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Impact of external conditions on energy consumption in industrial halls

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Abstract. The energy demand for heating the halls buildings is high. The impact on this may have the technology of production, building construction and technology requirements (HVAC systems). The isolation of the external partitions, the location of the object in relation to the surrounding buildings and the degree of the interior insolation (windows and skylights) are important in the context of energy consumption. The article discusses the impact of external conditions, wind and sunlight on energy demand in the industrial hall. The building model was prepared in IDA ICE 4.0 simulation software. Model validation was done based on measurements taken in the analyzed building.

1 Introduction

Understanding heat transfer and the temperature distribution through building materials is important for assessing energy use. The heat transfer coefficient is the first and the most considered factor for determining the energy consumption in a building. The value of the heat transfer coefficient must not be greater than the maximum values in Regulation [1]. The thermal insulation requirements apply to the buildings being designed or renovated.

Wind is one of those parameters that characterize the meteorological conditions and which can influence the heat demand variation in the room. This parameter generates a difference in pressure inside and outside the building and thus infiltrates the cold air. The influence of wind depends on the tightness of the partitions (especially windows size), the size of the building and its location (detached, serial, etc). Solar radiation is an additional, noticeable but very variable source of heat and is increasingly important, especially in low-energy construction. Knowledge of the solar energy on a building envelop is crucial for good architecture and energy concept of the building [2]

The analyzed building was built in 2005 and met the requirements of thermal insulation for buildings during this period. Production hall is located in Wroclaw in built-up areas. Due to its production of electrical and electronic components it is an example of a modern light industry hall. It is a one-storey building without cellar, with a height of 7.7 m and a production area of 790 m^2 with additional office and social space. The analyzed hall is a continuation of the existing facility, both in terms of dimensions (height and width) and

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external finishing standards. It has two exterior walls (exposed on north and west) and 12 skylights on the roof.

The article below analyzes the effect of wind and solar gain on an existing building.

2 Building model

As part of the research, the hall's energy model was developed in IDA ICE 4.0. It is an application not only for energy consumption analysis in the building but also for thermal comfort analysis.

IDA ICE 4.0 can be applied to most types of buildings for calculations [3]:

- heat balance (dynamic heat balance in many zones); taking into account heat gains from: insolation, people, appliances, lighting, ventilation, heating and cooling, leaks, thermal bridges and indoor objects such as furniture, office equipment – computers, printers;
- sunlight through transparent seams, with full regard for local shadows, as well as surrounding buildings and other objects;
- air and surface temperatures;
- temperature range, near hot or cold surfaces, taking into account the radiation between surfaces;
- definition of comfort factors: PPD and PMV;
- daylight intensity in rooms;
- moisture and CO_2 concentrations which can be used to control the VAV system;
- vertical air temperature gradient;
- leaks through holes through a fully integrated model air flow (allows examination, e.g. temporary open window or door between rooms);
- airflow, temperature, humidity, pressure and CO_2;
- power and temperature levels of primary and secondary system components;
- Total cost of energy consumption as well as detailed energy bills;
- reports.

Equation based modelling, using the Modelica-like Neutral Model Format (NMF), makes it straight-forward to quickly expand the software with new modelling capabilities. The newly created component models can also easily be shared with other IDA ICE users. Below is an example equation used to determine local wind speed based on wind speed:

$$WindVel = a0\_coeffWindVel_{\mathrm{Ref}}\left(\frac{Height}{Height_{\mathrm{Ref}}}\right)^{a\_\mathrm{exp}} \tag{1}$$

where:
Height – height of the building [m]
Heightref – the reference height (usually 10 m), [m]
a0_coeff – the wind profile coefficient, [-]
a_exp – an exponent of the wind profile, [-]

The wind direction and speed are transmitted through the "climate model" and "Face model".

Computer simulations give the opportunity to model and analyze energy consumption, estimate energy savings resulting from design changes and applied energy saving algorithms. Energy consumption modeling can detect irregularities in the operation of individual installations. It allows estimate performance factors and HVAC systems and assess the reduction in energy consumption in a building. The following analysis uses IDA

ICE 4.0 software to analyze the impact of building location on energy consumption. All information necessary to determine boundary conditions for the model has been collected and verified. Technical documents as well as their own measurements were used for this purpose.

Construction and parameterization of the model took place in several stages:

1. Reflecting the geometry of the building, including the design of walls, ceilings, windows, shutters, doors and skylights.
2. Parameterization of building components and their thermal properties.
3. Division of rooms into zones and definition of comfort conditions.
4. Define for each zone the heat gains from lighting, appliances and people and work schedules.
5. Identify external conditions such as climate, location, location to the world, and elements shading the building.
6. Build a model of indoor installation, including ventilation unit and define the operating conditions of the equipment.
7. Model validation based on measured data.

Validation of the constructed model was performed by comparing the results of the simulation with the measured data. In order to match the energy model of the production hall to the real object 38 validation tests were performed to correct the following parameters:

- internal gains,
- times the air exchange,
- work schedules of people,
- conditions for the end of the heating season.

As the criterion of correctness, the compatibility of variation was adopted:

- annual electricity consumption [kWh],
- annual heat consumption [kWh],
- air temperature in the hall in a weekly cycle,
- CO_2 concentration in the hall in a weekly cycle.

The results of simulation with measurements in a real object are presented below. The difference between the electricity consumption for the ventilation unit is only 993 kWh, which is 2.21%. The difference between the heat demand is 5985 kWh, which is only 5.1%.

Table 1. Comparison of simulation results with measurements.

Energy	IDA ICE	Real building
Electrical power of the ventilation unit [kWh]	44913	43920
Heat demand [kWh]	117348	123333

3 Energy simulations

3.1 Wind effect

A simulation of the location impact on annual energy consumption was performed for the production hall. For this purpose, equation number 1 was used to calculate the height of the building (7m), the reference height (10m) and the wind profile coefficient (a_0coeffi) and the wind profile exponent (a_exp). After conversion, the values shown in Table 2 were obtained.

Table 2. Heat demand for different locations of the object.

Locations	$a\_0coeffi$	a_exp	$\left(\frac{Height}{Height_{Ref}}\right)^{a\_exp}$	$a\_0coeffi\left(\frac{Height}{Height_{Ref}}\right)^{a\_exp}$	**Heat demand [kWh]**
Ocean	1.3	0.1	0.9650	1.25	118173
Airport	1	0.15	0.9479	0.95	117348
Open area	0.85	0.2	0.9311	0.79	116829
Suburban area	0.67	0.25	0.9147	0.61	115855
City center	0.47	0.35	0.8826	0.41	115047

The heat demand for building heating obtained from the simulations taking into account the location of the building and the wind speed defined in the program are shown in Figure 1. It is evident that there is an increase in heat demand for heating as the wind speed increases due to the change in the location of the constructed model. By comparing the two most extreme locations: the city center (the total wind speed factor A = 0.41) and the ocean shore (factor A = 1.25) the difference in the heat demand for the hall heating is only 2.6%.

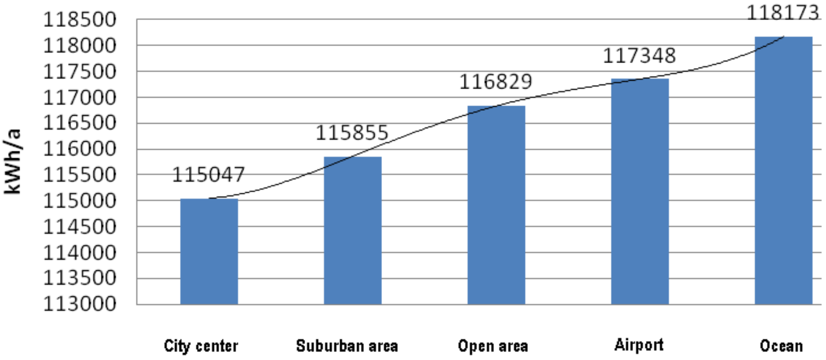

Fig. 1. Energy for heating depending on the wind speed.

In the next step, hall location (suburban zone)was analyzed. An analysis was conducted examining how the lack of wind throughout the year would affect on the hall heat consumption [4]. The results from the simulations showed that in the absence of wind, the heat consumption would change only by 1.45%. Analysis of the results showed that the influence of wind on the location of the production hall depending on the world`s side and urban development is low.

3.2 Sunlight

Solar radiation is an additional, noticeable but very variable source of heat. This parameter is increasingly important, especially in low-energy construction. This applies to direct sunlight, incident on any plane and to radiation scattered on air molecules. In the winter, the dispersed component is usually larger than direct and can account for 60–70% of total radiation [5]. However, the direct sunlight is characterized by a direct radiation component.

As part of the simulation research, the impact of solar radiation on the hall energy consumption was analyzed. The simulations show that due to the specific distribution of the windows, only on the northern wall and only 12 roof skylights, the effect of solar radiation

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in the winter on the lighting of the production hall is small. During the winter there is practically no direct radiation to the room through the transparent partitions. This is very clearly visible in Figure 2. It is clear that in the southern hours in January direct radiation entering the hall through roof skylights passes through the north-east walls without ever falling to the center of the hall. Hence, it was proposed that reducing the amount of electricity used to light the hall during autumn and winter, by using the building automation controlling the lighting intensity in the hall depending on the hall zone is practically impossible.

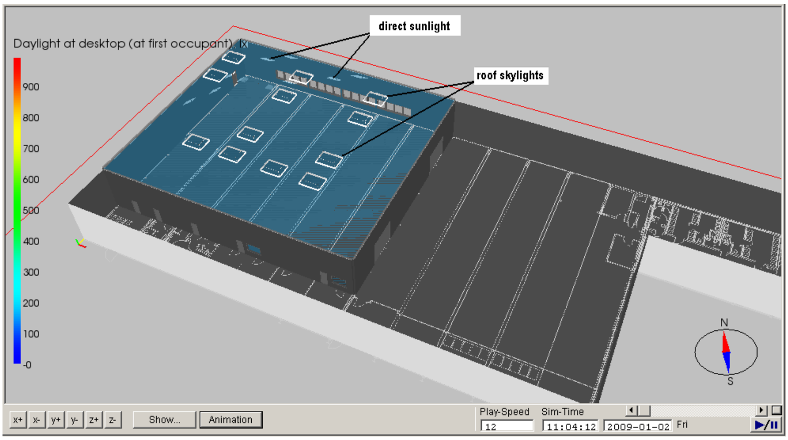

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Fig. 2. Influence of solar radiation on the lighting during the winter.

Below in Figure 3 we can see how the sun's position is related to the hall changed with the change of season. At 11:30 in the first days of April and the southern hours of July, direct radiation reaches the hall directly through 12 skylights.

The variability of heat gain from sunlight considering direct radiation and absorbed on the surface of the windows was considered. The monthly variability of heat gains from solar radiation is shown in Table 3 and Figure 4.

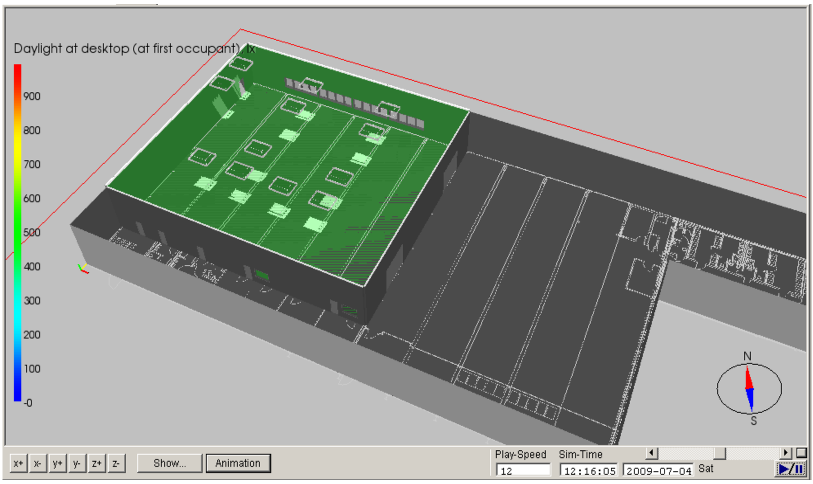

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Fig. 3 Influence of solar radiation on the lighting during the summer.

Table 3. Heat loss through structural components.

	Without sunlight			With sunlight		
	walls and floors, [W]	**direct radiation, [W]**	**windows + radiation absorbed, [W]**	**walls and floors, [W]**	**direct radiation, [W]**	**windows + radiation absorbed, [W]**
January	-16246.3	-11.8	-4547.3	-16031.1	685.5	-4224.2
February	-16219.6	-11.7	-4599.6	-15978.8	977.1	-4158.8
March	-15593.2	-11.5	-3963.3	-15412.2	1788.4	-3187.1
April	-14445.4	-11.9	-2928.8	-14078	2680.1	-1805.7
May	-13014.6	-11.3	-2028.5	-12478	3636.8	-514.1
June	-12671.9	-11.9	-1226.4	-12286.5	3780.3	274.4
July	-12834	-12	-1464.9	-12216.1	3752.1	-6.5
August	-12082.2	-11.3	-1124.8	-11640.7	3239.9	184.1
September	-13146.2	-11.9	-1942.7	-12789.6	2210.4	-982.5
October	-14084.9	-11.8	-2804.9	-13820.9	1354.3	-2204.7
November	-15220.5	-11.4	-3776.5	-15193.8	740.7	-3454.9
December	-16341	-12	-4694.9	-16188	630.2	-4406.7
Sum	**-171900**	**-140.5**	**-35102.6**	**-168114**	**25475.8**	**-24486.7**
Annual average value	-14314.2	-11.7	-2916.3	-13997.7	2129.8	-2029.0

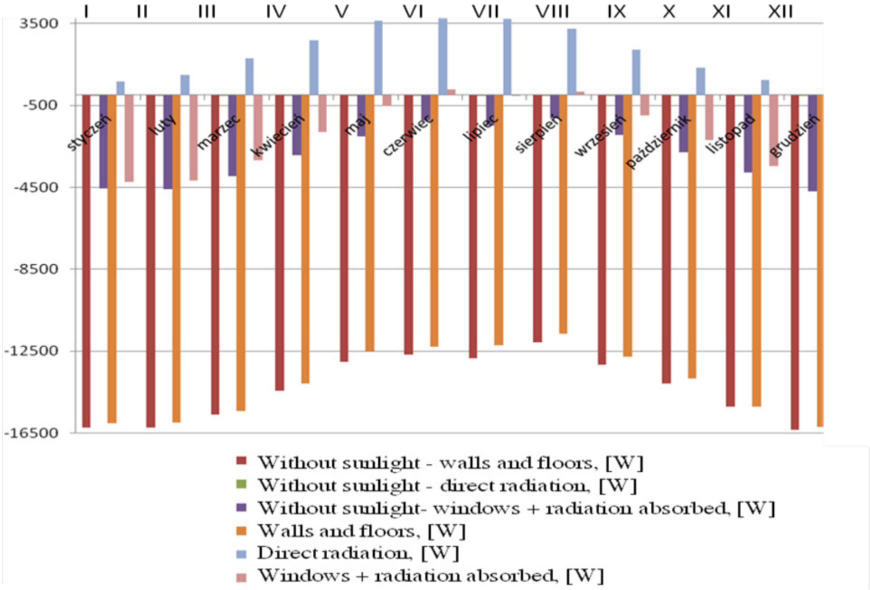

Fig. 4. Monthly variation of heat gains by buildings structure.

Looking at presented variation of heat loss by the structural components it can be considered that the effect of sunlight on the energy consumption is significant. However, the analysis of total heat consumption in the hall showed that when we take into account the heat gains from sunlight in the total annual heat demand for amount of 117616 kWh and in the absence of solar radiation of 113223 kWh in the case of the production hall we will observe only 3.7% increase in heat consumption to heat it.

4 Conclusions

The most popular source of energy is sunlight. This is due to the widest access to energy in such form and the large potential for its use in the form of direct benefits to heating. Unfortunately, high levels of solar radiation do not coincide with the heating period of the building. This requires the designer to refer to solar energy for three distinct strategies: heating, cooling and daylight. The building's enclosure should have high thermal insulation to separate the interior of the building from changing outdoor conditions and consequently to significantly reduce the losses and heat gains of these walls. Additionally, the orientation of the building and its shape, (A/V), can significantly reduce its heat demand.

Looking at the building as a whole the main façade of the production hall is on the south side. In this part offices are located. The production part is on the north side and have limited number of window openings (no direct solar radiation).

Energy simulations have shown that this is the most optimal shape of a building and locations that could be designed for production. The analysis of total heat consumption in the hall showed that when we take into account the heat gains from sunlight in the total annual heat demand for amount of 117616 kWh and in the absence of solar radiation of 113223 kWh in the case of the production hall we will observe only 3.7% increase in heat consumption to heat it. In the absence of wind, the heat consumption would only change by 1.45%. Analysis of the results showed that the influence of wind on the location of the production hall depending on the world`s side and urban development is low.

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