Building Simulation 2005

Ninth International IBPSA Conference
Montréal, Canada
August 15-18, 2005

VARIATION OF ENERGY CONSUMPTION AND DEMAND DUE TO DIFFERENT HEATING TIMING

Milorad Bojić, Milan Despotivić
Faculty of Mechanical Engineering at Kragujevac, University of Kragujevac
Sestre Janjić 6, 34000 Kragujevac, Serbia and Montenegro

ABSTRACT

When designing district heating serving different buildings, an architectural engineer should suggest optimal operation policy of heating, based on social aspects and on minimizing costs for used energy and for investment in building heaters. In this paper by using HTB2 software, the energy simulation was carried out for two small Serbian residential buildings with different heating timing (starting and ending time of heating). These buildings had different types of partitions: one with thermal insulation layer and one with bricklayer. It was found out that if heating starts later in the morning, the energy consumption in the both buildings may be lower and they may require smaller heaters. The thermal behavior of house does not depend on type of building partitions.

INTRODUCTION

In Serbian residential buildings, the largest part of energy is used for heating as the heating season lasts for 6 months. Energy used in built environment represents around 50% of total used energy. During last years, this percentage rises continuously. Compared to other forms of residence heating, district heating is extensively used in Serbia and its use will be increased in future. Namely, further district-heating development in Serbia will be supported by a donation of government of United States (GSR, 2005). First, 757,245 USA$ will be spent for feasibility study to build combined power plant in New Belgrade serving about 250000 households. It is expected that domestic companies will provide 40% of equipment, which will increase employment in the country.

Because of actual international efforts to protect environment, district heating of buildings is an issue of permanent interest to the government of Republic of Serbia and its two ministries: Serbian Ministry for Mining and Energy and Serbian Ministry of Science and Environmental Protection. Serbian Ministry for Mining and Energy founded the Serbian Agency for Energy Efficiency in 2002 where one of its activities is to increase energy efficiency in district heating (MMERS, 2003). Furthermore, Serbian Ministry of Science and Environmental Protection, gives prominent funds to universities in Serbia to work on National Research Programs in Energy Efficiency. Two interesting programs that would be active in this and subsequent years are “Energy Efficiency in Communal systems” and “Energy Efficiency in Built Environment”. Especially important topic of the first program is “Advancement in energy efficiency of centralized distribution of heat” (MSTDRS, 2003).

Among multitude of issues for advancement in energy efficiency of centralized distribution of heat, for architectural engineers the most interesting is operation policy of these energy systems. Namely, previous research showed that the time of heating start might highly influence energy consumption (Römer, 2001) and design size of used heaters depending also on size and type of thermal mass used in some heated buildings. In Serbia, the usual operating policy of district heating is that the heating operates 16h (heating duration) continually, starting at 6am and finishing at 10pm. An exact time of heating start is decided by district-heating-company officials and cannot be controlled by consumers in residences. This decision would be hard one for the officials as they should take into account energy efficiency of such a system and social, commercial, and business life of people.

As the policy of heating schedule is very important to minimize energy consumption for its users and district-heating company, this policy should be informed either by using field measurements or by using software simulations. As field measurements are expensive, software simulations are usually the best choice. For the district system already in operation, time of heating start can be checked by simulation of the energy consumption in heated buildings. For district heating in design, the time of heating start can be selected during its design by energy simulation of the energy consumption in buildings that will be heated. The design simulation is very important as the heating start also may influence the size of heaters needed in these buildings. To simulate energy and environmental performance of the buildings in its design and operation stage of the district heating system, we use building energy simulation program HTB2 as the first check program because this program requires less man-time for run preparation than that of DOE2, and EnergyPlus.

For two typical small buildings (houses) in Serbia (with two flats), research was performed on their heating. Each of these houses differs only in composition of its partitions. For each house, we will simulate heating of 16-hours duration, however the heating will either start at 5a.m., or 6a.m., or 7a.m., or 8a.m. We would evaluate its total yearly heat load and the maximum yearly heat load. The total heat load is proportional to the total yearly heat consumption and the maximum yearly heat load is proportional to the size of heaters inside these houses.

THE SIMULATION SOFTWARE HTB2

The simulation software HTB2 (Lewis and Alexander, 1990) is dynamic building energy software that can account for complex time varying climatic and occupation conditions in the prediction of heating and cooling loads and indoor environmental conditions in a building. The building fabric model uses the finite difference method to solve the one-dimensional dynamic heat conduction equation for modeling heat transfer through the fabric elements, which could be composed of multiple layers of different materials. The model can predict the thermal performance of a building when it is subject to the influence of outdoor temperature, solar gain, shading, and ventilation and infiltration. It also allows the user to define complex cooling and heating schedules, occupancy, lighting, and internal load intensity patterns, and to vary control settings during run-time, to mimic realistic occupation conditions.

In order to allow a year-round simulation to be accomplished efficiently, there are necessary limitations imposed by the assumptions implicit in the algorithm. Similar to other simulation models, HTB2 assumes that the air temperature within each simulated zone is uniform. Radiation and convection are taken into account independently. The solar gains are distributed over the walls according to decision of a user. The software supports several types of control thermostats: on/off, ideal and proportional. The software does not simulate heating systems in operation, but the software gives the energy that should be provided to the building by a heating system. HTB2 has been shown to be able to yield predictions that mach well with measurements for buildings in cold climate (Lomas et al. 1997).

SIMULATION

Inputs for HTB2 were prepared for 2 model houses designated as 1BK and 2IN. These houses had the same layout, patterns of use, and composition of envelope; they had partitions of different composition.

Two model houses (we simulated their energy behavior) were contemporary Serbian residential houses (low-rise buildings) shown in Fig.1. Each house had two stories and comprised two identical apartments where one was on its first and another on its second floor. These apartments had plans shown in Fig.2. Each apartment consisted of two bedrooms B1 and B2, one living room L, one kitchen K, one bathroom T, and one anteroom A. One corridor C contained stairs serving the both apartments. The investigated apartments and their rooms were sized as given in Table 1. It was assumed that each flat would accommodate a family of four: two working adults and one elderly and one child.

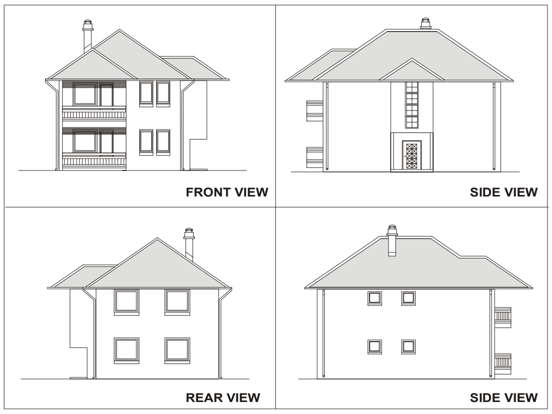

Fig. 1 Model house in Serbia

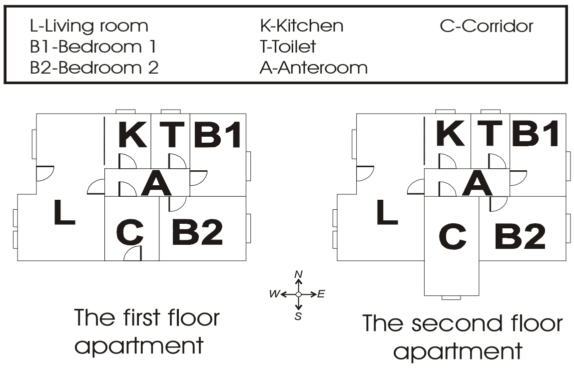

Fig. 2 Plans of the apartments in the model house.

Table 1
Size of investigated apartment at the first floor and their rooms[1,2]

ROOM	SIZE (m^2)
Living room	21.9
Bedroom 1	8.7
Bedroom 2	10.2
Kitchen	5
Bathroom	3.7
Anteroom	4.2
Σ	53.7

[1]Size of the flat and its rooms at the second floor is assumed to be the same.
[2]Size of the corridor with stairs at the first floor was $6.8m^2$ and at the second floor $9.3m^2$.

The each flat had the same patterns of occupancy, of lighting, and of small power, shown in Tables 2-4.

Table 2
Pattern of occupancy for the flat at the first floor[1,2]

TIME	NUMBER OF OCCUPANTS					
	LR	K	T	B1	B2	A
00:00-07:00	0	0	0	2	2	0
07:00-08:30	2	1	1	0	0	0
08:30-09:00	0	1	1	0	0	0
09:00-12:00	0	1	0	0	0	0
12:00-16:00	1	0	0	0	0	0
16:00-22:00	4	0	0	0	0	0
22:00-24:00	0	0	0	2	2	0

[1]Occupancy pattern for the flat at the second floor is assumed to be the same.
[2]Corridor for each floor is assumed to be unoccupied all the time.
[3]LR=Living room, K=Kitchen, T=Toilet, B=Bedroom, A= Anteroom

Table 3
Pattern of use of lighting load for the flat at the first floor[1,2]

TIME	LIGHTING LOAD (W)				
	LR	K	T	B	A
00:00-18:00	0	0	0	0	0
18:00-19:00	200	150	100	0	100
19:00-20:00	200	150	0	0	100
20:00-22:00	200	0	0	0	100
22:00-23:00	200	0	0	120	100
23:00-24:00	0	0	0	120	0

[1]Lighting-load pattern for the flat at the second floor is assumed to be the same.
[2]Corridor for each floor has the lighting load of 100W from 18:00 to 23:00h; otherwise it is without lightning load.

Table 4
Pattern of use of small power load for the flat at the first floor[1,2]

TIME	SMALL POWER LOAD (W)				
	LR	K	T	B	A
00:00-08:00	0	0	0	0	0
08:00-12:00	0	1700[3]	0	0	0
12:00-18:00	0	0	0	0	0
18:00-19:00	150	0	0	0	0
19:00-22:00	0	0	0	0	0
22:00-23:00	150	0	0	100	0
23:00-24:00	0	0	0	100	0

[1]Small-power-load pattern for the flat at the second floor is assumed to be the same.
[2]Corridor for each floor does not have any small power load.
[3]Cooking is usually done by elderly from 8am to 12am when employed family members are outside of home and before it is too hot in the flat due to higher outside temperatures after 12am.

Table 5
Temperatures maintained in different rooms

ROOM	TEMPERATURE (DEG. C)
Living room	20
Bedroom 1	20
Bedroom 2	20
Kitchen	20
Bathroom	24
Anteroom	15
Corridor	10

Table 6
Ventilation in ach/h[1]

	IR	VR1	VR2
Living room	1.25	1.0	5.0
Bedroom 1	0.75	0.75	5.0
Bedroom 2	0.75	0.75	5.0
Kitchen	1.00	1.5	5.0
Bathroom	0.75	0.75	5.0
Attics	2.0	2.0	2.0

[1]Ventilation rate 1 (VR1) was enabled during heating from 8:30 to 18:00h, otherwise only infiltration ventilation rate (IR) was enabled. The ventilation rate 2 (VR2) was enabled when temperature in some room is above 25^0C.

Table 7
Compositions of non-modified constructions (1)

LAYER	CONSTRUCTIONS		
	ENVELOPE[1]	DOORS	WINDOW
1	Polystyrene, 60mm	Wood, 6mm	Glass, 3mm
2	ACB[2], 250mm	Air cavity, 38mm	Air cavity, 30mm
3	Plaster light, 15mm	Wood, 6mm	Glass, 3mm

[1]The first layer faces outdoors and the last indoors

The assumption was that all rooms used heaters that were ideally controlled by thermostats. The room temperatures were set as shown in Table 5. The heater operation did not depend on the room occupancy. This heating pattern was characteristic to that of radiators served by district heating. Heating was run only during 6-month of heating season: from October 15th until April 15th.

The assumption was that during heating season, all rooms were naturally ventilated with periodically open windows. The ventilation and infiltration rates were as in Table 6.

Each house had the same composition of its envelope, doors, windows, floor, ceilings, and roof, however it had different composition of its partitions. The compositions of non-modified constructions are given in Tables 7 and 8.

Table 8
Compositions of non-modified constructions (2)

LAYER	CONSTRUCTIONS[1]		
	FLOOR[2]	CEILING 1[2]	CEILING 2[2]
1	Wood block, 24mm	Thermalite, 100 mm	Wood block, 24mm
2	Concrete (light), 30 mm	Concrete (heavy), 40mm	Thermalite, 20mm
3	PVC, 1mm	ACB[3], 160mm	Concrete (heavy), 40mm
4	Thermalite, 60mm		ACB, 160mm
5	Bitumen felt, 2mm	Plaster light, 15mm	Plaster light, 15mm
6	Concrete (heavy), 40mm		
7	Granolithic screed of 50mm		

[1]Roof is made of clay tiles of 10mm; [2]For floor and ceilings, layers are listed from up to down; [1]ACB- Aerated concrete block.

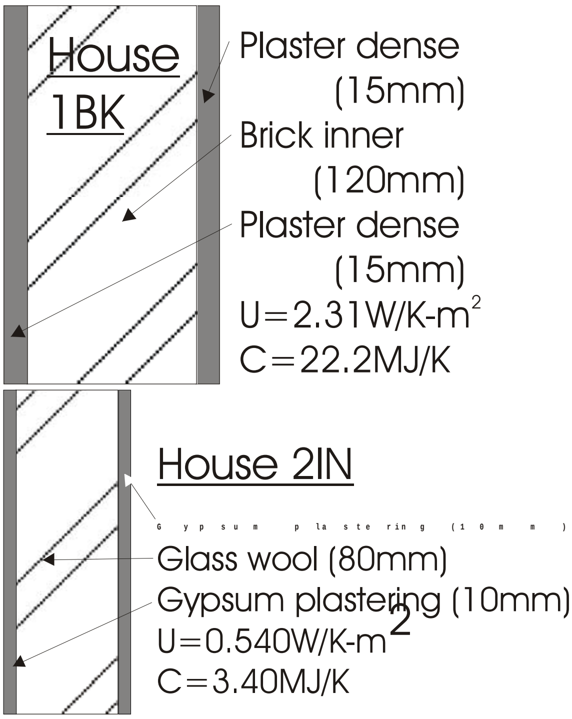

Fig.3 the composition of the partition assembly for different houses 1BK and 2IN

For each house, the compositions of the partitions are given in Fig.3 together with their overall U and C-values.

RESULTS

For two houses 1BK and 2IN, on the basis of their characteristics defined above, the total yearly heating load (Q) and maximum yearly heating load (D) have been predicted by using HTB2 based on hourly weather conditions in Belgrade, Serbia (DOE, 2003). These values were obtained for different heating timing (HT). For the both houses, Q is given in Fig.4 and D in Fig. 5 as functions of the heating timing. Q, D, and HT will be defined in the following paragraphs.

In this investigation, Q was calculated as

$$Q = \sum_{I=1}^{8640} \sum_{J=1}^{N} Q_{I,J} \tag{1}$$

where $Q_{I,J}$ stands for the heating load (an output of HTB2) of room J during hourly time interval I where I = 1,......., 8760 and J= 1,....N. Here, N stands for the total number of heated rooms in a house. Q is practically proportional to the total yearly consumption of heat and primary fuel of the district heating plant and total yearly CO_2 production, which is a measure of the global environmental performance of this house and the district heating plant.

In this investigation, D represents sum of the maximum values among the predicted hourly heating loads in the entire year for each heated room

$$D = \sum_{J=1}^{N} D_{\max,J} \; . \tag{2}$$

Here, $D_{max,J}$=max ($Q_{I,J}$) where I = 1,......., 8760. Higher D would mean higher power of baseboard heaters, their bigger size, higher capacity of the heat plant (that generates their heat), their higher embodied energy, and higher embodied energy of the heat plant. Then, the environmental performance of the house and flats should, therefore, be regarded as poorer as higher embodied energy may yield higher CO_2 production.

In this investigation, the heating timing was characterized by the heating start and heating end. The four heating timing were investigated where the heating start and end was varied as given in Table 7. The heating was of the constant heating duration of 16h.

DISCUSSION

In this section, we discuss how the space temperatures in the morning, and predicted Q, and D would be affected by the starting time of heating for two houses that differ only in the type of used partitions.

Table 7
Heating timing (HT) with constant heating duration of 16h

HT	HEATING START	HEATING END
5-21	5h	21h

6-22	6h	22h
7-23	7h	23h
8-24	8h	24h

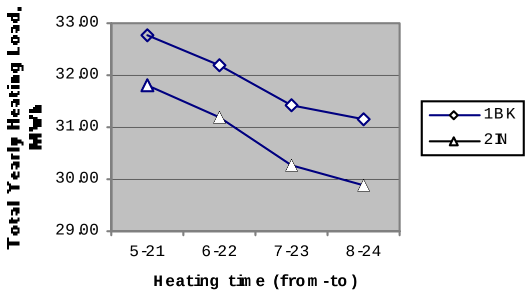

Fig. 4 Total yearly heating load (Q) for two houses and four heating timings.

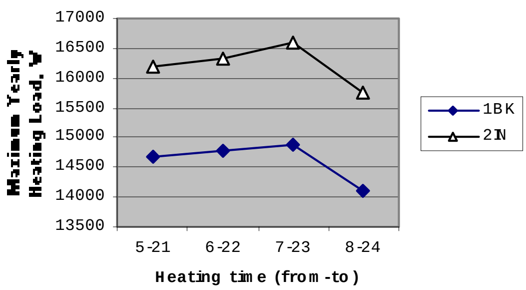

Fig. 5 Maximum yearly heating load (D) for houses with different types of partition.

Space Temperature in the Morning

According to the pattern of occupancy given at Table 2, people get up at 7am. This means, that if heating starts from either 5am or 6am or 7am people (getting ready for work) already would have heated rooms to the required temperatures given in Table 5. When heating starts at 8am, the space temperatures in these houses at 7 am would be somewhat lower than that given in Table 5.

Total Yearly Heating Load

From Fig.4, we analyze (1) how for house 1BN, *Q* change with the increase in the starting time of heating, (2) how for house 2IN, *Q* change with an increase in the starting time of heating, and compare (3) how change in *Q* depends on the composition of applied partitions inside the buildings.

For house 1BN, Fig. 4 shows the following change in *Q* with increase in the starting time of heating. When heating starts at 5h (and ends at 23h), the maximum for *Q* exists at 32.8MWh. Furthermore, a value of *Q* decreases with increase in the starting time of heating. Finally, when the heating starts at 8h (and ends at 24h), the minimum for *Q* exists at 31.1MWh. The decrease in *Q* with increase in the starting time of heating from 5 to 8h is around 5%. To conclude, for house 1BN, *Q* steadily decreases with increase in the starting time of heating.

For house 2IN, Fig. 4 shows the following change in *Q* with increase in the starting time of heating. When heating starts at 5h (and ends at 23h), the maximum for *Q* exists at 31.8MWh. Furthermore, *Q* decreases with increase in the starting time of heating. Finally, when the heating starts at 8h (and ends at 24h), the minimum for *Q* exists at 29.9MWh. The decrease in *Q* with increase in the starting time of heating from 5 to 8h is around 6%. To conclude, for house 2IN, *Q* steadily decreases with increase in the starting time of heating.

Analyses in two previous paragraphs show that decrease in *Q* with the heating timing slightly depends on the composition of building partitions. For house 1BN, this decrease will be 5%, while for house 2IN this decrease will be 6%. So, the decrease when partitions are mainly from thermal insulation is almost the same as when partitions are made mainly from masonry.

Maximum Yearly Heating Load

From Fig.5, we analyze (1) how for house 1BN, *D* change with the increase in the starting time of heating, (2) how for house 2IN, *D* change with an increase in the starting time of heating, and (3) compare how change in *D* depends on the composition of applied partitions inside the buildings.

For house 1BK, Fig.5 shows the following change in *D* with increase in the starting time of heating. When heating starts at 5h, *D* was 14.7kW, then when heating starts at 7h *D* was 14.9kW (the maximum value of *D*). With further increase in the starting time of heating, *D* decreases. The lowest *D* of 14.1kW was recorded for the starting time of heating at 8h. This decrease in *D* compared to its maximum was around 5%.

For house 1IN, Fig.5 shows the following change in *D* with increase in the starting time of heating. When heating starts at 6h, *D* was 16.2kW. Then when heating starts at 7h *D* was 16.6kW (the maximum value of *D*). With further increase in the starting time of heating, *D* decreases. The lowest *D* of 15.8kW was recorded for the start time of heating at 8h. This decrease in *D* compared to its maximum value was around 5%.

Analyses in two previous paragraphs show that decrease in *D* with the starting time does not depend on the composition of building partitions. For house 1BN, this decrease in *D* will be 5%, while for house 2IN this decrease will be also 5%.

QUALITY ASSURANCE

Our predicted results should pass quality assurance test to guarantee that they may be used by building designers. Some foundation of quality assurance approach is discussed by Donn, in 1999. The goal is to improve use of design tools hoping that it will lead to better building performance. A quality assurance system would comprise of a simulation test that compare obtained results to information on building performance in some database. We did our test comparing our results to the building performance results (heating energy consumption and maximum yearly heating load) given by Zrnic and Culum, 2005 for Serbian houses. We found out that our predicted results and results given by Zrnic and Culum are of the same order.

CONCLUSION

For small building in Serbia, we simulated how its heating depends on heating timing when we varied the starting time of heating keeping the heating duration at 16h. The simulation is performed for two houses 1BK and 2IN that differ in type of partitions applied inside the house. The following facts were found. First, Q decreases with the starting time of heating during day. Second, the decrease in Q for the both buildings is around 5%. Third, D first increases slightly with the starting time of heating for the both buildings, reaches its maximum and then decreases considerably. This decrease is around 5%. Fourth, the percentage of decrease in D is around 5% and does not depend on type of thermal mass inside some house.

Further research will be done to determine the effect of the timing of heating start/stop on the people in homes.

REFERENCES

DOE. 2003. Weather data at international locations, Retrieved February 1, 2003, from US Department of Energy, Energy efficiency and renewable energy WEB site http://www.eere.energy.gov/buildings/energyplus/cfm/weatherdata_int.cfm

Donn, M. 1999. Quality Assurance - Simulation and the Real World. Proceedings of Building Simulation '99, Volume 3:1139 -1146.

GSR. 2005, Donation of USA for building of power plant for district heating (in Serbian), Retrived January 18, 2005, from Government of Serbian Republic (GSR) WEB site, http:// www. arhiva. srbija. sr. gov. yu/ vesti/ 2004-02/10/343534.html

Lewis, P.T., Alexander, D.K. 1990, HTB2: A flexible model for dynamic building simulation, Building and Environment, 25, 1, 7-16.

Lomas, KJ., Eppel, H., Martin, CJ. Bloomfield DP. 1997. Empirical validation of building energy simulation programs. Energy and Building 26: 253-73.

MMERS. 2003. Draft of energy law, Retrieved August 20, 2003, from Ministry of Mining and Energy of Republic of Serbia (MMERS) WEB site http://www.mem.sr.gov.yu.

MSTDRS. 2003. National program of energy efficiency, Retrieved August 20, 2003, from Ministry of Science, Technology, and Development of Republic of Serbia (MSTDRS) WEB site http://www.mem.sr.gov.yu.

Römer, J.C. 2001, Simulation of demand controlled ventilation in a low-energy house, Seventh International IBPSA Conference, Rio de Janeiro, Brazil, August 13-15.

Zrnic, S., Culum, Z. Heating and Air Conditioning (in Serbian), Naucna knjiga, Beograd, 2005.

NOMENCLATURE

A Size of partitions in m^2

D Maximum of yearly heating load, W

$D_{max,J}$ Max of $Q_{I,J}$

HT Heating timing

I Hourly time interval

J Room index

N Number of heated rooms in the building

Q Total yearly heating load, Wh

$Q_{I,J}$ Heat load (an output of HTB2) of room J during hourly time I, Wh