Analysis of annual energy consumption by a warehouse building

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Abstract. This analysis was carried out to present the distribution of energy demand for air heating, air cooling and technology equipment for a warehouse through the year. The supplied energy is used to maintain the assumed temperatures in the rooms and for the needs of technology. During the work, the calculation model of the building was prepared and imported into the calculation program. The simulation was based on the planned building parameters (partitions structure, dimensions, technology) taken from the architectural executive design. Several versions of the structure of the construction and technical equipment have been analyzed. The obtained results show differences in the formation of energy demand and indoor room conditions.

1 Introduction

This article presents the results of calculations of the possibility of obtaining the „zero energy” effect by an exemplary warehouse building. This effect will be obtained using innovative technical and construction solutions limiting the energy demand of building. By increasing the use of elements that acquire renewable energy, it will be possible to achieve the „plusenergetic” conditions of the building [1, 6, 9, 10]. The analysis was based on:

1. Execution of heat and cool balance and electricity consumed by the building.
2. Analysis of heat and cooling demand of the building based on several versions of the proportions, dimensions, different orientations in relation to the sides of the world and different constructions of partitions
3. Determination of energy demand for the technology purposes.
4. Calculation of the possibility of obtaining of renewable energy from the additional devices supporting the building energy efficiency.

2 Assumptions analysis

The analyzed warehouse building is a free-standing object consisting of two parts, one of which is a low part with a height of 10 m, while the other is a high part with a height of 24 m. The width of the high part about 36 m, the low part about 16 m, the total length of the

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building about 155 m. In the lower part inside air temperature is 20–28°C, in higher part the inside air temperature 5–28°C.

In simplest version, ventilation was based on natural ventilation. In version with the mechanical ventilation air flow was determined based on the number of air change rates, which was assumed as 25% of the total building volume. The air flow is therefore 26500 m³/h. The supply air to the lower part can be taken directly from the outside (and can be further treated in AHU) or it can be previously passed through the ground heat exchanger (and pre-treated can be directed to the AHU). According to the assumptions, pre-treated air is supplied to the lower part by the ventilation system. Depending on the period, the air is either removed directly outside (summer periods) or is further directed to the higher part (winter, autumn and spring periods). It is also planned to use in the lower part additional air-conditioning systems. For the higher part a separate ventilation system is planned. In summer periods, when the entire air stream from the lower part is removed directly to the outside, a total air stream is prepared and treated in the AHU – 26500 m³/h. In other periods (winter, autumn, spring), when the air stream from the lower part is directed to the higher part, in the AHU for the higher part, the difference between the supply and exhaust air stream 15000 m³/h, is prepared and treated - the exhaust air stream remains constant 26500 m³/h. In addition, for the higher part, additional devices are envisaged, such as air conditioning units and destratificators, whose task will be to shed warmer air from the space under the roof to lower zones (due to rising and accumulating masses at elevated temperature) and leveling the air temperature.

![Fig. 1. 3D building model with division into computing zones.](image1)

![Fig. 2. The initial building model with the orientation towards the sides of the world.](image2)

The influence of temperature of stored products on indoor air temperature was not taken into account. In assumptions, it was not much different from the internal air temperature.
However, in fact, the additional mass would better stabilize the internal conditions.

For the purposes of model analysis, the building was divided into 2 m wide horizontal zone. The lower part of building consisted of 5 zones, the higher consisted of 12 zones. The calculations take into account the building accumulation and possibility of energy transfer between the zones.

For the analysis, the following assumptions were made:
- work on three shifts – according to the information from the Investor, 30 working people at the same time,
- heat gains from people were taken at 100 W/person,
- according to the information from the Investor, the installed electrical power 70 kW in the lower part and 100 kW in the higher part (80% coefficient of simultaneity).
- 40% of heat gains from installed electric power, 90% heat gains from lighting,
- for the higher part no heat gains from lighting installed, no heat gains from the people,
- for the lower part 30% of heat gains from installed electric power and lighting, 70% heat gains from technology and heat gains from 30 people,
- all internal heat gains were determined based on the area of calculation zones,

Examples of the Variants of the developed building simulation models:
1. **The output model No.1** – partitions very good thermal-insulated, heat transfer coefficient $U = 0.1 \text{ W/m}^2\text{K}$. In all computational areas natural ventilation.
2. **The output model No.2** – partitions very good thermal-insulated, heat transfer coefficient $U = 0.1 \text{ W/m}^2\text{K}$. Mechanical ventilation system (supply-exhaust) with ground heat exchanger – air supply to the lower part, exhaust from the higher part.
3. **The output model No.3** – partitions very good thermal-insulated, heat transfer coefficient $U = 0.1 \text{ W/m}^2\text{K}$. Mechanical ventilation system (supply-exhaust) with heat recovery from the higher part – air supply to the lower part, exhaust from the higher part. High efficiency ground heat exchangers. Extended air supply-exhaust system in the lower and higher parts.

### 3 Results of calculation and analysis

The results of simulation model of the analyzed building, are presented below. The simulation was carried out on the actual parameters of the building (transparent, opaque walls, geometry) and was taken from the architectural executive design.

The table presents a comparison of heat gains depending on the position relative to the world sides. The building is heated using internal heat gains (technology, lighting). By turning the building towards the world sides, a slight impact of the energy demand was observed.

The numbers on the horizontal axis represent the day of the year and the time of the day (e.g. January 1 to January 1, 01:00). The series numbers indicate the horizontal zone number measured from the bottom of the room. The zones have a thickness of 2 m. The line without markers in the diagrams indicates the outside air temperature values.

On the figures below some results are shown for the days with minimum and maximum outside temperature (16th of February and 7th of June).
| Building insulated | Non-insulated building | Difference |
|---------------------|------------------------|------------|
| Higher part rectangular, Gates east orientated | Higher part rectangular, Gates north orientated | Higher part rectangular, Gates west orientated |
| Higher part square, Gates east orientated | Higher part square, Gates north orientated | Upper zones square, Gates west orientated |
| Higher part square, Gates south orientated |
| W | W | W | W | W | W | % |
| 57451 | 73411 | **130862** | 80960 | 90662 | **171622** | 23.75 |
| 58571 | 70996 | **129567** | 81844 | 86035 | **167879** | 22.82 |
| 59730 | 71144 | **130874** | 83719 | 86319 | **170038** | 23.03 |
| 59902 | 72225 | **132127** | 84047 | 88732 | **172779** | 23.53 |
| 56524 | 85267 | **141791** | 77669 | 101284 | **178953** | 20.77 |
| 56667 | 84277 | **140944** | 78195 | 99387 | **177582** | 20.63 |
| 56095 | 84219 | **140314** | 76750 | 99276 | **176026** | 20.29 |
| 55280 | 85796 | **141076** | 77174 | 102299 | **179473** | 21.39 |

Fig. 3. Heat demand in the higher part – 16th of February – the output model No. 1.
Using mechanical ventilation and ground heat exchangers, there is a need to reheat the lower zones (it is calculated). The upper zones (roofs) also require a slight heating [3, 5, 8].

Internal heat gains allow to maintain the assumed minimum temperature without heating up.

In this system it is planned to supply air into the lower zones above the floor and exhaust from the upper zones. In the winter period the exhaust air will be transferred to the lower zones. Additionally, the air will be supplied into the warehouse by the AHU with the
use of ground heat exchangers [4]. The amount of heat supplied is sufficient that, with the participation of internal heat gains, there is no need to heat up the warehouse [1, 7].

**Fig. 7.** Heat demand in the upper zones – 16th of February – the output model No. 3.

The building required only to heat the lower part in the winter season. Heat gains from operating indoor devices and lighting in the lower part were taken into account in the calculations. An additional element limiting the heating demand of the higher part is the difference in maintained air temperatures in the rooms in both parts. In the higher part higher temperatures were obtained than the lowest acceptable for the room.

In addition can be shown how the inside temperatures were shaped in model No. 3 in winter and in the summer. Interesting is that in winter in higher part of the building the higher temperatures were got than the lowest admissible for this space without additional heating energy.

With a more extensive microclimate shaping system, more room temperature stability was obtained in the rooms.

**Fig. 8.** Heat demand in the lower part – 16th of February – the output model No. 3.
Fig. 9. Air temperatures in lower part – 16th of February.

Fig. 10. Air temperatures in higher part – 16th of February.

For the summer period, due to good insulation, the operation of ground heat exchangers and building accumulation, there is also no need to sub-cool the rooms [4, 7].

Fig. 11. Air temperatures in lower zones – 7th of June.
4 Conclusions

The obtained results of the building energy demand allow to optimally match the thermal and cooling capacities of the designed devices [2, 7]. There is also the possibility to determine the required sizes of systems obtaining renewable energy and ensuring the zero-energy effect of the building [8].

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