The Influence of Air-Conditioning Operating Schedule and Ventilation needs on Energy Consumption

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This paper analyses the influence of air-conditioning operating schedule and ventilation needs on the daily energy consumption. Analysis has been made on the basis of a computer program for dynamic simulation of air-conditioned rooms thermal behavior. The program has been developed at the Department for Thermal Engineering at the Faculty of Mechanical Engineering, University of Belgrade. Analysed are three different air-conditioning operating schedules and three different flow rates of fresh air in the system. Given are cooling loads, energy needed for outdoor air treatment, fan energy consumption and overall daily energy consumption for summer design conditions for Belgrade. The obtained results have been compared, and hereupon given a review of the daily energy savings.

Keywords: *Air-conditioning, Energy consumption, Operating schedule, Cooling load.*

1. INTRODUCTION

In order to investigate the influence of air-conditioning operating schedule on the daily cooling energy consumption, simulated are three different operating schedules for a typical air-conditioned room. Simulation has been aided by a computer program for dynamic simulation of air-conditioned rooms thermal behaviour, which has been developed at the Department for Thermal Engineering at the Faculty of Mechanical Engineering in Belgrade. The program, written in C language, which operates under Windows operating system, is based on a detail mathematical model of non-steady state heat transfer in an air-conditioned space [7].

2. HEAT TRANSFER IN AN AIR-CONDITIONED ROOM

The analysed air-conditioned room is considered to be typical of residential or commercial buildings. Its shape, dimensions, construction and position are in common with many rooms in a multi-story building. The building is in an open position, with no objects nearby; therefore its windows are not shaded. Internal dimensions of the room are 5 by 4 by 2.6 m. Its double-glazed window in the facade wall measures are 2.4 by 1.5 m. Facade wall is insulated, and its U-value is 0.8 W/m^2K. Wooden 1 by 2 m door is in a facade-facing wall, leading into the central corridor. All other surfaces are adjacent to the air-conditioned spaces (figure 1.).

Mathematical model of non-steady state heat transfer consists of a system of equations that describes convection, conduction and radiation, and includes appropriate boundary and initial conditions. The equation system describing one-dimensional non-steady state conduction is solved using finite volumes explicit numerical method [6]. Appropriate boundary conditions for the points at the surface in contact with the air and for the points at the surface between two wall layers are taken into account. Initial conditions are defined by walls and air temperature values, needed as an input data.

Convection is defined by appropriate criteria equations, for vertical and horizontal, as well as for indoor and outdoor surfaces, separately.

Radiation heat transfer is very complex due to many radiation sources.

Outside the room, there appear:

- Solar radiation,
- Sky radiation, and
- Ground radiation.

Solar radiation is treated differently depending on whether it is about direct or diffuse one, thus enabling more precise calculation of Solar radiation heat transfer for each surface. All outside surfaces are considered to be exchanging heat by temperature radiation with the Sky and ground. Model of non-steady state heat transfer for window is based on ASHRAE method [2].

Inside the room, there appear:

- Radiation heat transfer among the indoor surfaces,
- Solar radiation transmitted through the window,
- Short and long wave bulb radiation.

In this analysis heat gain from occupants has not been taken into account.

Thermal balance has been made for each surface. For the case of the air-conditioning system being “off”, infiltration of the outside air has been taken into account. When the air-conditioning system is “on” there is no outdoor air infiltration.

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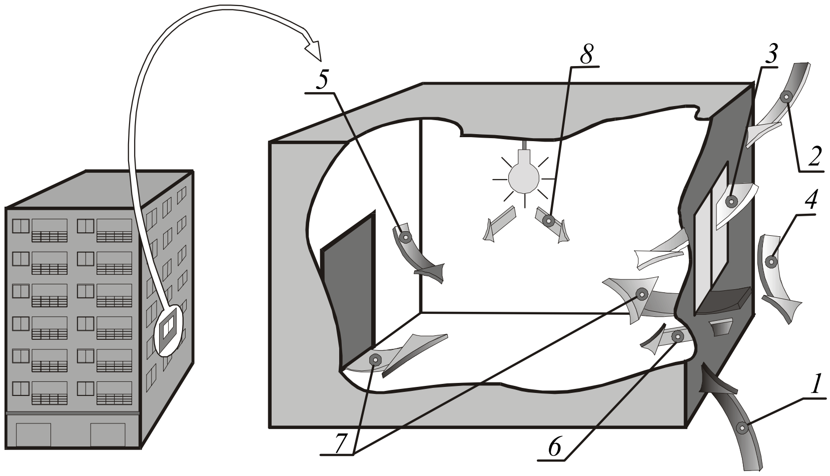

Figure 1. Air-conditioned room in a multi-story building and mechanisms of heat transfer:1 - Ground radiation, 2 – Sky radiation, 3 – Solar radiation, 4 – Outdoor convection,5 – Indoor convection, 6 – Conduction, 7 – Air infiltration, 8 – Bulb radiation.

3. SIMULATION OF THE ROOM THERMAL BEHAVIOR FOR DIFFERENT AIR-CONDITIONING SYSTEM OPERATING SCHEDULES

In order to investigate the influence of an air-conditioning operating schedule on the daily cooling energy consumption, simulated are three different operating schedules:

- 8 hours per day operation (8-16 h),
- 12 hours per day operation (7-19 h), and
- 16 hours per day operation (6-22 h).

Calculation of the room envelope temperature fields is done with periodical outside influencing values (such as outdoor air temperature, earth temperature, Sky temperature, Solar radiation etc.), for a one-day period. Simulation has been done for the summer design conditions for Belgrade [1] (figure 2.). The initial temperature value for calculation has been set to 27^{o}C, and the program runs until the daily temperatures and cooling load become steady state.

The results shown in figure 3. indicate heat gain and cooling load for the period of one week, and three different operating schedules of an air-conditioning system for south oriented air-conditioned room.

The simulation results have proved that decrease of the system operating period leads to an increase of the daily cooling load peak. Once the air-conditioning system is shut down, the indoor air temperature starts rising, on account of walls cooling, until thermal equilibrium is reached. Since there are no conditions for heat to be transferred to the indoor air (due to the fact that air-conditioning system does not eliminate warm air from the room), a certain amount of heat is being stored in the building envelope. The next day, when the air-conditioning system is started, the indoor air temperature starts dropping, thus enabling heat transfer. But, at that moment, the cooling load value is higher than the previous day, because of the superposed heat gain and the heat stored inside the walls.

This process is repeated continuously until the same periodical change of cooling load is reached. From the figure 3. it is evident that the same periodical change of cooling load is reached after a period of seven days (differences between cooling load daily profiles are less than 1%). Thus, diagram in figure 4. shows daily cooling load profiles on the 7th day for three different operating schedules.

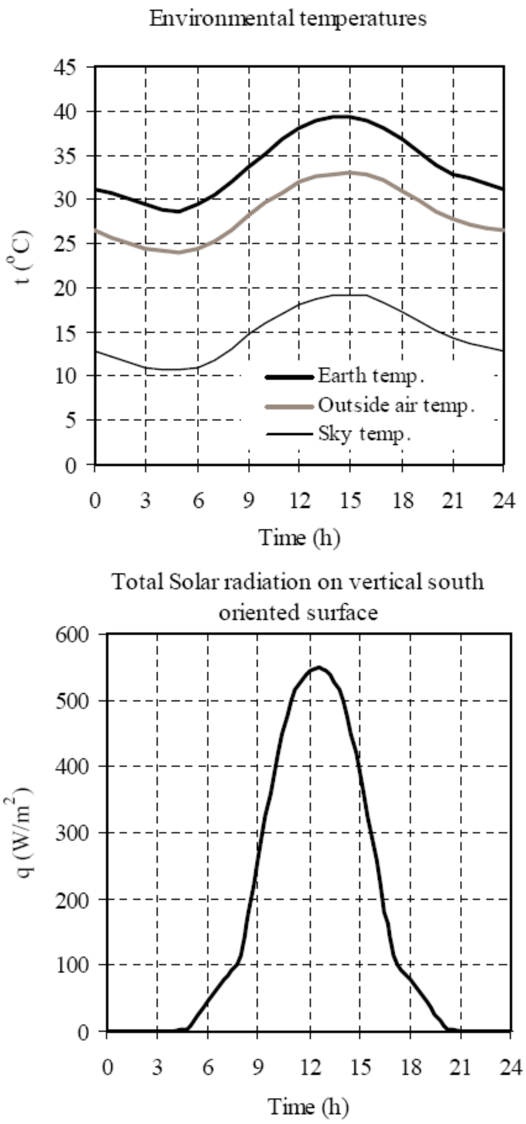

Figure 2. Weather data for summer design day for Belgrade

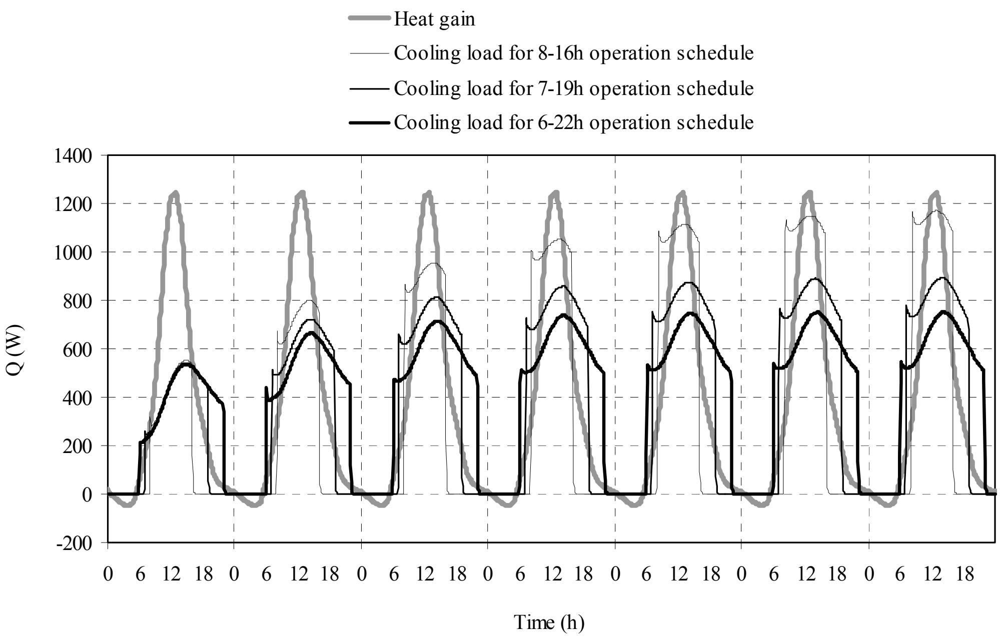

Figure 3. Heat gain and cooling load for south oriented air-conditioned room under three different operating schedul

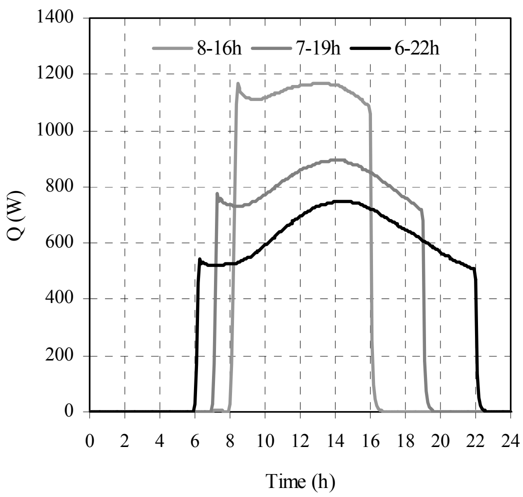

Figure 4. Cooling load for three different operating schedules

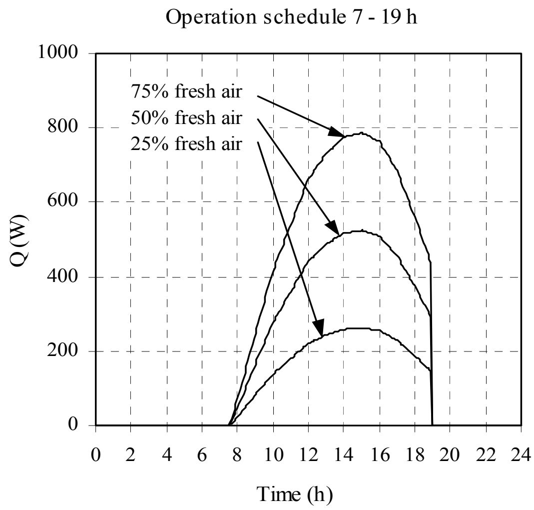

Figure 6. Energy needed for outdoor air treatment for operating schedule 7-19 h and three different flow rates of fresh air in the system

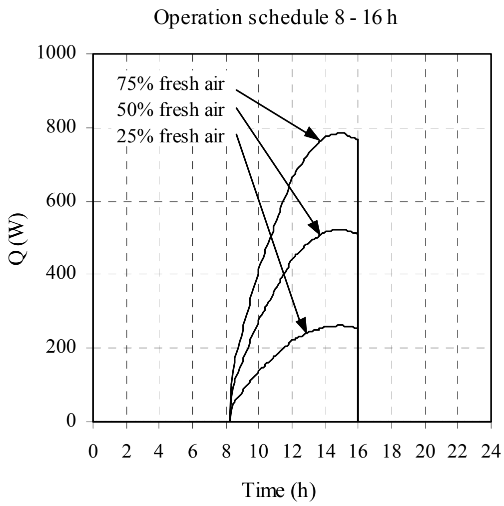

Figure 5. Energy needed for outdoor air treatment for operating schedule 8-16 h and three different flow rates of fresh air in the system

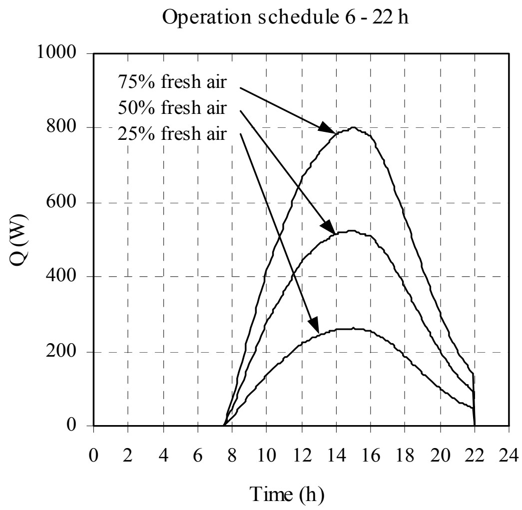

Figure 7. Energy needed for outdoor air treatment for operating schedule 6-22 h and three different flow rates of fresh air in the system

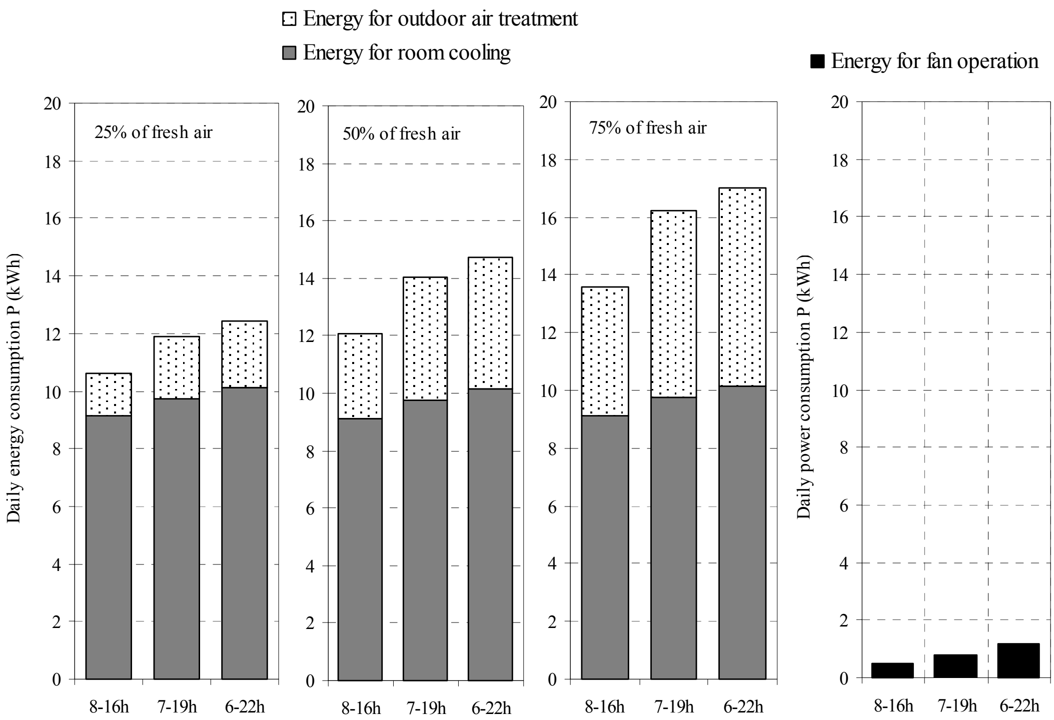

Figure 8. Air-conditioning system daily energy consumption needed for room cooling, outdoor air treatment and energy needed for fan operation

Ventilation needs are determined by number of people in the room and by fresh air flow per person. Occupants number increase leads to an increase of fresh air rate in the system. In order to investigate the influence of ventilation needs on the daily energy consumption, simulated are three different flow rates of fresh air in the air-conditioning system:

- 25% of fresh air,
- 50% of fresh air, and
- 75% of fresh air.

Simulation results are shown in figures 5-7.

Comparing diagrams shown in figures 5., 6. and 7. it can be seen that energy needed for outdoor air treatment increases both with increase of fresh air flow rate in the system and number of operating hours.

4. DAILY ENERGY CONSUMPTION

Daily consumption of energy is determined as:

$$P(\tau) = \int_0^{\tau} Q(\tau) \cdot \mathrm{d}\tau \qquad (1)$$

The simulation program works with the fixed 5 seconds time step, but the obtained results of temperatures, heat gain and cooling loads are written in output files for every 60 seconds. Such a data storing is chosen in order to avoid too large number of output values not affecting accuracy. The output file can be imported into a spreadsheet application for further calculation process.

The daily energy consumption in correlation with air-conditioning operating hours per day is given in figure 8, for south-oriented room.

From the diagram shown in figure 8. it is evident there is influence of air-conditioning system operating schedule on energy consumption for:

- fan operation,
- outdoor air treatment and
- room cooling.

Air-conditioning system works with constant air flow, thus fan power remains constant, too. Therefore, energy consumption for fan operation is directly proportional to the number of operating hours. With increase of fresh air quantity in the system, increased is energy consumption needed for its treatment. Room cooling demands vary during the day, thus control of cooling capacity is performed by change of inlet air temperature down to minimum 18^{o}C. Energy consumption for cooling is 7,3% increased if the system operating period is prolonged from 8 hours (8-16h) to 12 hours daily (7-19h). However, if the air-conditioning system operation lasts for 16 hours (6-22h), energy consumption for cooling is increased for extra 3.4%. The above said shows that proportional increase of operating hours does not result in proportional increase of energy consumption for cooling.

5. CONCLUSION

In this paper three air-conditioning operating schedules are analyzed, including three different flow rates of fresh air in the system. Obtained simulation results have shown that intermittent air-conditioning operation leads to an increase of the daily cooling load profile values. Cooling load maximum value rises if the system operation period is reduced from 16 hours to 12 hours per day, even more if reduced to 8 hours per day, which leads to higher capacity of installed cooler.

With increase of fresh air quantity in the air-conditioning system, energy consumption needed for its treatment is increased. The increase of energy consumption is proportional to fresh air flow rate in the system.

In order to optimize overall energy consumption, it is necessary to reduce energy consumption for room cooling by enabling room envelope cooling during the night. Optimum energy consumption could be achieved by introducing night ventilating (without outdoor air treatment) along with room cooling during the period of room occupancy.

NOMENCLATURE

P	[kWh]	energy consumption
q	[W/m^2]	heat flux per square meter
Q	[W]	heat flux
t	[^{o}C]	temperature
τ	[s]	time

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УТИЦАЈ РЕЖИМА РАДА КЛИМАТИЗАЦИОНОГ ПОСТРОЈЕЊА И ПОТРЕБА ЗА ВЕНТИЛАЦИЈОМ НА ПОТРОШЊУ ЕНЕРГИЈЕ

Маја Тодоровић, Бранислав Живковић

У раду је приказан утицај режима рада климатизационог постројења и потреба за вентилацијом на дневну потрошњу енергије климатизоване просторије. Анализа је спроведена на основу компјутерског програма за динамичку симулацију термичког понашања климатизоване просторије. Програм је развијен на Катедри за термотехнику Машинског факултета, Универзитета у Београду. Анализирана су три различита режима рада и три различите количине свежег ваздуха у систему за климатизацију. Приказани су токови топлотних оптерећења, енергије потребне за припрему свежег ваздуха и енергије за погон вентилатора, као и укупна потрошња енергије система за летње пројектне услове за Београд. Добијени резултати симулације су упоређени и дати су предлози за дневну уштеду енергије коју троши систем за климатизацију.