Energy savings of large buildings

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Abstract: *The aim of this paper is to present the possibilities and methods useful for energy savings in ventilation and heating of large buildings typical for industrial and agricultural application. The main principles focused on the energy saving methods are completed by examples from the practical applications and measurements in real conditions of existing buildings and calculations based on the theoretical background. The results are generalized in the conclusions useful for applications in different large capacity buildings in agriculture and industry.*

Key Words: *Agriculture; air-conditioning; heating; industry; ventilation.*

INTRODUCTION

Large buildings are typical for industrial and agricultural applications as well as open-plan shopping, cultural and social centres, exhibition centres, sports centres, logistics centres, warehouses etc. An important operational factor of these buildings is in many cases economic effectiveness of the final product, which is in those buildings manufactured or stored. Significant impact on the value of the final product has also energy input, which primarily includes cost needed for creation and control of optimum indoor environment, mainly for ventilation, heating or air conditioning.

There are important principles and technical solutions for energy savings in these large area buildings. Some principles can be applied already during the construction of new buildings, or there are suitable for modernization and reconstruction of buildings. This article lists some main principles focused on the energy saving methods, completed by experience and examples from the practical applications and measurements in real conditions of existing buildings mainly in agriculture and industry.

At the analysis of these problems is necessary to focus on two basic extreme conditions during the year, i.e. the coldest winter (energy needs for heating) and warmest summer (energy needs for cooling). For these periods, it is advisable to think about possibilities for energy savings. Some basic principles and methods that can be used in solving these problems for application in winter and summer seasons are described in following sections of this article.

HEAT LOSSES AND REDUCTION OF ENERGY FOR HEATING

Geometric and architectonic layout of the building

Calculation of heat losses by transfer through surrounding constructions needs first to calculate the basic heat loss Q_0, which is usually increased by multiplication of several special coefficients (according to the position, properties, purpose and use of building etc.).

$$Q_0 = \Sigma U_j . A_j . (\theta_i - \theta_e), \quad (1)$$

where Q_0 is basic heat loss (W);

U_j - overall heat transfer coefficient of j-th wall ($W.m^{-2}.K^{-1}$);

A_j - cooled surface of j-th wall (m^2);

θ_i - design temperature of the interior air (°C);

θ_e - design temperature of outside air (°C).

The aim in search of a suitable shape-plan building is to maximize the volume of the building and minimize areas of surroundings structures, which reduces the cost of construction while minimizing surface of cooled constructions.

An example can be a rectangular building with plane dimensions of 250 x 100 m, which has a ground area of 25,000 m^2 and the length of perimeter 700 m. The hall height is 10 m, the area of cladding is 7,000 m^2. Building which has the same ground area 25,000 m^2 but has the layout L-shaped with a length of outer side wall 150 m and 400 m, a width of 50 m has the length of the perimeter 1,100 m, which is longer by 400 m. In the same height of the hall 10 m, the area of cladding is 11,000 m^2, which increase the cooled area of the walls by 57%.

Dividing of a large building from the previous example into several separate pavilions e.g. four separate buildings 50 x 125 m with ground plan area of 6,250 m^2 also leads to an increase in perimeter of 700 m to 1,050 m which is longer by 50%, and increase cooled claddings by 50% from 7,000 m^2 to 10,500 m^2.

As the buildings for these purposes are usually single-storey there will be not studied further the issue of multi-storey buildings, although we have experience with multi-storey buildings also for livestock (e.g. three-storey building for laying hens, or a six-storey building for rearing calves, etc.). These buildings were functional. In terms of heat loss was winter heat balance better than ground floor buildings, but due to the fact that these buildings caused many technological problems, the positive effects and results expected from the compactness of these buildings were not achieved.

Optimizing the thermal state of the indoor environment

Thermal state of the indoor environment should conform to the requirements of workers [2] or technological needs. In some cases it is possible to detect inefficient overheating of buildings (especially industrial), when the inside temperature θ_i significantly exceeds the appropriate temperature according to the workload (metabolism workers) of 3-7 K; this will greatly increase the need for heating energy according to the equation 1.

Enterprises in many cases did not pay sufficient attention to those issues, because the increased costs of energy transferred to the higher prices paid by the customer. Based on measurements and research companies have gradually become aware of these problems and regulate the intensity of ventilation and heating according to actual needs.

Improvement of thermal properties of buildings

Improvement of thermal properties of buildings is currently the most common form of improvement of the winter heat balance. The aim is to improve the overall heat transfer coefficient U (this is achieved by reduction of coefficient of thermal conductivity and/or by increased thickness of the walls).

$$U = \frac{1}{\frac{1}{h_i} + \sum_{1}^{n} \frac{t_j}{k_j} + \frac{1}{h_e}} \quad , \qquad (2)$$

where U is overall heat transfer coefficient ($W.m^{-2}.K^{-1}$);

h_i - heat transfer coefficient on the inside of the wall ($W.m^{-2}.K^{-1}$);

t_j - thickness of the j-th layer in the wall (m);

k_j - coefficient of thermal conductivity of the j-th layer in the wall ($W.m^{-1}.K^{-1}$);

h_e - heat transfer coefficient on the external side of the wall ($W.m^{-2}.K^{-1}$).

Improvement of thermal properties of buildings is a long-term investment whose return depends on local climatic conditions and costs of materials and energy [6, 7,14].

From the construction point of view it is particularly suitable outer insulation of buildings. There can be used a variety of insulating materials. Several most common of them are listed in the Table 1.

In some cases, sources of great heat losses are roof windows and skylights for natural lighting of buildings. A suitable solution can be achieved by reduction of these losses, and important is also reduction excessive heat gains in the summer.

Table 1

Coefficients of thermal conductivity and prices of selected thermal insulation [14]

Material (thickness 0,1 m)	Coefficient of thermal conductivity λ, $W.m^{-1}.K^{-1}$	Average price VAT inc., $CZK.m^{-2}$
Polystyrene EPS	0,037	127,40
Blown mineral. insulation	0,039	247,30
Contact mineral boards	0,036	270,30
PUR, Sprayed polyurethane foam	0,026	342,00

Use of heat recovery systems

There are rather big heat losses by ventilation according to the equation (3) in some buildings during the winter:

$$Q_V = c_V.V_V.(\ \theta_i - \theta_e\ )\ , \tag{3}$$

where Q_v is heat losses by ventilation (W);

c_v - volumetric heat capacity of air ($J.m^{-3}.K^{-1}$);

V_v - volume flow of ventilation air ($m^3.s^{-1}$).

A great saving of energy can be achieved by the use of heat recovery. According to the type of building and internal environment and especially the purity of the exhaust air, heat recuperation or heat regeneration from exhaust air can be used in ventilation or air-conditioning [3, 4, 5, 9]. The efficiency of heat recovery from exhaust air can be expressed by the equation (4).

$$\eta RQ = \frac{V_e.(\ t_e{}' - t_e\ )}{V_i.(\ t_i - t_e\ )} 100\ , \tag{4}$$

where η_{RQ} is efficiency of the heat recovery from exhaust air (%);

V_e - airflow of incoming air into the building ($m^3.s^{-1}$);

V_i - airflow of outgoing air from the building ($m^3.s^{-1}$);

t_e - temperature of incoming air (°C);

t_e' - temperature of incoming air after the heat exchanger (°C);

t_i - temperature of outgoing air (°C).

The measurement results show that a large influence on the efficiency of heat recovery has purity of filters which prevent clogging of heat transfer surfaces of recuperators or regenerators by dust [5]. E.g. the efficiency of heat recuperation in industrial application with polluted filters was η_{RQ} = 17.6% and later with new filters η_{RQ} = 50.2%.

Air-conditioning with a broken driving of regenerator in the lecture room resulted in a lower efficiency of heat regeneration η_{RQ} = 34.1%. The efficiency of heat regeneration of well-functioning regenerator was about η_{RQ} = 78%, and it was only slightly Influenced by the dust pollution of filters. In some cases, simple and cheap construction of the regenerative heat exchanger is an advantageous for agriculture even at low efficiency, due to its low cost and maintenance-free operation [5, 9].

Use of non-conventional energy sources

To reduce the costs for heating may be also helpful to use the appropriate energy sources [11]. Big roles in selecting a suitable fuel also play price policy, subsidies and other market-based mechanisms. As an example, can be comparing traditional and alternative sources of energy in the Czech Republic that is continually changing over the years, but some figures are surprising. Approximate prices of the heat in $CZK.kWh^{-1}$ of selected types of fuel are in accordance with [13] given in the Table 2.

Table 2

Approximate price of the heat in the $CZK.kWh^{-1}$ [13]

Fuel	Heating value, $MJ.kg^{-1}$	Heat price, $CZK.kWh^{-1}$
Brown coal	18	1.29
Black coal	23.1	1.45
Wood	14.6	0.99
Wood pellets	17	1.3
Wood briquettes	17	1.36
Cereal grains	18	0.75
Natural gas	---	1.72
Propane	46.4	2.44
Light fuel oil	42	2.7
Electric heaters	---	2.54
Electricity accumulation	---	2.22
Heat pump	---	0.97
Central supply of heat	---	1.47

Increasing the efficiency and operational optimization of heating equipment

The efficiency of boilers, heating systems and radiators for heating increased in recent year. Replacing old boilers for new ones is supported by the state subsidy policy. The use of regulation and control models can help to reduce the costs for heating.

Large open-plan buildings usually have great height, so for them, in many cases (industry, garages, warehouses, etc.), is suitable ceiling radiant heating [17]. This method of heating ensures favourable microclimatic conditions and reduces the consumption of heating energy.

For intensive ventilation of large-scale buildings typical in agriculture (poultry or pig houses, etc.) it is better to install axial fans with large diameter, which supply a big flow of air and have low specific energy consumption than larger number of small fans, which usually have higher specific energy consumption.

HEAT GAINS AND REDUCTION OF ENERGY FOR COOLING

Passive systems of air-conditioning

Heat gains include all external and internal heat flows entering in the inner space. Internal heat gains are usually difficult to reduce. To improve the situation can the use of technological equipment and techniques with minimal power consumption, energy-saving lighting, etc.

Heat gains from the external environment can be reduced by use of appropriate building materials on external walls and roofs, external shielding of windows, selective glass and shielding of facades and roofs. There is rather significant is to minimize temperature around the building, which should be surrounded by tall deciduous trees as well as other vegetation and water surfaces.

From our measurements is obvious that the improved insulation is less significant for summer than in winter [7]. Besides the insulating properties of the building it is important also a sufficient energy storage mass of the building. The building should allow natural ventilation, used primarily at the night. Accumulated coldness helps effectively to shorten and overcome periods of high temperatures during the day [8, 10].

Optimizing the thermal state of the indoor environment

The simplest method for improvement of indoor thermal conditions during the hot weather is to increase the convection cooling effect by a higher air velocity [15, 16]. Sources of air streams are most often the circulation fans (large axial fans) installed inside. Rather significant impact on the deterioration of thermal-moisture microclimate has a high relative humidity. This fact is very common especially in buildings for housing of livestock and in some industrial plants [12]. In some older buildings, this problem is simultaneously accompanied by wetting the structure. Therefore, it is important to use technologies which do not cause air humidification. Ventilation systems should be able to suck moisture as close to the source (e.g. open water surfaces such as reservoirs, channels etc.) and remove out of the building.

Low-energy cooling using adiabatic cooling of air

The most common method of low-energy cooling in large agricultural buildings (poultry, rabbits, pigs) is the use of a direct adiabatic cooling of air with a spraying of water (usually high pressure nozzles) or evaporative panels [1]. But for some buildings it is necessary to limit the increase of air humidity, and then it is advisable to use indirect adiabatic cooling. If there is available sufficient amount of cold water (e.g. the water well) it can be used in recuperative cooler.

CONCLUSIONS

Construction of low-energy buildings is focused mostly on residential houses. This article presents some basic principles and options that may be applied in large buildings for agriculture, industry and similar branches. Respect of these principles will help to reduce energy consumption without a significant increase in construction or operational costs. Any higher construction costs, for example better insulation is a long-term investment, which in view of the very long life will return back. Therefore, these ideas should be systematically promoted at all levels of decision-making and approval of projects of new buildings or modernization and reconstruction of older buildings.

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