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EVALUATION OF COLD STORAGE INSULATION BY THERMAL IMAGES ANALYSIS

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Abstract

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Thermal camera is useful tool to check the situation of cold storage insulation envolope and to determine spatial distribution of temperature. In this research, insulation of an experimental cold storage was checked by using thermal camera images. Experimental cold storage volume was 60 m^3. Granny Smith apple was stored. Storage temperature was +2^{o}C. Transmission heat was calculated as 18.95 kcal/day for the cold storage. According to the thermal image analysis, some insulation problems were determined around sliding door of cold storage.

Key words: cold storage, insulation, thermal image, thermal analysis

Introduction

When fruits and vegetables are harvested, they are cut off from their source of water and nutrition and soon start to deteriorate. They lose weight, texture, flavor, nutritive value and appeal. In other words, they lose quality and potential storage life. Both time and temperature are important factors in post-harvest product deterioration (Anonymous, 2001a). The optimum storage conditions for a product held in either short or long term storage depend upon the nature of the individual product, the length of time the product is to be held in storage and whether the product is packaged or unpackaged (Tastoush, 2000).

The use of infrared (IR) imaging is a valuable tool for inspecting and performing non-destructive testing of building elements, detecting where and how energy is leaking from a building's envelope, collecting data for clarifying the opretaing condition of hard to reach heating, ventilatinf ang air-conditioning HVAC) installations, identifying problems with the electrical and mechanical installations under full-load operating conditions. IR inspections involve the detection of IR electromagnetic radiation emmitted by the inspected object. The collected information can be used as part of other investigative procedures to identify potential problems, quantifyingpotential energy savings, Schedule interventions and set priorities for preventive and predictive maintenance or the need for immediate service to minimize the risk of failure (Balaras and Arigiriou, 2002).

Nowadays, there are systems that can be used effectively in outdoor and/or indoor building surveys; indication and monitoring of problems such as voids, detached areas, deposits of humidity, etc. However, the principal problem where infrared thermographic measurements are concerned is the emissivity-emittance of the material(s). Given that an infrared camera detects the radiation emitted by a material under investigation and renders this energy to a temperature-thermal image, the feature that describes the relation between the emitted radiation and the material's temperature, is termed as emissivity. Emissivity is actually a surface property that states the ability of the investigated material to emit energy. Correct emissivity values could provide valuable information concerning the interpretation of thermal images obtained from thermographic surveys (Avdelidis and Moropoulou, 2003).

Infrared thermography (IRT) is used at Onera in large facilities for boundary layer visualization and for heat flux assessment. Modern IR cameras and insulating paints enable efficient visualization of the laminar/turbulent transition region. This technique is now applied in large transonic test facilities. Heat flux assessment is one of the main purposes of hypersonic tests (Le Sant et al., 2002).

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The recent development of available cold storage materials for air conditioning application weere reviewed by Gang et al. (2012). According to the type of storage media and the way a storage medium is used, water and ice, salt hydrates and eutectics, paraffin waxes and fatty acids, refrigerant hydrates, microencapsulated phase change materials/slurries and phase change emulsions are separately introduced as suitable energy storage or secondary loop media. Water storage and static ice storage, which are already well-established technologies, have little need for further study. Dynamic ice slurry application is discussed especially for its generation method, relating to the efficiency and reliability of converting water or aqueous solution to ice crystals or ice slurry. Thermal and physicochemical properties of different phase change materials have been summarized including latent heat, thermal conductivity, phase separation, supercooling, and corrosion. In addition, the principle of the sorption cold storage is described and different kinds of working pairs are introduced. Relevant perspectives for commercialization of storage materials are discussed (Gang et al., 2012).

Thermal insulation is one of the most effective energy conservation for the cooling applications. For this reason, determination of the optimum thickness of insulation and its selection is the main subject of many engineering investigations. In their study, the optimum insulation thickness on the external walls in the cooling applications is analyzed based on two different methods used to determine annual energy consumption. One of the methods is the degree-hours method (Method 1) that is the simplest and most intuitive way of estimating the annual energy consumption of a building. The other is the method (Method 2) which using the annual equivalent full load cooling hours operation of system. In this paper, a Life Cycle Cost (LCC) analysis is used to evaluate accuracy of these methods, and the results are compared. The results show that the life cycle savings are overestimated by up to 44% in Method 2, while the optimum insulation thickness and payback period are respectively overestimated by up to 74% and 69% in Method 1(Keyfeci et al., 2013).

A new modeling method with the discrete ordinate (DO) model and GKT model was proposed to simulate the thermal insulation performance of a low temperature cold box. Experimental data from the thermal insulation experiment of a cold box were used to validate the model. The thermal insulation performance and the coupled radiation and conduction heat transfer were analyzed at various pressures, shield numbers and shield positions. The results confirmed that the thermal insulation performance can be significantly improved by the addition of a thermal insulation shield (Feng Yu et al., 2009).

This review presents the previous works on thermal energy storage used for air conditioning systems and the application of phase change materials (PCMs) in different parts of the air conditioning networks, air distribution network, chilled water network, microencapsulated slurries, thermal power and heat rejection of the absorption cooling (Al-Abidi et al., 2012).

A comprehensive analysis on the optimal control protocol to minimize the daily operating cost of an air-conditioning system in a 33 600 m^2 office building was presented by Kintner and Emery (1995). The system consists of two chillers, one designated for cold storage charging, the other for direct cooling, an air-handling unit, a cooling tower, and water pumps. This analysis determines the optimal protocol for indoor temperature and humidity control as well as operating point settings for the chiller control considering two thermal storage sources: (i) the thermal capacitance of the building, and (ii) a cold storage facility. The analysis is based on the thermodynamic modeling of the air-conditioning system including the thermal response of the building structure (Kintner-Meye and Emery, 1995).

Fukuyo et al. (2003) developed a new air-supply system for improving the thermal uniformity and the cooling rate inside a fresh food cabinet of a household refrigerator. For these purposes, they added a blower and jet slots to a conventional cooled air supply system. The jet slots circulate the air inside the cabinet at a higher velocity to optimize airflow velocity and its distribution.

Wherever necessary, the emissivity values of the investigated materials were taken into account, after their determination in the laboratory on representative samples. The outcome of this work provides strong evidence that infrared thermography is an effective technique for the evaluation of historic buildings and site (Avdelidis and Moropoulou, 2004).

Chieh et al. (2004) worked on, experimentally and theoretically, the thermal performance of cold storage in thermal battery for air conditioning. Thermal battery utilizes the superior heat transfer characteristics of heat pipe and eliminates drawbacks found in the conventional thermal storage tank.

Neto et al. (2006), among the different existing methods to characterise the aerodynamic sealing effect provided by an air curtain device placed over the opening between two contiguous compartments, infrared hermography has revealed to be a very useful tool. Good concordance between the thermographs obtained with this technique and the temperature fields measured for the same plane with a rack of 16 low velocity omni-directional thermal anemometer probes allowed its validation. Various elucidative examples of the use of this technique as a complementary tool for analysis and visualization of the complex physical phenomena occurring for the studied flow are presented in this article.

An infrared inspection was performed in accordance with International Standard ISO 6781-1983 (E) using a FLIR Systems Thermovision® 550 infrared imaging system. Based on a qualitative interpretation of the thermal scans, wall areas were selected for invasive examination and correlated with moisture-meter readings. Observations were photographed and the free water content of building components was measured. These investigations demonstrate that qualitative infrared thermography coupled with an informed visual inspection and quantitative substantiation using moisture (Kominsky et al., 2006).

By using quantitative thermal scanning of building surface structures, it is possible to access the temperature field. For further calculation of the heat flux exchanged by these structures with the environment, one must quantify as finely as possible the temperature field on the bodies surfaces. For this purpose we have to take into account that real bodies are not black, who implies that a part of the ambient radiation received by the infrared camera detectors is reflected radiation. In this paper, we present a method to quantify the reflected flux by using an infrared mirror, which allows large surface temperature measurements by infrared thermography under near-ambient conditions with improved accuracy. In order to validate the method, an experimental study was carried out on a multi-layer wall, which simulated an insulation default. A good agreement was noticed between the thermocouple temperatures and the infrared corrected ones. Then, the method is applied to outdoor measurements (Datcu et al., 2005).

A methodology, based on the solution of the inverse heat transfer problem, for the detection and evaluation of flaws in buildings is discussed. The temperature varying in space and time is recorded by thermographic equipment and each point belonging to the inspected area is analysed quantitatively. Data are processed to give a map of defects of the wall, based on the most suitable local thermal parameter. Experimental results are reported for insulation deficiencies and thermal bridges evaluation, air leakage detection and moisture content mapping (Grizento et al., 1998)

In the this work, the emissivity values of numerous building and structural materials, such as stones, plasters, mortars, marbles and mosaics' tesserae, were calculated in accordance with the relevant ASTM standard approach or by the use of an empirical laboratory developed approach. The obtained emissivity values were discussed and explained in terms of the approach used the wavelength effect, as well as the materials surface condition (Moropoulou and Avdelidis, 2002).

Agricultural products must be protected after harvesting. One of the methods of protection is cold storage widely used in the world. A cold storage includes building and cooling system elements. Cooling system creates cold air and cold air ventilated in the cold storage. Designing and construction of any cold storage are important. Cold air must be protected in the cold storage to protect agricultural products. After construction of a cold storage, thermal camera is useful tool to check the situation of insulation envolope of cold storage. Insulation of experimental cold storage evaluated in this article by using thermal camera images.

Materials and Methods

Cold storage, apple, thermal camera were use as materials in this research.

Cold storage

This study was carried out in a cold storage which sandwich panels were used for insulation (Figures 1 and 2). Granny Smith variety apple were stored. Cold storage volume was 60 m^3. Cooling capacity was 15kW and cold air ventilated into cold storage by inlet air channels. Consequently, homogen distribution of cold air establish in cold storage

Sizes of the cold storage were 4 x 5 x 3 m (in length, width and height) (Figure 1.). Working temperature and relative humidity varied between 0°C /+30°C and 55-95%, respectively. Tolerance of relative humidity was ± % 5 and ± 0.5°C.

Walls, ceiling and base of the cold storage established with prefabricated sandwich panel of polyurethane. Heat transfer coefficient of polyurethane was 0.025 $Wm^{-1}K^{-1}$ due to DIN 4108. In addition, surface of the wall and ceiling panels were covered with galvanised steel sheet painted polyester based paint in 0.5 mm thickness. Ground panels were produced from 9 mm plywood with filled polyurethane and covered one side with 0.5 mm stainless steel and another side with 0.5 mm galvanised steel plate. Panel thickness was 80 mm.

Sizes of the door of cold storage were 200 x 200 (h) cm and type of the door was sliding door. Surfaces of the door were covered same materials of panels.

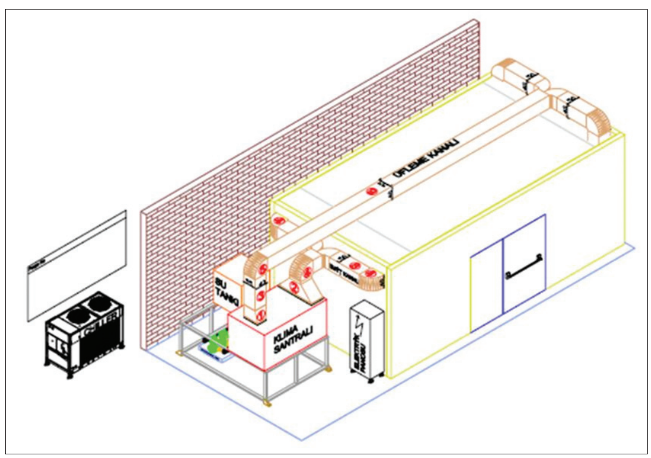

Fig. 1. Experimental cold storage

A) General view

B) Sliding door

C) inside of the cold storage

D) Air conditioning unit

Fig. 2. General view of experimental cold storage pictures

Air conditioning system includes an axial type ventilator which its flow rate was 8 000 m^3h^{-1}. Air flow rate can be arranged by inverter. Cooling system capacity was 10 kW, heating system capacity was 5 kW.

Cold air ventilation and suction channels were made of galvanised steel plates.

An automatic control system used to change ambient temperature and relative humidity of the cold storage (Figure 3).

Apple

Granny Smith apple variety was stored (Figure 4). The cold storage was full of apple when the thermal pictures were taken. Total amount of the apple in the cold storage was 2500 kg.

Thermal camera

Testo 881-3 thermal camera was used to take photos (Figure 5).

Some technical specifications of Testo 881-3 are; high-quality wide-angle lens 32° x 23°, detector 160 x 120, NETD < 80 mK, minimum focus distance 10 cm, integrated digital camera with power LEDs for illumination, dynamic motorfocus, isotherm, min/max on area, audio comments, display of surface moisture distribution, high-temperature filter (optional)

Transmission heat calculations and insulation

Transmission heat (q_c). The calculation of the transmission heat created by walls, floor and ceiling requires information on thickness and type of isolation material used in construction of cold room, construction of building, physical specifications

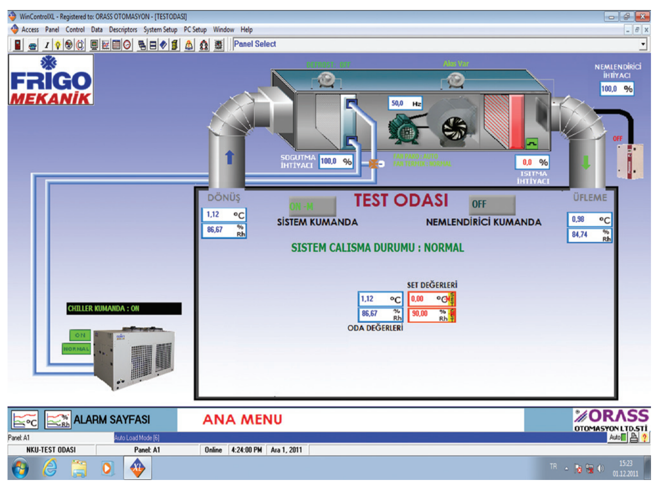

Fig. 3. Control panel of the cold storage

Fig. 4. Granny smith apple and boxes in the cold store

of the cold storage volume, inside and outside environment temperatures, and the effect of sunshine. Following equations were used to calculate transmission heat (Anonymous, 1996; Anonymous, 2001b; Akdemir, 2008; Taner, 2005,).

$$q_c = K.A(t_{out} - t_i) \tag{1}$$

q_c = transmission heat at flat surface (kCal)
K= Total heat transmission coefficient (kCal/hm^{2}C)
A= Area of heat transmission (m^2)
t_o= Temperature of outside or neighbour volume (^{o}C)
t_i= Inside volume temperature (^{o}C)

$$\frac{1}{K} = \frac{1}{\alpha_i} + \sum_{i=1}^{n}\frac{x_i}{\lambda_i} + \frac{1}{\alpha_o}, \tag{2}$$

Where:
α_o= Coefficient of heat transmission of outside surface (kCal/hm^2 ^{o}C)

Fig. 5. Testo 881-3 Thermal Camera

α_i= Coefficient of heat transmission of inside surface (kCal/hm^2 ^{o}C)
x_i = Material thickness (m)
λ_i = Thermal conductivity (kCal/hm ^{o}C)

Data used for calculation are given in Table 1.

Thermal Camera Images

Surface temperature was measured by thermal camera when the experimental cold storage was full, ambient temperature +2^{0}C. Thermal images were taken from outside of the cold storage. Temperature distribution of the walls were

Table 1
Temperature, relative humidity and heat transmisision coeficient of cold storage

	Wall	Temperature (t), °C	Relative humidity (RH), %	Coefficient of heat transmission, kCal/hm^2 ^{o}C	Thermal conductivity, kCal/hm^{o}C
Neighbor volume	IW-1	35			
	IW-2	35			
	IW-3	35			
	IW-4	35			
Room (R)		0	90		
Floor (FL)		25			
Ceiling (CL)					
Polyurethan					0.021
Outside surface				18	
Inside surface				18	

determined and evaluated. Thermal pictures were taken from estimated heat leakage areas of the cold storage.

Results and Discussions

Transmission heat

Calculation results of the transmission heat for the experimental cold storage are given in Table 2.

In the cold storage polyurethan were used for insulation at all surfaces. Total transmission heat was 18.959 kCal/day.

Cold Storage Thermal Images

Thermal camera pictures of wall which door located on it were given in Figures 6, 7, 8, 9 and 10.

Temperature was changed between 2.4^{0}C according to the pictures.

It can be seen that temperature around sliding part of the door is higher than that other parts because connections of door.

Temperature of the sliding system of the door was higher than other surface of the wall (Figure 10).

In this type of the cold storage, air is cooled outside and ventilated it into cold room. Temperature distribution of the air channels is given in Figure 11. Temperature varied between 2.5^{o}C ...4.0^{o}C.

Conclusions

Thermal camera images are usefull tool for evlatuation cold storage. Insulation problems can be determined and evaluated by using thermal images. Spatial distribution of temperature of the experimental cold storage was determined. According to the thermal analysis results; there were insulation problems especially coonection areas of the sliding door. Temperature values on the thermal camera pictures showed the heat leakage area to focus on it. In addition, thermal analysis may help to determine optimum insulation thickness.

Acknowledgements

We would like to thank to TUBITAK to support establish of this cold storage.

Table 2
Size and heat gaines of cold storage walls, ceiling and floor

	W, m	L, m	A, m^2	T, m	Thermal conductivity, kCal/hm^{0}C	K, kcal/h^{0}C m^2	Δt ^{0}C	Heat gain, kcal/h	Daily heat gain, kcal/days
IW	4.00	3.00	12.00	0.08	0.021	0.2551	35	107	2.571
IW	4.00	3.00	12.00	0.08	0.021	0.2551	35	107	2.571
IW	5.00	3.00	15.00	0.08	0.021	0.2551	35	134	3.214
IW	5.00	3.00	15.00	0.08	0.021	0.2551	35	134	3.214
CL	4.00	5.00	20.00	0.08	0.021	0.2551	35	179	4.285
FL	4.00	5.00	20.00	0.08	0.021	0.2587	25	129	3.105
Total Trasmıssion Heat Gain (Kcal/days)									18.959

W: Width, L=Length, A: Area, T: Thickness

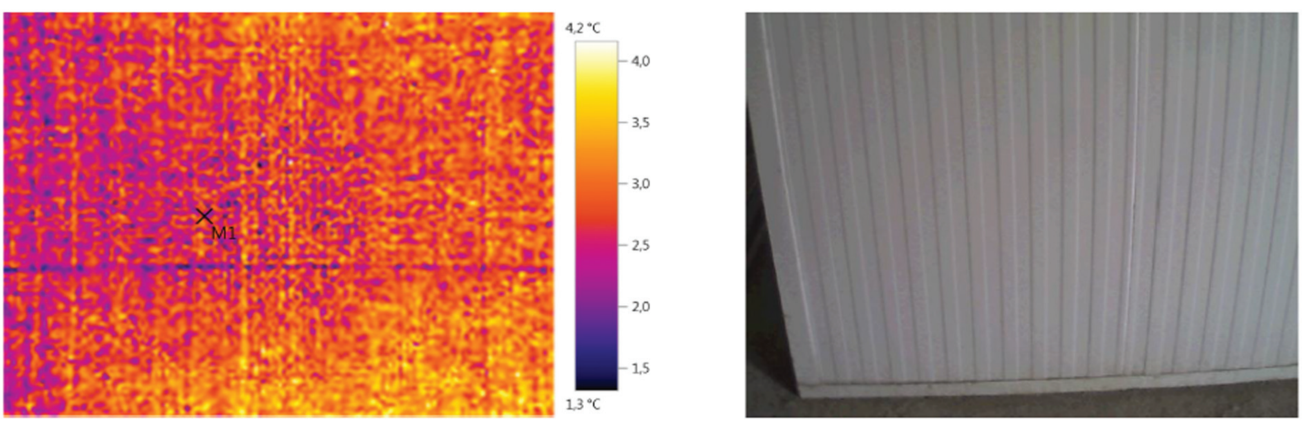

Fig. 6. Left side of front walls of cold storage

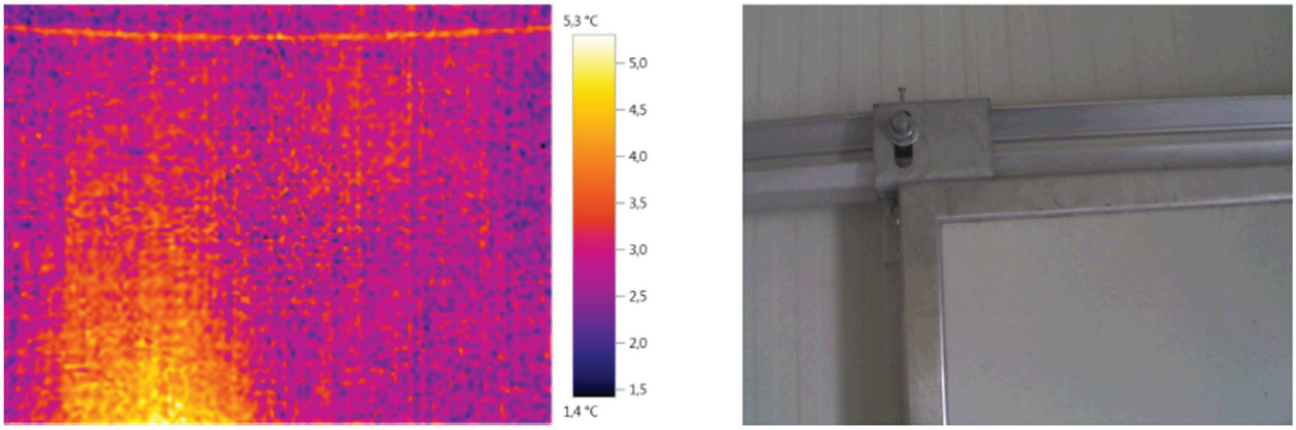

Fig. 7. Top of the door

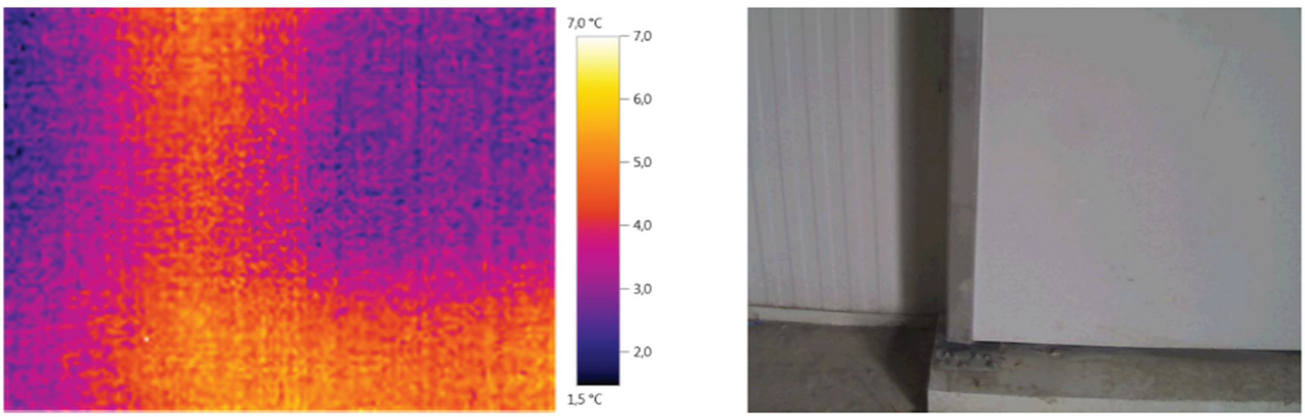

Fig. 8. Left corner of the door

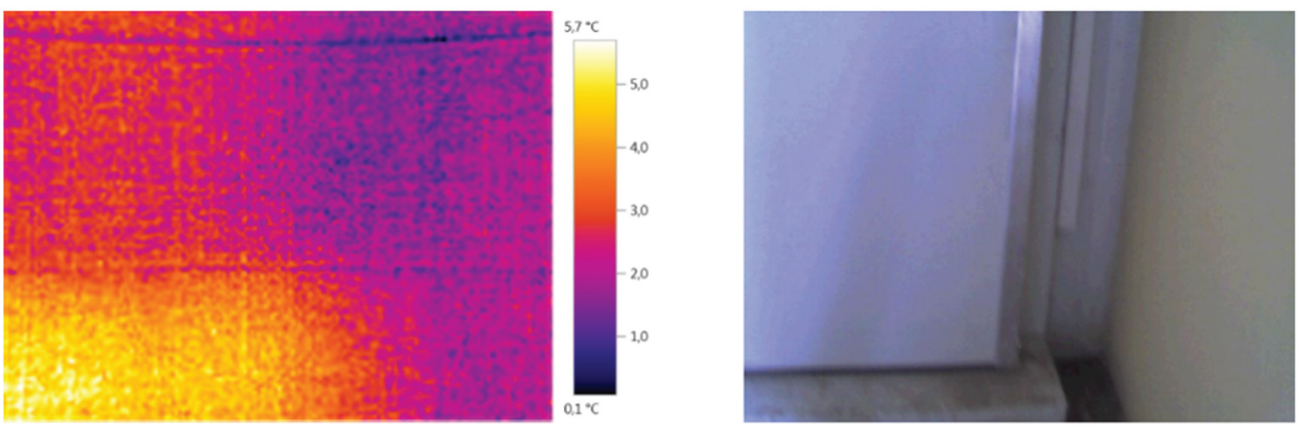

Fig. 9. Right corner of the door

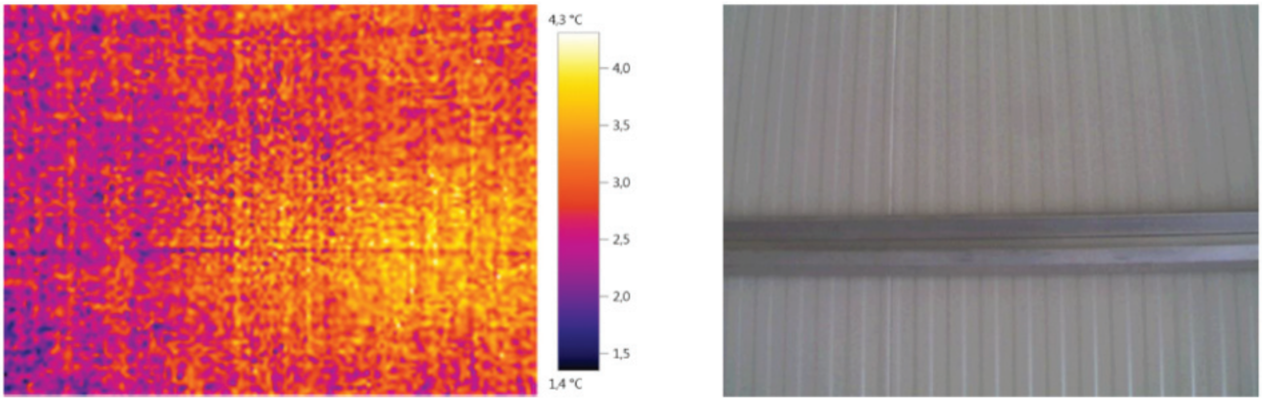

Fig. 10. Sliding system of the door

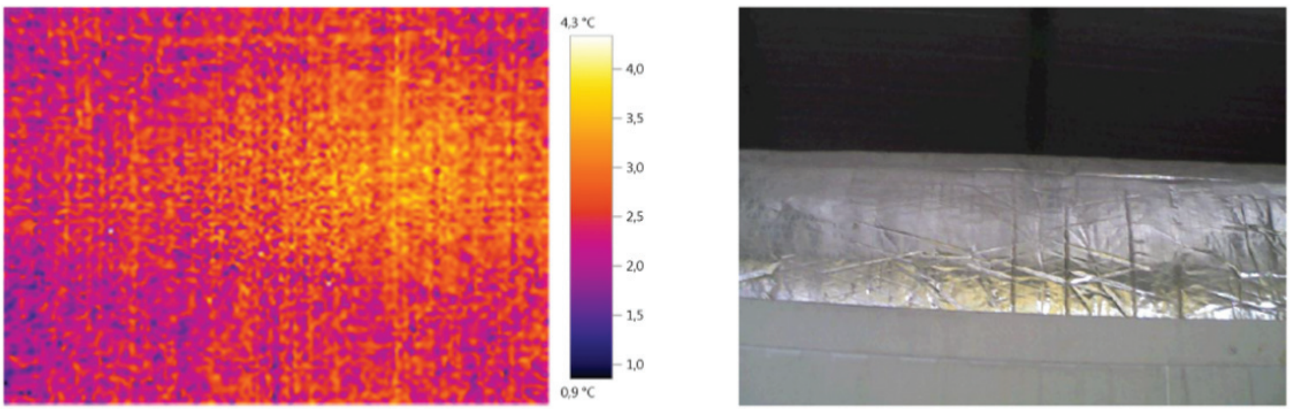

Fig. 11. Cold air ventilation channels

References

A. Al-Abidi, A., Bin Mat, S., Sopian, K.., Sulaiman, M. Y., Lim, Abdulrahman Th. C. H., 2012. Review of thermal energy storage for air conditioning systems. *Renewable and Sustainable Energy Reviews,* **16**: 5802–5819.

Akdemir, S., 2008. Designing of Cold Stores and Choosing of Cooling System Elements. *Journal of Applied Sciences*, **8**: 788-794

Anonymous, 1996. ASHRAE –Fundamentals, Part 3- Heat transition, Association of Installation Engineers, *Technical Publications* No:2, Ankara

Anonymous, 2001a. Small Scale On–Farm Cold Storages, British Columbia Ministry of Agriculture, http://www.agf.gov.bc.ca/resmgmt/publist/300Series/306300-3.pdf (acces date: 17 Feb.2013)

Anonymous, 2001b. Cooling Installation, Chamber of Mechanical Engineers (MMO) Publication No:MMO/2001/295, 192 p., Ankara.

Avdelidis, N. P. and A. Moropoulou, 2003. Emissivity considerations in building thermography. *Energy and Buildings*, **35:** 663-667.

Avdelidis, N. P. and A. Moropoulou, 2004. Applications of infrared thermography for the investigation of historic structures. *Journal of Cultural Heritage*, **5**: 119–127.

Balaras, C. A. and A. A., Argiriou, 2002. Infrared thermography for building diagnostics. *Energy and Buildings*, **34:** 171-183.

Chieh, J-J., Lin, S-J. and Chen, S-L., 2004. Thermal performance of cold storage in thermal battery for air conditioning. *International Journal of Refrigeration*, **27**: 120–12.

Datcu, S., L. Ibos, Y. Candau and S. Mattei, 2005. Improvement of building wall surface temperature measurements by infrared thermography. *Infrared Physics and Technology*, **46**: 451–467.

Feng, Yu, Yanzhong Li and Yinhai Zhu, 2009. Numerical and experimental investigation on the thermal insulation performance of low temperature cold box. *International Communications in Heat and Mass Transfer*, **36**: 908–911.

Fukuyo, K., T. Tanaami and H. Ashida, 2003. Thermal uniformity and rapid cooling inside refrigerators. *International Journal of Refrigeration*, **26**: 249–255.

Gang, L., Y. Hwang and R. Radermacher, 2012. Review of cold storage materials for air conditioning application. *International Journal of Refrigeration*, **35:** 2053-2077.

Grinzato, E., V. Vavilov and **T. Kuppinen,** 1998. Quantitative infrared thermography in buildings. *Energy and Buildings*, **29**: 1-9.

Kayfeci, M., A. Keçebasand E. Gedik, 2013. Determination of optimum insulation thickness of external walls with two different methods in cooling applications. *Applied Thermal Engineering,* **50**: 217-224.

Kintner-Meyer, M. and A. F. Emery, 1995. Optimal control of an HVAC system using cold storage building thermal capacitance. *Energy and Buildings,* **23**: 19-31.

Kominsky, J. R., J. Luckino, S. Thomas and F. Martin, 2006. Passive Infrared Thermography—A Qualitative Method for Detecting Moisture Anomalies in Building Envelopes, http://www.tedfordpond.com/wp-content/uploads/article_1181567898.pdf (acces date: 16.02.2013)

Le Sant, Y., M. Marchand, P. Mıllan and J. Fontaine, 2002. An overview of infrared thermography techniques used in large wind tunnels. *Aerospace Science and Technology*, **6** (5): 355-366.

Moropoulou, A. and N. P. Avdelidis, 2002. The role of emissivity in infrared thermographic imaging and testing of building and structural materials, in X.P.V. Maldague. Thermosense XXIV, SPIE Press, Orlando, Florida, USA, pp.281-287.

Neto, L. P. C., S. M. C. Gameiro and J. J. Costa, 2006. On the use of infrared thermography in studies with air curtain devices. *Energy and Buildings,* **38**: 1194–1199.

Taner, K., 2005. Refrigeration, Nobel Press, **ISBN:** 975-591-780-2, Ankara, Turkey.

Tashtoush, B., 2000. Natural losses from vegetable and fruit products in cold storage. *Food Control,* **11**: 465±470.

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