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TOMASZ KISILEWICZ*

ON RATIONAL DESIGN OF LOW ENERGY BUILDING EXTERNAL COMPONENTS

O RACJONALNYM KSZTAŁTOWANIU NIEKTÓRYCH ELEMENTÓW OBUDOWY ZEWNĘTRZNEJ BUDYNKÓW NISKOENERGETYCZNYCH

A b s t r a c t

An attempt at the verification of simple designing rules of chosen building components is made in this paper, taking into account not only heating energy demand but also avoidance or at least reduction of cooling demand. Large south-oriented windows supply a large amount of solar energy and thus minimize the heating demand. Oversized windows and the resulting large energy gains, which are not accumulated in building's thermal capacity and used immediately for heating, do not reduce energy demand but create unbearable conditions or a big cooling load in living spaces. A green flat roof is today a very popular solution. Its insulating and dynamic properties have been evaluated.

Keywords: low energy buildings, window area sizing, overheating, green flat roof

S t r e s z c z e n i e

W artykule podjęto próbę weryfikacji prostych zasad kształtowania budynków niskoenergetycznych, zwracając przy tym uwagę zarówno na ograniczenia energii potrzebnej do ogrzewania jak i na uniknięcie przegrzewania wnętrza lub konieczności chłodzenia. Okna południowe pozwalają bowiem na bierne pozyskiwanie energii słonecznej, ale nadmierne przeszklenia prowadzą do wzrostu zapotrzebowania na ogrzewanie, a także stwarzają realne zagrożenie dla komfortu wewnętrznego. Poddano ocenie także izolacyjne i dynamiczne właściwości chętnie obecnie stosowanego rozwiązanie w postaci stropodachu zielonego.

Słowa kluczowe: budynki niskoenergetyczne, powierzchnia okien, przegrzewanie, zielony stropodach

* D.Sc. Tomasz Kisilewicz, Division of Building and Building Physics, Institute of Building Materials and Structures, Faculty of Civil Engineering, Cracow University of Technology.

1. Introduction

Presently overheating is becoming nowadays a very important aspect of a building's use and a big part of the maintenance costs. It is relatively easy to minimize heating needs and usually the formal requirements are oriented to this aim. Because of the common pressure on energy saving, a designer may easily find information on how to decrease energy losses, maximize and efficiently use solar and internal heat gains. In these conditions it is relatively easy to decrease heating needs but also to increase overheating risk. The methods of how to protect buildings against overheating are not commonly known and understood because of the complicated dynamic aspects of heat flow and storage in the building shell. In winter, south oriented windows supply building space with solar gains proportional to window area. Oversized windows and the large resulting energy gains, not accumulated in the building's thermal capacity and used immediately for heating, do not reduce the energy demand as it was expected due to increased night energy losses. High temperature rise may create unbearable conditions or big cooling load in living spaces.

A flat roof, that is commonly used in public utility or commercial buildings, is in summer often a source of large heat gains because of extremely high external surface temperature. Solar radiation, intensively absorbed by the bituminous coating on a horizontal roof area and combined with high air temperature, results in high energy flux entering the building space.

Due to minimized thermal losses through a well insulated external shell and substantially decreased ventilation losses, the thermal balance of a low energy building is extremely sensitive to energy gains. That is why the new and more comprehensive procedures of rational design of external building components are needed today [1].

2. South oriented window area versus heating and cooling load

The basic research on south oriented window sizing took into consideration the following features of building shell and environment [2, 3]:

– local climate conditions (especially air temperature, solar radiation intensity),
– space heating load that depends on thermal resistance of the whole building shell, ventilation intensity, heat recovery and internal energy gains,
– space thermal capacity,
– thermal resistance and solar transmittance of glazing.

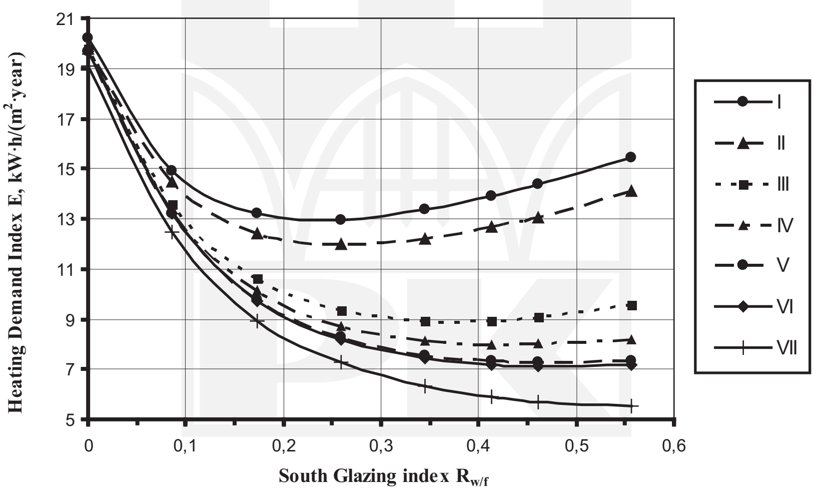
The relation between window area and demand on heating and cooling energy was investigated by means of computer simulation in the Energy Plus program. The whole simulated object may be one storey of a single-family building or a repeatable unit of a multi-storey residential or office building. Although the dimensions of the entire floor area of the simulated unit were 10 × 10 × 3 m, the main object of the simulation reported in this paper is the unit's south-west part only (modeled as a separate thermal zone), with floor dimensions 5 × 5 m and a height of 3 m.

It was assumed that:

– variable high density internal layers are in good thermal contact with the space,
– the minimum internal air temperature is set at +20°C and the maximum at +25°C,

– the measure of the passive system's thermal efficiency is the amount of purchased heating and cooling energy,
– considered heating period: 15.IX–15.VI, four computational time-steps per hour,
– ventilation rate: 1/2 air change per hour with highly efficient heat recovery (80%), no extra infiltration was assumed,
– standard apartment occupancy heat gains are constant in time,
– air or material humidity was not considered,
– seven thermal capacity variants were investigated, the first one (I) corresponds to lightweight technology with hardly any thermal mass (79.31 kJ per 1 K and 1 m^2 floor) and the last one (VII), is a massive building with 20 cm of concrete structure and additional internal walls (1919.40. kJ per 1 K and 1 m^2 floor)
– meteorological data for Kraków were used in computer simulations.

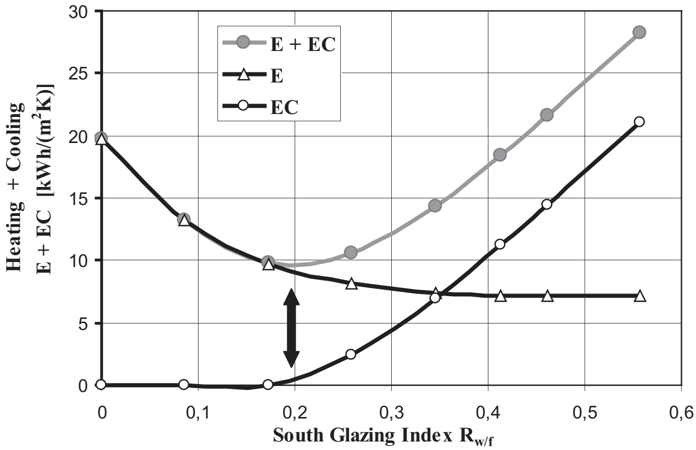
The curves displayed in Ill. 1, joining the separate data points obtained from the – simulations have been approximated using 5-th order polynomial regression.



Ill. 1. Heating demand index of the south building space versus thermal capacity and south window area – passive house insulation standard with 80% ventilation heat recovery and LE triple glazing

It may be observed that well insulated south glazing may actually reduce the space heating demand. But what is very important, oversized windows in case of lightweight building structure would again increase the energy demand. It means that a simple and commonly used rule of the thumb by designers: "big window area of the south windows assures big savings of conventional energy", is not always true. Available big solar gains do not necessarily become conventional energy savings. There is an optimum glazing index value for which space energy demand on heating would be minimized. In case of the lightweight buildings optimum window to floor ratio should be equal to 0.22 and for the massive buildings it even goes up to 0.57. For double glazed windows with a much higher than for triple glazing transmission of solar radiation, the values of optimum glazing index were much smaller [2, 3] then the ones above.

Data shown in Ill. 1 are oriented only on minimization of heating needs and include only demand on heating energy. In this sense they are adequate to the common approach today, where protection against overheating is usually not considered. In Ill. 2, combined energy demand on heating and cooling was presented for one capacity variant of a very massive building (case VI).



Ill. 2. Heating and cooling demand indices of the south building space versus south window area – passive house insulation standard with 80% ventilation heat recovery and LE triple glazing

Total energy demand minimum can in this case be achieved for glazing index value equal to 0.2 instead of 0.55 as it was suggested before. Oversized windows would induce enormous overheating in the analyzed zone or necessitate an intensive and energy consuming cooling process. An optimized window area would practically allow cooling to be avoided while keeping heating demand at a low level.

Rational design of the external building shell would in this case demand a comprehensive optimization of south oriented window area, considering the total demand on energy and various technical features of a building and its equipment. Such an approach is unfortunately not yet a standard procedure as decision regarding window size is usually subjective and has nothing to do with rational measures.

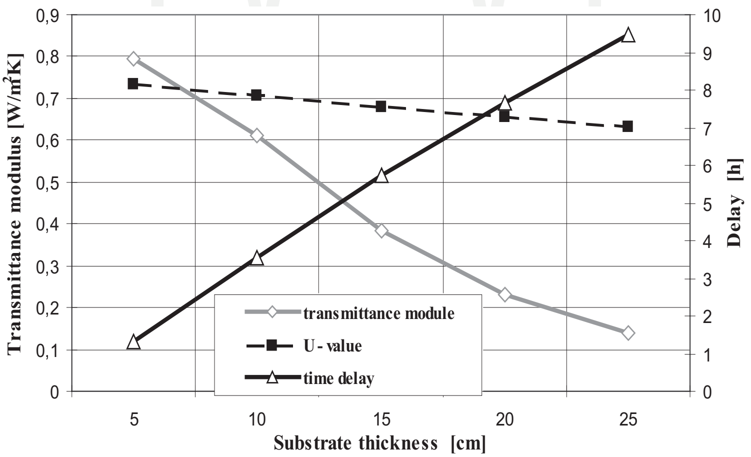
3. Dynamic thermal features of a flat roof

In large scale commercial or industrial buildings, the roof is very often the biggest component and the source of intensive solar gains. Solar energy gains via flat roof combined with internal gains may create a big dynamic cooling load and high demand on energy. Well insulated but lightweight (low thermal capacity) structure of the external shell does not ensure thermal comfort in internal space. Flat roof exposure to solar radiation on a summer day and a highly absorbing external coating, result in very high external surface temperature, inducing an intensive heat wave that flows across the roof. High thermal resistance of a contemporary roof allows to damp down efficiently heat flux amplitude. However, a space under the roof would be effectively protected against overheating not only when the ceiling flux amplitude is minimized, but also when it is shifted in time up to the moment when ambient air temperature is significantly decreased. This effect is efficiently used as so called night cooling that improves thermal conditions within the space without substantial demand on energy. Expected minimum time lag for an apartment roof is 10 hours and in case of a cold store, even 12 hours [4].

The dynamic thermal characteristics of a building component describe the thermal behaviour of the component when it is subject to variable boundary conditions i.e., variable heat flow rate or variable temperature on one or both of its boundaries. In International Standard EN ISO 13786 [5], only sinusoidal boundary conditions are considered, building boundaries are submitted to sinusoidal variations of temperature or heat flow rate. Thermal transmittance is a complex quantity defined as the complex amplitude of the density of heat flow rate through the surface of the component adjacent to zone *m*, divided by the complex amplitude of the temperature in zone *n* when the temperature in zone *m* is held constant. Thermal transmittance Y_{ei} was used here as a concise description of a dynamic roof characteristic that includes information regarding amplitude ratio and time lag between the waves of external temperature and internal heat flow. The assumed time period is 24 h.

A typical lightweight roof structure was taken as a reference roof case: asphalt over and undercoat layers 1 cm, thermal insulation 5 cm, corrugated metal sheet 0.1 cm.

Thermal transmittance of the reference roof under steady state boundary conditions (U value) depends only on its thermal resistance. While under harmonious conditions the role of the combination of thermal diffusivity and resistance becomes important.



Ill. 3. Green roof transmittance versus substrate thickness, 5 cm of thermal insulation

Increased thermal resistance of a roof is not a sufficient measure to avoid overheating [4]. During a hot summer day ceiling heat flux amplitude will be significantly reduced, but its maximum will occur a few hours after the sun culmination, when ambient temperature is still very high. At this moment even a very small temperature rise would intensify thermal discomfort in the space. In this situation an expensive and energy consuming mechanical cooling is the only chance to reduce space overheating.

In Ill. 3, a poorly insulated lightweight roof was turned into a green roof with a substrate layer added on its top. A thick (25 cm) substrate layer with a density equal to 1800 kg/m^3 is practically not increasing the thermal resistance of the roof (U value curve), but transmittance module reduction is significant and phase shift (delay curve) is 9.5 h. If the assumed solar culmination is at 13.00 (summer time), internal heat flux would reach its maximum at 22.30. At this moment ambient temperature is relatively low, even after a very hot summer day, and intensive ventilation would effectively reduce space overheating.

An intermediate 15 cm thick substrate layer (reduced mechanic load upon the structure) also improves also the dynamic features of the roof in a considerable way: transmittance module is 0.39 W/m^{2}K and phase shift ca. 6 h. In the case of an increase of up to 20 cm in thermal insulation and 15 cm substrate layer (diagram not included in this paper), phase shift would even be equal to 8.15 h.

4. Conclusions

Low energy building design should be based on rational, optimized decisions regarding any component of the final product. Because of a low level of energy demand such a building is very vulnerable to unbalanced energy gains and overheating. The approach to total energy demand (heating, cooling) should be considered to avoid thermal discomfort or increased costs of building use. Appropriate window sizing procedure that takes into consideration various technical features of a building and is focused not only on heating needs, but also on overheating load, seems currently to be one of the most important tools for a building designer. In the case of some commercial or public utility buildings space, overheating could be avoided or at least reduced by conversion of a lightweight roof into a green roof due to its enhanced thermal capacity.

Acknowledgements
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