Żaneta BOGUSŁAWSKA
Poznań University of Technology
ul. Piotrowo 3, 60-965 Poznań
e-mail: zanetaboguslawska@gmail.com

GENERAL ENERGY BALANCE OF COLD STORE BUILDINGS FOR FOOD PRODUCTS

Summary

The paper discusses the general energy and mass balance of refrigeration systems of food storage objects. To obtain the universality of the description allowing the use of the balance for different kinds of cold store buildings the variability of energy flux as a function of time was taken into account. The presented balance takes into account the possibility of maintaining of the set temperature and air humidity in cold store buildings at variable ambient temperatures (with a daily or annual resolution).

Key words: food; storage; cold store; temperature; humidity; physical properties; energy balance

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Streszczenie

W pracy przedstawiono podstawowy bilans energii i masy opisujący system chłodzenia dowolnego obiektu do przechowywania żywności. W celu uzyskania uniwersalności opisu umożliwiającego jego adaptacje do różnych obiektów w bilansie uwzględniono możliwość zmienności strumieni energii w funkcji czasu. Przedstawiony bilans uwzględnia możliwość utrzymania założonych temperatur i wilgotności powietrza w obiektach chłodniczych przy zmiennych temperaturach otoczenia w okresie dziennym lub rocznym.

Słowa kluczowe: żywność; przechowalnictwo; chłodnia; temperatura; wilgotność; właściwości fizyczne; bilans energii

1. Introduction

Proper food storage is an important element in the human food chain and is a priority in world economy. Non-compliance of the temperature conditions in the refrigeration systems when storing food during transportation may lead to significant losses. Another aspect of the problem is the minimization of the energy consumption necessary to obtain the required temperature parameters. To fulfill this condition we need to develop an effective energy demand balance to generate cold and an efficient control system due to a very high ambient temperature variability and the possibility of technical realization of the refrigeration system.

The performed analysis takes into account various possibilities of maintaining of the food storage temperatures in multi room buildings after supplementing with additional refrigerating modules.

The balance also takes into account the internal sources of heat as the effect of generating thermal energy by the stored food items and installations in the analyzed space. The balance allows a development of simulation software of the operation of a system that provides the possibility of minimizing of the energy consumption with the use of an effective control system of the object.

The presented analysis is related to the global balance described with the average values of the temperature and does not include the three dimensional differentiation of the temperature field in the cold store.

2. Literature overview

The possibility of storing food items is one of the most important social economic issues. Yet, due to a wide range of stored products and their temperature and humidity requirements during storage [1] the climate control systems need to be flexibly adjustable to the given requirement.

Due to a high variability of the ambient conditions climate systems need automatic control systems. An example of such a system has been presented in [2].

The aim of this work is to supplement the literature data [3, 4] by proposing a general balance of the cold store building that would constitute a basis for the development of the simulation software of a climate control system under different conditions.

3. Cold store building energy balance

A general balance of the cold store building for food storage pertains to an object shown in figure 1. The basic assumption in the balance is that inside the cold store the maintained temperature will be above zero and the required humidity will remain irrespective of the ambient conditions.

Hence, the climate system of the object must ensure the possibility of heating in the winter and cooling in the summer. The proposed analysis does not include objects where products are deep-frozen when the there is no need for heating up the cold store.

The presented schematic includes the elements of the cooling system needed to maintain proper air temperatures in the object the balance refers to. When realizing individual objects certain modules can be removed thus obtaining simplified systems of lower climate capacities.

Assuming a constant temperature inside the cold store and a steady humidity level resulting from the technological data as presented in [1] the equation of the global energy balance can be expressed in the following form:

$$\dot{Q}_{out} + \dot{H}_l + \dot{Q}_w + \dot{Q}_h + \dot{H}_{out} + \dot{H}_{in} + \dot{H}_w + \dot{Q}_{h1} + \dot{Q}_{h2} + \dot{Q}_r + \sum N_i + \Delta Q = 0 \tag{1}$$

where:

$\dot{Q}_{out}$ - collective heat flux passing through the cold store walls,

$\dot{H}_l$ - rate of enthalpy flowing through the leaks in the walls,

$\dot{Q}_w$ - collective internal heat flux (stored items, personnel, lighting, ventilation),

$\dot{H}_{out}$ - rate of air enthalpy flowing out of the system,

$\dot{H}_{in}$ - rate of air enthalpy flowing into the system $\dot{H}_w$ - rate of water enthalpy humidifying the air,

$\dot{Q}_{h1}$ - heat flux of the primary heater,

$\dot{Q}_{h2}$ - heat flux of the secondary heater,

$\dot{Q}_r$ - flux of heat (cold) in the cooler,

$\sum N_i$ - the sum of the power outputs of the blower electric motors and regenerative exchanger,

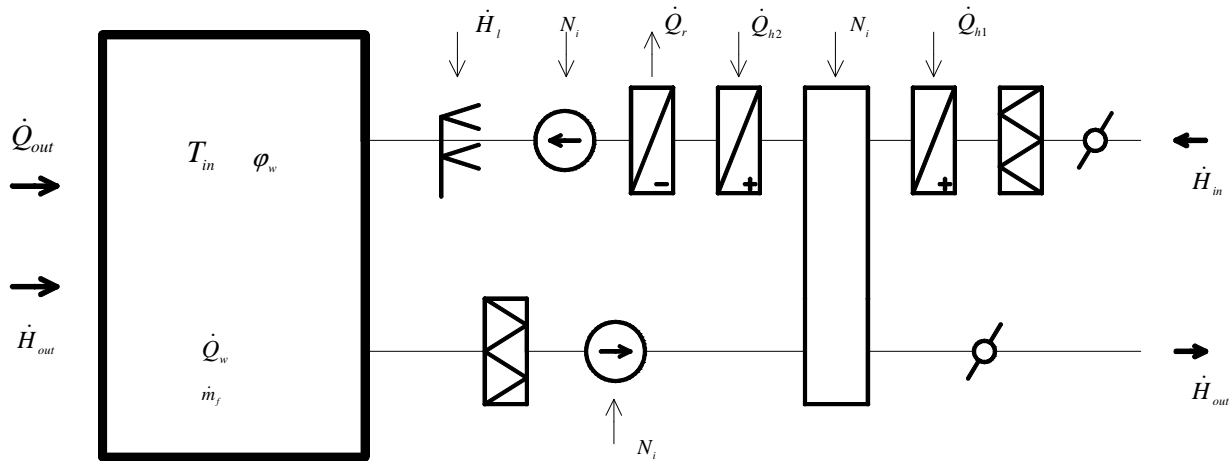ΔQ - thermal capacity of the building and stored products.

Fig. 1. Schematics of the climate control of the cold store building for food

The schematics of the climate control installation presented in figure 1 ensure realization of the technological assumptions for the stored products. The system has been composed of modules that chill down the air if the ambient temperature (including sun intensity) is higher than that required inside the cold store. Under extreme winter conditions when the ambient temperature is lower the system enables heating up the air inside the cold store. The reduction of the energy consumption of the system is ensured by the regenerative heat exchanger operating when there is a need of cooling of the air inside the cold store.

Other elements of the system are dampers and filters fitted in the intake and outlet ducts.
The selection of the active elements of the system described for example in [4, 5] is a consequence of calculations done based on balance (1) taking into account the detailed calculation procedures of the individual elements of this equation.

The heat flux going through the building walls is a function of the conditions of heat transfer through these walls, thermal bridges and the daily and annual ambient temperature variability range. In the balance we also need to include the variable rate of energy of solar radiation and the location of the walls in relation to the geophysical directions.

As a consequence the heat flux can be expressed as

$$\dot{Q}_{out} = \dot{Q}_k + \dot{Q}_r \qquad (2)$$

where:

$\dot{Q}_k$ - heat flux transferred through the walls

$\dot{Q}_r$ - radiation heat flux

These quantities can be calculated using the calculation procedures provided in literature [3].

The energy balance (1) also includes the possibility of transfer of external air through leaks and gates during product handling in the cold store - marked as a rate of enthalpy H_l.

Important components of the energy balance are the sources of heat generated inside the cold store. They are difficult to assess. The basic element is the heat generated by the stored products (variable in time) and the heat generated by the personnel and lighting. The balance must also include the possible power output of the blowers inside the chamber whose task is to ensure even temperature distribution.

This gives the following relation:

$$\dot{Q}_w = \dot{Q}_f + \dot{Q}_p + \dot{Q}_l + N_{iw} \qquad (3)$$

where:

$\dot{Q}_f$ - heat flux generated by the stored products,

$\dot{Q}_p$ - heat flux generated by personnel,

$\dot{Q}_l$ - heat flux generated by lighting, UV lamps etc.,

N_{iw} - power of the blowers ensuring even temperature field inside the chamber.

The heat generated by the stored food should be calculated according to the data obtained from the literature dedicated to a given product. Example data have been presented in [1].

Ensuring proper hygiene and environment protection requires an installation of filters at the air intake and outlet. The consequence of their installation is increased airflow resistance, which translates into an increased power demand of the blowers. The final effect of the influence of the filters is an elevated temperature of the flowing air.

An important module that improves the efficiency of the system operation is the use of a regenerative exchanger. When the system operates in the cooling mode, thanks to the regenerative exchanger we can limit the power of the

cooling system (compressor o absorption) necessary to chill the air at the intake to the cold store.

In the winter conditions it could be used for preheating of the fed air thus reducing the heating power demand.

In the winter at the air parameter of -18°C and the need to maintain the temperature of +6°C inside the cold store we need to heat up the fresh air. The intake air is processed in the primary heater and then reaches the expected temperature in the secondary heater. Then the humidified air is fed to the cold store. In the summer the heaters are off and the temperature is adjusted through fresh air dampers and radiators. The regenerative exchanger in the system is for heating up the air in the winter or chilling the air in the summer thanks to which the electrical energy consumption needed to reach the set temperature is reduced. The versatility of the available devices allows chilling of the air through chillers or CFC-based system and the heating may be realized with the use of electrical energy, heating water or heat pump.

Maintaining a given climate in the area where food products are stored requires not only appropriate temperature but also humidity. This depends on the type of products and needs to be determined by the technological conditions of storage.

Hence, the equation of the energy balance (1) must be supplemented with an equation of the balance of the rate of water (steam) mass in the analyzed system. Since the air humidity indicator is relative humidity φ then taking into account the barometric pressure, temperature and volume of the cold store this parameters can be converted into a rate of water mass (steam) contained in the air of the humidity of φ.

With the above assumption we can notate the water (steam) balance equation as follows:

$$\dot{m}_{in} + \dot{m}_{n} + \dot{m}_{f} + \dot{m}_{out} = 0 \qquad (4)$$

where:

$\dot{m}_{in}$ - rate of water mass at the inlet

$\dot{m}_{n}$ - rate of water mass fed to the humidifier (condenser)

$\dot{m}_{f}$ - rate of water mass exuded from the stored product

$\dot{m}_{out}$ - rate of water mass at the outlet

In equation (4) the humidity generated by the personnel present in the chamber has been omitted.

4. Conclusions

General energy and water mass balances may constitute a basis for the calculations simulating the operation of a cold store installation under variable conditions after the detailed equations have been used that determine the balances of the individual modules depending on the size of the system. As a result of the calculations we can select types and sizes of the system components for air processing in order to obtain the assumed temperature and humidity values at variable ambient conditions.

5. References

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