ENERGY DEMAND IN THE OFFICE BUILDINGS FOR VARIOUS INTERNAL HEAT GAINS

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Abstract
Ensuring proper indoor environment in office buildings requires, among others, the achievement and maintenance of comfort for those conditions abiding in the existing temperature of the air. The paper presents the results of an analysis of the influence of internal heat gains on the consumption of energy in an office building designed in compliance with passive technology. The main energy consuming process in such type of buildings is air-conditioning and cooling. The building was designed as a low-energy one, cooled by means of cooling ceilings. The architect's and designer's assumptions were checked by numerical simulation made by means of the ESP-r software. Based on the simulation results, the annual energy consumption was analyzed for different internal heat gains in the office rooms.

Streszczenie
Zapewnienie właściwej jakości środowiska wewnętrznego w budynkach biurowych wymaga, m.in. uzyskania i utrzymania stałej, odpowiadającej warunkom komfortu, temperatury powietrza. W artykule przedstawiono wyniki analiz wpływu wewnętrznych zysków ciepła na zużycie energii w budynkach biurowych zaprojektowanych w technologii pasywnej. W tego typu budynkach zużycie energii wynika głównie z potrzeb chłodzenia i klimatyzacji. Badany budynek zaprojektowany został jako nisko-energetyczny, chłodzony za pomocą sufitów chłodzących. Architektoniczne i projektowe założenia przetestowano metodami symulacji numerycznej, wykorzystując program ESP-r. W oparciu o wyniki symulacji przeanalizowano roczne zużycie energii dla różnych wariantów wewnętrznych zysków ciepła w pomieszczeniach biurowych.

Keywords: **Office building; Energy saving; Heat gains; Simulation methods; Indoor air quality.**

1. INTRODUCTION

The indoor environment quality was not always the main priority when the office buildings were designed. In the end of the last century the higher standard of the indoor environment was forced by users but the proper thermal comfort, indoor air quality as well as the office lighting was reached by the large energy consumption, very often more than 500 kWh/(m^{2}a).

In public buildings the problem is not the heating, but rather cooling of the rooms. The reason for that is specific use of the office space, where, in a relatively small cubature considerable internal heat gains do occur, resulting both from the presence of people and appliances[1]. When the thermal comfort is considered it should remembered that some of it's elements could be assessed only on the basis of the empirical or half-empirical models [2]. Also the detailed data of the ventilation air parameter distribution in the room for the optimization of the ventilation systems requires more complicated numerical models that base on the CFD methods [3].

Research programs and practical implementation of low energy public buildings were undertaken already in the 1980s. The effect of such actions were numerous studies and analyses concerning monitoring of the operation of such buildings [4] and preparation of the energy-efficient systems and methods of heating and cooling for such facilities [5]. Despite the above experiences, the subject of energy-efficient, passive or zero-energy buildings is still topical [6].

From the technical point of view, the existing air conditioning systems can ensure the required microclimate in the offices, the problem, however, concerns the energy effectiveness of the applied solutions as well as the investment and operating costs.

The performed research works point out the main factors determining the energy consumption in the public buildings [7]:

– external wall insulation

– internal heat gains

– strategies of heating and cooling.

These factors influence the energy consumption due to differences of the climatic conditions, the building and standards regulations, and buildings operation in particular countries.

2. METHODS

The analysis of the energy consumption in the building was performed by means of the simulation method using the ESP-r software. The software allows integrated calculations of the transfer of mass and energy inside the building, taking into account heating and air-conditioning systems as well as the sources of heat and the strategy of control [8].

The investigation concerned the newly designed, nine-storey office building with heavy reinforced concrete structure (external walls 25 cm, ceilings 30 cm). The external walls and the roof of the building are well insulated (U = 0.13 W/m^{2}K). The building is heated by means of fan-coils. The way of cooling is based on the application of thermo-active cooling ceiling with a cooling agent with temperature of 16°C. The total office space amounts to over 20000 m^2 and is subdivided into single, small office rooms and larger open space offices. The numerical model for simulation was created for a single small office of the dimensions 2.6 x 8.1 x 2.8 m and with a single window equipped with external shutter.

Table 1.
Construction data and main values of the heat transfer coefficients

External walls: reinforced concrete 25 cm, glass wool 30 cm	U= 0.13 W/m^{2}K
Ceilings: concrete slab 25 cm	U=1.30 W/m^{2}K
Roof: reinforced concrete, mineral fibre 40 cm	U=0.09 W/m^{2}K
Windows: Aluminium/PVC, triple glazed pane	U=0.80 W/m^{2}K

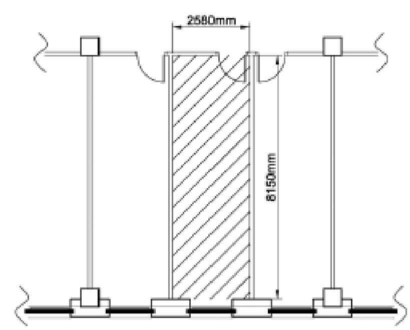

Figure 1.
Floor plan of the office room under consideration

Simulation calculations were carried out by means of the ESP-r program concerning climatic data of one of the Polish towns. The aim of the numerical calculations of the building system – HVAC system was to investigate the dynamics of cooling and heating load as well as the actual and annual demand for cooling and heating. Besides the internal heat gains, also the gains due to solar radiation have been taken into account in the calculations.

Simulations were carried out for single office segment, based on the following assumptions:

– indoor air temperature: 24°C for cooling, 20°C for heating,

– air supply with temperature of 20°C,

– the internal heat gains in the office result from the presence of occupants, appliances and lighting [9].

Several variants of the internal heat gains have been dealt with, varying both the number of persons working in the office and the power rating of the installed appliances (Table 2).

Table 2.
Variants of the internal sensible heat gains

	v. 1	v. 2	v. 3	v. 4
Occupants	1 x 77 W	3 x 77 W	3 x 77 W	3 x 77 W
Computers	1 x 150 W	1 x 150 W	3 x 150 W	3 x 300 W
Lighting	3 x 50 W	3 x 50 W	3 x 50 W	3 x 50 W
Total	377 W	531 W	831 W	1281 W

Additionally, the simulation for the office without internal heat gains was performed, giving the data on the energy consumption when the office is closed (variant 0).

The building was assumed to be used from Monday to Friday from 7 a.m. to 6 p.m. and on Saturday from 7 a.m. to 2 p.m.

Additional simulation was performed for a "traditional" office building: external wall insulation was five times worse (U = 0.55 W/m^{2}K), double glazed windows (U = 1.6 W/m^{2}K) without external blinds, poor possibilities of heat/cold accumulation inside the building partitions as well. Such type of buildings still exist and often dominate in many countries.

3. RESULTS

The simulations give self-evident results – if the internal heat gains in the office rise, the cooling demand to maintain the proper indoor air temperature also increases. It also depends on the ambient temperature (Fig. 2).

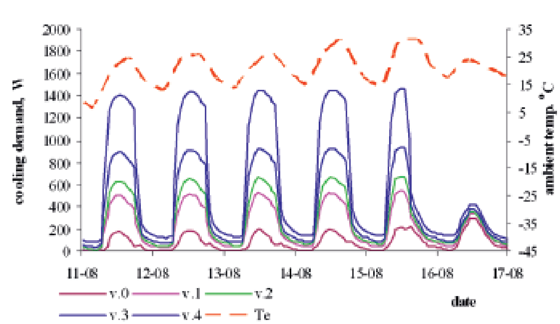

Figure 2.
Variation of the actual cooling load in the selected period in summer

Table 3 gives results of the simulation for all variants including annual energy consumption as well as the actual maximum cooling demand. The results of the simulation proved that in all variants of the assumed internal gains the office does not need to be heated even at a low ambient temperature, but should be cooled. The only exception is variant 1 (one person in the office) where heating is necessary for a few days in January - it needs total of 0.6 kWh of energy per year. Heating in winter is also necessary in the object where there are no internal heat gains (variant 0).

Table 3.
Cooling demand for different internal heat gains

	Annual energy demand for cooling, [kWh]	Maximum cooling load, [kW]	Period of cooling during the year, [month]
v. 0	148	320	2.5
v. 1	891	580	7.0
v. 2	1360	710	8.0
v. 3	2323	970	10.0
v. 4	4268	1490	10.5

The last column of Table 3 shows how long – during the year – the office should be cooled depending on the variants of the internal heat gains – it varies from seven up to eleven months in the year. When an unoccupied office is considered cooling is needed during two and a half month, mainly from June to August. In this case also heating is necessary during winter.

The heavy structure of the building is an advantage. As a result of accumulation of heat in building partitions the peak of cooling demand is considerably lower than internal heat gains penetrating into the room (Fig. 3).

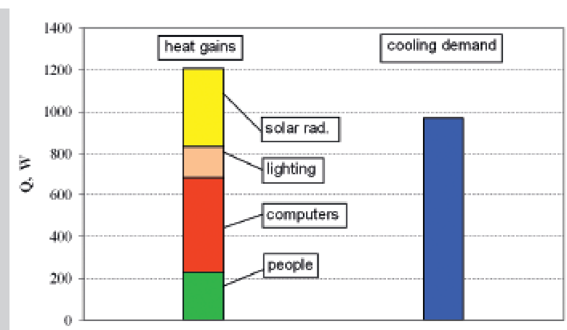

Figure 3.
Comparison of cooling demand and heat gains in the office (variant 3)

The role of solar radiation for cooling demand was checked by comparing the results of simulation for different window location (south – north): the aver-

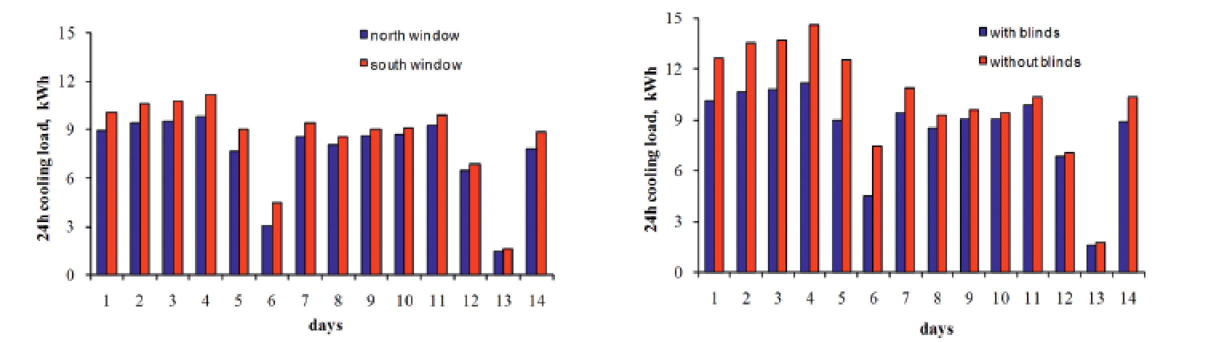

Figure 4.
Comparison of 24 hours cooling demand for different windows location. a) north vs. south window exposition, b) south exposition, windows with and without blinds

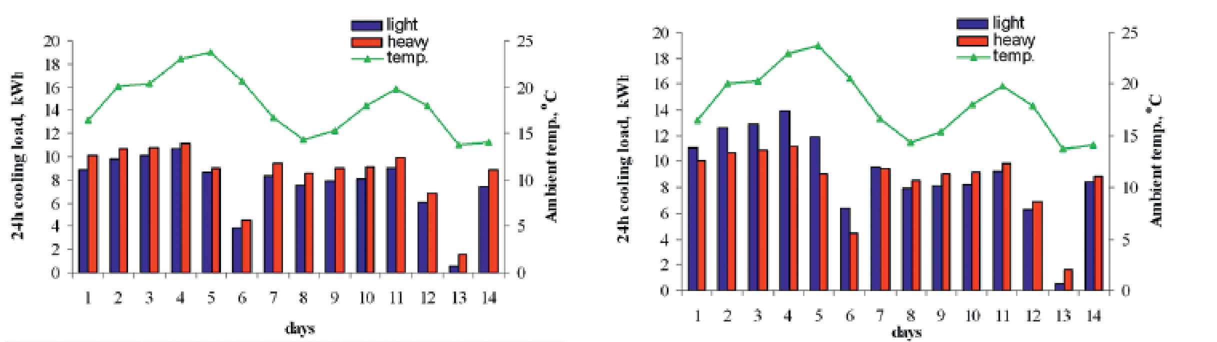

Figure 5.
Comparison of 24 hours cooling demand for different building construction. a) windows with blinds, b) windows without blinds

age 24 hours cooling load was higher for south windows location from 10% to 40% depending on weather conditions (Fig. 4a).

The influence of the external blinds on cooling demand is shown in Fig. 4b. The energy consumption increases from 10% up to 65% when the windows are without blinds (average about 20%).

Comparative calculations concerning the same segment of the office, but constructed with traditional partitions (lighter structure of the external walls, the heat transfer coefficient nearly three times higher) were performed. It can be noticed that when the ambient temperature is higher cooling demand is smaller for heavy construction building. For relatively lower external temperature just the opposite – heavy building requires more cooling than traditional one which results from its large heat capacity of walls and ceilings and worse heat transmission outside of the building (Fig. 5a).

When the windows of a traditional office building are equipped with the external blinds the energy demand for cooling is lower than for the building with heavy construction (about 15% on average – Fig. 5b).

4. DISCUSSION

Performed simulations indicate that practically for all variants of the assumed internal heat gains the office building with heavy concrete construction must be cooled for longer time of the year. The heating is unnecessary at all or is a small part of total energy consumption.

When the building envelope is well insulated there is a problem with the transmission of the redundant heat to the environment. A traditional building with worse insulation is cooled down during the night better than a building with a greater possibility of the heat accumulation in heavy partitions. Thus the question arises whether it is expedient to augment the insulation of the external walls in buildings where the offices are intensively utilized. It also means that in such office buildings the internal heat gains are an important component of the balance determining the cooling demand, and the insulation of the partitions is of a secondary importance.

The calculation results pointed out also the importance of the solar heat gains on the energy demand for cooling. The external blinds can reduce these gains from 10% up to even 60%.

The benefits of using heavy concrete construction of the partitions lay in the allowance to set down the peak demand for cooling. Thanks to the cumulative ability of walls and ceilings rooms can be cooled down also during the night.

The potential benefits of using low-energy and passive technologies are great. Although there are no significant technical barriers, these technologies are not universally introduced for economic reasons.

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