

Solar energy impact on space heating and cooling needs in moderate climate

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Abstract. The paper describes impact of solar energy on a standard new building of a low energy consumption for space heating, and shows a problem of overheating of such a building in summer, that occurs quite often nowadays in moderate climate. The paper presents how important is to analyse in details the solar energy availability for a building envelope, especially for glazing of different orientation and inclination. Impact of solar energy on the energy balance of a building is analysed. Results of numerical simulations of dynamics of a building and its surrounding are presented. The focus is put on monthly changes of the space heating and cooling energy needs for every month of the averaged year – with regard to the solar energy influence depending on the different orientation of the rooms of a building. It turns out that cooling demand previously very small, now can become very significant and can dominate the total energy demand of new buildings, especially for some location of rooms and apartments. The results of simulation studies presented in the paper indicate necessity of changes in existing regulations on determination of energy performance of buildings, especially for certification of thermal energy performance of residential buildings.

1. Introduction

In high latitude countries for many years the design and construction of buildings have been focused on the heating season only, mainly on reduction of the heat losses through building envelopes. In the past the heat losses used to be very high. Solar energy gained by the interior of a building was lost very quickly. However, nowadays situation is different. New buildings are constructed according to new codes and regulations [1]. They are very well insulated and heat losses are reduced a lot, not only through external walls but through windows, as well. Solar energy impact on thermal energy balance becomes more evident, especially in some rooms locations and with big windows. Cooling demand can become the dominant part of the energy balance in high latitudes. Therefore knowledge of solar energy availability and its impact on the energy balance of a building should be considered carefully to design buildings to be low energy throughout the year.

The existing regulations for residential buildings require determination of final and primary energy demand indices only for heating energy needed for the space heating and hot water [2]. However, it is necessary to determine the energy consumption of residential buildings throughout the whole year. It means that the energy consumption for space cooling (air-conditioning) should be also determined and indices of cooling energy should be introduced as soon as possible. The paper presents the problem of summer overheating of rooms and apartments in specific location in modern low energy buildings in Poland.

2. Solar energy in a building in high latitudes



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Reduction of the energy intensity of a building starts with decreasing its energy demand. In the case of space heating and cooling demand not only the use of sufficiently good insulation [3] and high thermal capacity of the building is required, but also a well thought through architectural and civil engineering concept. Any building can utilise energy available in the environment, mainly solar energy, when the building and its surrounding are well designed. Every building is under the influence of solar radiation. It is both a solar collector and a store of gained heat [4-5].

It is necessary to be aware of the climatic conditions of the place where the building is located. To determine the space heating and cooling load it is necessary to know the ambient temperatures, solar irradiation, wind speed etc. In Poland the average annual global solar irradiation is in the range 950 - 1150 kWh/m². There are big differences between summer and winter months, e.g. in Warsaw in June the monthly the solar irradiation is about 150 kWh/m² and in December about 11 kWh/m². It is evident that in winter solar energy availability is rather poor, but in summer is really good. However, it turns out that even so small a solar irradiation level in winter can have positive impact on the energy balance of a building and can lead to a reduction of space heating needs [6]. In summer the solar energy impact can be large if nothing is done to protect a building against too much solar radiation.

To analyse solar energy availability for different surfaces of a building it is necessary to determine solar irradiation of surfaces with different azimuth (orientation) and inclination angles. To determine solar energy availability the averaged representative hourly solar radiation data on horizontal surface located in Warsaw has been used as input data for calculations of hourly irradiation of inclined surfaces [7]. Hemispherical solar irradiances have been calculated using the HDKR anisotropic sky model (Hay - Davies - Klucher – Reindl [8]). A mathematical model of the dynamics of a building has been developed [4]. The model takes into account all energy fluxes flowing into and out of the building. During a day time solar radiation flows into a building. Variations of ambient air temperature, direct and diffuse solar radiation have been considered as hourly values averaged for a representative day of every month of the averaged year. The energy balance of air in a room or in a building takes into account the following energy fluxes coming out or into the room/building, or existing in a building:

- heat transferred through windows,
- solar energy transmitted through windows,
- heat transferred through walls,
- heat transferred through a roof,
- heat transferred through a floor on the ground or basement,
- heating/cooling needed for ventilation (supplied directly by a ventilation system or by a floor heating system or radiators to fresh air),
- internal heat gains,
- heating/cooling energy supplied by space heating/cooling system.

A bespoke MATLAB model has been developed for numerical simulations of a building dynamics. The simulations have been used to calculate all components of the energy balance mentioned above. Some results of simulation studies are presented in this paper to show the evident impact of solar radiation on space heating/cooling demands.

Monthly heating and cooling energy loads resulting from the energy losses and gains of rooms of different locations in the building are presented in Figures 1-4, which refers to attic rooms (inclined roof windows of large size: 2 x 2m²). These figures include the following components of the energy balance of air in the rooms: energy flows through external walls, energy flows through windows and energy needed for ventilation, for selected rooms with particular window sizes, orientations and inclinations. The calculations of heating/cooling needed for ventilation take into account heat recuperation (recuperative heat exchangers are used). It is evident that energy flow through a window, including solar energy entering the room directly, has a major influence on the energy balance of the room, and as a result on the heating/cooling demand. Location of a room strongly affects the contribution of energy transferred through a window to the energy balance of the room. It is characteristic that the large windows under consideration (with all four main orientations and two

inclinations) cause the energy gains, resulted from the solar radiation, to be higher than the heat losses during the entire year. What is more, the distribution curves of heating/cooling loads are very close to the curves representing distribution of energy transferred through windows. The influence of ventilation loads (heat recuperation is assumed to be applied) and then of the heat transferred through opaque walls on the heating/cooling demand is not significant.

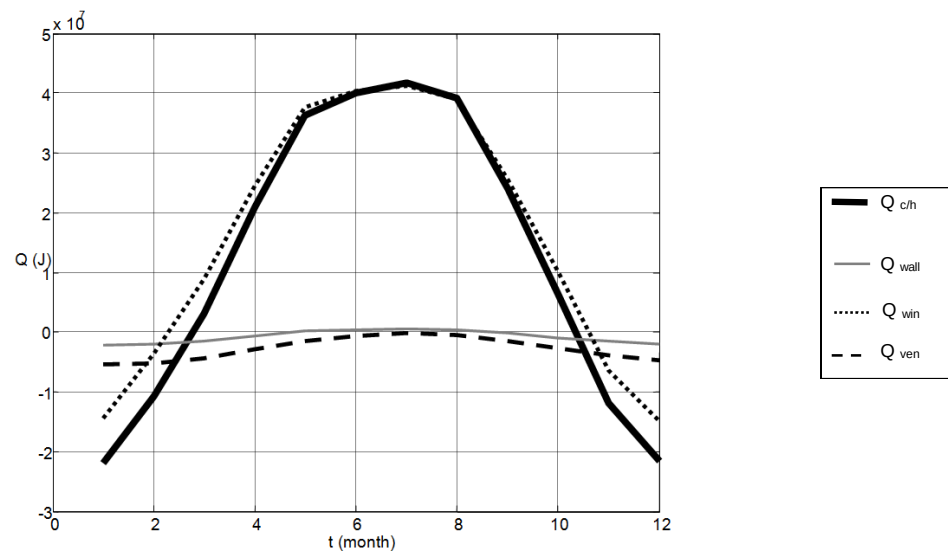


Figure 1. Distribution of monthly heating/cooling demand for the south facing attic room.

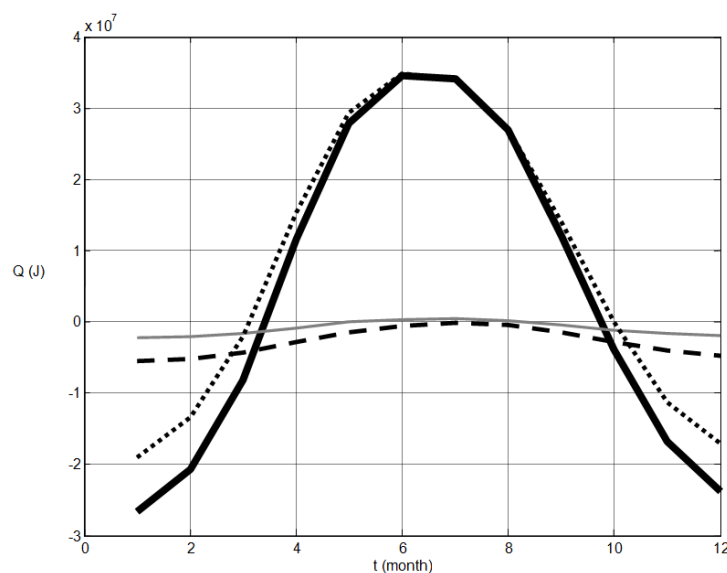


Figure 2. Distribution of monthly heating/cooling demand for the east facing attic room.

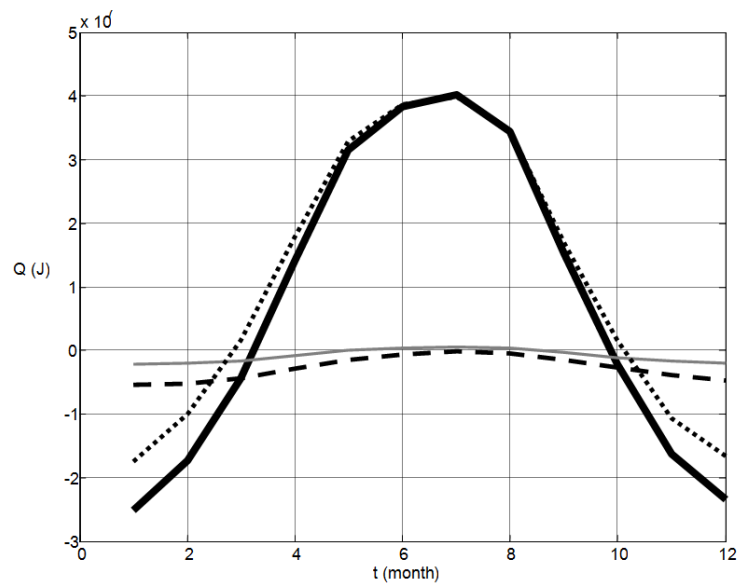


Figure 3. Distribution of monthly heating/cooling demand for the west facing attic room.

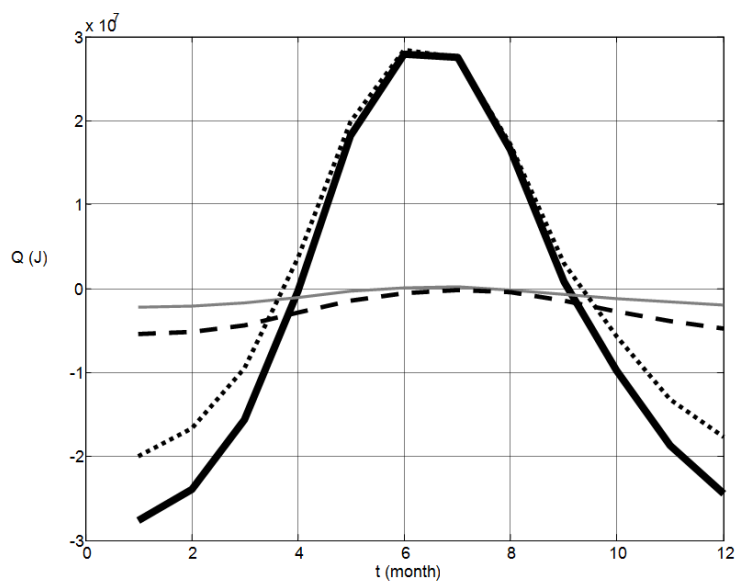


Figure 4. Distribution of monthly heating/cooling demand for the north facing attic room.

Thanks to the use of large windows the duration of the heating season is reduced to 4 months for the south oriented room and to 5 months for the west and east oriented rooms, and to 7 months for the north oriented rooms. (For standard windows size the heating season usually lasts 7 months). A shorter heating season can mean a longer cooling (air conditioning) season. In addition, the energy needs for cooling in warm months for the south and west oriented rooms are higher than the heating demands (for south orientation the cooling demand is twice the heating demand), if a constant room temperature is to be maintained for the whole year.

For south and west oriented rooms the energy needs for cooling, during 8 months from March till the end of October, are three times larger than heating demand in the rest of the year. The cooling demand is especially high from May to August. Generally, attic rooms require more energy for heating in winter (because of the radiative heat exchange between roof windows and the sky in the night) than

standard rooms with vertical windows and more cooling in summer (due to the strong influence of solar radiation, which is larger on inclined surfaces than that on vertical surfaces). However, in spring and autumn the energy required to maintain thermal comfort is at a low level.

Figure 5 presents the annual heating and cooling demand of apartments with attic or regular rooms. The figure also includes the energy losses or gains through windows. It is evident that depending on location of apartments the impact of energy transfer through the window (mainly solar energy) on the heating and cooling load can be very different.

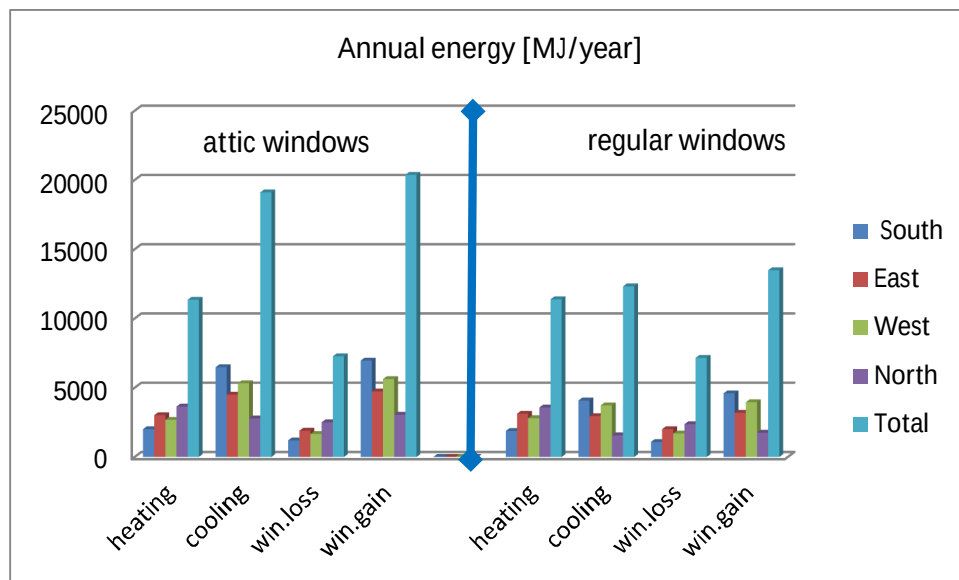


Figure 5. Annual heating and cooling demand, and energy losses and gains through windows for attic rooms - left side and regular rooms – right side.

Analysing Fig. 5 it can be seen that in case of the regular rooms the same pattern, as for the attic rooms, of the impact of the orientation of rooms and windows on the heating and cooling demand can be seen. However, the quantity of energy needed for heating and cooling demand is much lower, and the cooling demand is only a little higher than the heating demand. Energy gains through windows are nearly two times larger than heat losses. Heating demands for attic rooms and regular rooms are very similar (for regular rooms the demand is slightly higher), but there is a large difference in cooling demands, which for attic rooms are more than two times larger. This results from too much solar energy gains through the roof windows in summer (the size and structure of opaque walls of regular rooms and rooms of attics are the same).

3. Conclusions

The simulation results show that overheating in summer due to the high solar irradiation can be a real problem for the design of some buildings even in high latitude countries. It is noticeable that in new buildings, especially in attic apartments the cooling demand can be at the same level or even higher than heating demand. Overheating can be a problem of the south and west rooms in summer. However, in winter, solar gains are needed to reduce space heating demand. Therefore, it is necessary to pay special attention to windows. It would be good to apply windows which can change their optical parameters with time, high solar transmissivity in winter and low in summer. External shading elements should be used at the south and west side of buildings. Such shading elements, e.g. overhangs, light shelves, should be an obstacle for direct solar radiation in summer. In winter external shading elements should not cause any shading, at all. In winter solar energy availability is very

important and its impact on a building helps to reduce space heating demand in a natural very simple way.

In new buildings very well insulated and of high thermal capacity the energy flow through windows, mainly solar energy, strongly affects the energy balance of such rooms. South, west and east attic rooms require much more cooling energy than heating energy. The annual energy demand of attic rooms is much higher than the demand of regular rooms of the same orientation.

The results of simulation studies presented in the paper indicate necessity of changes in existing regulations on determination of energy performance of buildings, especially for certification of thermal energy performance of residential buildings, at the national level, as well as European. It is necessary to develop the energy efficiency certification procedure for residential buildings, which considers annual operation of energy systems and requires determination of final and primary energy indices for cooling demand. Limitation on cooling energy demand should be put into force for residential buildings in every geographical location (latitude).

4. References

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