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heat transfer, energy saving, temperature, model of walls layers

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COMPUTER MODELLING OF THERMAL TECHNICAL SPACESS IN ASPECT OF HEAT TRANSFER THROUGH THE WALLS

Abstract

This paper presents the analysis of complex problems in the field of energy savings and it is focused on the new concept of thermal analysis derived from harmonic character of temperature changes in building environment – especially in a fruit storages – with aspect on conductive heat transfers through walls. This changeable influence of variable weather temperature on internal temperature of technical chamber depends on thermal inertia of building. The paper describes research work on methods concerning heat transfers through walls of thermal technical chambers in the impact of sinusoidal nature of the changes in atmospheric temperature. The purpose for the research is to point out areas subjected to the highest energy losses caused by building's construction and geographical orientation of walls in the aspect of daily atmospheric temperature changes emerging on chamber exterior. The paper presents exemplary measurement results taken in Lublin region during various periods throughout a year.

1. INTRODUCTION

The presented new concept of thermal analysis is derived from periodic character of temperature changes in storage environment (Bzowska, 2005; Janczarek M. M, 2000). The paper presents also the physical model of heat transfer through chamber walls by means of a mathematical model suitable for sine waveform of internal temperature changes. The analysis has been performed on the basis of original numerical algorithms. They take into consideration hourly changes of ambient temperature in the central – eastern region of Poland (Fig. 1).

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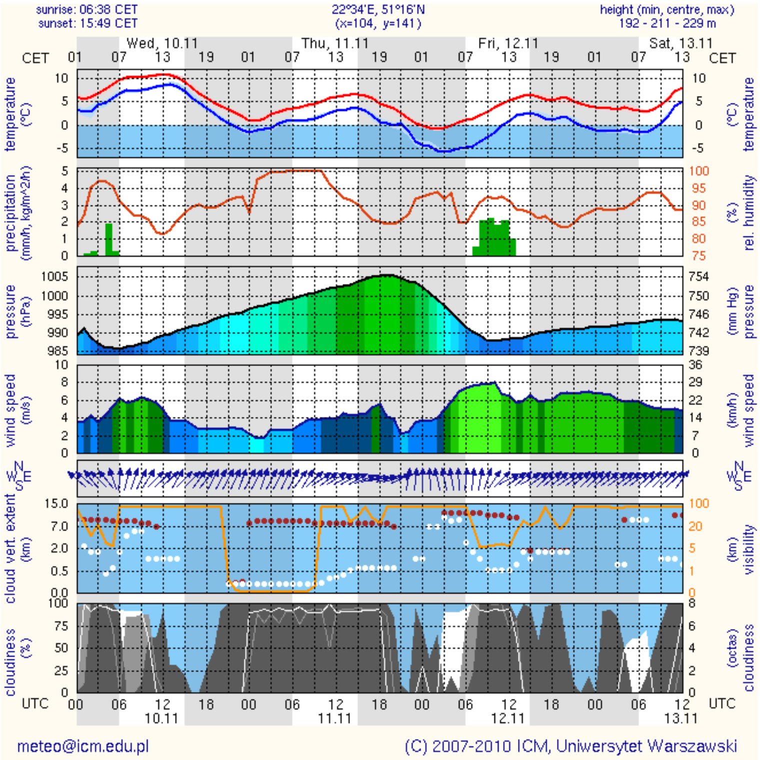

Fig. 1. Periodically temperature signal on the wall – image source: (Meteorological diagrams, 2017)

The accepted methodology of performance takes advantage of temperature dynamics which is necessary to solve physical and mathematical problems related to heat transfer processes occurring in chambers (Etheridge, 2002). The main purpose for fruit storage in central European climate is to provide products of high consumption quality during autumn, winter and spring (Hunt & Linden, 2001). Financial inputs connected with the maintenance of the storage are obviously related with the final cost of apple or any other fruit. It is necessary to prolong storage period energetically efficiently to maintain affordable price of apple. Contemporary technological processes make possible to inhibit biochemical and physiological processes that lead to ripening or overripe fruit. The prolongation of storage period is mainly achieved by the storage of apple of pear in chambers that can maintain low temperature of fruit, i.e.: within the range between 0÷ +1.5°C. Beside temperature conditions, it is necessary to provide the air of low oxygen and carbon dioxide contents and of high humidity and circulation in the interior of the cooling chamber. The differences among particular cases of thermal energy demand for storage depends mainly on different construction of cooling chambers. The construction can differ in materials and dimensions which results in different thermal resistance of external walls. Problems of thermal conductivity can be analyzed by many methods, for example: Laplace transformations method, Fourier transforms, etc. The paper presents two models: analog one and differential one. They can help to control heat processes during storage periods.

The above-mentioned diagram of atmospheric temperature changes indicates its sinusoidal nature at our latitude – Central and Eastern Europe. The picture of changes in atmospheric temperature refers to the month of November, but in the remaining months it is similar (Etheridge, 2002; Fracastaro, Mutani, & Perino, 2002). This indicates that in the design of external walls, this dynamics of atmospheric temperature changes should be taken into account (Chwieduk, 2006).

2. RESEARCH AND EXPERIMENTAL WORK OF HEAT TRANSFER THROUGH WALL

The originally constructed laboratory system consists of fully automatic stands to test construction material thermal characteristics (Fig.2). These characteristics form the basis to formulate the principles of temperature changes between adjacent layers. The laboratory enables also to trace the heat transfer on external border surfaces. The experimentally obtained results have been subjected to computer analysis (Janczarek & Świć, 2012).

Fig. 2. Registering positions laboratory with two temperature chambers and the test material in the middle

In aim of determined of coefficient of heat transfer of bricks in dependences upon of degree her moistures one chose method experimental. Research one passed on laboratory – position in Technical University of Lublin and referred of measurement of temperatures, thickness of streams warm and moistures relative bricks (Janczarek & Bulyandra, 2016). As material to driven researches used brick full red both wet and then this oneself brick dried in stove. In time of a few days' measurements driven former at a help of computer registration of temperatures in four points on external surfaces examined bricks as also in two central points in interior. Simultaneously driven former computer registration of moisture at help of two searchers of type WHT installed in center of brick. Values of thickness led of warm density became measured at help of electronic sensors of type PTP, which connected former to universal measure APPA (Suchorab, Sobczuk, & Lagod, 2016).

Position laboratory – to qualifications of coefficient of heat flow in aspect different moistures of equipped brick was in two chambers. Different conditions thermal in chambers held former at help of aggregates cooling and of controlled warmers. Among chambers one installed investigative sample in typical form full red bricks placed tight to capacity in plate of polystyrene about thickness 20 cm. Polystyrene. Plate used former in aim of isolating of surface external bricks from influence undesirable temperatures. Surfaces external bricks surrendered became {remained} to activity from one side of chamber to temperature +25°C and from second side of chamber to temperature +1,5°C. Values these of temperatures registered former independently for every from six sensors, and then recorded on disc of computer at measuring – step carrying out 15 of minutes. Simultaneously with measurement of temperature registered former at help of programmed computer values of moisture of brick on two separate files. Obtained from measurements of value of temperatures, of streams and moistures became placed in programmer EXCEL. At the help of suitable mathematical transformations coded values of temperatures and moistures exchanged on suitable individuals on degrees °C and on per cent definite values of relative moisture. Correlations among obtained values of coefficient of heat conduction permit on determination of characterizations of graphic coefficient for chance dry and wet bricks.

Obtained results of measurements permitted on qualification of dependence of coefficient of heat transfer from internal temperatures in full red brick wet and dry (Janczarek, Sklaski, Bulyandra, & Sobczuk, 2006).

Simultaneously obtained results of value of coefficient of heat transfer permitted on determination of coefficient lambda. From represented below graphs results difference among courses for wet and dry bricks (Fig. 3 and Fig. 4).

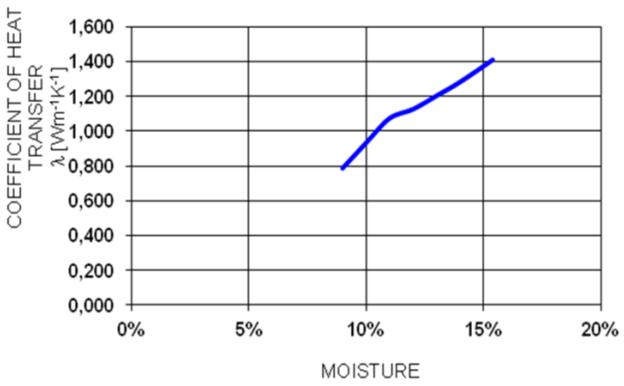

Fig. 3. Characterizations of changes of coefficient of heat transfer in wet full brick

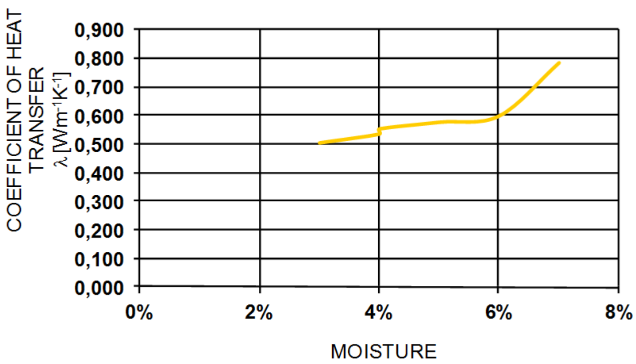

Fig. 4. Characterizations of changes of coefficient of heat transfer in dry full brick

The above graphs are the results confirming the dependence of the heat conduction coefficient on the moisture content in building materials. It is clear from them that in the energy balance of heat and mass exchange, we must pay attention to adequately insulating external building materials. Otherwise, we will suffer losses due to the increased heat transfer rate through the walls. On the upper picture of a damp brick, you can see a steep increase in the thermal conduction coefficient with an increase in the degree of humidity. The bottom picture shows the stabilized value of lambda coefficient in the humidity range for dry bricks.

3. EXPERIMENTAL WORK OF MEASUREMENT OF HEAT TRANSFER ON THE REAL OBJECT

The verification of the accepted methodology and results have been performed on the data thermal flux density obtained from rural thermal chamber in Radzyń Podlaski (Poland). The small sensor of low inertia has been developed especially for the purpose of the research. This sensor has been used to measure the heat flux density. The experimental analysis proves the necessity to consider the dynamic character of internal temperature when thermal chamber analysis is performed. The thesis includes also the presentation of elaborated methodology of analysis of industrial long term storage.

Two fruit storages have been subjected to the analysis of temperature distribution on the surfaces of technical chambers (Fig. 5.). The storages are constructed of materials of different physical properties

The purpose for the research is to point out areas subjected to the highest energy loss caused by building construction and geographical orientation of walls. Thermal detectors have been installed on external surfaces, internal surfaces and inside wall layers to measure temperature. The graphical presentation of temperature field distribution on wall surfaces have been performed by means of a thermal vision camera. The camera enables to distinguish visually the areas of the highest thermal loss from storages. The analysis of temperature distribution on vertical walls of storages makes possible to indicate proper building construction of objects. The analysis results are presented in figures. Moreover, temperature measurements taken on chamber external surfaces let us distinguish rooms that serve for other purpose than storage, e.g. a technical room. This room additionally protects the storage from disadvantageous influence of atmospheric conditions.

Article includes analysis of changeable influence in time of variable weather temperature on internal temperature of construction object depending on thermal inertia of building. Taken advantage influence of sinusoidal change external temperature on internal temperature of thermal technical spaces of thermo stability object will allow to get drop of cost of expendable energy of construction object on keeping of definite thermal condition in accommodation properly spaces. It shows harmonist of exemplary characteristic depending on length of time of measurement course of temperature and seasons of the year.

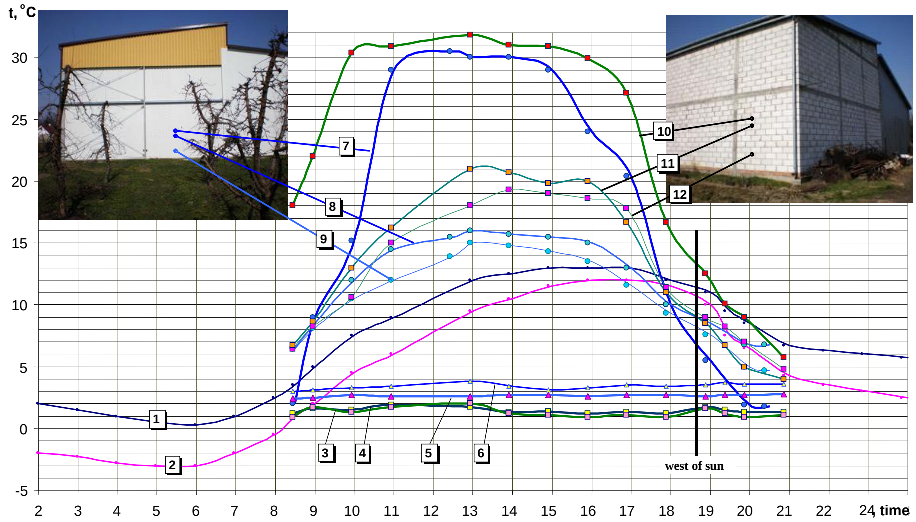

Fig. 5. Presentation of temperature field distribution on wall surfaces.

In the above picture we can see the distribution of sensors that measure the temperature on the two surfaces of the outer walls, which is an hour-long registration. They show the sinusoidal nature of changing the temperature with the maximum during the day and the minimum at the night. Characteristic curves represent also the course of the heat flux in the same figure below.

4. MODELS OF HEAT TRANSFER THROUGH WALL

The purpose of this paper is to describe the design of control systems of cooling and air conditioning systems in storage spaces. For a control systems its necessary to use only three elements: sensor, controller and controlled device. The main of those elements is temperature sensor which shows the picture of thermal decomposition in cold store. The very important are also devices, which provide control of humidity and cyclic potential motion of air in space. It must be noted, that all the control actions depend mainly on measurement of a controlled variable. It is, therefore, necessary to analyze very carefully what is actually being measured, how it may vary with time and which degree of accuracy is necessary in the measurement. Mostly, the temperature of the surfaces on which the sensors are mounted is different from the air temperature.

Conduction take place when a temperature gradient exists in a solid (or stationary fluid) medium. Energy is transferred from the more energetic to the less energetic molecules when neighboring molecules collide. Conductive heat flow occur in the direction of decreasing temperature because higher temperature is associated with higher molecular energy (Dzieniszewski, 2005).

The equation used to express heat transfer by conduction is known as Fourier's Law. The article presents the physical model of heat transfer through chamber walls by means of a mathematical model suitable for sine waveform of internal temperature changes. Below is a universal analog model for an external wall using an electrical analogy. It presents the wall as a layer having its resistance and thermal capacity (Janczarek & Bulyandra, 2017). Besides, the resistance resulting from heat transfer from the outside air is shown in the model. Also in the model there is a flux of heat flowing into the wall from outside as well as inside to the chamber.

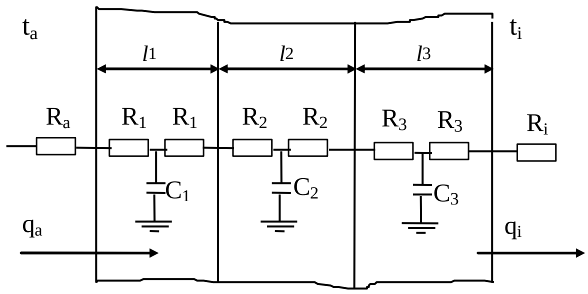

Fig. 6. Model of wall composed of three layers in electrical analogy

From it we can get matrix notation (eventually for n – layers of wall) and the final result of this calculation is a pair of linear relations between the temperature and fluxes at the two surfaces of the composite slabs (Janczarek M. M, 2000).

$$[\Delta t_i(p), \Delta q_i(p)] = [\Delta t_a(p); \Delta q_a(p)] \begin{bmatrix} 1 & 0 \\ -R_1 & 1 \end{bmatrix} \begin{bmatrix} 1 & -pC_1 \\ 0 & 1 \end{bmatrix} \dots \begin{bmatrix} 1 & -pC_n \\ 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} 1 & 0 \\ -R_{n+1} & 1 \end{bmatrix} \quad (1)$$

where: Δt – temperature increase,
Δq – thermal flux,
p – domain by Laplace transform,
R – thermal resistence,
C – thermal capacity,
1 – thickness of the wall layer,
i – index meaning internal,
a – index meaning outside.

The relation is precisely analogous to Ohm's law for the steady flow of electric current: the flux corresponds to the electric current, and the drop of temperature to the drop of potential. Thus R may be called the thermal resistance of the slab. Next suppose we have a composite wall composed of n slabs of different thickness and conductivities. If the slabs are in perfect thermal contact mat their surfaces of separation, the fall of temperature over the whole wall will be the sum of the falls over the component slabs and since the flux is the same at every point, this sum is evidently (Janczarek, 2013).

This is equivalent to the statement that the thermal resistance of a composite wall is the sum of the thermal resistance's of the separate layers, assuming perfect thermal contact between them. Finally, consider a composite wall as before, but with contact resistances between the layers such that the flux of heat between the surfaces of consecutive layers is H times the temperature difference between these surfaces. The differential equation to be solved is Fourier's equation.

These models we can confront with digital computer program Modelica, which allow to construct the walls of technical chambers. This model is similar to analogue but much more convenient due to the simple input of data. We can use it to enter any thermal conditions inside and outside the chamber. We can also use it to enter any physical values of the wall, causing specific functions.

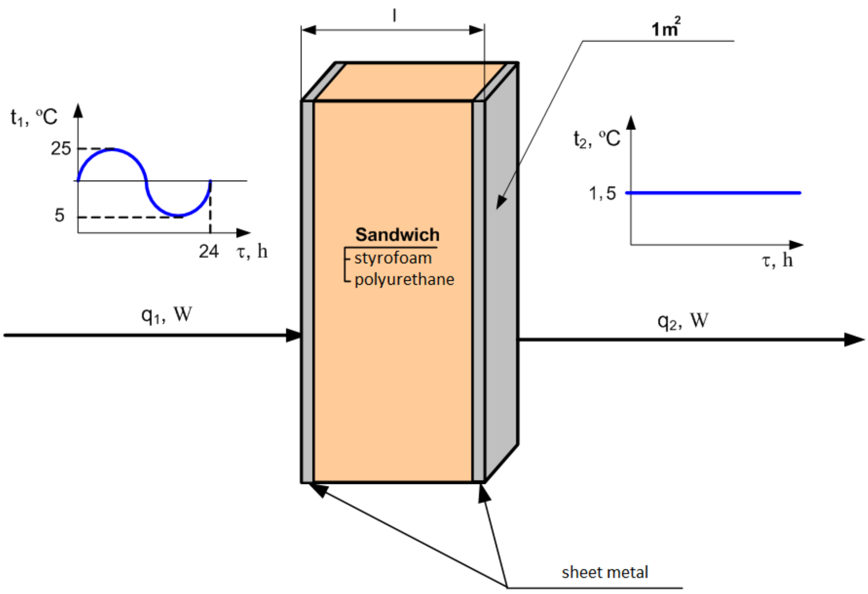

Fig. 7. Ideal model of wall

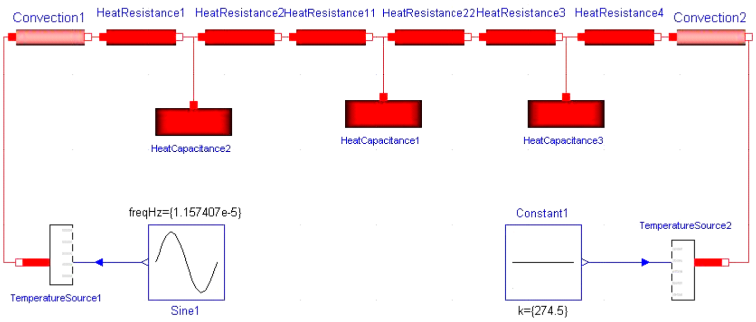

Fig. 8. Block schema using electrical analogue

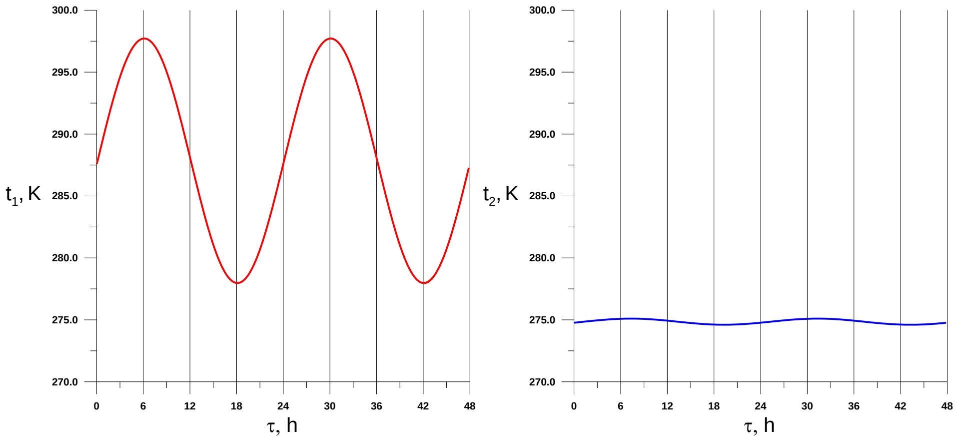

Fig. 9. Periodically temperature signal on the wall

By the suitable construction of the enclosure walls composed of several slabs of different thicknesses and conductivities, we can obtain phase shift (when the time lag attains twelve hours it is the best situation), which reduce the amplitude of internal temperature inside technical chamber and, in consequence, give equivalent of using energy. The influence of this periodically changing weather temperature upon the inside storages climate is depending on the material of walls and inertial property of thermal technical spaces, it means a fruit storage.

This analysis shows the periodic variability of outside temperature, changing in periods of each day and also in the year with maximum value in the afternoon or in summer and minimum value in the night or winter time. The influence of this periodically changing temperature on the inside storages climate is depending on thermal inertia of technical spaces. The proper construction of an object with prescribed thermo-stability characteristic can use the phase difference between internal and external temperature and allow to lower costs of energy, necessary for cooling or heating the technical spaces (Calderaro & Agnoli, 2007).

5. CONCLUSIONS

The paper describes atmospheric temperature analysis and their variability in time in aspect of their influence upon the thermal technical chambers – fruit storages. The influence of this periodically changing weather temperature upon the inside storages climate is depending on the material of walls and inertial property of thermal technical spaces, it means a fruit storage.

As a result of the tests it was found that a properly designed technical chamber can bring significant energy savings. In addition, energy savings can bring about the appropriate location of the building due to the geographic side of the world. Moreover, energy savings can be brought by the appropriate location of the building's cooling chamber in the north – this will provide additional cooling and a possible warehouse located in the south. Thanks to the Modelica computer program, we can simulate various variants of atmospheric conditions both inside and outside the object. Modeling appropriate layers of the external barrier will allow obtaining time constants that are a combination of thermal resistance and thermal capacity. Using the developed partition model in the RC electrical analogy, we can choose the components of the partition to achieve the desired phase shift. Resistance values and thermal capacity depend on the physical properties of the materials used to build the object. Optimal conditions of phase shift of the heat flow through the outer wall will allow to stabilize the thermal conditions inside the room, and thus save energy on the refrigeration unit.

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