Refrigerated Warehouse Model
Supplementary materials to the paper: ”Compressor schedule optimization for a refrigerated warehouse using metaheuristic algorithms”

February 2, 2021

1 Simulator - description

Simulator, presented here, is prepared based on the raport [1]. It is design to effectively model temperature of the key elements of the refrigerated warehouse. A zero-dimensional approach to model temperatures in refrigerated warehouse based on straight-forward energy balance and heat transfer between the key elements of the facility: essentially the storage room and its content: the outer layer of the products, the air inside the chamber and the coolers, which cool down the air and drives its flow. The cooling power of the cooler is computed based on the cooling system equipped with auxiliary container with allow to exchange heat/cold with the phase change material. Such flexible approach allows to increase a thermal inertia of the cooling system.

A sketch of the system is presented in Fig. 1

2 Simulator - set of equations

The simulator solves set of six ordinary differential equations which describe the conservation of energy in the six key elements of refrigerated warehouse. Essentially, the temperature of the elements may change duo to heat influx and outflux. The following equations are included:

1. The outer layer of products (p) with the mean temperature T_p:

$$\frac{dT_p}{d\tau} = \gamma_p \left[T_s(\tau) - T_p(\tau)\right] + \gamma_r q_{r0} e^{b[T_p(\tau)-273.15]}, \tag{1}$$

   the additional term on the RHS includes potential heat release from biological material, by default it is neglected; Here:

$$\gamma_p = \frac{k_p A_p}{M_p c_p},$$

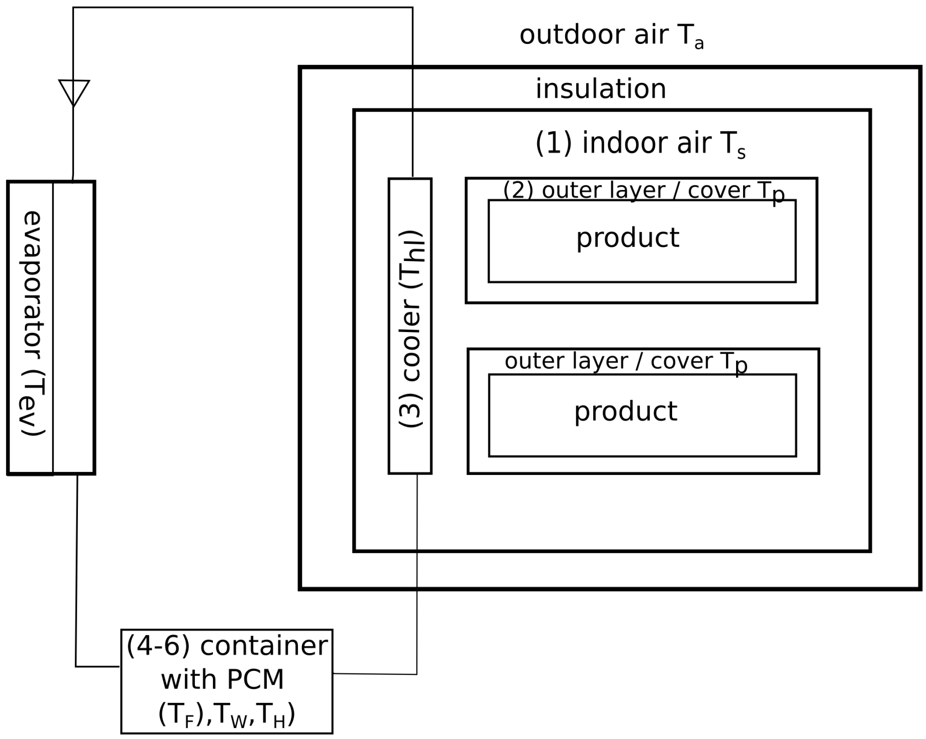

Figure 1: Sketch of refrigerated warehouse.

$$\gamma_r = \frac{1}{c_p},$$

2. The average temperature of air T_s in the storage chamber (s):

$$\frac{dT_s}{d\tau} = -2\beta_s(\tau)\epsilon_{hl}(\tau)\left[T_s(\tau) - T_{hl}(\tau)\right] + \gamma_{sp}\left[T_p(\tau) - T_s(\tau)\right] + \sum_i \gamma_{si}\left[T_{ai}(\tau) - T_s(\tau)\right], \quad (2)$$

where the operation of the cooler is included, and heat exchange to the out layer of the product and heat losses to the outdoor; Additionally:

$$\beta_s(\tau) = \frac{\dot{m}_g(\tau)}{M_{sg}},$$

$$\epsilon_{hl}(\tau) = \frac{k_h A_h}{2\dot{m}_g(\tau)c_{pg} + k_h A_h}.$$

$$\gamma_{sp} = \frac{k_p A_p}{M_{sg}c_{pg}},$$

$$\gamma_{si} = \frac{k_{si}A_{si}}{M_{sg}c_{pg}},$$

3. The mean temperature of cooling fluid flowing through the cooler T_{hl}:

$$\frac{dT_{hl}}{d\tau} = 2\beta_{hl}(\tau)\left[T_H(\tau) - T_{hl}(\tau)\right] - \gamma_{hl}\left[1 - \epsilon_{hl}(\tau)\right]\left[T_{hl}(\tau) - T_s(\tau)\right], \quad (3)$$

it depends on the temperature of the heat transfer fluid flowing through the cooler T_H and on the geometrical properties of the cooler; Here:

$$\beta_{hl}(\tau) = \frac{\dot{m}_l(\tau)}{M_{hl}},$$
$$\gamma_{hl} = \frac{k_h A_h}{M_{hl} c_l},$$

4. The mean temperature of the heat transfer fluid T_H inside the auxiliary container (heat exchanger) with phase changing material (PCM)

$$\frac{dT_H}{d\tau} = \beta_H(\tau) \left\{ \epsilon_e(\tau) T_{ev}(\tau) + \left[1 - \epsilon_e(\tau)\right] \left[2T_{hl}(\tau) - T_H(\tau)\right] - T_H(\tau) \right\} + \gamma_H \left[T_W(\tau) - T_H(\tau)\right], \tag{4}$$

where:

$$\beta_H(\tau) = \frac{\dot{m}_H(\tau)}{M_H},$$
$$\epsilon_e(\tau) = \frac{2k_e A_e}{2\dot{m}_l(\tau) c_l + k_e A_e},$$
$$\gamma_H = \frac{k_{HW} A_W}{M_H c_l},$$

5. The mean temperature of the PCM material T_F

$$\frac{dT_F}{d\tau} = \gamma_F(T_F) \left[T_W(\tau) - T_F(\tau)\right], \tag{5}$$

here:

$$\gamma_F(T) = \frac{k_{FW} A_W}{M_F c_F(T)},$$

6. The mean temperature of the heat exchanger plates T_W

$$\frac{dT_W}{d\tau} = \gamma_{FW} \left[T_F(\tau) - T_W(\tau)\right] + \gamma_{HW} \left[T_H(\tau) - T_W(\tau)\right], \tag{6}$$

where:

$$\gamma_{FW} = \frac{k_{FW} A_W}{M_W c_W},$$
$$\gamma_{HW} = \frac{k_{HW} A_W}{M_W c_W},$$

Notation

A – surface are, m^2
c – heat capacity, $\frac{J}{kgK}$
HTF – heat transfer fluid
k – thermal conductivity, $\frac{W}{m^2 K}$
$\dot{m}$ – flow rate, $\frac{kg}{s}$
M – mass, kg

PCM – Phase Change Material
Q – heat source, J
$\dot{Q}$ – heat flux, W
T – temperature, $K(^{\circ}C)$
τ – time, s
subscripts:
a – outdoor temperature
e – evaporator
F – PhaseChangeMaterial
g – air inside the cooler
h – cooler
H – Heat Transfer Fluid exchanging heat with the PCM
l – HEat Transfer Fluig inside the cooler and evaporator
p – outer layer of product
s – air in the storage chamber
W – material of plate in the tank
1 – inlet to the heat exchanger
2 – outlet from the heat exchanger

References

[1] Roman Kwidziński *In Polish: Model dynamiki temperatur w komorze przechowalniczej z materiałem zmiennofazowym w pośrednim obiegu chłodniczym*, Gdańsk 2015.