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heat transfer, thermal technical chambers, physical modeling, control process

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COMPUTER AIDED THERMAL PROCESSES IN TECHNICAL SPACES

Abstract

This paper describes research work on methods concerning heat transfers through walls of thermal technical chambers. The paper presents the mathematical and physical analysis of problems in the field of energy savings and material selection in thermal chambers in controlled gaseous environment. 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. Thermal problems were solved using computer aided support. The paper presents exemplary measurement results taken in Lublin region during various periods throughout a year.

1. INTRODUCTION

The main purpose for thermal technical storages in central European climate is to provide products of high consumption quality during autumn, winter and spring. 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 $0 \div +1.5^{o}C$. 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.(Janczarek & Świć; 2012;) 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.

It has to be noted that building design processes require fluent acquaintance of rules and processes described by building physics also in the aspects of thermal preservation. Buildings should meet requirement related energy savings at simultaneous maintenance of thermal comfort in rooms. Some ignorance of thermal processes occurring in such objects, in particular – insufficient thermal conductivity levels in walls can lead to exaggerated energy losses (Bzowska, 2002). This is particularly important because of continuously raising price and increasing pollution of the atmosphere. The parameter that describes wall thermal conductivity is the coefficient of thermal conductivity $\lambda[Wm^{-1}K^{-1}]$ (*k* – in some international reference), which is dependent among others on volume density and material structure, water content and temperature. The coefficient of thermal conductivity is the information of energy flux that flows through a unit area of a material layer of 1 m thickness at the temperature difference at both surfaces of this layer equal to 1 K (1°C). The higher the volume density, the higher is the described coefficient and the material transfers heat more easily. Moreover, the materials composed of the same substance can have different coefficients of thermal conductivity when volume density is different. Thermal conductivity can vary in the function of temperature and the heat loss increases at some proportion together with the temperature difference. This phenomenon is the result of complex changes of heat transfer through: conductance in materials which the layer is composed of, convection in fluid components of porous construction and even through heat radiation on internal and external surfaces of the layer. The more porous material is, it causes the lesser heat transfer and through this it prevents heat from the flow outside the structure (Bzowska, 2000, 2005; Chwieduk, 2006). Practical implementation of this phenomenon was previously described by the author in extremely low or high temperature i.e.: hot tank insulation (Janczarek & Bulyandra, 2016). In building envelope the variation of temperature is comparatively small (except for instance – sun exposed dark surface) and the variation of thermal conductance in dependence on temperature can be omitted. It is, however important to provide information of temperature when λ is determined.

The phenomenon of heat transfer through external walls is one of the most important components of heat loss from buildings. This is either important in buildings of constant occupation or in objects of short time use. Thermal conductance of external walls plays a significant role in these losses. The external walls not only protect the building from thermal losses but also influence interior air quality and its humidity. The building envelope should enable, in some extent, the exchange of air and water vapor at simultaneous humidity stabilization. Moreover, one of the most important physical properties qualifying external wall is its thermal capacity – decisive to building thermal stability in the result of thermal inertia (Dzieniszewski, 2005; Fracastaro, Mutani, & Perino, 2002; Janczarek, 2013). The phenomenon of thermal inertia occurs as a phase shift of heat transfer into the room. Physical properties of wall construction materials undergo disadvantageous changes in the result of dampness which lessens its quality and durability. The efficient protection of building is to avoid negative influence of moisture and to prevent from the following damage. The condition to meet microclimate comfort in rooms is its dry envelope (Lomas, Cook & Fiala, 2007). Damp walls make it impossible even at very intensive heating. Water vapor flow is important in the protection against moisture. Water vapor diffusion through building walls is a process of partial water vapor pressure equalization between two environments divided by the wall. The water vapor flow occurs from the environment of higher concentration to the environment of lower concentration which means that water vapor flows always in the direction of a drier room. The coefficient of vapor transmittance [mg/(m·h·Pa)] characterizes material and structure properties related to vapor diffusion. This coefficient describes the content of water vapor expressed in mg that diffuses through 1 m^2 of a material layer of 1 m thickness during 1 hour and at 1 Pa pressure difference on both sides of this layer. Similarly to the heat transfer through the external building envelope, the diffusive resistance of material layers can be determined, i.e.: $Z = d / \delta$, where d is layer thickness [m]. Water enclosed in pores is of λ equal to 0,56 [$Wm^{-1}K^{-1}$], which is about 20 times the one of air in pore diameter of about 0,05 mm in such material as bricks (Suchorab, 2013). Some additional influence on heat transfer is exerted by water vapor diffusion which increases this transfer and by moisture capillary transport. The moisture content increase is followed by some intensification of thermal conduction and among others, that is why thermal insulation gets worse because water gets inside pores instead of the air (Hunt & Linden, 2001; Voeltzel, Carrie & Guarracino, 2001). This process does not occur identically in different materials and depends on material structure, its origin, e.g. cellular concrete the increase of λ is about 4,5% per 1% moisture content increase.

2. 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 (Calvadero & Agnoli, 2007; Kisielewicz, 2003).

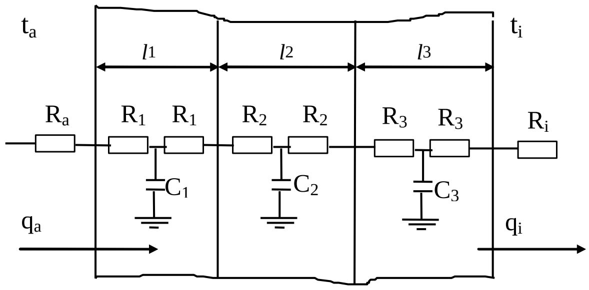

Fig. 1. Model of wall composed of three layers in electrical analogy

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 (Etheridge, 2002). 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.

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.

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

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.

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.

3. THERMAL RESEARCH ON 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.

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 (Fig.3., 4). 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.

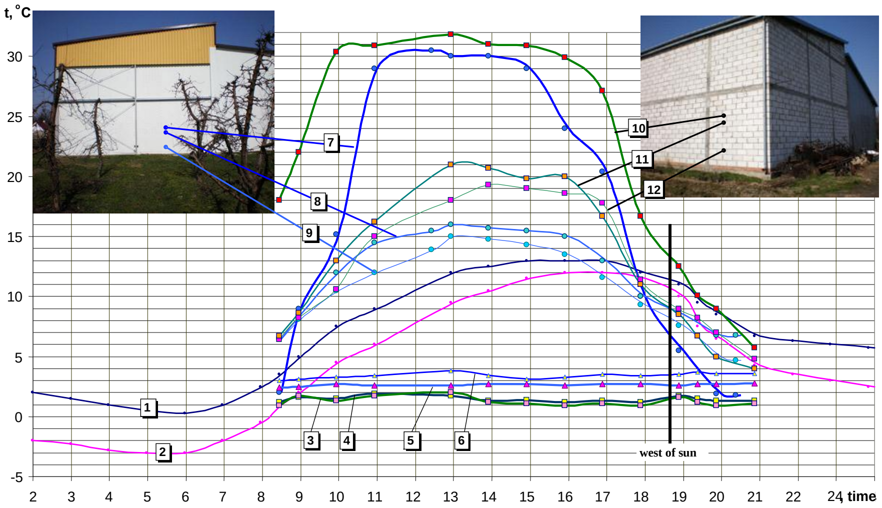

Fig. 2. Presentation of temperature field distribution on wall surfaces

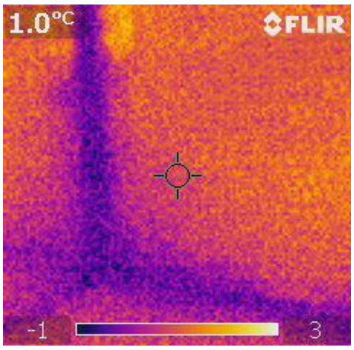

Fig. 3. Temperature field distribution on the corner of wall

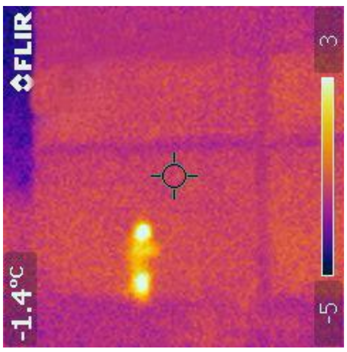

Fig. 4. Temperature field distribution on wall surfaces

4. MEASUREMENT POSITION FOR THE RESEARCHING COEFFICIENT OF HEAT TRANSFER IN MATERIALS

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. 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.

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 + 25^0 C and from second side of chamber to temperature + $1,5^0$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 ^{0}C and on per cent definite values of relative moisture.

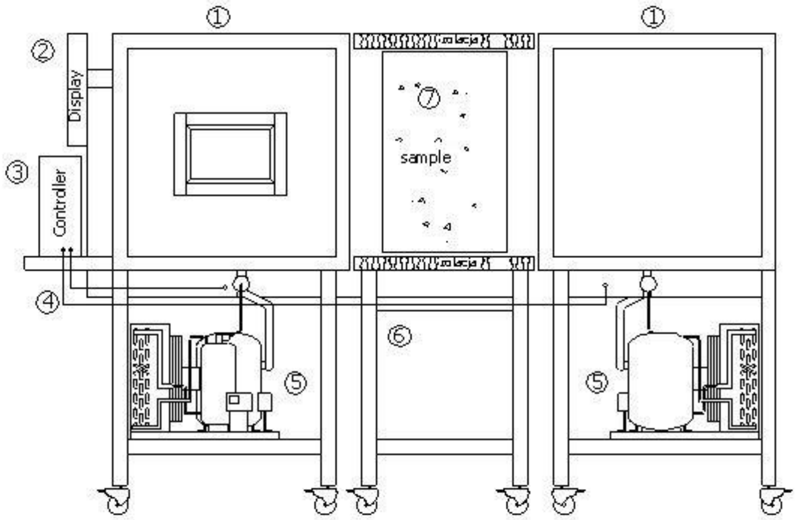

Fig. 5. Schema ideological positions laboratory – to measurement of coefficient of heat transfer.

1. Chamber measuring – executed from aluminum – profiles. Thickness of side 10 cm, with full mineral.
2. Display – LCD Samsung SyncMaster about diagonal 15".
3. Driver – computer PC class with operating – system UNIX.
4. Wires driver steering of generative of microclimate in chambers.
5. Laboratory set of Danfoss firm to generating conditions thermal prevalent inside of chambers. Range of temperatures from -40°C to + 50°C.
6. Table made from aluminum – profiles with variable construction making possible securing and arrangement of prepared samples to investigations.
7. Primary standard sample of builder's material - full red bricks - placed in polystyrene plate.

Fig. 6. View general positions laboratory – measuring – chambers

Fig. 7. Registering positions laboratory

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.

Example – course of changes of value of coefficient of heat transfer. 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.

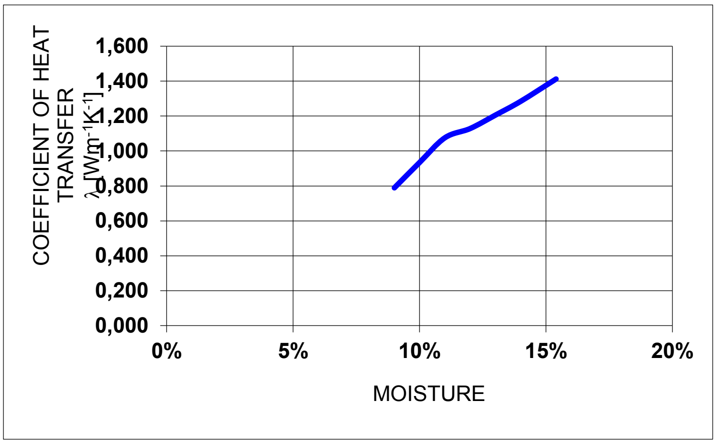

Fig. 8. Characterizations of changes of coefficient of heat transfer in wet full brick

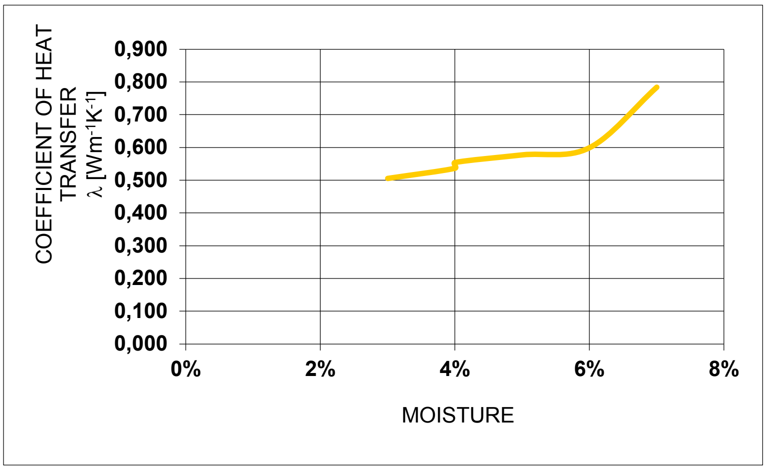

Fig. 9. Characterizations of changes of coefficient of heat transfer in dry full brick

5. CONCLUSION

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.

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