EXPERIMENTAL AND NUMERICAL MODELLING OF THERMAL PERFORMANCE OF A RESIDENTIAL BUILDING IN BELGRADE

by

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The main objective of this paper is to evaluate simulation of thermal performance of a residential 4 floors high building placed in the suburb of Belgrade (ground and 3 upper floors) with it's total surface area of 1410 m^2. It's supplied with liquid petroleum gas storage tank as a fuel reservoir since there is automatic gas boiler in each apartment. Measurements have been carried out in first floor apartment (68 m^2 heating area) in heating season period. Measured parameters are: inside and outside air temperature and U-value of apartment envelope. Weather data is obtained by using METEONORM, the software package for climatic data calculation based on last 10 years measurements. TRNSYS 16 has been used as the simulation tool. The behavior of the building in terms of heating loads for climate on a daily and monthly basis in heating season is investigated. The calculations show possibility for saving energy by optimization inside temperature during different gas boiler working regimes.

Key words: *TRNSYS, building behavior, building simulation, temperature measurement, optimization*

Introduction

After all what have been happening in the world last years, we can clearly see that we are facing, more or less, period of serious energy crisis. The existing buildings energy consumption in European countries accounts for over 40% of total energy [1]. In developing countries, with no oil and gas sources, all systems comfort and all industry production based on energy use will have very unpredictable future.

The long-term state strategy for saving energy and get it from renewable sources is needed. Firstly, by planning investments for making electricity from wind and biomass, and by stimulations for solar energy use. Secondly, by making quite new architecture, not only in the building structure, but also with everything necessary for high-energy efficient buildings.

As a capital of Serbia, in the last decade Belgrade was passing through different phases. It's now very obvious that city is running into time of energy addicted society and that will change the way of thinking about city developing and energy consumption in a future period. Beside, already mentioned, new architecture, the uppermost task for engineers in Belgrade will be to think about existing residential building stock sustainability. The high buildings and settlements energy use is mainly under control of regulations, but there are thousands small buildings in the suburb (the total space surface area exceeds all others) with no taking care about energy wastage.

Anyway, talking about old buildings, it is necessary to make large analysis about losses to be able to propose the way of decreasing U-value by adding new isolation layer or new windows and doors for the saving energy purpose. However, Belgrade is a city with a moderate climate with higher energy consumption during the winter heating comparatively with summer cooling. Before spending any money on changing building envelope structure and making compromise between thermal comfort and energy consumption, dwellers should get advice how to save the energy by different heating regimes, wherever that is possible.

This paper deal with indoor and outdoor air temperature and envelope U-value measurements in apartment placed in a four floors building in the Belagrade suburb during the heating season. The building is supplied with an outside liquid petroleum gas tank as a fuel reservoir and each apartment with separate gas boiler. The experiments were performed in four days of December and comparison with TRNSYS 16 [2] simulation results was made for the similar weather period obtained by using METEONORM [3] software package. Based upon difference between inside air temperatures by measurements and simulations, as well as analysis of the cause, the system was calibrated only for this case by increasing internal heat gains during the night in the apartment we were focused on.

Thermal energy demand for the whole heating season and three different regimes was calculated. It was done by the time integration of hourly sensible heating demand got by TRNSYS simulation and shown in percentage of the worst regime.

Measurements

The experiments were performed in a second half of December from December 19-22, in a first floor apartment of residential building in the Belgrade suburb (fig. 1). The weather was very humid and cloudy and average outside temperature was a few degrees above zero. Gas heater was working in the regime of keeping indoor air temperature at 22.6 ºC during a day (from 6.30 h in the morning until 22.00 h in the evening) and keeping at 20.0 ºC during a night. In the measuring period four persons were present in the apartment. The difference between indoor and outdoor air temperature was very clear (about 15 ºC).

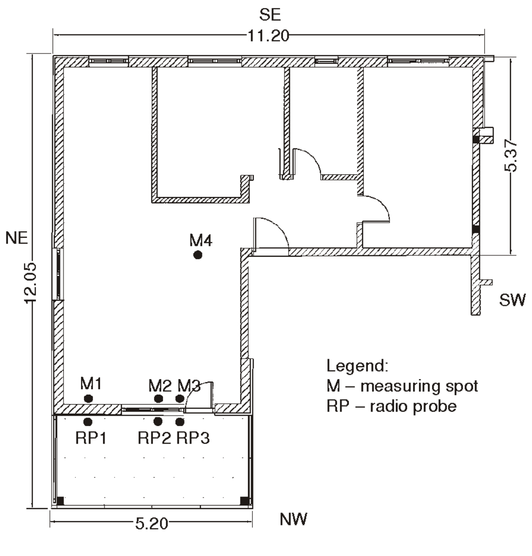

Figure 1. Apartment blue print

Outside wall structure consists from five layers as it is shown in tab. 1. The measurements were made with two measuring instruments: Testo 635-2 and Testo 435-4.

The first instrument (Testo 635-2) is supplied with a radio probe (for outdoor temperature and air humidity measurements), temperature probe for U-value determination (for inside wall surface) and temperature sensor in the instrument body (for the indoor air temperature measurement near to wall surface). In order to obtain correct measurement results, the radio probe was placed about 30 cm from the outside wall, window glass or window frame surfaces (positions RP1, RP2 or RP3, respectively, of wall, window glass or window frame) protected from the cold or heat radiation at the same height as the temperature probe (positions M1, M2 or M3, respectively, of wall, window glass or window frame). The temperature probe consists of three thermocouples fixed with sticking plasticine to the inside wall surface with a 10 cm distance in-betweens. The instrument calculates average inside surface temperature from those three measured values. The inside heat transfer coefficient h = 7.7 W/m^{2}K is set in the instrument, suitable for most standard cases, since almost constant [4]. Under the steady-state condition, heat transfer between indoor air and inside surface is equal with heat transfer between indoor air and outdoor air both per square meter of surface area and per degree of temperature. Based on that fact and measured or calculated values: the outdoor air temperature, the indoor air temperature near to the inside surface, the inside heat transfer coefficient, and the inside surface temperature the instrument calculates U-value.

Table 1. Description of wall structure

Material	λ value [Wm^{-1}K^{-1}]	Thickness d [mm]
Plasterboard	0.99	15
Bricks	0.61	150
Expansed polystyrene	0.041	50
Bricks	0.61	150
Plasterboard	0.99	15
U-value [Wm^{2}K^{-1}]	U = 0.524	d = 380 mm

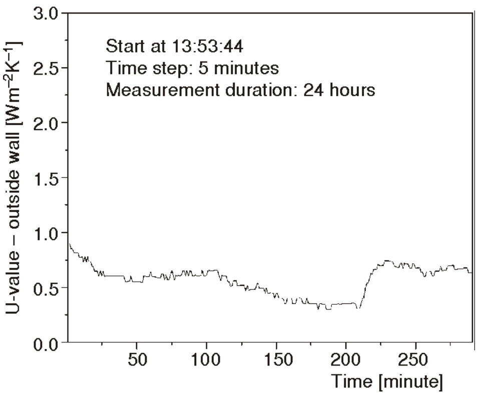

Figure 2. U-value of outside wall

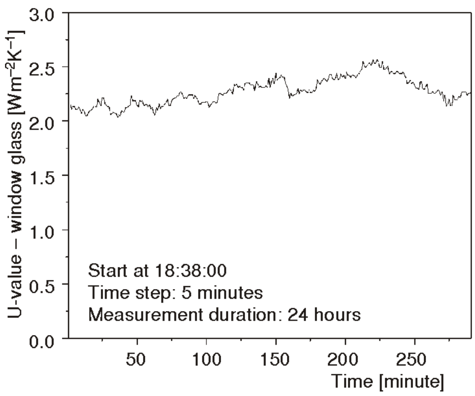

Figure 3. U-value of window glass

The second instrument is supplied with temperature sensor inside the instrument body for measuring indoor air temperature. Position of the instrument was in the centre of the apartment M4 [5, 6]. U-values of outside wall, window glass and window frame were measured every 5 minutes in 24 hours each. Results are shown in figs. 2, 3, and 4.

Modelling and simulations

In this section, a basic model was developed using multizone building modelling (Type56) of TRNSYS [2] to simulate thermal behaviour,

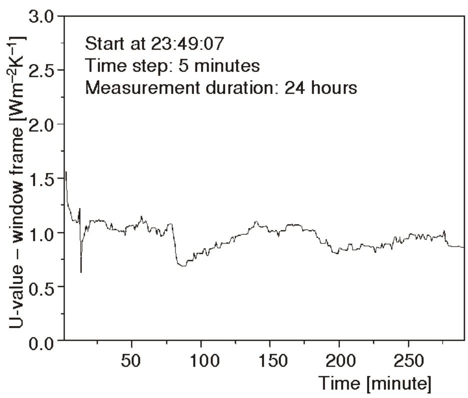

Figure 4. U-value of window frame

which is to be compared with indoor air temperature measurements. Simulation studio was used as a complete simulation package containing tools for simulation and graphical connection, plotting and spreadsheet software covering process from the design of a project to its simulation (fig. 5).

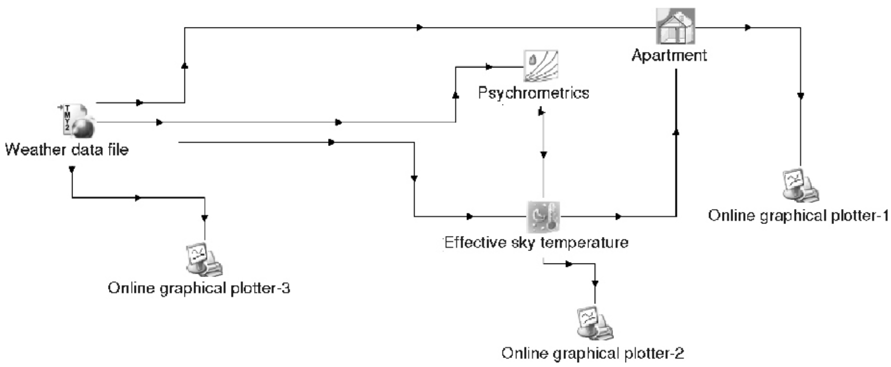

Figure 5. The visual interface

The Weather data file component serves the main purpose of reading weather data at regular time intervals from a data file, converting it to a desired system of units and processing the solar radiation data to obtain tilted surface radiation and angle of incidence for an arbitrary number of surfaces.

The Psychrometrics component takes as input the dry bulb temperature and relative humidity of moist air and giving as an output corresponding moist air properties: dry bulb temperature, dew point temperature, wet bulb temperature, relative humidity, absolute humidity ratio, and enthalpy.

The Effective sky temperature component determines an effective sky temperature, which is used to calculate the long-wave radiation exchange between an arbitrary external surface and the atmosphere.

The Apartment component models the thermal behaviour of a flat as a one thermal zone. The apartment description is read by this component from a set of external files.

The *Online graphical plotter* components are used to display selected system variables while the simulation is progressing. Plotter-1 was used to show results of simulation: indoor air temperature and heat loads for the apartment. Plotter-2 was showing calculated cloudiness factor of the sky and plotter-3: ambient temperature and ralative humidity based on METEONORM [3] data.

For the simulation purpose, whole apartment (B3) in residential building was treated as a single zone. Below (B1) and above (B6) flats (as two adjusted zones) are with the same surface area as the previous one. Those two flats were inhabited with no measurements inside. The following assumptions were made: B1 and B3 zones are continually heated keeping inside temperature at 20 ºC. At the same floor, two other zones were adjusted to the (B3). Uninhabited flat (B5) and stairs space with no heating.

In the B3-zone there is no ventilation and cooling. Infiltration presumed to be 0.6 changes per hour. Internal gains consist of gain from artificial lightening (adopted 10 W/m^2 for moderate lightening) gains from occupancy and appliances (occupancy related data for residential buildings given in [5] was used). Parts of apartment envelope are: double-glazed windows with PVC frame and outside wall made of layers as it is shown in tab. 1.

The gas boiler in the B3-zone is turned on all the time during the heating season with possibility to change working regimes.

The basic heating regime (regime 1) is to keep indoor air temperature at 22.6 ºC during a day (from 6.30 h in the morning until 22.00 h in the evening) and to keep at 20.0 ºC during the night every day in a week (already explained).

The second working regime (regime 2) compared with a previous one has only different heating schedule. It is to keep indoor air temperature at 22.6 ºC from 6.30 h until in the morning and from 16.00 h until 22.00 h in the afternoon. Other time in working days, the apartment was heated to keep at 20.0 ºC. During weekends, heating schedule was the same as for every day in a week for the basic heating regime.

The third working regime (regime 3) has the same heating schedule as second one (different schedule for working days and weekends) but different set temperatures. It is to keep indoor air temperature at 21.6 ºC from 6.30 h until 7.00 h in the morning and from 16.00 h until 22.00 h in the afternoon. Other time in working days, the apartment was heated to keep at 20.0 ºC. During weekends to keep indoor air temperature at 21.6 ºC during the day (from 6.30 h in the morning until 22.00 h in the evening) and to keep at 20.0 ºC during the night.

For the model improvement, basic heating regime was simulated and indoor air temperature of B3-zone was compared with measurements on daily basis. Period from December 1st to 4th (from the METEONORM [3] data) had very similar daily average temperatures, very cloudy and high humidity weather as the measuring period. From that period, ambient temperature and humidity on December 2nd are compared with measurements of real ambient conditions on December 20th as it shown in figs. 6 and 7.

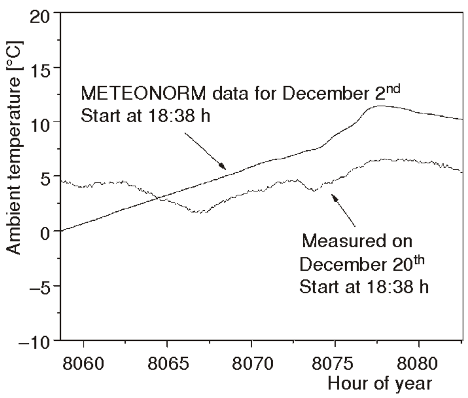

Figure 6. Ambient temperature comparison

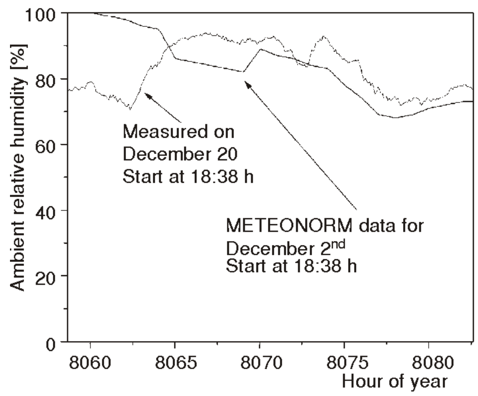

Figure 7. Ambient relative humidity comparison

The ambient measured temperature is a few degrees lower then the same temperature from METEONORM [3] data (fig. 6). The fig. 8 shows very high level of cloudiness (METEONORM [3] data for the December 2nd).

The basic heating regime simulation is performed and indoor air temperatures are compared with measurements for the very similar day as it already explained before. It is shown in fig. 9.

The simulation results very satisfying stand with measurements. The difference in indoor air temperature during the night is very small and the difference during the day arises from the following. Along with performing measurements dwellers were present using kitchen aspirator, manually ventilating apartment, opening entrance door *etc*., which brought an increase in

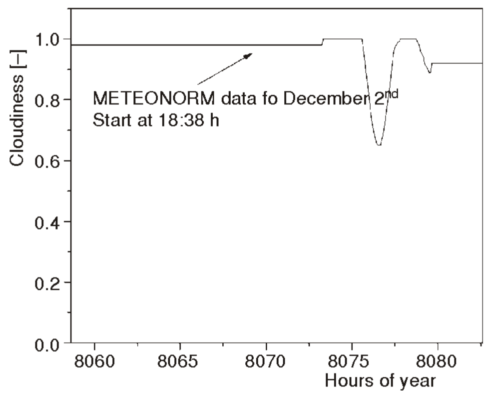

Figure 8. Cloudiness

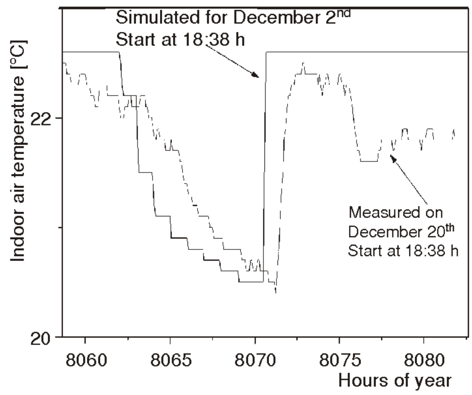

Figure 9. Indoor air temperature comparison

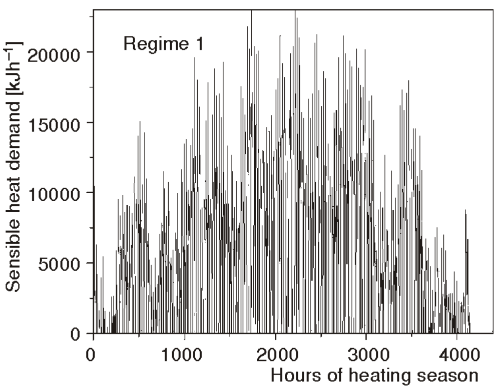

Figure 10. Sensible heat demand for the basic regime over whole heating season

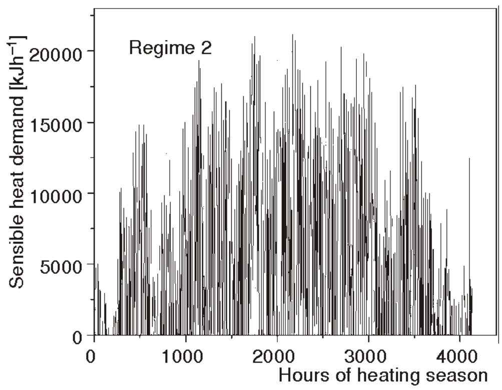

Figure 11. Sensible heat demand for the second regime over whole heating season

the infiltration loss (both by infiltration flow and ambient air temperature influence). From the other side, temperature sensor (serving to give a signal to the gas boiler to fire), is placed at some distance from the indoor air measuring point M4 . There is a time lag shift between simulated and measured graphs (fig. 9) caused by internal thermal mass, such as furniture and internal concrete or brick partitions does not expose directly to the ambient air but only to the indoor environment [7].

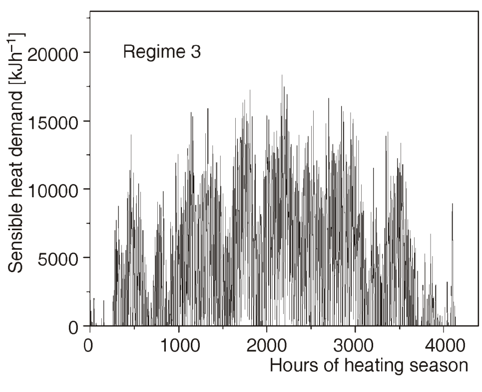

Figure 12. Sensible heat demand for the third regime over whole heating season

Simulations of the B3-zone indoor air temperature and thermal energy demand (in kJ/h) for all three regimes (1, 2 and 3) are performed for the whole heating season (October 15th to April 15th) with a one-hour time step (figs. 10, 11, 12). Thermal energy demand for the whole heating season (in kJ) and three different regimes was calculated by the time integration and shown in percentage of the worst (basic) regime in tab. 2.

Conclusions

In fact, many families mainly are not present in their apartments during working days. They need warm flat in the morning when all are preparing for work or school and in the evening when they are coming back home. During an absence period, apartment can be heated to keep some lower temperature in order to save energy.

Table 2. Heat energy demand for different heating regimes

Heat energy demand	(in % of regime 1)
Regime 1	100
Regime 2	86
Regime 3	75

Results presented in tab. 2 show possibilities for saving energy with no envelope renovating investments. Making changes only in the heating schedule, with no decrease in thermal comfort (second regime in comparison with the basic one), is possible to get about 14% of saving. On the other side, if we are ready to make compromise between thermal comfort and energy consumption with taking care of heating schedule, it is possible to make 11% more in saving (the difference between second and third regime based on first one).

Responsible dweller's behaviour can bring a reduction in fuel consumption. Whenever there are heating systems with automation capability (gas, oil, electricity boilers) it is necessary among all to adjust the heating schedule.

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