ANNALS OF FACULTY ENGINEERING HUNEDOARA
– INTERNATIONAL JOURNAL OF ENGINEERING
Tome X (Year 2012) – FASCICULE 2 (ISSN 1584 – 2665)

[1.] Marian Marek JANCZAREK, [2.] Antoni ŚWIĆ

SCIENTIFIC AND TECHNOLOGICAL DESCRIPTION OF HEAT AND MASS TRANSFER PROCESSES IN CHAMBERS

[1-2.] LUBLIN UNIVERSITY OF TECHNOLOGY, DEPARTMENT OF MECHANICAL ENGINEERING, UL. NADBYSTRZYCKA 36; 20-618 LUBLIN, POLAND

ABSTRACT: *This paper describes research work on methods concerning heat transfers through walls of thermal technical chambers – especially in a fruit storages. The paper presents the analysis of complex problems in the field of energy savings and material selection during long term storage of fruit 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. The presented paper is focused on the new concept of thermal analysis derived from harmonic character of temperature changes in building environment –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 presents exemplary measurement results taken in Lublin region during various periods throughout a year.*
KEYWORDS: *control of heat processes, thermal conductivity, mathematic and physic modeling of heat transfer, temperature dynamics*

INTRODUCTION

The main purpose for fruit storage 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 ÷ +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 presented new concept of thermal analysis is derived from periodic character of temperature changes in storage environment. The analytical approach seems appropriate to obtain established purposes i.e.: the description of temperature changes and heat transfer within the chamber walls and its gaseous environment. The storage parameters of apple range is the following: temperature 1 – 3°C, oxygen (O_2) concentration 1,5 – 3%, carbon dioxide (CO_2) concentration 1-5%.

Observations of the ambient air temperature in Deblin and Lublin (and also in a large number of meteorological stations in all over the world, for example in Sophia - Anthipolis in France) showing, that the variations of the temperature from the heat by day to the cold by night and yearly changes from the cold of winter to the heat of summer may vary harmonically – figures 1. - 5. These variations of external temperature have influence upon the internal temperature, which depending upon the conductive heat transfer through walls of thermal technical spaces. By the suitable construction of the enclosure walls composed of several slabs of different

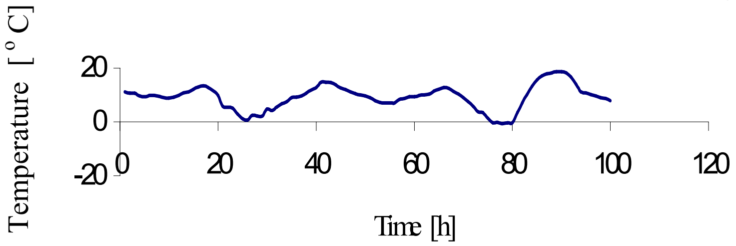

Figure1. Diagram of atmospherics temperature in the four days of April

thickness and conductivities we can obtain phase angle displacement (when the time lag attains twelve hours it is the best situation), which reduce the amplitude of internal temperature inside buildings.

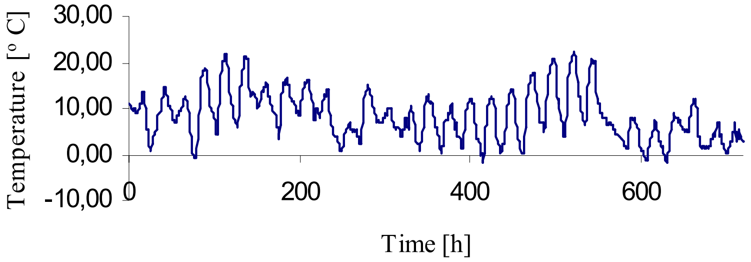

Figure 2. Diagram of atmospherics temperature in the month of April

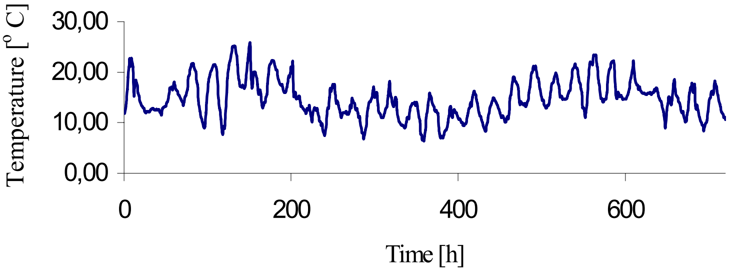

Figure3. Diagram of atmospherics temperature in the month of June

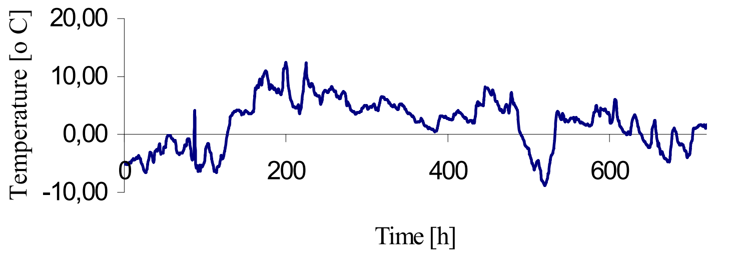

Figure4. Diagram of atmospherics temperature in December

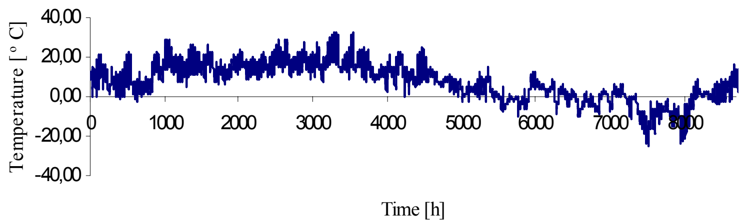

Figure5. Diagram of atmospherics temperature of year 2007 in Lublin

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. 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.

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 control systems it's 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 occurs in the direction of decreasing temperature because higher temperature is associated with higher molecular energy.

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.

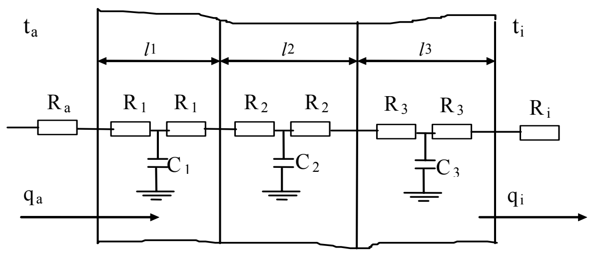

Figure 6. Model of wall composed of three layers in electrical analogy

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.

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

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. 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.

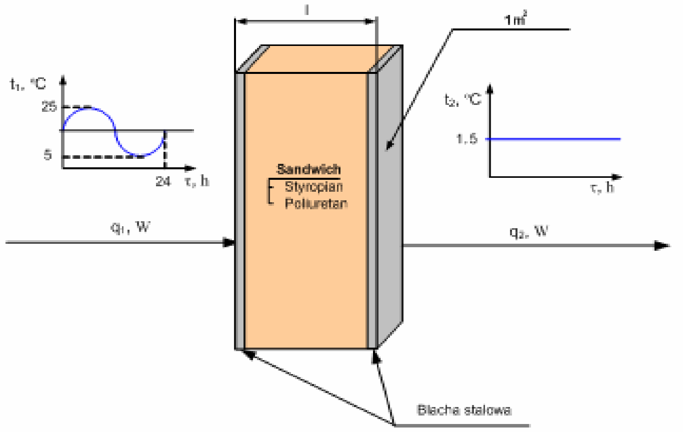

Figure 7. Ideal model of wall

These models we can confront with computer program modelica, which allow constructing the walls of technical chambers.

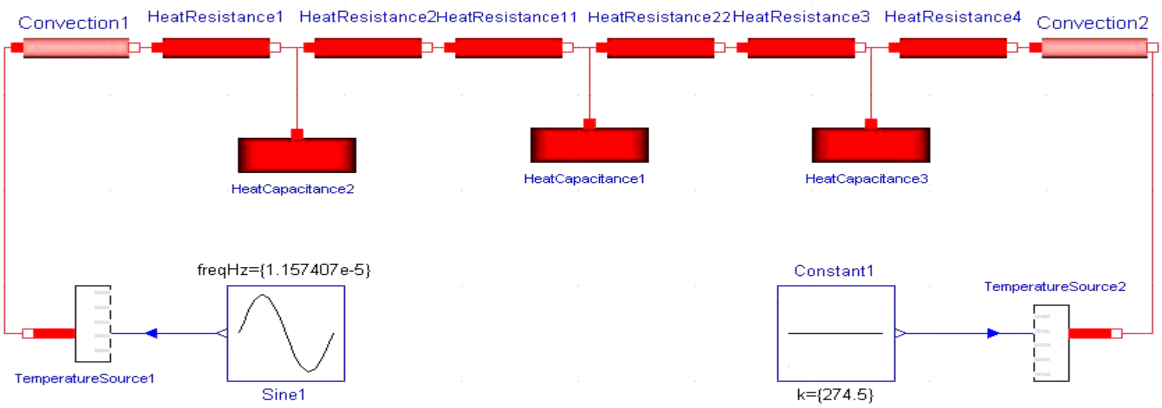

Figure 8. Block schema using electrical analogue

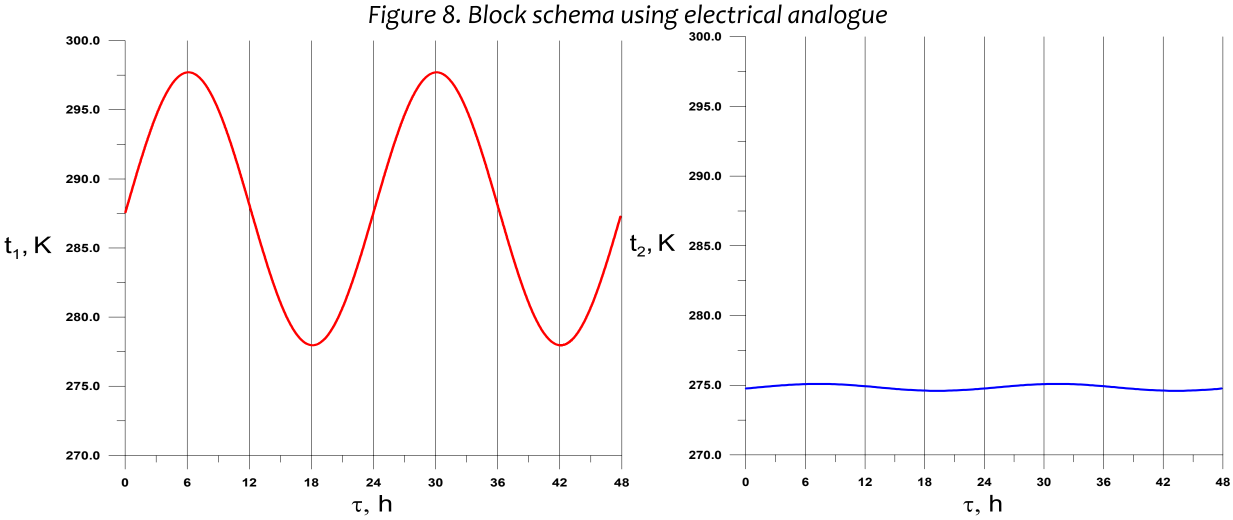

Figure 9. Periodically temperature signal on the wall

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.10). 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.

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.

Figure 10. Registering positions laboratory

Two fruit storages have been subjected to the analysis of temperature distribution on the surfaces of technical chambers (Fig. 11). 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 (Fig.12, 13.). 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.

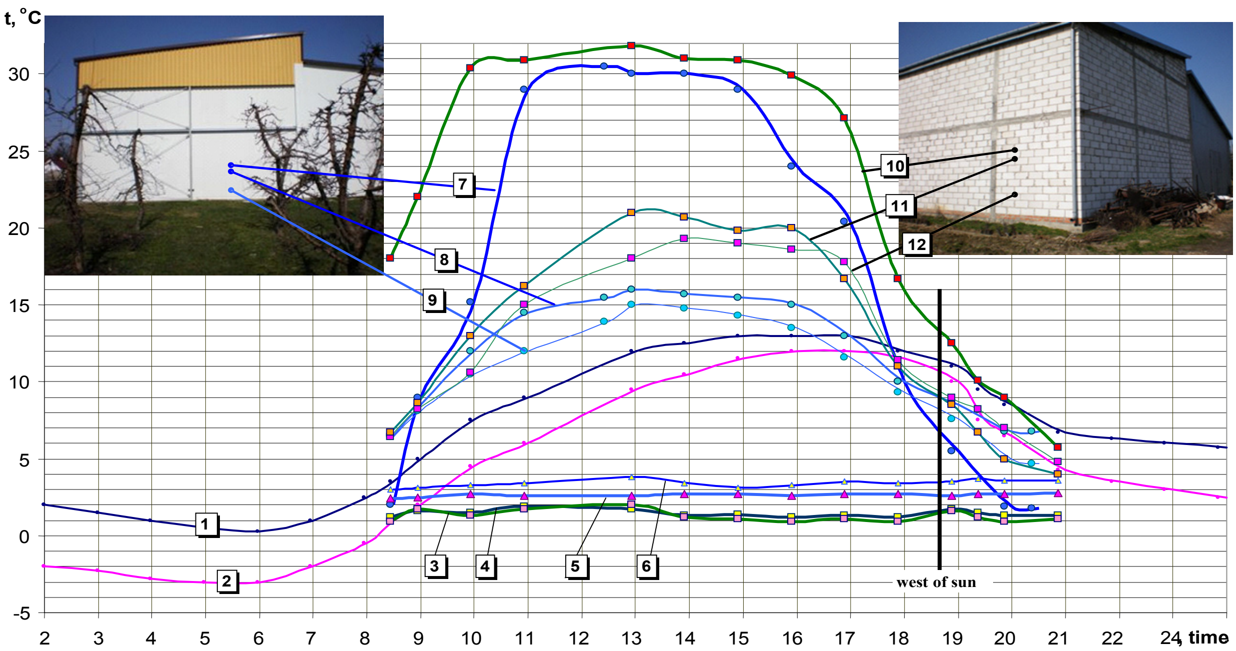

Fig. 11. Presentation of temperature field distribution on wall surfaces

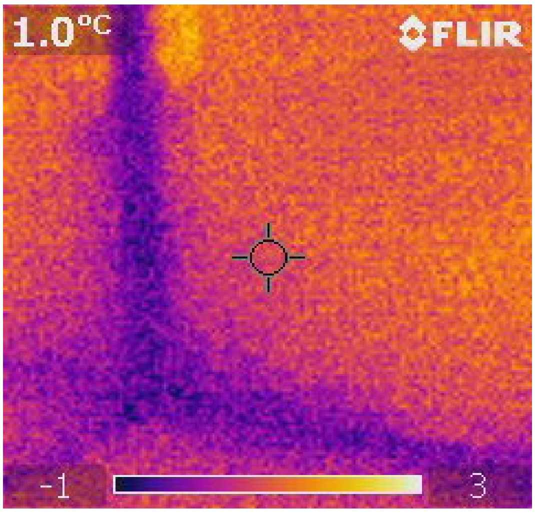

Fig. 12. Temperature field distribution on corner of wall

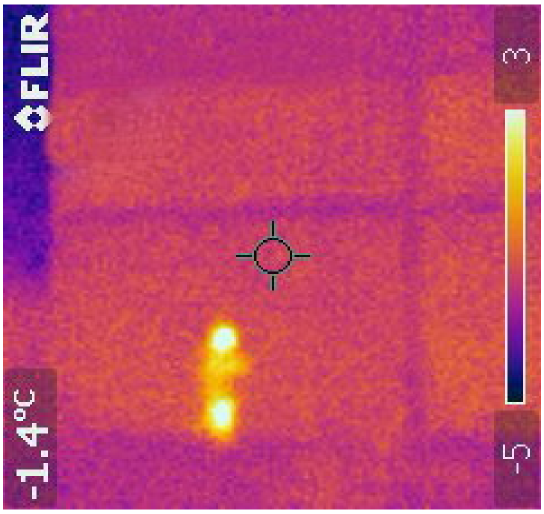

Fig.13. Temperature field distribution on wall surfaces

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.

CONCLUSIONS

The paper describes atmospheric temperature analysis and their variability in time in aspect of their influence upon the thermal technical chambers – fruit storages. 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. 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 fruit storage.

REFERENCES

[1.] Carlslaw,H., Jaeger,J. (1959) Conduction of heat in solids, Oxford University.
[2.] Takahashi,Y., Rabins,M., Auslander,D. (1976) Sterowanie i systemy dynamiczne, WNT, Warszawa.
[3.] Janczarek M., M. (1992) Methods concerning conductive heat transfers through walls of thermal technical spaces, MATAR ‘ 92 Prague, pp. 166-170.
[4.] Bulyandra O.F., Yancharek M.M.: (2005) Analiz peredachi teploti kriz zownischniu stinku skladskowo primischenia z urahowaniam dinamiki zmin atmosfernoi temperaturi – Harchowa Promislowist, nr 4. UDK 664(04)(082) – Kyiv.
[5.] Janczarek M., Skalski P., Bulyandra A., Sobczuk H. (2006) Przewodność cieplna zewnętrznych ścian budynków w aspekcie wilgotności i oszczędności energii, Rynek Energii nr 4 (65) Kaprint – Lublin.
[6.] Janczarek M., M. (2007) Energooszczędność eksploatacji obiektów budowlanych w aspekcie zmiennej temperatury atmosferycznej, Rynek Energii nr 1 (68) Kaprint – Lublin.
[7.] Janczarek M.M., Bulyandra O.F.: „Charakterystyki dynamiczne wpływu atmosferycznych zmian strumieni cieplnych na powierzchnie przegród komór obiektów technicznych" – Informatyka w technice. Lubelskie Towarzystwo Naukowe. str. 124 – 128. Lublin 2008.

[8.] ВИНОГРАДОВ-САЛТЫКОВ В. А., ЯНЧАРЕК М., ФЕДОРОВ В. Г., КЕПКО О. И.: ”ТЕПЛОМЕТРИЧЕСКОЕ ИССЛЕДОВАНИЕ ТЕПЛОЗАЩИТНЫХ СВОИСТВ ОГРАЖДЕНИЙ” – P. 116 – 123. INDUSTRIAL HEAT ENGINNEERING - INTERNATIONAL SCIENTIFIC AND APPLIED JOURNAL - VOL. 31, NR 4/2009 – KYIV, UKRAINE.
[9.] Janczarek M.M.: „Определение теплового баланса кладовых холодильных” – XVIII. международной научно-технической конференции – Донецк: ДонНТУ, 2011. Т. 4. ISDN 2079-2670.
[10.] Janczarek M.M.: „Eksploatacja technicznych obiektów budowlanych w aspekcie przejścia ciepła przez przegrody – Postępy Nauki i Techniki nr 9/2011. str. 112 -124. Politechnika Lubelska/Oddział SIMP w Lublinie.

ANNALS OF FACULTY ENGINEERING HUNEDOARA

– INTERNATIONAL JOURNAL OF ENGINEERING