SIMULATION OF NIGHT VENTILATION PERFORMANCE AS A SUPPORT FOR AN INTEGRATED DESIGN OF BUILDINGS

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ABSTRACT

Passive cooling by night ventilation is one of the most promising approaches to reduce cooling energy demand of office buildings in moderate climates. However, the effectiveness of this system depends on many parameters. Some of them are related to characteristics of building (percentage of glass in building envelope, shading devices, accessible thermal mass of partitions, height of building), some to installed ventilation (type of ventilation, cross-section of ducts, location of air intake and exhaust) and finally some are related to use of building (profile of occupation, heat gains form lighting and equipment, required indoor parameters etc.).

The existing case-study buildings with night ventilation indicate that close to optimal performance of night ventilation requires detailed analysis performed at very early design stage when change of some input parameters is still possible. That is typical for concept of integrated design of buildings.

The paper describes simulations of night ventilation for the office building (floor area 3640 m^2 for approximately 400 persons) located in Warsaw, Poland. The calculations were performed with utilisation of quite simple but satisfactory accurate method 6R1C that is a modification of simply hourly method described in EN ISO 13790 (Energy performance of buildings - Calculation of energy use for space heating and cooling).

Achieved results confirmed big impact of night ventilation intensity and thermal capacitance of building on energy use in office buildings. Taking into account integrated design of buildings the paper provides also basics of methodology for selection of the optimal level of thermal capacitance and optimal intensity of night ventilation.

KEYWORDS

Night ventilation, Integrated design, Simulation, Energy demand

1 INTRODUCTION

The implementation of EU policies related to energy efficiency forces scientists and technicians to pay more attention to integrated design of buildings. Collaboration in multi-disciplinary teams, discussion and evaluation of multiple design concepts at early design stage are of great importance. In case of buildings with high energy and environmental ambitions integrated design seems to be necessity. Experiences from projects that applied integrated design show that the investment costs may be slightly higher about (5 %), while at the same time the annual running costs are reduced by as much as 40-90 %.

Meeting the EU requirement of nearly zero emission energy buildings (nZEB) in 2020 calls for intensive studies on practical application of low energy cooling of buildings. In moderate climates one of the most promising approaches to reduce cooling energy demand of office buildings is passive cooling by night ventilation. As the effectiveness of this system depends on many parameters, night ventilation is a very good example for integrated design approach.

The potential of night ventilation have been proved in number of studies and in many countries including USA (e.g. Keeney and Braun 1997 or Braun et al. 2001), UK (e.g. Kolokotroni and Aronis, 1999), France (e.g. Blondeau et al., 1997), Greece (e.g. Geros et al., 2005) or China (e.g. Wang et al. 2009).

After analysis of climatic data from 259 weather stations all over Europe Artman et al, (Artman et al, 2007) proved a high potential for night-time ventilative cooling over the whole of Northern Europe and still significant potential in Central, Eastern and even some regions of Southern Europe. However, in later publication Artman et al, (Artmann, et al. 2008) presented high sensitivity of simulation results to climatic conditions that should draw attention of the scientists to quality of climatic data for building energy simulations. They additionally state that simulations based on commonly used semi-synthetic 1 year data sets such as DRY or Meteonorm data tend to underestimate the extent of overheating compared to measured weather data.

2 PERFORMANCE OF THE NIGHT VENTIALTION IN POLISH CLIMATE

2.1 Concept of the Study

Unluckily, despite huge interest of scientists all over the world in night ventilation there is very limited information on similar studies for Polish conditions (e.g. Górzeński and Odyjas, 2003). Study of Dębowczyk and Sowa (Dębowczyk, 2012) presented huge potential for energy saving due to night-time ventilation of office buildings. It should be pointed out that, according to EU estimations (Pardo et al., 2012) the useful energy demands for office buildings in Poland for 2009 are quite high: 35.2 PJ for space heating, 9.4 PJ for water heating and 24.1 PJ for space cooling. Moreover, trends on construction market leads to the situation that the share of demand for space cooling in recently constructed office buildings is increasing. The aim of the study is to provide information on potential savings due to night ventilation and to promote the concept of integrated design that can help to reverse observed trend of rapidly rising cooling demand of office buildings.

2.2 Short description of applied simulation tool 6R1C +AHU

There are number of simple simulation tools capable to perform energy calculation for buildings with night ventilation. Balaras (Balaras, 1996) presented 16 simplified models for estimating the cooling load of a building, taking into account the building's thermal mass. The progress is quite fast and some of the models have been incorporated to Standard ISO 13790:2007 (ISO 2007). One of described methods, simplified hourly method utilizes the analogy between heat flow in buildings and current flow within electric circuits and is often called 5R1C (5 thermal resistances and 1 thermal capacity). The authors developed further this concept into 6R1C model (thermal resistances of controlled ventilation and uncontrolled infiltration have been split) and extend it by equations modelling behaviour of air handling units 6R1C +AHU (Narowski et al., 2009).

Depending on the type of air conditioning system the following processes can be taken into account:

- heat recovery (sensible and latent) during winter and summer,
- heating,

- humidifying,
- cooling,
- dehumidifying,
- preheating and precooling of air in ground-air heat exchanger.

Although the equations describing air conditioning processes are simple and well know (e.g. from EN 15241 (CEN, 2007)) the annual behaviour of AHU may be quite complex. The advanced logical analysis (the substitution of control system modelling) is often necessary. The model has an open structure and may be extended by other air treatment processes (e.g. evaporative cooling). The model introduced to Microsoft Excel spreadsheet may be utilized in personal computers.

2.3 Description of analysed building

The annual energy consumption simulations were performed for a virtual office building located in Warsaw, Poland. The building of total area of 3640 m^2 and volume of 10920 m^3 is occupied by 400 persons. The building is equipped with water based 4 pipe air conditioning system and constant air volume mechanical ventilation. Total ventilation rate for whole building is 20000 m^3/h (50 m^3/h per person). Additionally it has been assumed that the air tightness test (blower door test) gave the result $n_{50} = 2\ h^{-1}$. Heating and cooling loads were calculated assuming profiles of operation (from 7.00 a.m. to 8 p.m.). Peak internal heat gains from people lighting and office equipment reach 25.6 W/m^2. Simulations took into account weekends and free days with the assumption that in these cases indoor temperature is running freely with lower limit of 16°C.

The analysed building is quite well insulated and is characterised be the following parameters (symbols according to ISO 13790:2008, ISO, 2008):

- total thermal transmission coefficient of opaque building elements H_{tr_op}=1651 W/K
- total thermal transmission coefficient of doors, windows, curtain walls and glazed walls H_{tr_w}=861 W/K

It was assumed that the basic model of the building with active cooling can be additionally equipped with night ventilation, which operation can start an hour after leaving office by employees and can be switched off an hour before the regular operation of the building. In addition, the following restrictions for temperatures were considered:

- night ventilation is activated when indoor air temperature at the end of the work day exceeds 25°C,
- in the cooling period, minimum indoor air temperature during the operating hours is 22°C,
- in the cooling period, maximal indoor air temperature during the operating hours is 28°C.

Simulation were performed for different intensity of the night ventilation 5 ACH, 10 ACH and 15 ACH and different thermal capacitances of the building corresponding to medium, heavy and very heavy classes of dynamic parameters of building, according to ISO 13790:2008. In medium class the area of effective thermal mass is 2.5 times higher than the conditioned floor area, while in heavy and very heavy classes this coefficient is equal 3 and 3.5 respectively. At the same time internal heat capacity divided by the conditioned floor area equals 165 kJ/(K m^2) for medium class, 260 kJ/(K m^2) for heavy class and 370 kJ/(K m^2) for very heavy class.

3 DISCUSSION OF SIMULATION RESULTS

3.1 Analysis of the distribution of power demand over the year

Reference building for comparisons in presented study is a building with moderate thermal capacitance and without night ventilation. Simulations performed for this building show very high cooling power in comparison with heating power and long cooling period in comparison with heating period. The results can be astonishing but the experiences from other projects confirm that this phenomenon is observed in number of office building in Poland.

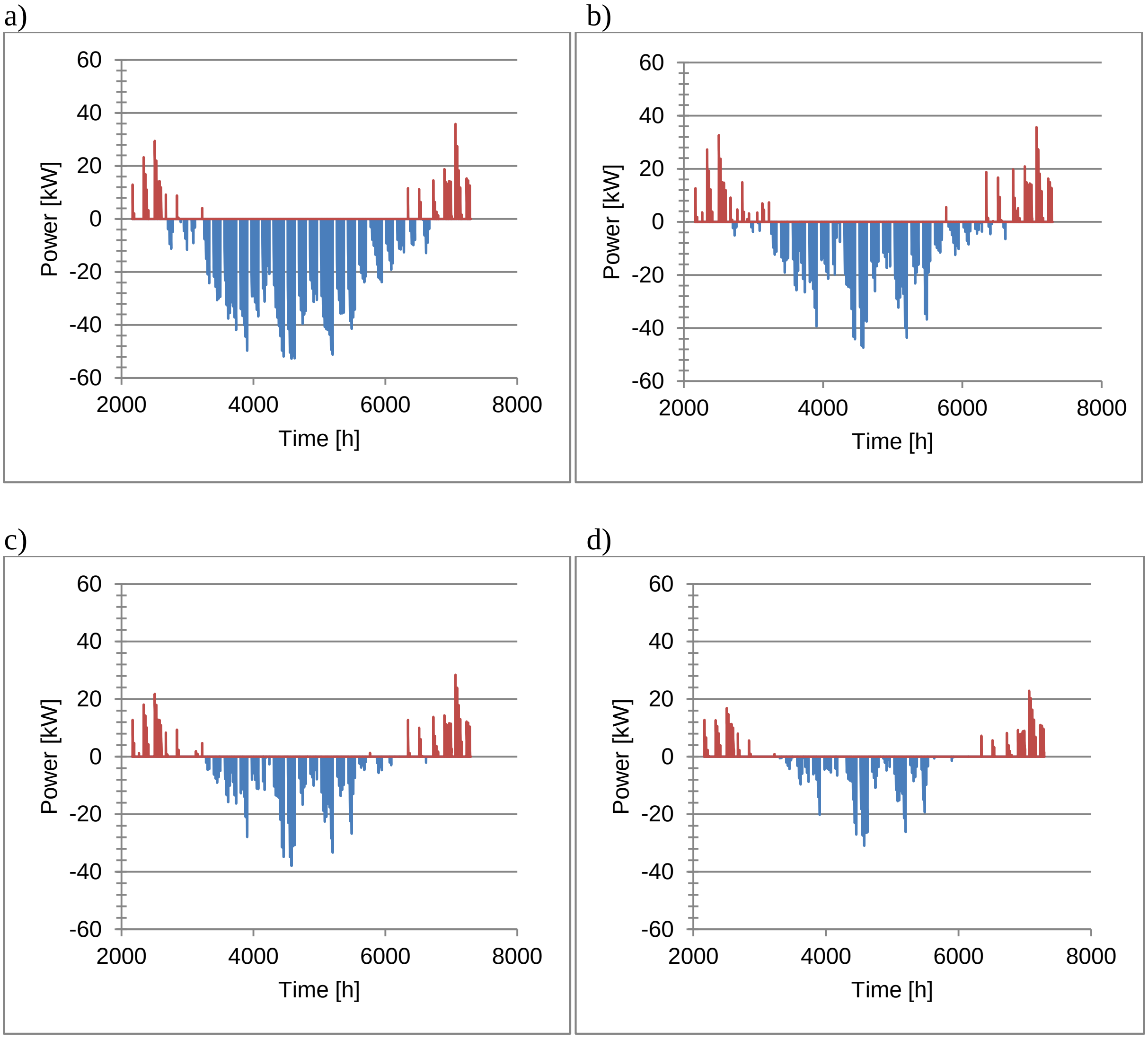

Fig. 1. Distribution of cooling power and heating power necessary to maintain comfort conditions in analysed office building, a) dynamic class – medium, no night ventilation, b) dynamic class – medium, night ventilation 5 ACH c) dynamic class – heavy, night ventilation 5 ACH, d) dynamic class – very heavy, night ventilation 5 ACH, (red line – heating, blue line – cooling).

The set of graphs presented at Fig. 1 allows the analysis of the influence of night ventilation with intensity 5 ACH on variable cooling and heating power for buildings with different types of construction. The mere fact of the introduction of night ventilation to building with medium thermal capacitance can noticeably reduce energy consumption for cooling. Maximum demand for cooling power decreases just by 10% after the introduction of night ventilation, however the cooling system operating time is reduced from 1,254 to 795 hours for the entire year. Increasing the thermal capacitance of the building allows further reduction of both cooling power and working time of the cooling system. In building corresponding to heavy thermal class cooling system operates only 602 hours per year while in case of building with very high thermal capacitance (very heavy class) operating hours are reduced just to 446 hours per year. In building with medium and high thermal capacitance the use of night ventilation slightly increases the operation period of heating system.

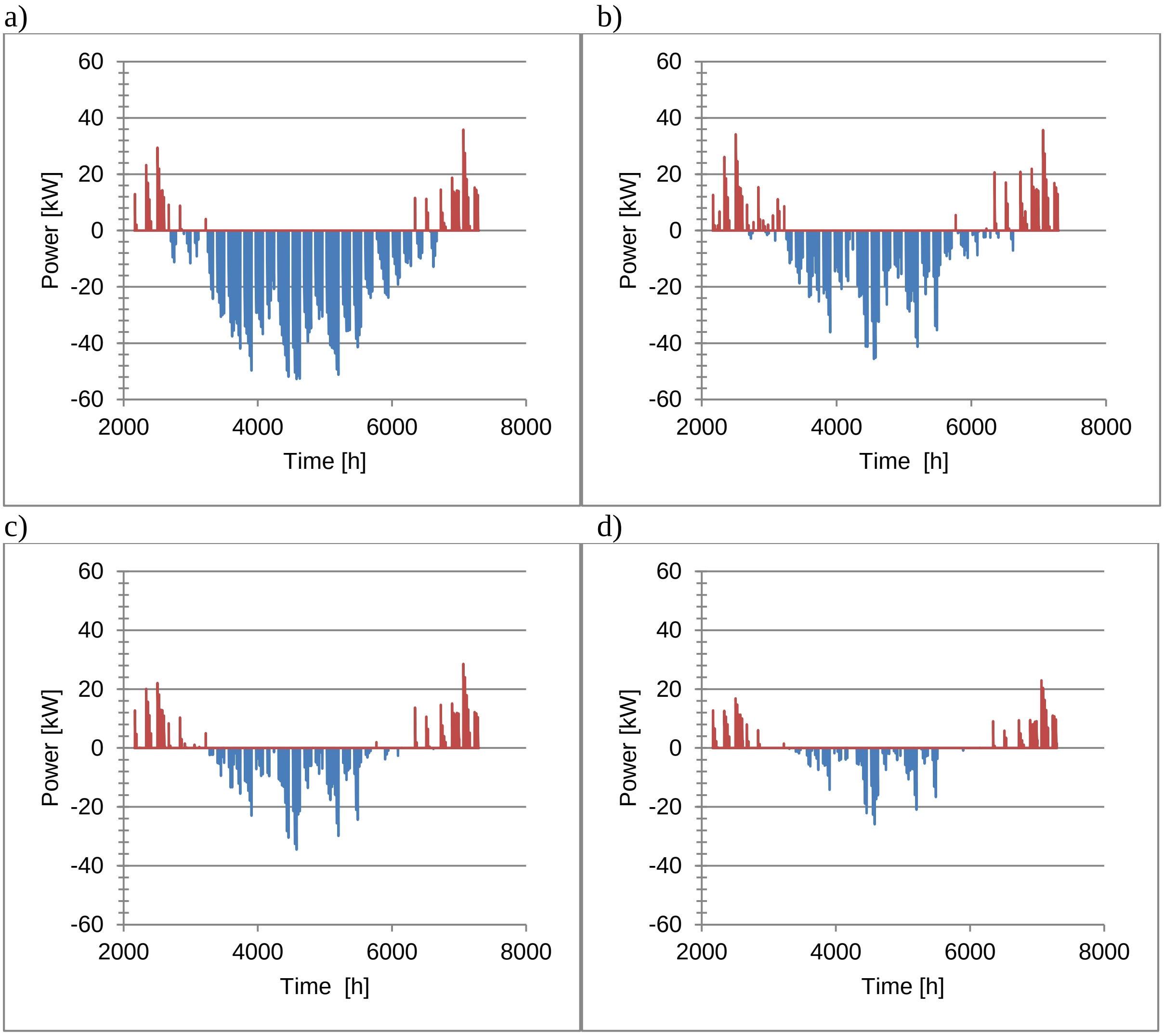

Fig. 2. Distribution of cooling power and heating power necessary to maintain comfort conditions in analysed office building, a) dynamic class – medium, no night ventilation, b) dynamic class – medium, night ventilation 10 ACH c) dynamic class – heavy, night ventilation 10 ACH, d) dynamic class – very heavy, night ventilation 10 ACH, (red line – heating, blue line – cooling).

The graphs presented at Fig. 2 illustrate the impact of night ventilation with intensity of 10 ACH on power demand in analysed building assuming its different dynamic properties (different thermal capacitances). A significant reduction in the power required for cooling is observed as well as the reduction of the working time of the cooling system from 1254 to 707 hours can be notices. For heavy building with night ventilation 10 ACH peak demand for cooling power is 34.53 kW that is an important reduction in comparison with reference variant (52.76 kW). Increasing the weight of the building structure to a level corresponding to a very heavy class (370 kJ/(Km^2)), allows to reduce the peak energy consumption by 51% in comparison with the reference variant. Cooling system operating time is reduced to 312 hours per year.

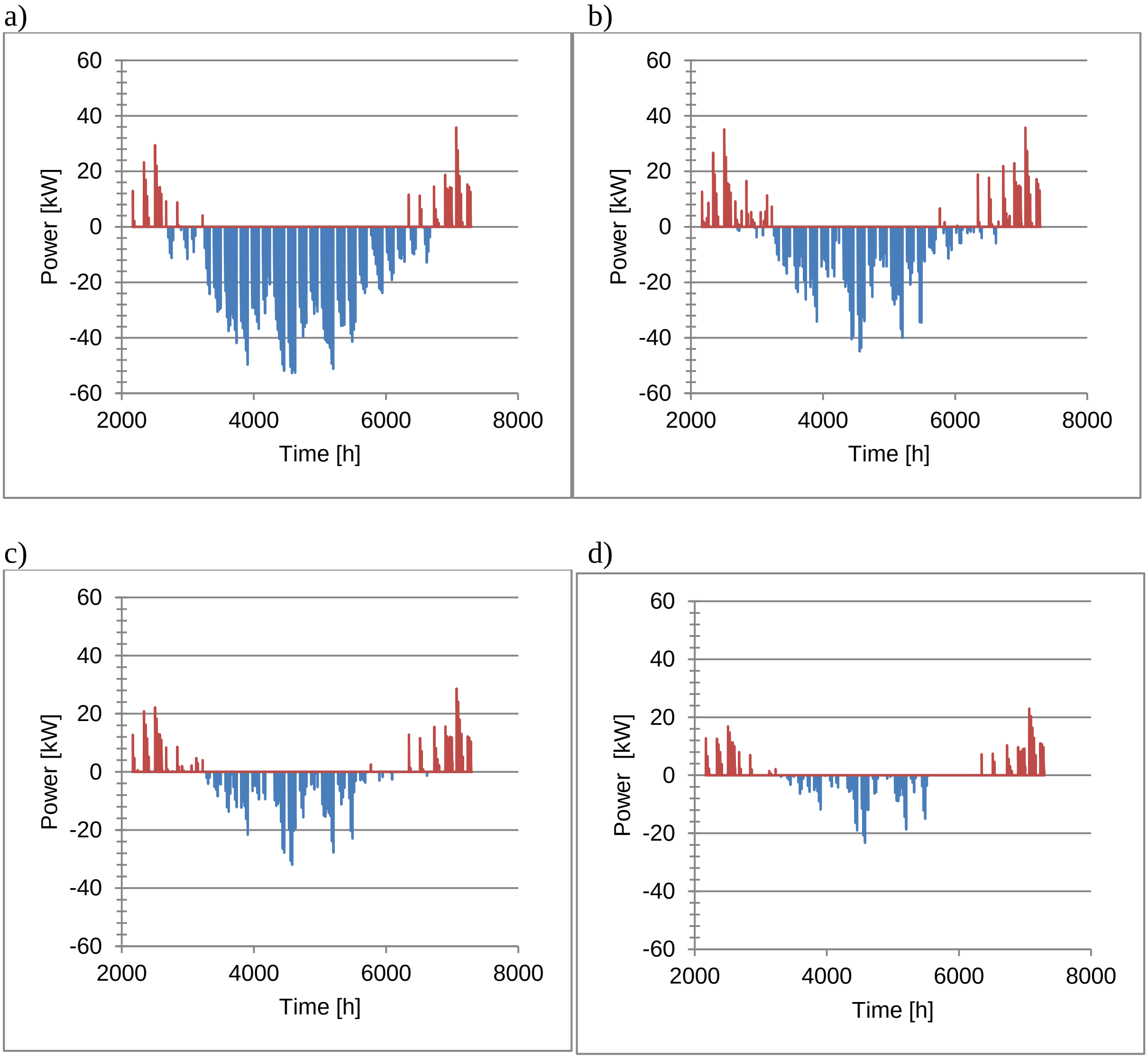

Fig. 3. Distribution of cooling power and heating power necessary to maintain comfort conditions in analysed office building, a) dynamic class – medium, no night ventilation, b) dynamic class – medium, night ventilation 15 ACH c) dynamic class – heavy, night ventilation 15 ACH, d) dynamic class – very heavy, night ventilation 15 ACH, (red line – heating, blue line – cooling).

Charts presented at fig 3 allow reader to analyse how different dynamic properties of the building influence cooling and heating power in case when night ventilation with intensity 15 ACH is used. For the moderate thermal capacitance the average working time of the cooling system is reduced by almost 50%. However, for the heavy class building cooling time is limited to 457 hours per year and peak demand for cooling power is just 32.00 kW. In case of very heavy class operating time is equal 264 hours per year, which is a very good result compared to the base building without night ventilation (1 254 hours).Moreover, peak cooling power demand decreased by 56%, and the demand for thermal power has decreased by more than 11% in relation to the reference variant.

3.2 Comparison of annual energy demand

Performed simulations can be summarised by presentation of energy use (fig 4). For the reference variant (building with medium class of thermal capacitance, no night ventilation), the total energy required for cooling in the reference year is 27 631 kWh and the demand for energy for heating at 2 024 kWh. Application of night ventilation with intensity 5 ACH leads to 60% reduction of total energy use for cooling, while the energy use for heating is higher by approximately 20% (fig. 4). Increasing the intensity of night ventilation to 10 ACH allows to reduce the energy use for cooling by an additional 5% while the heating energy requirement of supplementary 4%. Night ventilation with intensity 15 ACH can drop cooling energy use to below 30% of reference variant.

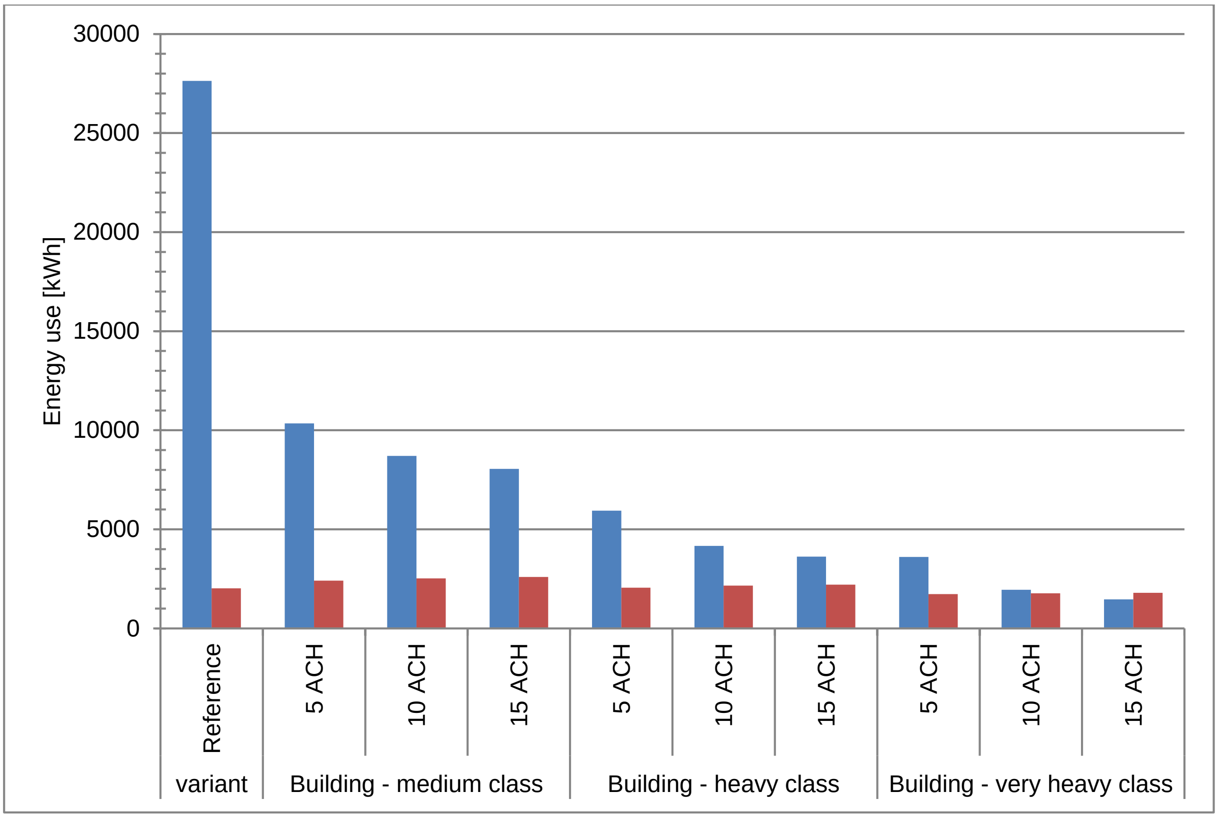

Fig. 4. The energy demand for cooling and heating for the presented variants in analysed building (red - heating, blue - cooling).

An increase of thermal mass of the building to 260 kJ/(K m^2) can give even higher reductions. Additional reductions can reach 5% to 10% compared to the reference building, depending on the intensity of the night ventilation. It is worth to point out that this scenario also, decreases energy use for heating by approximately 5-15% when compared to the moderate building and corresponding intensity of night ventilation.

The best results in terms of energy have been achieved for building with very heavy construction (very high thermal capacitance) with additional ventilation night. Cooling energy use for such a building with night ventilation at 5 ACH is reduced by more than 80% in relation to the reference building (medium construction and no night ventilation). The use of night ventilation of 10 ACH is characterised by more than 90% reduction in cooling energy use. High intensity of night ventilation 15 ACH leads to impressive 95% reduction of cooling energy use to 1 464 kWh per year. Furthermore the energy demand for heating of the building is reduced by more than 10% compared to the reference building and by approximately 20-30% compared to the building with moderate thermal capacity and active night ventilation.

4 FURTHER ECONOMIC ANALYSIS IN INTEGRATED DESIGN

The analysis described above indicated the big impact of the night ventilation intensity and thermal capacitance of building on energy use in office buildings also in Polish climate. The experiences of the authors indicate that similar trends can be observed in other office buildings excluding those with low thermal capacitance.

Parameters used in simulations (intensity of night ventilation and thermal capacitance of building) can be obtained due to variety of technical solutions at different investment costs. Also achieved savings in energy use can be converted into different costs depending on sources and prices of energy, efficiencies of devices etc. Further analyses are therefore presented just as a general scheme.

As recommended by EU (EU, 2012) total costs for buildings and/or building elements shall be calculated as a sum of the different types of costs after applying to them the discount rate (it means expressing them in terms of value in the starting year), and taking into account discounted residual values (equation 1).

$$C_g(\tau) = C_I + \sum_j \left[\sum_{i=1}^{\tau} \left(C_{a,i}(j) \times R_d(i) \right) - V_{f,\tau}(j) \right] \tag{1}$$

where:

τ the calculation period

$C_g(\tau)$ global cost (referred to starting year τ 0) over the calculation period

C_I initial investment costs for measure or set of measures j

$C_{a,i}(j)$ means annual cost during year i for measure or set of measures j

$V_{f,\tau}(j)$ means residual value of measure or set of measures j at the end of the calculation period (discounted to the starting year τ 0).

$R_d(i)$ means discount factor for year i based on discount rate r to be calculated by equation 2

$$R_d(p) = \left(\frac{1}{1 + r/100} \right)^p \tag{2}$$

where p means the number of years from the starting period and r means the real discount rate.

Than final selection of different combinations technical solutions (e.g. technical solutions for night ventilation, materials and technology for inner surfaces influencing thermal capacitance of the building) can be made taking into account:

- the lowest energy use
- the lowest primary energy consumption
- the lowest payback time
- the highest net present value of the investment
- the lowest life-cycle cost

or any other criteria agreed upon the designing team.

5 CONCLUSIONS

Integrated design can be a valuable approach to reduce the complexity of the design process and to facilitate the interactions between the members of the design team. This procedure allows the design team to provide the best solution for the whole building. The design team should have an access to simple but accurate simulation tools. Performed analysis using calculations with 1 hour time step gave much more information (e.g. peak power demand or operating hours) than monthly method.

Night ventilation can be a very attractive technology for low cost cooling of office buildings. Active systems (mechanical ventilation operating during favourable conditions during nights) require additional energy for fans but can be more efficiently controlled in comparison with ventilation systems run by natural forces. Buildings with high thermal capacitance are more appropriate for application of night ventilation. Achieved results confirm potential for huge energy savings during building operation. Presented approach is quite universal, however one should remember that recommendations for optimal variants can be different in similar cases as economic analyses are strongly dependent on local contexts (construction technologies, local materials, prices of energy etc.).

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