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COMPUTER PROGRAM FOR LOAD CALCULATION OF COLDROOMS, WITH INCORPORATED DATABASES AND RECOMMENDATIONS

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Abstract

The proper calculation of cooling load for the cold rooms is very important from many aspects, especially for the energy consumption. In this paper, the structure of heat gains for cold rooms is performed, which consists of the transmission loads (transfer of heat through the walls), cooling and respiration of food products, infiltration of outdoor air, electric lights, people presence and work of fans of air coolers.

All heat gains are expressed with mathematical formulas so a mathematical model of the procedure is made for a complete calculation. The methodology for calculating is mostly based on the literature published by ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers). On this basis, a computer program is created whose use is simple and interactive. It is not necessary to looking for thermophysical properties, such as of food products, and other properties in other books. There are database based on the ASHRAE handbooks built in the same computer program.

The program has a universal application because it can be used for all types of cold rooms. A concrete example is presented in the form of report from which you can see a lot of details of the methodology for calculating of cooling capacity.

Key words: *Cold room, Heat gains, Mathematical model, Computer program.*

1. Introduction

The cold storage of perishable products is maybe the most important link in the cold chain, and the coldrooms are maybe the most important link through which pass the food products. One cold storage consists of usually several coldrooms in which food products are kept at lower temperatures in order to preserve them in short or longer term. The storage temperature of food products in one coldroom is very important for many aspects such as the product quality and durability, but also for the energy consumption. The choice of proper temperature can be made from the recommendations published in [1]. The temperature in the coldrooms should be from 0 to 4 ^{0}C for chilled and -18 to -25 ^{0}C for frozen products.

Due to the higher temperature of the surrounding air, the heat passes through the walls of coldroom to its interior. In order to prevent or reduce heat gains, the enclosure surfaces are performed with thermal insulation. Besides, there are additional heat gains (of products, equipment, etc.) in the coldroom which should be taken into account in order to obtain the total refrigeration load required for the selection of equipment.

Coldrooms may vary depending on the insulation material, the structure (layers) of walls, type of product, the temperature mode of use, etc. All these facts affect the larger or smaller amounts of the heat gains, so that the two coldrooms with equal size can have a large difference in cooling capacity. Therefore, it is incorrect that the cooling capacity, and choice of equipment to be done according to the volume or floor area of coldrooms.

It is very important to accurately determine the capacity of coldrooms. If less than required, the refrigerating system will run non-stop and may not achieve the required temperature regime.

If the calculated capacity is greater than required, the refrigeration equipment will be bigger and unnecessary more expensive, and the system will work with a lot of stops because it will achieve the temperature regime very quickly. In this way, and the energy efficiency of the system will be lower.

2. The structure of heat gains, mathematical model and computer program for calculation of the capacity of coldrooms

2.1 The structure of heat gains and mathematical model

In order to be made a universal mathematical model for calculation of heat gains, it is necessary to be included in all types of coldrooms that may be of different storage temperature (chilled or frozen food), mounted outdoor or in a hall, to know the thermal properties of almost all products, to know how is the exploitation (opening doors, people stay), the way of defrosting etc..

The main structure of heat gains consist of the following components [2]:

Q1 - through enclosure surfaces,

Q2 - product cooling,

Q3 - product respiration,

Q4 - infiltration of surrounding air,

Q5 - electric lights,

Q6 - heat of people,

Q7 - fans of air coolers.

2.1.1 Heat gains through enclosure surfaces (transmission and radiation)

Enclosure surfaces include the vertical walls, ceiling and floor. The heat gains can be from transmission (heat transfer due to the temperature difference) and solar radiation. Transmission gains are calculated according to the following equation:

$$Q_1 = \Sigma(A \times k \times \Delta t)_i \text{ [W]} \quad (1)$$

The overall heat transfer coefficient (k) is calculated for each surface particularly.

$$k = \frac{1}{\frac{1}{\alpha_i} + \frac{x_1}{\lambda_1} + \frac{x_2}{\lambda_2} + \frac{x_3}{\lambda_3} + \ldots + \frac{1}{\alpha_o}} \quad (2)$$

The coefficient of convective heat transfer inside a_i is approximately 9.5 W/m^{2}K in case of still cooling (without fan), and approximately 20 W/m^{2}K in case of air coolers (with fan).

The coefficient of convective heat transfer outside a_o can be assumed according the recommendations of ASHRAE [3]:

- 11 W/m^{2}K - exposed to a low intensity of wind,

- 18 W/m^{2}K - exposed to a medium intensity of wind,

- 30 W/m^{2}K - exposed to a high intensity of wind.

One of the most important questions there is how to be a thickness of thermal insulation. First of all, it depends on the type and cost of materials, prices of electricity, storage temperature, size of coldroom, etc. The most applied insulating material is a polyurethane (usually in the form of sandwich panels), but its thermal conductivity vary from 0.020 to 0.035 W/mK depending of manufacturer. Most relevant is the techno-economic criteria according to which the total annual cost (investment + energy costs) is minimal. According to this criteria and experienced data it is recommended the value of specific heat flux ($q = Q/A = k \times Dt$) to be in ranges:

q = 6 do 8 W/m^2 - coldrooms for frozen products,

q = 7 do 11 W/m^2 - coldrooms for chilled products.

The heat gains from solar radiation depend on the intensity (latitude of locations), orientation and color of surface. Simplified method is to use expression (1) which takes a so called equivalent temperature difference that can be assumed according to ASHRAE [4].

2.1.2 Heat gains from product cooling

It happens often that the products enter the coldroom with a temperature that is higher than the storage temperature. In this case, it should be taken heat gains of cooling products and packaging.

$$Q_2 = m \times c \times (t_1 - t_i)/(3600 \times \tau) + m_a \times c_a \times (t_1 - t_i)/(3600 \times \tau) \text{ [kW]} \quad (3)$$

It should be careful to take a corresponding specific heat because it is different for chilled and frozen products. In the previous expression it is not taken into account (latent) freezing heat that occurs in the tunnels for products freezing.

2.1.3 Heat gains from product respiration

These gains occur in the storage of fruits and vegetables at a temperature higher than 0 ^{0}C.

$$Q_3 = m \times q_{res} / 1000 \text{ [kW]} \quad (4)$$

q_{res} [W/kg] is a respiration heat released from 1 kg of product. The values for q_{res} can be found in [4].

2.1.4 Heat gains from infiltration of surrounding air

With the opening of the door surrounding air enters the coldroom and this heat gain that must be taken into account. The amount of this gain depends on the number of door openings in the day and the size of coldroom. If there is a system for ventilation of coldrooms, then it has to be calculated the heat for cooling of fresh air.

$$Q_4 = \dot{V} \times \rho \times [(h_o - h_i) + 0.335 \times (x_o - x_i)] \quad (5)$$

The volume flow rate of air from door opening can be calculated by:

$$\dot{V} = n_i \times V / (24 \times 3600) \tag{6}$$

where V [m^3] is a volume of coldroom, and n_i is a number of air exchanges per day.

Recommendations for approximated values of n_i are given in [5]. However, in order to be easier to use in the computer program, the authors of this paper have developed a polynomial for calculation depending on the volume of coldroom.

For $V \leq 200$ m^3:

$$n_i = 32.24833\text{-}0.697123V + 0.8107671\text{E-}2V^2 - 0.4363497\text{E-}4V^3 + 0.87\text{E-}7V^4 \tag{7}$$

For $200 \leq V \leq 2800$ m^3:

$$n_i = 9.303918 - 0.02251713V + 0.3071145\text{E-}4V^2 - 0.1959158\text{E-}7V^3 + 0.4617926\text{E-}11V^4 \tag{8}$$

For $V > 2800$ m^3:

$$n_i = 75 / V^{0.5} \tag{9}$$

2.1.5 Heat gains from electric lights

For approximate calculation the following expression can be used:

$$Q_5 = A \times q_A \times t / (24 \times 1000) \tag{10}$$

- A [m^2] - surface of floor,
- q_A [W/m^2] - intensity of electric lights (power of electric lights per 1 m^2 of floor),
- τ [h] - number of hours per day when the electric lights are turn on.

Recommended values for q_A (depending of volume of coldroom):

- $V \leq 100$ m^3: $q_A = 3.0$ W/m^2
- $100 < V \leq 500$ m^3: $q_A = 2.5$ W/m^2
- $V > 500$ m^3: $q_A = 2.0$ W/m^2

2.1.6 Heat gains of people

Their contribution is small and depends on the number of persons (n_p) and the time of their stay (t) in the coldroom.

$$Q_6 = q_p \times n_p \times t / (24 \times 1000) \text{ [kW]} \tag{11}$$

For the heat released from one person (q_p) a following equation can be used [4]:

$$q_p \times = 272 - 6t \text{ [W]} \tag{12}$$

2.1.7 Heat gains from fans of air coolers

As a result of the work of fan from air coolers a heat is got. Since that is not known in advance the size and type of air cooler, the power of electric fan should be assumed and, after the selection of equipment, you need to compare whether there is a larger deviation.

On the basis of data from several manufacturers, the authors of this paper empirical formulas are developed depending on the volume of coldroom.

For $V \leq 600$ m^3:

$$Q_7 = 2.222626 + 5.078022V - (0.6265753\text{E-}2)V^2 + 0.509243\text{E-}5\,V^3 \tag{13}$$

For $V > 600$ m^3:

$$Q_7 = 545.7142 + 2.157143V \tag{14}$$

The total amount of heat gains is:

$$\Sigma Q = Q_1 + Q_2 + Q_3 + Q_4 + Q_5 + Q_6 + Q_7 \tag{15}$$

For more safety in the result a correcting factor f is introduced which can be from 1.05 to 1.15. If the defrosting operation has more influence, this factor can be increased.

$$Q_o = f\,\Sigma Q \tag{16}$$

At the end, it is necessary to take into account the operating time (t) of compressor during the day. So, the required refrigeration load of the system is:

$$Q_{sys} = Q_o \times 24/\tau \tag{17}$$

2.2 Computer program for calculation of the capacity of coldrooms

On the base on the mathematical model presented in the previous section a computer program is created where an interactive mode is performed [6].

At first, the dimensions of coldroom are input, and then starts calculation of heat gains through enclosure surfaces (vertical walls, ceiling and floor). After calculating of each wall it appears an inter-result: the amount of heat gains for that wall, the coefficient of heat transfer and the specific heat flux by which the effectiveness of wall is assessed. The program contains a database for thermal conductivity of insulation and building materials that can be used if it is needed. Also, the program includes a table of equivalent temperature differences due to solar radiation.

In the calculation of heat gains from the product cooling (entering), the input data are the mass (amount) of products, their input temperature and cooling time. Also, there is a database for the specific heat of products above and below the freezing temperature, and for various packaging materials as well.

For the calculation of respiration heat a database from ASHRAE is added for fruits and vegetables. A respiration occurs only at the storage temperature above 0 ^{0}C.

Infiltration heat gains from the surrounding air are calculated by the thermodynamic properties of external and internal air. Therefore, a separate subprogram is incorporated for calculation of properties for moist air.

At the end, a recapitulation of all heat gains are displayed, and the total load of system as well. There is an option to the user wish for printing a complete report which contains many of detailed calculations. Such report is attached on a separate page of this paper.

3. Conclusions

- Calculation of heat gains in the coldrooms is a necessary step to achieve the required cooling capacity, which is used for a selection of cooling equipment. The calculation procedure is extensive and associated with the need of a larger number of data. Besides, the coldrooms differ in their size, design, type of food products, etc. This was the reason to make a computer program with which in a fast, effective and accurate way the desired results are got and in a very short time. A number of databases are incorporated in it, so the user does not need to use extra textbooks. The program has universal application because it comprises large and small capacity, the walls with one or more layers with different materials, normal and lower temperature, various types of products, locations outdoor or in the halls, etc. There is an option to print the entire report, in which a number of detailed calculations are contained.

- The computer program for calculation of the required cooling load of coldrooms under the name COLDROOM is distributed by ASHRAE (presented on the ASHRAE website) since 2001, and this is a great recognition for the quality of the program.

Nomenclature

A - surface [m^2]

c - specific heat [J/kgK]

h - enthalpy [kJ/kg]

k - overall coefficient of heat transfer [W/m^{2}K]

m - mass flow rate [kg/s]

Q - heat or refrigeration load [W]

q - specific heat flux [W/m^2]

t - temperature [^{o}C]

V - volume [m^3]

$\dot{V}$ - volume flow rate [m^3/s]

x - thickness [m]

x - humidity ratio of air [kg/kg]

α - coefficient of heat transfer [W/m^{2}K]

λ - thermal conductivity [W/mK]

τ - time [s], [h]

4. References

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