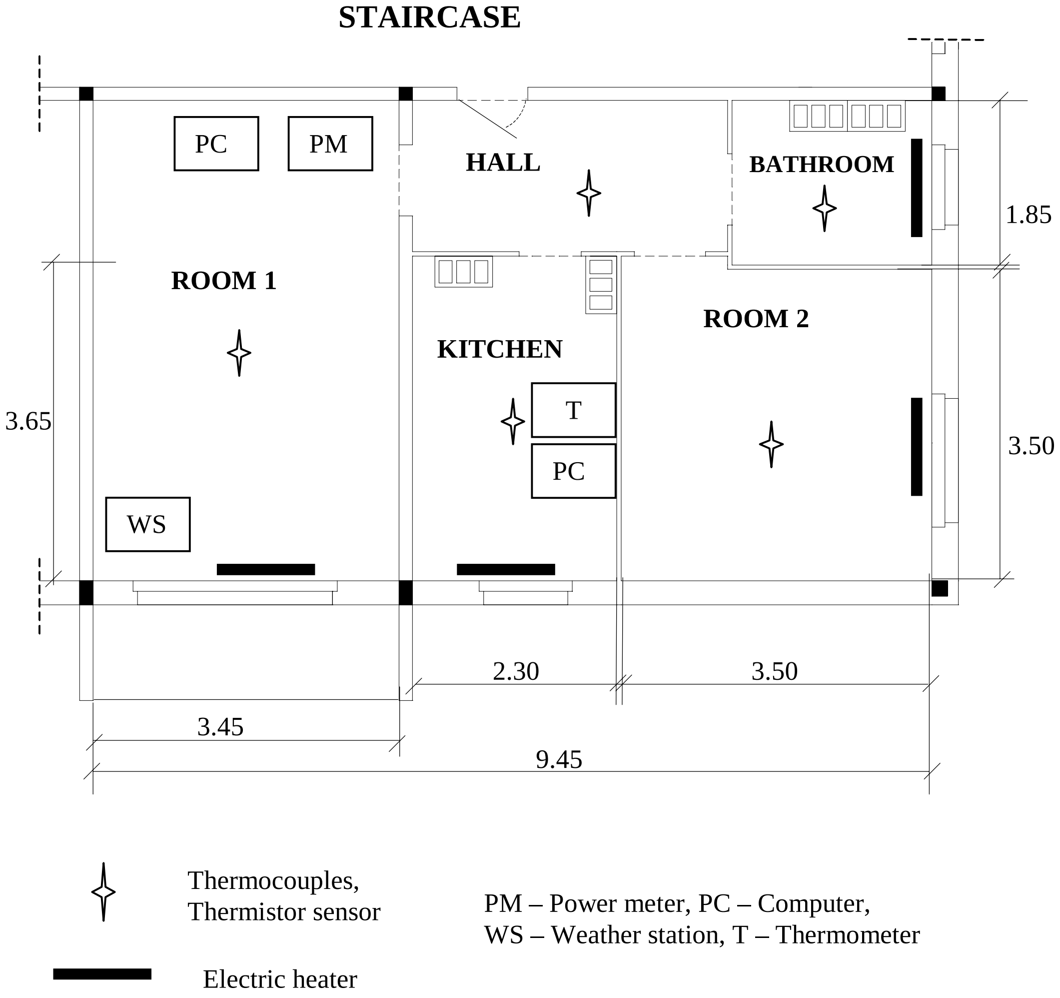

Figure 3.Measurement stands in the flat

The ambient weather conditions during the experiment were one of the most important data for infiltration simulation reliability. The compact weather monitoring station, located on the roof of the building and connected to the monitoring device in the flat was used. It gave the possibility for the continuous measurement and recording of barometric pressure, outdoor temperature, wind speed and direction and solar radiation. All weather parameters were recorded with a 5- minute time step.

2.2. Air tightness measurement

It was necessary to know the characteristic of windows air tightness to carry out numerical calculations of the air infiltration in the flat. This was determined as the relation between the air volume flowing through the windows and the pressure drop [charl]. A so-called blower door was constructed and installed in the entrance doorframe. The air volume flow was determined by measuring the pressure drop in a testing system with 4 nozzles of different diameters, constructed on the basis of ASHRAE Standard [3]. The pressure drop across windows was measured by the recording of static pressure values in both sides of windows by means of micromanometers. The test results are shown in Figure 4.

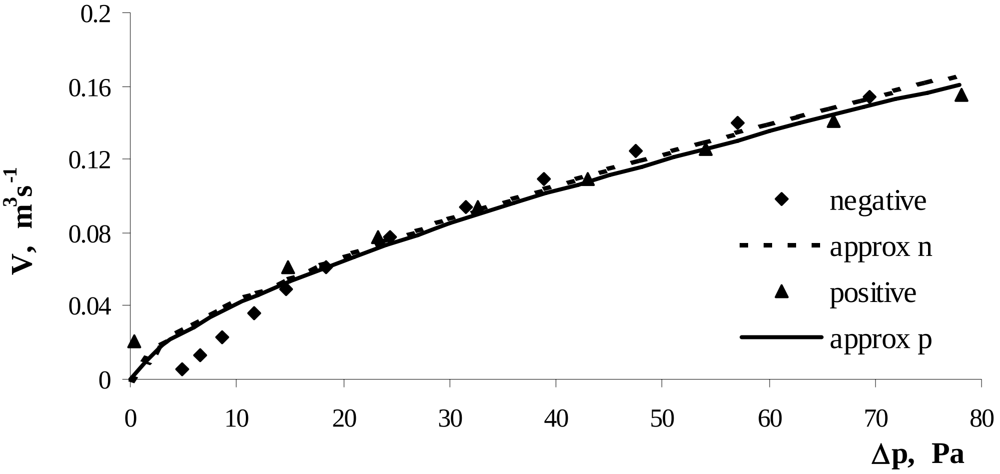

Figure 4 Characteristic of airtightness

2.3. Air change rate measurement

The airflow through a room is usually evaluated using one of three tracer-gas methods: the concentration-decay, constant emission method or constant concentration method [4]. In the experiment, the tracer gas concentration decay method was selected. This is the most basic method for measuring air exchange rates and it is used to obtain discrete air exchange rates over short periods of time. In this method a certain amount of tracer gas is introduced to the room and than it is mixed with the air to get its uniform concentration in the whole room. Then the gradually decreasing concentration of tracer gas in the air is recorded. Carbon dioxide was the selected tracer gas. This gas is a natural component of air, and therefore its initial concentration as the tracer gas must be several times higher than the CO_2 concentration in air. In order to facilitate the measurement, solidified carbon dioxide was used – so called dry ice, which sublimates when placed in a room. Lumps of dry ice, whose mass was proportional to the cubature of rooms (both rooms, kitchen and bathroom) where placed in containers in the middle of each room, crushed and covered with hot water. Air mixing in the room was obtained by turning on the fans. The doors between all rooms and the entrance hall were open. The air was exhausted from separate rooms to a CO_2 concentration meter. When the CO_2 concentration in the air reached at least 4 000 ppm, fans were turned off and automatic registration of the CO_2 concentration in the air began. Nobody was present in the room during the measurement, and also there were no other CO_2 sources. The Carbon Dioxide Monitor – Model CO_2 was used as the CO_2 concentration meter. Its measurement range was equal to 0-10 000 ppm. The analogue voltage signal from the meter was changed into the digital signal by means of the analogue – digital module. Then it was calculated as concentrations in ppm and recorded in the computer disk by means of a specially written for that purpose software. The software enabled continuous registration of the data every 1 ÷ 600 s during 25 days. It was also possible to save the measurement results as a text file and to watch them on the screen as a plot of the CO_2 concentration in the air. The measurement results were recorded every 2 sec during 6-8 hours. The concentration decay data were fitted by the exponential curve using the least square approximation method. Air change measurements were repeated several times under different weather conditions. The results of the measurement compared with the simulation results are shown in Figure 7.

4. SIMULATIONS

4.1 Software description

The integrated simulation of thermal behaviour and air infiltration was carried out by means of the ESP-r software. The ESP-r [5] is a transient energy simulation system which is capable of modelling energy and fluid flows within combined building and plant systems. The package comprises a number of interrelating program modules addressing project management, simulation, results recovery and display, database management and report writing.

ESP-r may be used to explore a range of problem, including:

- building fabric,
- heat and mass flow,
- ideal and detailed plant systems – separately or in combination.

The system offers sophisticated input/output facilities which enable the user to answer on different design questions. The ESP-r is equally applicable to existing buildings and new designs, with or without advanced technological features. The software is designed for the Unix operating system with supported implementations for the Solaris and Linux. More detailed description can be found in [5].

The ventilating air flows in the whole building was independently simulated using author’s own programme Multiven. There were a few reasons of these additional simulations:

- experimental verification of the Multiven software using the air exchange measurement results in the given flat,
- inter-model programme verification, comparing the ESP-r and Multiven results of simulations,
- adjusting or calibration of the Multiven software.

The advantage of the Multiven programme used was that that the source code was available and all necessary changes were feasible and simple for the author. The numerical procedure belongs to the group of network models. The program was built with several assumptions. The main of them are as follows:

- one flat is treated as a single calculating zone,
- internal pressure and air temperature are constant in the given zone,
- changeability of air density in zones can be neglected,
- calculating zone is not tight and the airflow between zones is possible,
- mass accumulation can be neglected.

The model of building was created under given above conditions using the volume balance equation of airflow for each declared zone. Additionally, in the whole staircase artificial zones were created (one in every floor) thus enabling the calculation of vertical airflow when stratification of temperature in the staircase is declared. All important types of airflow were taken into account in the balance equation for the zone:

- air infiltration through the windows leakages;
- ventilating ducts flows;
- the flows between the flat and the staircase.

The stack effect and wind pressure on a building envelope were taken into consideration as the driving forces of ventilating flows. The wind pressure coefficient converting the dynamic wind pressure to the static pressure acting on building walls was calculated according to the approximation function prepared on the basis of experimental data [6]. The mathematical model consisted of a set of non-linear algebraic equations. The solution was found by adapting one of the optimizing theory methods – Rosenbrock's modifying algorithm. In this method the minimum of a target function created from the set of equations was searched.

The necessary input data for simulation are:

- geometry of the building,
- air tightness characteristics of windows and their location,
- climatic data: outdoor temperature, wind speed and direction.

The simulation was carried out in a quasi-dynamic mode with the time step depending on the meteorological data.

4.2. Integrated simulation of heat and air flow

The flat thermal load was simulated by means of the ESP-r software with certain assumptions necessary to compare the measurement and simulation results. The flat was treated as a single thermal zone and the internal partitions were taken into account only as heat accumulation units. The internal heat gains from people were neglected since the flat during the experiment was not occupied, and the visits of technical staff were quite brief. The heat gains caused by all electrical devices in the flat were also passed over in simulation – the total electric energy consumption were measured during the experiment including all appliances. During the measurement all windows in the flat were closed. For this reason only infiltration through windows cracks was taken into account in the simulation. The calculation zone was assumed to be tight and the airflow between the flat and staircase was not possible.

The input data for the heat and air flow simulation were as follows:

- geometry and technical data of the building,
- varying air temperature in the flat tested and in neighbouring flats recorded during the measurement,
- fluctuation of meteorological conditions obtained from a local weather station recorded during the heat demand measurement,
- air tightness characteristics of windows and their location.

In the simulations text files containing values of the total heat demand and also separate components of the flat thermal balance (heat transmission, heat loss for the air infiltration and heat gains from the solar radiation) were obtained. The results are presented in Figure 5 and 6 in comparison to the measurement.

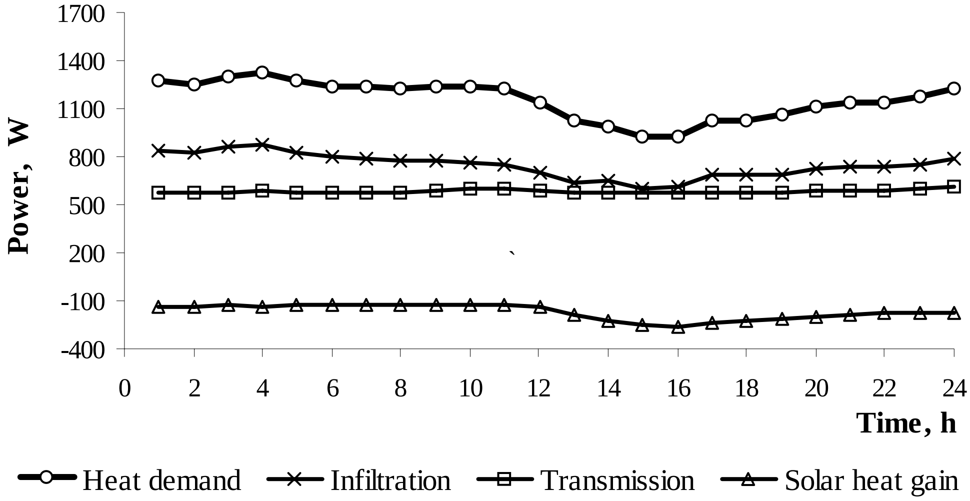

Figure 5 Example result of simulation with ESP-r (16th March)

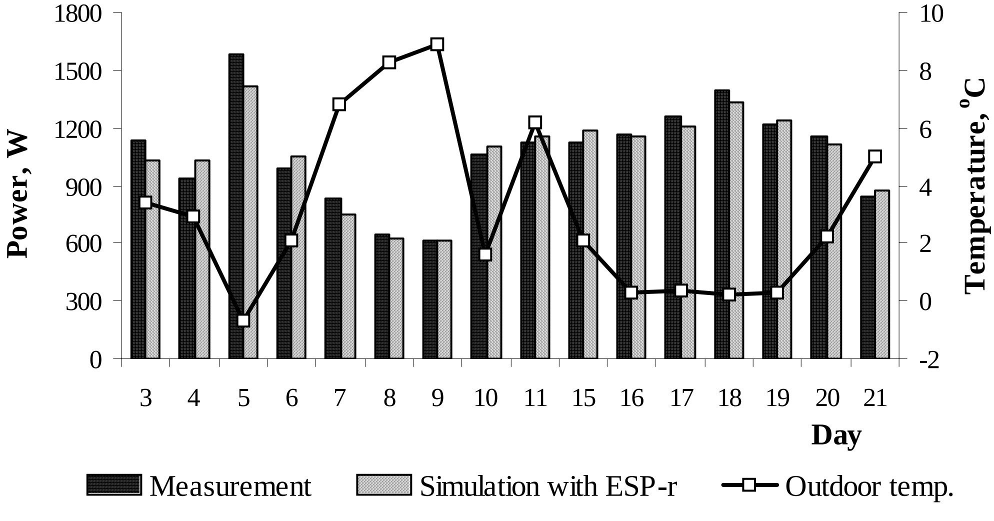

Figure 6 24-hours' heat requirement (simulation with ESP-r versus measurement, 3-21 March)

4.3. Ventilating air flow simulation

For the same weather data ventilating air flows in the whole building were simulated by means of the Multiven software. The first run of the simulation was done using the standard version of the programme.

The values of the air change rate obtained by the simulation differed from the measurement results in the range of ± 25%. The greatest differences were observed when the wind pressure exceeded thermal buoyancy, creating the dominant driving force of ventilating flows. When the software was prepared a particular attention was paid to the program module in which the wind effect is calculated. In the standard simulation a value of the wind speed, normally obtained from a nearest meteo-station, was recalculated depending on a terrain class and building surrounding, and the logarithmic profile was assumed along the height of a building. In the next simulations the software was slightly calibrated by changing the multiplication factor in the module of wind pressure coefficient calculation. Moreover, it was decided that for the weather data coming from the measurement on a site (the roof of the building) there was no necessity to recalculate the wind speed because of local obstacles. The constant wind profile was also assumed along the whole height of the building. The simulations were repeated and the results were more close to the experiment – the mean error of the air change rate estimation was approximately equal to 6 %. Figure 7 shows the run of infiltration variation obtained by the Multiven (continuous line) and the ESP-r (dashed line) simulation and the measurement results (points).

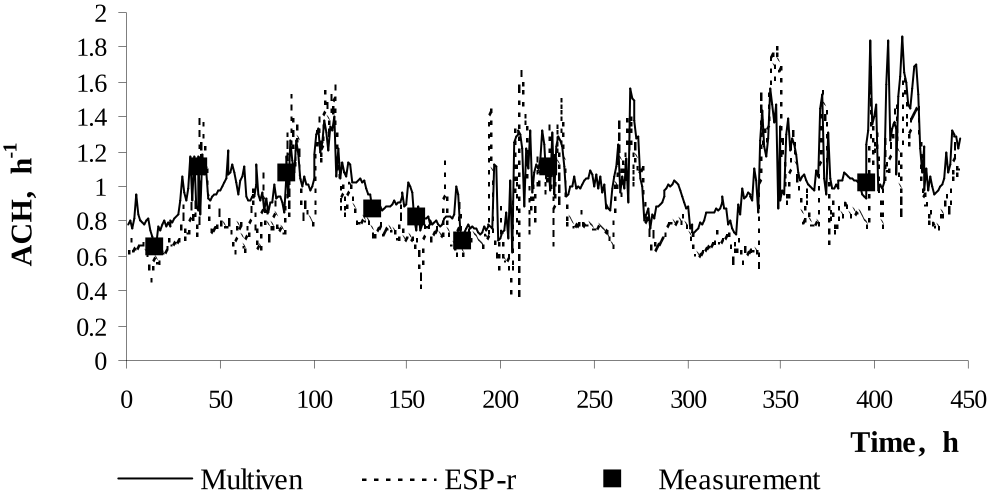

Figure 7 Comparison of measured and simulated of ACH

It can be noticed that Multiven results are closer to the measurement than those coming from the ESP-r simulation. One should take into account that although the ESP-r programme was used “as it was”, without any adjustment, the results of air exchange simulation yield a very good agreement with the experiment.

5. CONCLUSIONS

The work performed shoved that the measurement in an existing object is the best way for validation of a simulation software. It has been proved that the simulating codes yields reliable calculation results. This is particularly essential in reference to the determination of a thermal load in an inhabited multi-family dwelling house where the complex measurement of the energy consumption, air temperature distribution and air change would be very difficult due to technical reasons and costs of such experiment. Comparison of the simulation results with the energy consumption measurement yields a very good agreement in the global heat demand assessment: the mean relative error does not exceed 4%. The simulation program employed in the work gave very good results of air infiltration simulation when comparing them to the experiment. It should also be noticed how important are the weather data, especially wind effect, on results credibility. The case study performed gave information on thermal behaviour concerned only one flat of a selected building. Nevertheless these fragmentary results should be very useful in the simulation of the whole building. Such a short-time, fragmentary measurement campaign can be very valuable in software calibration, when the simulation should be prepared for a non-typical object and allows one to apply the simulation in a wide range without the great risk of inaccuracy of results and errors.

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