Reduction of Air Condition Energy Consumption by Redundant Energy Gains Modification

Redukcja zużycia energii przez klimatyzację dzięki modyfikacji nadmiarowych zysków energii

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For a selected building in a specific location and conditions encountered, heat gains from sun exposure, resident people, equipment, lighting, and window partitions were calculated depending on the time of day (hourly for a year), the number, and the activity of people in the building. The heat and humidity balance was performed. This allowed the cooling and heating demand to be determined. The air conditioning system was adjusted to the demand. The operation of the system was simulated by showing the loads (hourly for a year). The load flexibility of the air conditioners was presented. Heat gains have been determined and ranked according to which has the greatest influence on the air conditioning load. Solutions were proposed to reduce the heat load in the building. As a result of the research, methods were presented for reducing the energy consumption of air conditioning by modifying the factors causing redundant energy gains.
Keywords: building air-conditioning, energy consumption, energy saving, heat gains

Dla wybranego budynku w określonej lokalizacji i napotkanych warunkach obliczono zyski ciepła od nasłonecznienia, ludzi, urządzeń, oświetlenia i przez ściany oraz okna, w zależności od pory dnia (co godzinę przez rok), liczby i aktywności osób przebywających w budynku. Przeprowadzono bilans ciepła i wilgotności. Pozwoliło to na określenie zapotrzebowania na chłód i ciepło budynku. Do wyznaczonego zapotrzebowania dostosowano system klimatyzacji. Zasymulowano jego pracę pokazując obciążenia (co godzinę przez rok). Przedstawiono elastyczność obciążenia systemu klimatyzacyjnego. Określono zyski ciepła i uszeregowano je według tego, które mają największy wpływ na obciążenie klimatyzacji. Zaproponowano rozwiązania mające na celu zmniejszenie obciążenia cieplnego budynku. W wyniku badań przedstawiono sposoby zmniejszenia energochłonności klimatyzacji poprzez modyfikację czynników powodujących zbędne zyski energii.
Słowa kluczowe: klimatyzacja budynku, zużycie energii, oszczędność energii, zyski ciepła

Introduction

Reducing the energy intensity of processes and equipment has become a key aspect of human activity in recent times. Energy demand adaptation is one of the five dimensions of the Energy Union strategy established by the EU Commission [1]. The goal of the transition to a more energy-efficient economy is to accelerate the diffusion of innovative technological solutions and improve industrial competitiveness, stimulating economic growth and the creation of high-quality jobs in a wide range of sectors related to energy efficiency [2]. The Energy Union Strategy has five mutually reinforcing and closely interrelated dimensions to ensure greater energy security, sustainability, and competitiveness: energy security, solidarity, and confidence; a fully integrated European energy market; energy efficiency contributing to demand reduction; decarbonization of the economy, and research, innovation, and competitiveness [3]. Ideally, urban energy use modernization efforts should be combined with sustainable development strategies and redevelopment policies [4]. In addition, climate change has a significant impact on the energy performance of buildings [5]. In this light, reducing the energy consumption of air conditioning (AC) by taking into account and modifying the energy gains in existing buildings and newly designed buildings seems to be a special issue [6], [7]. Heating, ventilation, and air conditioning (HVAC) systems are major energy consumers, contributing significantly to the annual total energy

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consumption of buildings, especially in variable climates [8], [9]. Therefore, improving the energy efficiency of the HVAC system is becoming an increasingly important issue in reducing energy consumption and CO_2 emissions in both existing and newly constructed buildings [10], [11]. Analyzing and evaluating the impact of various energy-saving strategies on energy consumption and CO_2 emissions, including a range of modifications that can be applied to the HVAC system in buildings, is becoming a key issuehttps://www.deepl.com/translator?utm_source=windows&utm_medium=app&utm_campaign=windows-share [12]. Especially since recent studies and discussions at the International Conference on Sustainability of Energy, Water and Environmental Systems indicate that in the coming years, the cost of cooling buildings in central Europe will equal that of heating [13], and currently buildings account for about 40% of total energy consumption, and their potential for primary energy savings is significant [14]. That's why it's so important to study and optimize air conditioning loads [9], as well as adaptive approaches to thermal comfort [15], [16] such as by dynamically adjusting the temperature according to clothing [17] or studying the effect of physical properties of different heat gains on air conditioning energy consumption, or parametric studies of the effect of window furnishings on air conditioning energy consumption [18], [19]. All this directs the researchers on the right track to the reduction of air condition energy consumption by unnecessary energy gains modification, which is the subject of this paper.

Materials and methods

Depending on the purpose of the room, an appropriate selection of values of air parameters and other factors characterizing the microclimate of the room is used. A distinction is made between domestic and industrial purposes [20]. Due to the nature of the analyzed object, further consideration is given to the air conditioning of the room providing thermal comfort for the people staying in it (domestic use).

Heat gains are closely related to the heat and moisture balance of the ventilated or air-conditioned room. This balance determines the magnitude of the heat and humidity loads, which are defined as the heat fluxes and moisture mass fluxes that must be assimilated by the supply air to that room to maintain the desired air parameters in the room. In summary, heat and moisture gains or losses are components of the heat and moisture loads of a room. Heat gains can be useful (from the space heating point of view) and detrimental at the same time (from the air conditioning point of view) [21].

Air conditioning makes it possible to maintain the required parameters of indoor air throughout the year. Physiologically, the sensation of freshness in the air depends on factors that act to stimulate the innervation of the human skin. If the human body is in perfect thermal equilibrium with the surrounding environment, then there are no changes in the temperature of the skin, and thus the skin innervation, which is sensitive to temperature changes, is not stimulated and the person feels neither hot nor cold, this applies both indoors and outdoors [22].

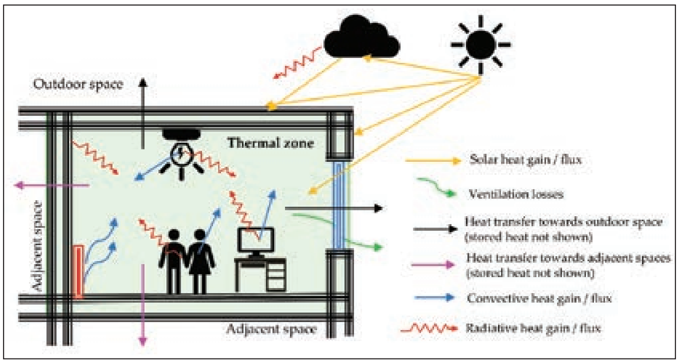


Figure 1.
Illustrative scheme of the main energy/heat fluxes (gains/losses) affecting the building's energy balance [10]
Rys. 1. Przykładowy schemat głównych strumieni energii/ciepła (zyski/straty) wpływających na bilans energetyczny budynku

In such an environment, a person feels relaxed, due to the lack of local stimuli, and the air can give the impression of being stuffy or stale. For the environment to have an invigorating effect on a person, the air must be slightly colder, and the air velocity and humidity must vary periodically. Then a person feels the effect of the environment as invigorating, and the surrounding air as fresh.

The study was conducted for a one-story office building located in Poland near the city of Wroclaw. A view of the building's plan and spatial orientation is shown in Figure 2. The research used local average hourly climate data for the year 2020.

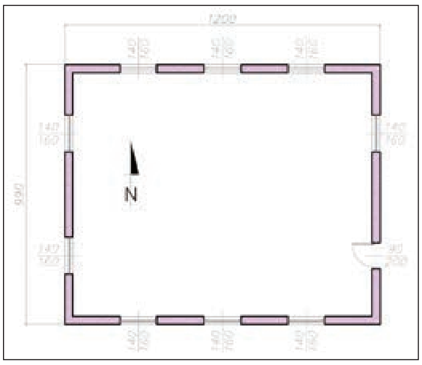


Figure 2.
Plan and orientation of the analyzed building
Rys. 2. Rzut i orientacja analizowanego budynku

The building under review is used for office activities. The equipment includes 5 computers with monitors, a network laser printer, coffee maker with a total electrical power of 2.26 kW. The existing incandescent lighting with a total power of 1.58 kW and capacity factor = 0.3, is launched between 8 am and 4 pm. Windowed surfaces with a total area of 20.16 m^2 with PVC frames and single-chamber standard glazing 4/16/4. Windows are without sun shades and their heat transfer coefficient is U_W = 0.9 W/(m^2K). External walls (without windows and doors) have a total area of 96.0 m^2 and a heat transfer coefficient of U = 0.2 W/(m^2K). The roof surface is 118.8 m^2 and its heat transfer coefficient is U = 0.15 W/(m^2K). Five people are working in the office.

In the considered building, there is a ventilation and air-conditioning system that intakes outside air, processes it, and injects it into the room. For outdoor air temperatures $t_{out} \le 21°C$ the indoor air temperature $t_{in} = 21°C$ is maintained in the room. For outdoor air temperatures $t_{out} > 21°C$, the room air temperature follows the outdoor air temperature according to the equation $t_{in} = 0.5278t_{out} + 9.9167$. The indoor relative humidity is maintained in the range of 40-55%. Recirculation occurs with a minimum proportion of outside air in the supply air. The maximum temperature difference allowed between exhaust air and supply air is $\Delta t^{max} = 10°C$.

The following ranges have been defined for the selected location of the study object: warm period *WP*, which covers the months from April to September; cold period (*CP)*, which covers the months from January to March and October to December [23].

Total redundant heat balance for air-conditioned rooms in the warm period (WP):

$$\dot{Q}_{rt}^{WS} = \dot{Q}_{tPe} + \dot{Q}_{sLi} + \dot{Q}_{sT} + \dot{Q}_{lT} + \dot{Q}_{sWi} + \dot{Q}_{sOP} \quad (1)$$

Balance of redundant total heat for air-conditioned rooms during the cold period (CP):

$$\dot{Q}_{rt}^{CS} = k\cdot\dot{Q}_{tPe} + \dot{Q}_{sLi} + m\cdot(\dot{Q}_{sT} + \dot{Q}_{lT}) + \dot{Q}_{hl} \quad (2)$$

Where:
- $\dot{Q}_{rt}^{WP}$ – Total redundant heat for air-conditioned rooms during the Warm Period, W
- $\dot{Q}_{rt}^{CP}$ – Total redundant heat for air-conditioned rooms during the Cold Period, W
- $\dot{Q}_{tPe}$ – Total heat gain from people, W
- $\dot{Q}_{sLi}$ – sensible heat gains from lighting, W
- $\dot{Q}_{sT}$ – sensible heat gains from technology, W
- $\dot{Q}_{lT}$ – latent gains from technology, W
- $\dot{Q}_{sWi}$ – sensible gains from the sun through windows, W
- $\dot{Q}_{sOP}$ – sensible gains from the sun through opaque partitions, W
- $\dot{Q}_{hl}$ – static heat loss, W
- k – correction factor, taking into account the minimum occupancy of people in the room, at which the assumed microclimate parameters should be maintained in the cold period (for residential spaces k = 0.1 – 0.2, for industrial spaces (k = 0.85 – 0.95)), –
- m – correction factor for heat gains from technology (m = 0.85 – 0.95), –

All the components of equations (1) and (2) were calculated following the methodology for determining heat gains in Polish legislation. For example, the heat gain from insolation through opaque partitions is given by the formula (3):

$$\dot{Q}_{sOP} = A_P \cdot U_P \cdot \Delta t_e,\ W \quad (3)$$

Where:
- A_p – the area of the external partition, m^2
- U_P – heat transfer coefficient of the partition, $W/(m^2K)$,
- Δt_e – equivalent temperature difference determined for typical partitions in terms of structure and thermal properties, which in the case of a greater diversity of construction or thermal characteristics of partitions should be corrected according to the formula (4).

$$\Delta t_e^a = \Delta t_e + (t_{av}^{out} - 24) + (26 - t^{in}) + \beta, K \quad (4)$$

Where:
- Δt_e^a – adjusted Δt_e,
- t_{av}^{out} – average hourly outdoor temperature, °C,
- t^{in} – indoor temperature, °C,
- β – correction factor considering the transparency of the atmosphere.

Heat gains from sunlight through transparent partitions are given by equation (5):

$$\dot{Q}_{sWi} = \dot{Q}_T + \dot{Q}_R,\ W \quad (5)$$

Where:
- $\dot{Q}_T$ – Heat gains through transparent partitions from the transmission, W,
- $\dot{Q}_R$ – Heat gain through transparent partitions from radiation, W.

Heat gains by transmission are calculated according to relation (6):

$$\dot{Q}_T = A_W \cdot U_W \cdot (t_{out} - t_{in}),\ W \quad (6)$$

Where:
- A_W – area of the window seat, m^2,
- U_W – window heat transfer coefficient, $W/(m^2K)$,
- t_{out} – instantaneous outdoor air temperature, °C,
- t_{in} – instantaneous indoor air temperature, °C.

Heat gains by radiation are calculated according to equation (7):

$$\dot{Q}_R = [A_1 \cdot I_{c_{max}} + (A - A_1) \cdot I_{r_{max}}] \cdot b \cdot s,\ W \quad (7)$$

Where:
- A – glass area, m^2

$$A = A_W \cdot g,\ W \quad (8)$$

- A_1 – insolated area of the window glass, m^2
- $I_{c_{max}}$ – maximum intensity of total solar radiation in a given month for a specific exposure direction, W/m^2,
- $I_{r_{max}}$ – maximum intensity of scattered solar radiation in a given month, W/m^2,
- b – transmittance coefficient of solar radiation through the window, – ,
- s – heat accumulation coefficient in the partitions surrounding the room, – ,
- g – share of glass area in the window area, – .

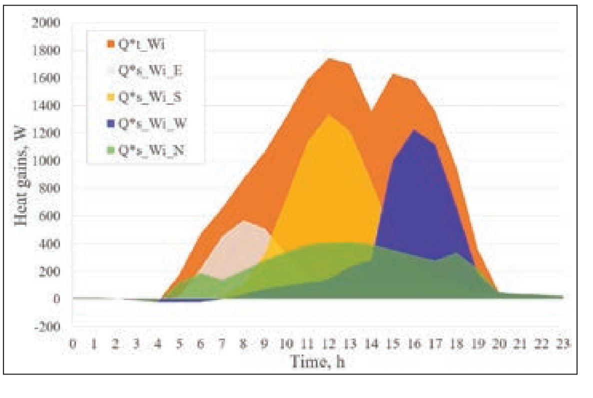


Figure 3.
Example graph of solar heat gain through transparent partitions (windows), separately for each side of the building, and the total gain going into the room
Rys. 3. Przykładowy wykres zysków ciepła od słońca przez przegrody przezroczyste (okna), oddzielnie dla każdej strony budynku i całkowity zysk ciepła przechodzący do pomieszczenia

The values of total and diffuse solar irradiance ($I_{c_{max}}$, $I_{r_{max}}$) were selected from tables for average monthly atmospheric transparency indexes, with insolation lasting more than 50% of the astronomical time of solar irradiance on a given partition in a given month.

The coefficient of solar transmittance through a window (b) takes into account the type of glazing and sunshades. The heat accumulation coefficient in the partitions surrounding the room (s) is determined by the relative mass of the building. The relative mass of the building is calculated according to the relation (9):

$$g = \frac{\sum A_{ep}\cdot g_{ep} + 0.5\cdot\sum f\cdot A_{inp}\cdot g_{inp}}{\sum\left(A_{ep} + A_{inp}\right)},\ \frac{kg}{m^2} \quad (9)$$

Where:
- A_{ep} – area of external partitions (walls, ceilings, ceilings bordering the attic, floors lying on the ground), m^2,
- A_{inp} – area of internal partitions (walls and ceilings bordering other rooms), m^2,
- g_{ep} – external partition mass (walls, ceilings, ceilings bordering the attic, floors lying on the ground) related to 1 m^2 of surface area, kg/m^2,
- g_{inp} – area of internal partitions (walls and ceilings bordering other rooms) related to 1 m^2 of surface area, kg/m^2,
- f – correction factor considering the type of interior finish of the room, – .

The above small section of the methodology is exemplary. The entire methodology is thoroughly described in [24]–[26]. The results of the calculations performed on this basis are presented in the results section below.

Results

The sensible, latent, and total heat gains in the analyzed room as a function of time were counted. The results are presented for the warmest day of the analyzed period (July 28) and the entire period –

one year. Considering the daily graph, it turns out that some time profiles of sensible heat gains from different sources (e.g., gains through transparent partitions – windows for different sides of the building) in the analyzed period do not coincide exactly, as illustrated in Figure 3.

If one considers the entire year for Polish conditions, one can see the differences between the warm period and the cold period forming a characteristic profile as shown in Figure 4.

Based on the evaluation of the above profiles, it is clear that the peak gains do not overlap but eventually accumulate. A plot of the daily balance of calculated heat gains by component is shown in Figure 5. Based on this, it is revealed which of these gains is dominant and during which time.

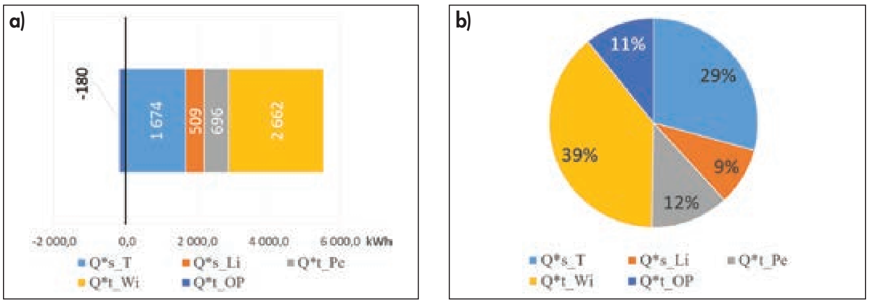


Figure 6.
a) Warm period (WP) heat gain and loss balance, b) Percentage of total heat gains for the warmest day of the year under review (July 28)
Rys. 6. a) Bilans zysków i strat ciepła okresu ciepłego (WP), b) Odsetek całkowitych zysków ciepła dla najcieplejszego dnia w badanym roku (28 lipca)

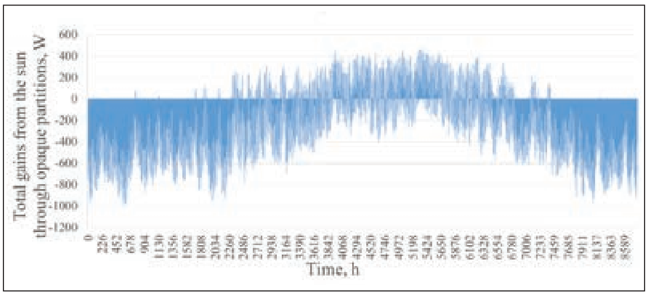


Figure 4.
Example graph of heat gain/loss through opaque partitions (exterior walls) for the entire study period (1 year)
Rys. 4. Przykładowy wykres zysków/strat ciepła przez nieprzezroczyste przegrody (ściany zewnętrzne) dla całego okresu badania (1 rok)

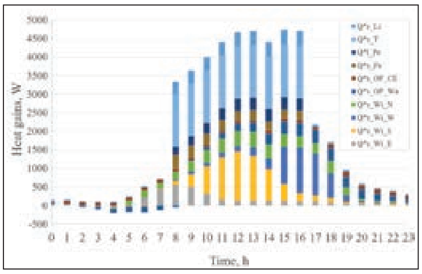


Figure 5:
Daily components of heat gains on July 28
Rys. 5. Dzienne składowe zysków ciepła z dnia 28 lipca

The main goal is to reduce the energy consumption of air conditioning by finding out if and how much we can affect these gains, and then modifying redundant energy gains, i.e. flattening the bars of the graph in the warm season. Ultimately, some guidelines will be determined to advise actions for the case of existing and newly designed buildings.

The first step to reducing the energy consumption of an air-conditioning system is to look for methods that will reduce the dominant heat gains in the first place. As a result of research and calculations, the dominant heat gains were determined, as shown in Figure 6.

The air-conditioning system is most heavily loaded during the warm period (WP). For the investigated building, the dominant heat gains during this period are heat gains from the sun through transparent partitions (2662 kWh/a) and from technology – office equipment (1674 kWh/a). The occurrence of small heat losses through the opaque partitions (-180 kWh/a) can also be observed, which occur mainly during the night, as shown in Figure 6.a. They slightly compensate the resulting heat gains in the office (5541.6 kWh/a), supporting the operation of the air conditioning system.

The analysis of the warmest day of the year (July 28) shows that opaque partitions are also a source of gains (11%), which are comparable to heat gains from people (12%) and lighting (9%). The dominant gains are from the sun through transparent partitions (39%) and from technology (29%), which accounts for 68% of the

Table 1 The real average hourly indoor and ou tdoor temperatures and computational solar irradiance values for the warmest day, with maximum values for the month of July
Tabela 1. Rzeczywiste średnio godzinowe temperatury wewnętrzne i zewnętrzne oraz obliczeniowe wartości natężenia promieniowania słonecznego dla najcieplejszego dnia, z wartościami maksymalnymi dla miesiąca lipca

Time	t_{in}	t_{out}	I_c				I_r			
h	°C	°C	E	S	W	N	E	S	W	N
			W/m²	W/m²	W/m²	W/m²	W/m²	W/m²	W/m²	W/m²
0	21.7	22.3	0	0	0	0	0	0	0	0
1	21.6	22.1	0	0	0	0	0	0	0	0
2	21.1	21.2	0	0	0	0	0	0	0	0
3	21.0	20.6	0	0	0	0	0	0	0	0
4	21.0	19.8	0	0	0	0	0	0	0	0
5	21.0	19.6	147	17	17	62	42	77	77	62
6	21.0	19.3	359	38	36	77	92	38	36	77
7	21.0	20.1	492	59	51	62	118	59	51	62
8	21.8	22.5	528	98	64	70	128	80	64	70
9	23.7	26.1	475	186	74	78	127	99	74	78
10	24.5	27.7	344	287	84	85	120	115	84	85
11	25.6	29.7	180	359	92	89	110	125	92	89
12	26.5	31.4	100	385	100	90	100	129	100	90
13	26.9	32.1	92	359	180	89	92	125	110	89
14	27.1	32.5	84	287	134	85	84	115	120	85
15	27.2	32.8	74	186	475	78	74	99	127	78
16	27.1	32.5	64	98	528	70	64	80	128	70
17	27.5	33.3	51	59	492	62	51	59	118	62
18	26.2	30.9	36	38	359	77	36	38	92	77
19	23.8	26.3	17	17	147	62	77	77	42	62
20	23.8	26.3	0	0	0	0	0	0	0	0
21	23.2	25.1	0	0	0	0	0	0	0	0
22	23.0	24.8	0	0	0	0	0	0	0	0
23	22.4	23.6	0	0	0	0	0	0	0	0
			$I_{c\ max}$				$I_{r\ max}$			
			528	385	528	90	128	129	128	90

redundant heat (Fig. 6.b). Selected climatic parameters are shown in Table 1. However, for a different building, this distribution may be different. Therefore, when optimizing an air-conditioning system, it is always necessary to perform an accurate heat and moisture balance of the optimized rooms.

Based on the prepared heat and moisture balance of the building, the cooling and heating power requirements of the air-conditioning system were determined, as shown in Figure 7:

Table 2 Minimum and optimum energy requirements for cooling and heating purposes for the office room and the threshold temperature above which the blinds were activated

Variant	Threshold temperature	Minimum cooling energy flux	Optimal cooling energy flux	Maximum heating energy flux	Optimum heating energy flux
	°C	kWh/a	kWh/a	kWh/a	kWh/a
V0	-	5002.7	5002.7	12667.9	12667.9
V1	14	4007.6	4010.9	12885.8	12853.0
V2	13	3162.2	3177.2	13243.0	12801.6
V3	20	3287,2	3360.0	13166.3	12969.5
V4	20	4339.4	4388.6	12798.5	12708.3
V5	-	4142.1	4142.1	12847.9	12847.9

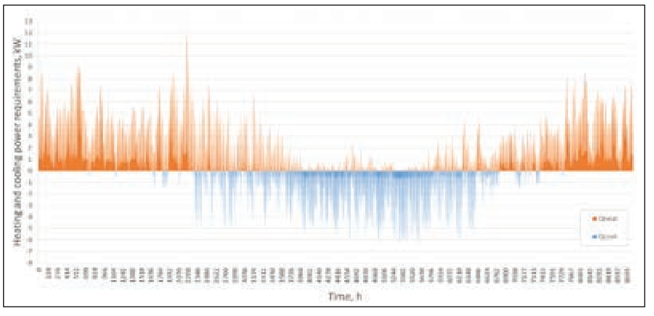


Figure 7.
Average hourly cooling and heating power requirements of the air conditioning system
Rys. 7. Średnio godzinowe zapotrzebowania na moc chłodniczą i grzewczą systemu klimatyzacyjnego

For the original configuration of the building (VARIANT 0), the maximum demand for cooling power was 6.5 kW, energy consumption for cooling was 5002.7 kWh/a. The maximum demand for heating power was 12.8 kW, and energy consumption for heating was 12667.9 kWh/a.

Since the largest percentage of the office room's heat gain came from the sun through the transparent partitions, the focus was on reducing these gains by using the following glazing and shading variants:

- VARIANT 1 – double glass with coating (metal oxide), coating on the inside of the outer glass, standard glass on the inside, and interior blinds with an opening angle of 45°.
- VARIANT 2 – standard double glass and external blind with an opening angle of 45°.
- VARIANT 3 – double glass with coating (metal oxide), coating on the inside of the outer glass, standard glass on the inside, and an external blind with an opening angle of 45°,
- VARIANT 4 – standard double glass and an interior blind with an opening angle of 45°,
- VARIANT 5 – double glass with coating (metal oxide), coating on the inside of the outer glass, standard glass on the inside.

The outdoor air temperature t_{av}^{out} was used as the parameter that influenced the use of movable solar blinds (V1, V2, V3, and V4). The threshold temperature at which the blinds were used was chosen to optimize both the energy flux required for cooling and heating purposes, as shown in Table 2. The maximum cooling and heating capacities that were required for the office building during the analysis period are shown in Table 3.

Table 3 Maximum cooling and heating capacity for an office room

Variant	Maximum cooling power	Maximum heating power
	kW	kW
V0	6.5	12.8
V1	5.3	12.8
V2	4.4	12.8
V3	4.5	12.8
V4	5.7	12.8
V5	5.5	12.8

Discussion and conclusions

Analysis of the results (Fig. 6.a) revealed, in particular, the dominant gains through transparent partitions Wi (48.0%) and from technology (T) (30.2%), which should be reduced first. Gains from people (Pe) and lighting (Li) account for 21.75% of the remaining excess heat, which should also be reduced if possible. Recorded losses in WP through opaque partitions (OP), positively affect the operation of the air conditioning system by offsetting 3.25% of the redundant heat. Analysis of the results for the warmest day of the year (Fig. 6.b) showed that on warm days OP are also a source of heat gain. This causes an additional load on the air conditioning system on these days.

Let's consider what can be done to reduce these gains and affect greater energy and economic efficiency of the air conditioning system.

Sensible gains through windows (Wi) can be reduced through the use of special coatings on glass and exterior and interior shading elements. Another way is to plant leafy trees or vines or other vegetation that drops its leaves during the winter season, shading the windows (transparent partitions). A radical solution is also to consider walling up or reducing window slots. However, such a solution for office operations may adversely affect working conditions, which will have to be compensated by artificial light.

The paper shows how gains through windows are affected by the configuration of glazing and additional solar control devices. The greatest reduction in heat gains through the windows (32.8-36.5%) was achieved with external movable shades, regardless of special glass coating. The use of a special glass coating, regardless of cooperation with internal solar shades, induces a heat gain reduction through the windows by 17.2-19.9%. The lowest reduction in gains through windows is provided by internal solar shades in combination with uncoated glazing (13.3%).

Under Polish conditions, it is good practice to select the design and material solutions in such a way as to allow solar heat gains during periods of heating demand. At the same time, it should allow protection against overheating of building interiors during summer. Selective coating reduces solar energy yield during summer, but unfortunately reduces it during winter and transitional periods when heat gains are desired. Therefore it is better to use movable sunshades because they do not reduce the solar radiation input to the glazing in winter, although they reduce it in summer, especially if they are installed outdoors. Proper selection of the window parameters interacting with the building's equipment will ensure that overheating of the building in the summer will not occur, while the yield of thermal energy from solar radiation in winter will contribute to improving the energy balance of the building.

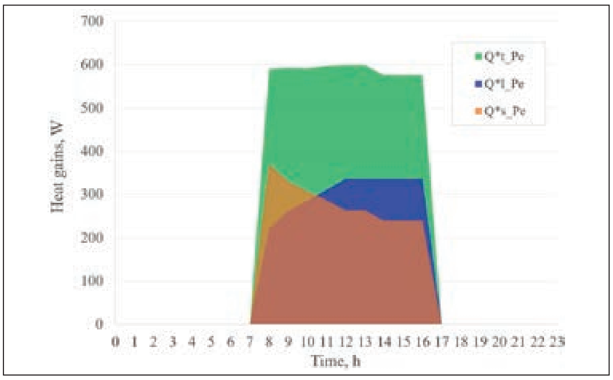


Figure 8.
Sensible, latent and total heat gains from people for the warmest day (July 28)
Rys. 8. Zyski ciepła jawnego, utajonego i całkowitego od ludzi dla najcieplejszego dnia (28 Lipca)

The production of domestic hot water in the warm period (WP) is an example of the possibility of using redundant heat gains for this purpose. In such a solution, the heat source is an air-to-water heat pump (HP). Connecting it to the ventilation system, it can use the hot air, drawn in from overheated rooms, to heat water. The HP will result in a cooled air stream (it can even be partially dehumidified), which can be recirculated into the room. In this way, the air conditioning system is decompressed.

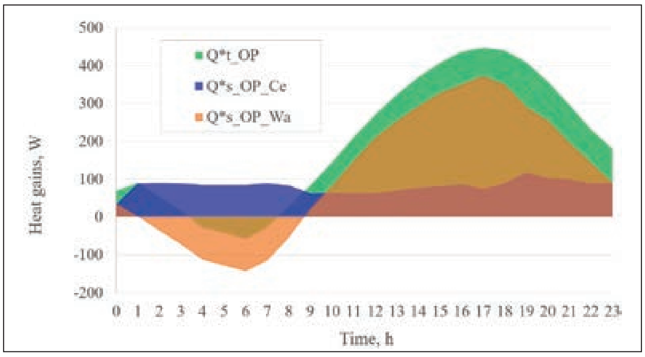
Sensible gains from technology from office equipment T can be reduced by using more energy-efficient equipment. It is also possible to optimize their usage time by eliminating standby periods.

Total gains (sensible plus latent) from people (Pe) are mainly due to human physical activity in principle, during office work, they cannot be significantly reduced, but it has been noted that there is a temporary substitution of sensible gain for a latent gain during a certain period of activity as shown in Figure 8. This can be exploited by replacing the air with drier air, turning off the air conditioning system during this time, and recovering the cold through recuperation. Condensing moisture from the air is a more energy-intensive process than cooling dry air.

Sensible gains from incandescent lighting (Li) can be significantly reduced by using fluorescent or LED lighting. However, it is necessary here to pay attention to the human factor in the form of various hypersensitivities. Incandescent light still most closely resembles natural sunlight in its spectrum. Conventional fluorescent lighting, on the other hand, can reduce productivity, negatively affect mood, increase mental and physical fatigue, and even reduce alertness. Light emitted from LED sources can cause similar problems. Its spectrum consists of separate bands (corresponding to amber, red, green, or blue), which are then converted into white light. The more white the light, the more blue wavelengths are included. Intense exposure to blue light, on the other hand, can lead to eye damage, natural sleep disorders, can contribute to migraine attacks, headaches, eye fatigue, and other symptoms. Both fluorescent and LED lighting exhibit rapid flickering. Therefore, in some cases, replacing incandescent lighting with more energy-efficient and lower heat gain emitting light sources may be troublesome [27]. This type of situation occurred in the presented case.

Sensible gains through opaque partitions (OP) account for a negligible share WP, while it has been noted that heavy building materials cause walls to take away some of the heat gains through accumulation, during higher room temperatures, and give back the accumulated heat during periods when the internal temperature drops, as shown in Figure 9.

Figure 9: Sensible heat gains through the walls, and ceiling and the sum of these gains for the warmest day (July 28)
Rys. 9. Jawne zyski ciepła przez ściany i strop oraz suma tych zysków dla najcieplejszego dnia (28 Lipca)



However, in cases where OP gains component is significant, the exterior walls and roof can be insulated and an appropriate color scheme can be used (for example white best reflects solar radiation). In Polish conditions, though, the exterior color of the building should preferably change from bright at high outdoor temperatures to dark at low outdoor temperatures to make the most of environmental conditions. For this purpose, thermochromic coatings for buildings can be used [28].

There is another aspect of this issue like retrofitting old buildings or designing new buildings to reduce air conditioning energy consumption by modifying redundant energy gains.

This stage should be carried out jointly by the architect and the installation designer. They can use the heat gain model to prepare a preliminary concept for the operation of the systems along with an analysis of their technical capabilities. The selection criteria in the first place will be to ensure high parameters of climatic comfort and minimize primary energy consumption including the air conditioning system. On this basis, the following can be proposed: building orientation and configuration (layout, walls, windows, curtains, climate, equipment) that best meet the above criteria.

It can be concluded here that there are many factors during AC operation, but the most noteworthy may be the effect of overall building optimization on heat gains generated in the building at the design stage, which will be the subject of further research. In this way, a solution matrix can be created, from which the most favorable optimization solutions best suited to the individual conditions of the building or its location will be selected.

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