Applied Computer Science, vol. 12, no. 3, pp. 47–60

Submitted: 2016-08-24
Revised: 2016-09-12
Accepted: 2016-09-21

heat transfer through the walls, the thermal technical chambers, energy saving, temperature sinusoidal signals

Marian JANCZAREK[*], *Oleksij BULYANDRA*[**]

COMPUTER MODELLING OF ENERGY SAVING EFFECTS

Abstract

The paper presents the analysis of the dynamics of the heat transfer through the outer wall of the thermal technical spaces, taking into account the impact of the sinusoidal nature of the changes in atmospheric temperature. These temporal variations of the input on the outer surface of the chamber divider result at the output of the sinusoidal change on the inner wall of the room, but suitably suppressed and shifted in phase. Properly selected phase shift is clearly important for saving energy used for the operation associated with the maintenance of a specific regime of heat inside the thermal technical chamber support. Laboratory tests of the model and the actual object allowed for optimal design of the chamber due to the structure of the partition as well as due to the orientation of the geographical location of the chamber.

1. INTRODUCTION

Designing technical heat chamber, home or any building structure due to their thermal protection, it requires knowledge of the principles and processes described by physics building (Janczarek, 2007; Recknagel & Sprenger1976). Buildings in particular chamber should meet the technical requirements for saving energy required for their operation, while maintaining thermal comfort indoors (Janczarek, Bulyandra, Szapowalenko & Winogradov-Saltykov, 2007). Ignorance of thermal processes occurring in buildings and in particular, keeping the level of the coefficients of thermal conductivity through the wall, may lead to a waste of continuously soaring energy and thus to excessive air pollution.

[*] Institute of Technological Systems of Information, Faculty of Mechanical Engineering, Lublin University of Technology, Nadbystrzycka St. 36, 20-618 Lublin, Poland, m.janczarek@pollub.pl
[**] National University of Food Technologies, Volodymyrska St, 68, Kiev, Ukraina, 01033, phone: 00380442879453, info@nuft.edu.ua

The problem of saving energy in the twenty-first century becomes more important than in the seventies of the last century, when it first appeared the energy crisis associated with the armed conflict in the Middle East. This conflict continues until today varying degrees swollen and also relates to the control of any energy sources (Winogradov-Saltykov, Janczarek, Fiedorow & Kiepko, 2009).

2. DYNAMICS OF ATMOSPHERIC AIR TEMPERATURE AND ITS EFFECT ON THE ENERGY EFFICIENCY OF TECHNICAL CHAMBERS

In the analysis of mathematical-physical technical chambers were not taken into account the heat capacity external partition the design and construction thermal space building, but managed only strength of construction and in the case of wall insulation these outsider partitions (Janczarek & Świć, 2012). Skills of calculating the amount of exchanged heat and maintain the temperature of the medium is the paramount importance for the design and maintenance of proper use in the power of heat, refrigeration, food industry and in construction (Janczarek & Bulyandra, 2007; Janczarek, 2009a, 2009b).

The previously used method for designing the exterior shell of buildings shall take into account of the climatic conditions, unfortunately, only in a static way – the average air temperature in the region. However, as is common knowledge, atmospheric air temperature changes are inherently dynamics occurs in one component of the variable daily, decade, monthly or even yearly. The figures below are presented selected waveforms atmospheric temperature recorded in different seasons in the vicinity of Lublin and also in choosing towns in the world. In order to demonstrate the oscillating behavior in the form of sinusoidal variations measured and also the temperature profile at various time periods.

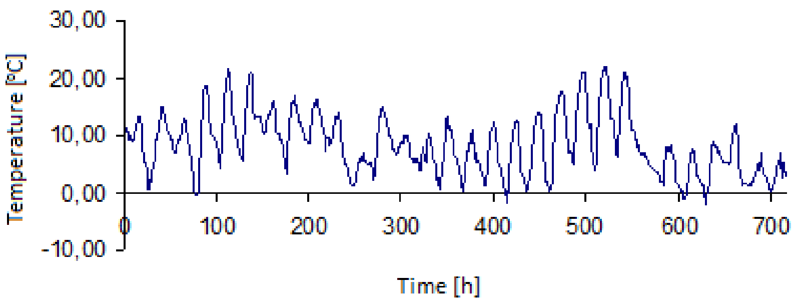

Fig. 1. Air temperature in Lublin, Poland area in the period of one month in the spring – autumn time (own study)

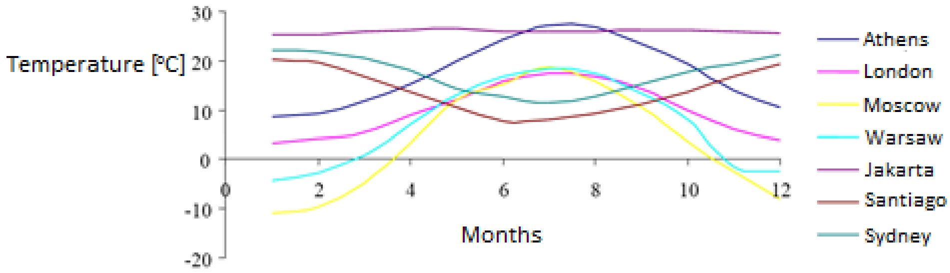

Fig. 2. Average air temperature for selected cities in the 12-month cycle (Recknagel & Sprenger, 1976)

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

Parameter determining the thermal conductivity, thermal conductivity is λ [Wm^{-1} K^{-1}], which depends inter alia on bulk density and structure of the barrier material, the humidity and temperature (Janczarek, 2006). The heat conduction coefficient is information about a stream of energy that flows through the unit area of the material layer having a thickness of 1 m, the temperature difference on both sides of the layer equal to 1 K (1° C) (Carlslaw & Jaeger, 1959).

The higher the bulk density, the greater the ratio, and thus the material is inferior insulation. In addition, materials of the same chemical substances but different densities are different coefficients of thermal conductivity (Janczarek, 2013). The increase in temperature increases the thermal conductivity of materials. This is because it takes to increase the thermal conductivity of the solid and the air contained in the pores (Janczarek, Skalski & Suchorab, 2007). At the same time the pores of the heat transfer occurs by radiation. The practical application of this phenomenon is relevant only when the materials are used at high or low temperatures, e.g. hot tank insulation. The building envelope variations in temperature are relatively low, allowing you to skip the change in thermal conductivity. However, the value of λ should always be given the temperature at which it has been marked.

The phenomenon of thermal conduction through exterior walls of the rooms makes the largest part of the heat exchange chambers (Janczarek, Skalski, Bulyandra, & Sobczuk, 2006). It dominates in the total heat balance of buildings designed for either permanent residence in them and people as well as facilities where workers are being short-lived. Envelope of chamber fulfill the protective function not only in relation to the heat loss but also it can regulate the conditions of moisture and air in the rooms. External walls should allow a certain degree of penetration of air and water vapor while absorbing moisture.

As is well known, the physical construction materials are unfavorable for the user to change under the influence of moisture wall. Moisture adversely affects the quality of the insulation partition as well and its stability. The objective of effective protection of the building against moisture is to avoid the negative influence of her presence and the resulting defects or damages. The condition of living in the rooms of the building are comfortable microclimate dry bulkhead surrounding the room. Moist partitions much impossible to maintain comfort conditions, it is impossible, even with very intense heating. The protection against moisture is very significant as the flow of steam. Diffusion of water vapor through the building envelope is the process of aligning the partial pressure of water vapor between the two environments, which are separated by the partition. The flow of water vapor takes place from the environment of higher vapor concentration to an environment with a lower concentration, so that steam will always be diffused in this direction, where the air is dry. Material properties related to the diffusion of water vapor through the building materials characterized by the coefficient of steam-permeability δ [mg/mhPa]. It corresponds to the amount of water vapor in milligrams, which diffuses through 1 m^2 of the material layer having a thickness of 1 m for one hour and a differential pressure on both sides of the layer equal to 1 Pa. Similarly, as for the heat transfer through the outer shell of the building, the concept of diffusion resistance of any material layers: $d = Z/\delta$, here: d - thickness [m].Water trapped in the pores has a coefficient λ approx. 0.56 [$Wm^{-1} K^{-1}$] or about 20 times greater than the rate λ of air trapped in pores with a diameter of about 0.05 mm building material. The additional impact on thermal conductivity is the diffusion of water vapor which is connected to increased heat transfer and capillary movement of moisture. With an increase in the humidity of materials is an increase of thermal conductivity. And lowering the value of insulation by humidity due to the fact that in place of the air contained in the pores falls just water.

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 (Fig. 3 and 4) 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 ininterior. 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° 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 computer programmer. 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.

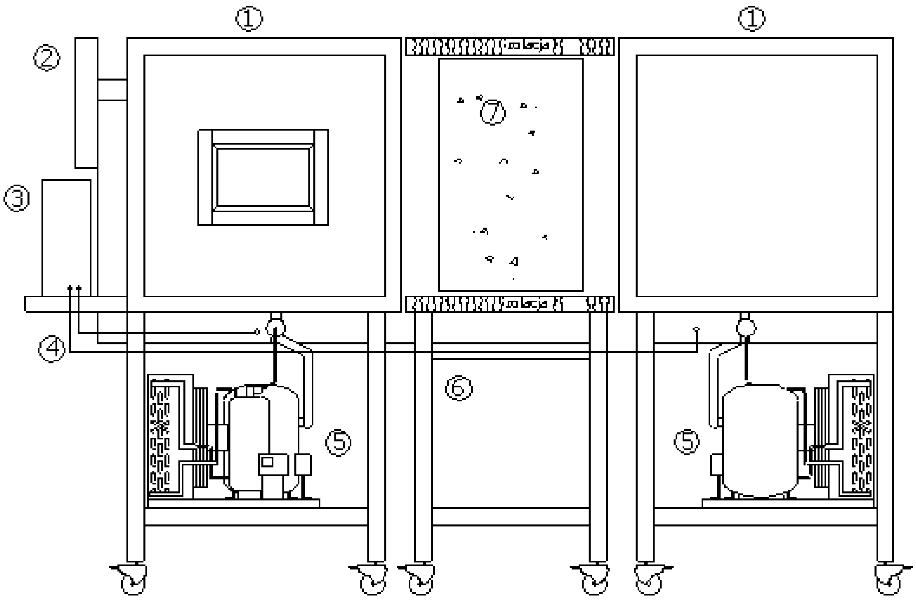

Fig. 3. Schema ideological positions laboratory – to measurement of coefficient of heat transfer (own study)

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. 4. View general positions laboratory – measuring – chambers (own study)

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.

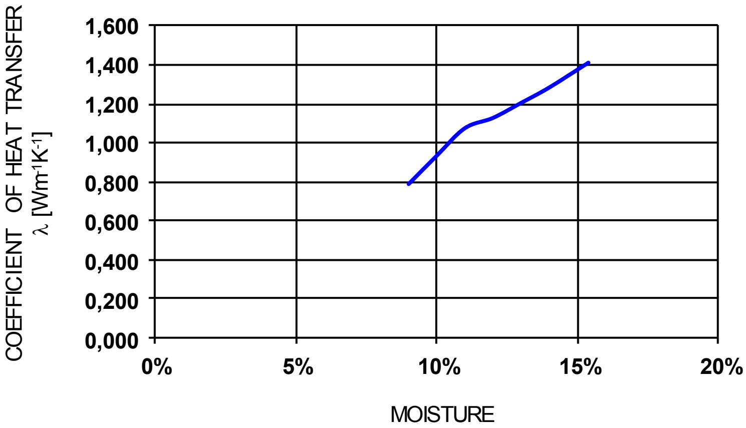

Fig. 5. Characterizations of changes of coefficient of heat transfer in wet full brick (own study)

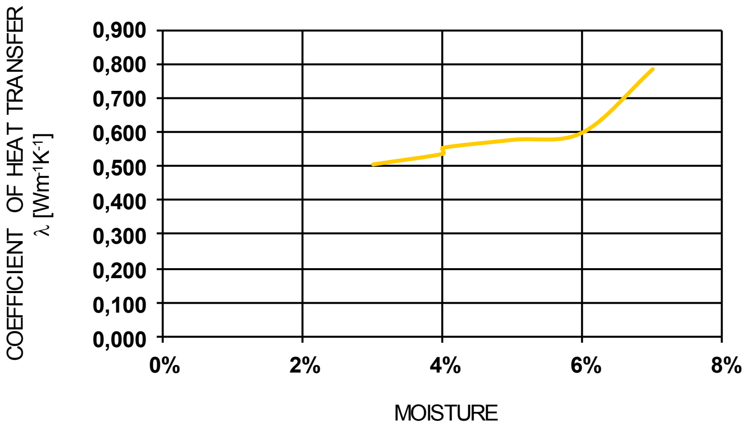

Fig. 6. Characterizations of changes of coefficient of heat transfer in dry full brick (own study)

In order to verify this phenomenon experiment was performed on a laboratory first for the wet material and then a similar experiment was repeated for the material directly taken out of the oven – drying, i.e. The brick dry (Fig. 6). External conditions of the experiment in both cases were the same. The temperature in the hot chamber was programmed at 25°C and the temperature in the cold compartment to the value +1.5°C. Measured temperatures on both surfaces of brick, and inside it were recorded independently for each of the installed sensors, and then stored on your computer using a measuring step of 15 minutes. In parallel with the measurement temperature was also recorded by a computer program humidity bricks. Obtained from measurements of temperature, heat flux density and moisture content were used for calculations of energy in the heat balance for a variety of technical chambers.

4. MATHEMATICAL ANALYSIS OF THE IMPACT OF A SINUSOIDAL TEMPERATURE CHANGE

With the help of the mathematical-physical analysis as well as with the support of Modelica programmer, shows a simulation of actual conditions of the cooling chamber for example with below temperature regime.

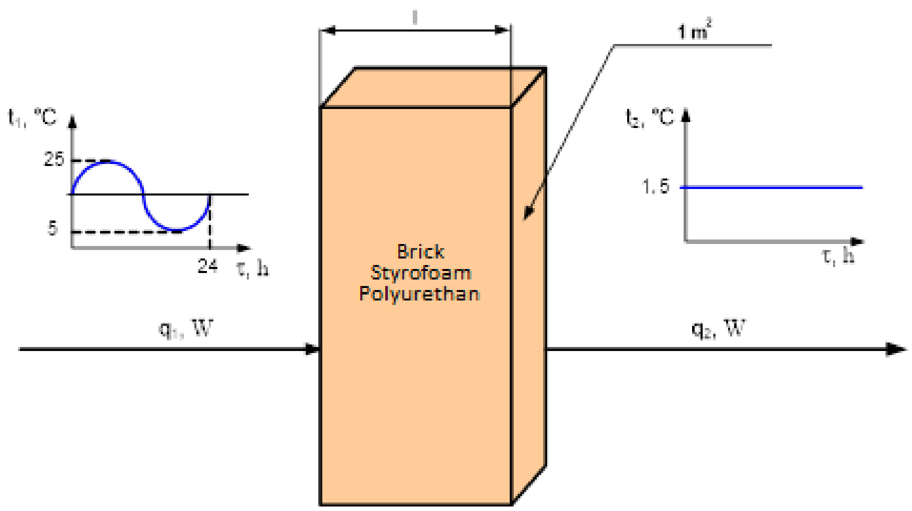

Fig. 7. Effect of the sinusoidal temperature change in order to achieve suppression of the indoor temperature (own study)

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. 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.

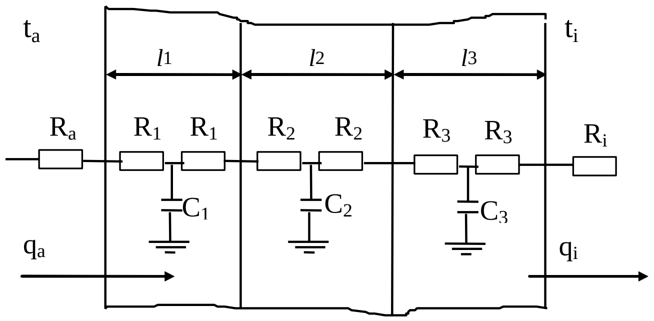

Fig. 8. Model of wall composed of three layers in electrical analogy (own study)

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 (1).

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

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 (Fig. 8). 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. These models we can confront with computer program Modelica, which allow to construct the walls of technical chambers (Fig. 9). The diagram of the process of heat transfer through the wall under the program Modelica is shown below. By this modeling, we can simulate any temperature regime and heat flow both inside and outside of the chamber periodically temperature signal on the outside surface of the wall. In Fig.10 and 11 we can obtain suppressed the course of the internal temperature.

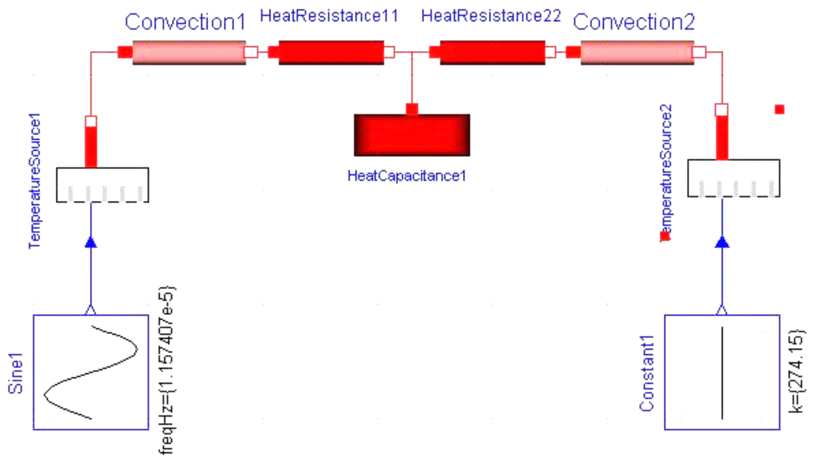

Fig. 9. Ideal model passage of heat through the baffle using an analogy to Ohm's law (own study)

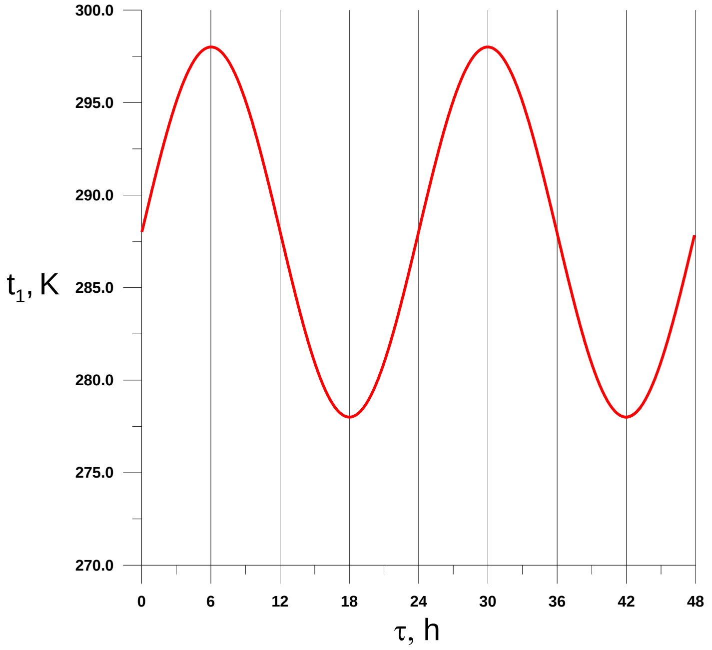

Fig. 10. Temperature t_1 plots obtained from simulations in the Modelica (own study)

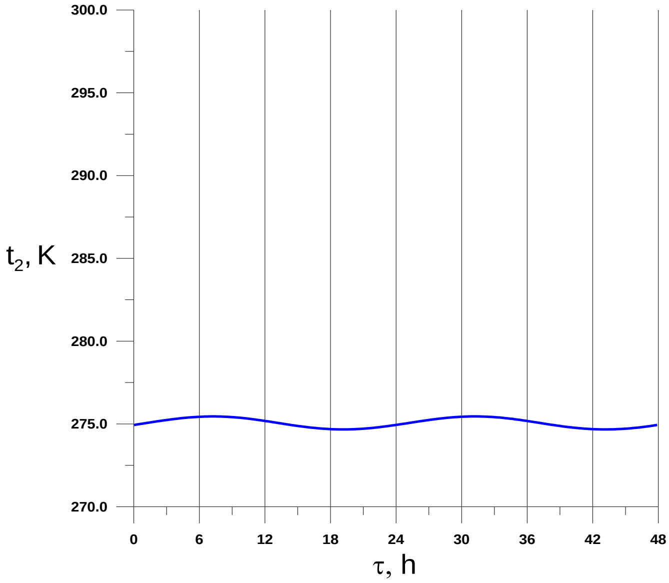

Fig. 11. Temperature t_2 plots obtained from simulations in the Modelica (own study)

Functions of the transition – the transfer – obtained on the basis of these relationships and describing the relationship between the output quantities and input will be helpful also in the design of the construction of exterior walls store-rooms. For the designer and constructor of thermal chambers technical model uses the analogy of electricity to thermal processes is the closest to real physical conditions among all ways of describing and calculating the flow of heat through the outer baffle buildings.

In practice, we can get confirmation of the considerations relating to the stability of heat buildings for example, existing to this day medieval buildings, eg. Churches, libraries and palaces in which there is no need to use air conditioners during the hot days of summer and winter respectively, high-power heating devices. Thus, today we can suitably so designed and constructed partition, which ensures the thermal inertia of the chamber, which would result in significant savings in the energy required to maintain a certain temperature inside a building structure. For example, the daily changes in atmospheric air temperature detrimental to the indoor climate is the effect of heat flow from the interior of space occurring after the 24-hour phase shift. In contrast, most preferred is a case in which the housing is owning outer baffle capable of producing 12-hour phase shift vector heat flux and result in suppression of the temperature change in the building. So in order to achieve measurable economic effects in the process of maintaining the desired temperature in the facility must be in the design of the exterior wall into account not only thermal resistance but also heat capacity of the partition. The product of the thermal resistance – as a function of the thickness and thermal conductivity of the wall and the heat capacity of the barrier – as a function of the density and specific heat of the construction material which has a dimension of a unit of time is the time constant characterizing the object taken into consideration by inertia applied control and regulation systems.

The higher the bulk density, the greater the ratio, and thus the material is inferior insulation. In addition, materials of the same chemical substances but different densities are different coefficients of thermal conductivity. The increase in temperature increases the thermal conductivity of materials. This is because it takes to increase the thermal conductivity of the solid and the air contained in the pores. At the same time the pores of the heat transfer occurs by radiation. The practical application of this phenomenon is relevant only when the materials are used at high or low temperatures, it means for example hot tank insulation. The building envelope variations in temperature are relatively low, allowing you to skip the change in thermal conductivity. However, the value of λ should always be given the temperature at which it has been marked.

The phenomenon of thermal conduction through exterior walls of the rooms of the largest part of the heat exchange chambers. It dominates in the total heat balance of buildings designed for either permanent residence in them and people as well as facilities where workers are being short-lived. Envelope fulfill the protective function not only in relation to the heat loss but also regulate the conditions of moisture and air in the rooms. External walls should allow a certain degree of penetration of air and water vapor while absorbing moisture.

As is well known, the physical construction materials are unfavorable for the user to change under the influence of moisture wall. Moisture adversely affects the quality of the insulation partition as well and its stability. The objective of effective protection of the building against moisture to avoid the negative influence of her presence and the resulting defects or damages. The condition of living in the rooms of the building are comfortable microclimate dry bulkhead surrounding the room. Moist partitions much impossible to maintain comfort conditions, it is impossible, even with very intense heating. The protection against moisture is very significant as the flow of steam. Diffusion of water vapor through the building envelope is the process of aligning the partial pressure of water vapor between the two environments, which are separated by the partition. The flow of water vapor takes place from the environment of higher vapor concentration to an environment with a lower concentration, so that steam will always be diffused in this direction, where the air is dry. Material properties related to the diffusion of water vapor through the building materials characterized by the coefficient of steam-permeability [mg/(mhPa)]. It corresponds to the amount of water vapor in milligrams, which diffuses through 1 m^2 of the material layer having a thickness of 1 m for one hour and a differential pressure on both sides of the layer equal to 1 Pa. Similarly, as for the heat transfer through the outer shell of the building, the concept of diffusion resistance Z of any material layers.

Water trapped in the pores has a coefficientλ approx. 0.56 [Wm^{-1} K^{-1}] or about 20 times greater than the rate λ of air trapped in pores with a diameter of about 0.05 mm building material. The additional impact on thermal conductivity is the diffusion of water vapor which is connected to increased heat transfer and capillary movement of moisture. With an increase in the humidity of materials is an increase of thermal conductivity. And lowering the value of insulation by humidity due to the fact that in place of the air contained in the pores falls just water.This process does not proceed uniformly in a variety of materials depends on the structure and origin of the material, eg. In the concrete cell is assumed that the gain coefficient λ approx. 4.5% to 1% gain moisture.

5. CONCLUSIONS

The measurement results in the publication are test piece related to the heat flow through the baffle chamber and technical be made in various embodiments of both temperature and time as well as on the actual and model objects. With a variety of probes can be read temperatures and heat fluxes at various locations on the test material. On a laboratory can be simulated on both sides of the baffle different conditions of the course of the atmospheric temperature and the desired regime of heat inside the chamber. The results obtained for optimizing the design of baffles to give the storage chamber, therefore, notable economic impact.

REFERENCES

Carlslaw, H., & Jaeger, J. (1959). *Conduction of heat in solids*. Great Britain: Oxford University.

Janczarek, M., Skalski, P., & Suchorab, Z. (2007). Przewodzenie ciepła przez przegrodę w stanach ustalonych i nieustalonych. *Postępy Nauki i Techniki, 1*, 13-16.

Janczarek, M. (2006). Wyznaczanie bilansu cieplnego komór chłodniczych. In *XII Konferencja Naukowo-Techniczna Rynek Ciepła 2006 - Materiały i Studia*. Lublin: Kaprint.

Janczarek, M. M. (2007). Determining of coefficient of heat transfer in bricks depended from degree of their moisture. *CEEPUS WEB Summer School 2007 "Informatics Systems in Automation"*. Slovenia, Maribor: University of Maribor.

Janczarek, M. M. (2009a). Technological describtion of heat and mass transfer processes in thermal treatment of fruit storage chambers. *Engineering Mechanics 2009*. Czech Republic, Svratka.

Janczarek, M. M. (2009b). The analysis of wall temperatures in a fruit storage in the aspect of transient heat flow. *Engineering Mechanics 2009*. Czech Republic, Svratka.

Janczarek, M. M. (2013). Analiza matematyczno-fizyczna cieplnych komór technicznych. In M. Janczarek & J. Lipski (Eds.), *Technologie informacyjne w technice i kształceniu* (pp. 128-137). Lublin: Politechnika Lubelska.

Janczarek, M. M., & Świć, A. (2012). Scientific and technological description of heat and mass transfer processes in chambers. *Acta technical convinieties – Bulletin of Engineering, 10*, 55-60.

Janczarek, M. M., Bulyandra, O. F., Szapowalenko, O. I., & Winogradov-Saltykov, W. A. (2007). Osobiennosti rasczieta tiepłowowo balansa tiepłowych kamer chranienia fruktow. *Naukowi Praci, 31*(2). Ukraine, Odessa: Odesska nacionalna akademia charczowych technologii.

Janczarek, M., & Bulyandra, O. F. (2007). Zbierigannia fruktiw u gazowich serediwiszczach. *Harchowa Promislowist* (nr 5). Kyiv, Ukraine.

Janczarek, M., Skalski, P., Bulyandra, A., & Sobczuk, H. (2006). Przewodność cieplna zewnętrznych ścian budynków w aspekcie wilgotności i oszczędności energii. *Rynek Energii, 65*(4), 32-35.

Recknagel & Sprenger. (1976). *Ogrzewanie i klimatyzacja – poradnik*. Warszawa: Arkady.

Winogradov-Saltykov, W. A., Janczarek, M. M., Fiedorow, W. G., & Kiepko, O. I. (2009). Tiepłometriczeskije issliedowanie tiepłozaszczitnych swoistw ograżdienij. *Industrial Heat Engineering – International Scientific and Applied Journal*, *31*(4), 116-123.