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В докладах представлены результаты научных исследований, посвященные холодильным компрессорам, теплообменным аппаратам, системам автоматизации, цифровизации, технологиям холодильного хранения и переработки плодов и овощей и практическим внедрениям, представленные из Казахстана, России, Украины, Германии, Австрии, Беларуси, Кыргызстана, Голландии, Швейцарии и Узбекистана. Сборник рассчитан на специалистов и ученых, работающих в областях холодильной техники, пищевой и химической промышленности, а также на специалистов систем кондиционирования воздуха и жизнеобеспечения жилых, коммерческих зданий и спортивных комплексов.

The proceedings present the results of scientific research on refrigeration compressors, heat exchangers, automation systems, digitalization, refrigeration storage technology and the processing of fruits and vegetables and practical implementations submitted from Kazakhstan, Russia, Ukraine, Germany, Austria, Belarus, Kyrgyzstan, Holland, Switzerland and Uzbekistan. The proceedings are devoted to professionals and scientists working in the fields of refrigeration, food and chemical industries, as well as to specialists in air conditioning systems and life support of residential, commercial buildings and sports complexes.

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FIELD MEASUREMENTS AND INVESTIGATION OF SUPERMARKET REFRIGERATION EQUIPMENT

ПОЛЕВЫЕ ИЗМЕРЕНИЯ И ИССЛЕДОВАНИЯ ХОЛОДИЛЬНОГО ОБОРУДОВАНИЯ ДЛЯ СУПЕРМАРКЕТА

Konstantinov I.^a

Khmelniuk M.^b, Doct. Tech. Sc., professor

Yakovleva O.^c, Cand. Tech. Sc., associate professor

Odessa National Academy of Food Technologies,
st. Kanatna 112, Odessa, 65039, Ukraine

E-mail: a – ikonstantinov9@gmail.com; b – hmel_m@ukr.net ; c – osarja@gmail.com

Abstract

Supermarket owners are looking for commercial refrigeration equipment in order to reduce electricity costs. With advancement in technologies, companies are moving towards introducing smart refrigeration system equipped with sensors. These sensors help in controlling the temperature and also provides temperature monitoring of refrigeration units. Low-power wireless solutions are also being developed, eliminating the cost of inaccurate and manual monitoring of refrigerator units. Persistence Market Research anticipates the global commercial refrigeration equipment to experience a steady growth throughout the forecast period from 2017 to 2026. The global commercial refrigeration equipment market is also projected to be valued at the US\$ 45,913.5 million revenues towards the end of the forecast period. This study is based on field measurements which were carried out in "JUKA-Invest" LTD laboratory. A number of experiments are carried out over pilot units and the detected temperatures were validated. The research site is developed by specifications, guidelines or characteristics that can be used consistently to ensure that materials, products, processes and services are fit for their purpose in accordance with ISO 23953-2: 2015 (E). Pilot Units are equipped with a modern data monitoring system. All equipment has been certified and complies with international standards. This part of the study investigates the performance of the freezer compartment M400S+. Using the field measurements, low temperature level cooling demands and COPs are calculated for peak loads, filtered and averaged to monthly values. The temperature fields are determined taking into account the features of the unit design, revealing the disadvantages and advantages for tested pilot unit. The obtained study results make it possible to determine the thermal fields for commercial refrigeration equipment, to determine the places of excessive thermal load and the ability to collect the input data to start the creation of a

single model for calculating the commercial refrigeration equipment for low temperature units.

Аннотация

Владельцы супермаркетов подбирают коммерческое холодильное оборудование таким образом, чтобы снизить расходы на электроэнергию. С развитием технологий компании переходят на интеллектуальные системы охлаждения, оснащенные датчиками. Эти датчики позволяют поддерживать температуру и обеспечивают мониторинг температуры в холодильных установках. Были разработаны беспроводные решения, исключая затраты на неточный ручной мониторинг состояния холодильных установок. Компания «Persistence Market Research» ожидает, что мировой рынок коммерческого холодильного оборудования будет стабильно расти в течение прогнозируемого периода с 2017 по 2026 год. По прогнозам к концу указанного периода размер мирового рынка коммерческого холодильного оборудования будет на уровне 45 913,5 млн. долларов США. Данное исследование основано на результатах полевых измерений, которые проводились в лаборатории "JUKA-Invest". Ряд экспериментов проводился на пилотных установках, на которых были подтверждены полученные температуры. Методика исследований разработана в соответствии со спецификациями, руководящими принципами или характеристиками, которые могут последовательно использоваться для обеспечения соответствия материалов, продуктов, процессов и услуг их назначению согласно ISO 23953-2: 2015 (E). Пилотные установки оснащены современной системой мониторинга. Все оборудование сертифицировано и соответствует международным стандартам. В части исследования рассматривается производительность морозильного отделения M400S+. На основе результатов полевых измерений были рассчитаны тепловая нагрузка и коэффициент COP при низкой температуре и наиболее тяжелых условиях, далее произведена фильтрация данных и усреднение до месячных значений. Температурные поля определены с учетом особенностей конструкции холодильной установки, выявлены недостатки и преимущества для тестируемой пилотной установки. Полученные результаты исследований позволяют определить тепловые поля для торгового холодильного оборудования, определить места поступления чрезмерной тепловой нагрузки, и дают возможность сбора входных данных, чтобы приступить к созданию единой модели для расчета торгового холодильного оборудования для низкотемпературных холодильных установок.

1. Introduction

The commercial refrigeration sector is moving forward with particular variability, quickly, due to government environmental regulations (Ukraine is trying to change current position and to meet global requirements according environmental standard deployment, protocols and commitment fulfillment) and the pushing on the market low-GWP refrigerants. One more issue is leading to change commercial refrigeration sector may come down to demographics. Global statistics demonstrate that young people are all the time more moving to tightly populated cities where they may not need any personal transport to get all over the place. So they will not have arranged right to use the suburban megastores, that is way supermarket holders will be expected start opening smaller stores in urban areas in order to provide service to this type of customer. And, again, self-contained refrigeration cases may be a good solution, particularly if a supermarket is taking over an existing building that offers less flexibility with the layout.

Manufacturers are responding by rolling out a wide array of new equipment that utilizes all types of refrigerants, providing end users with a number of new options to consider. Below are some of the products that manufacturers have recently introduced. Commercial refrigeration equipment is used to store and display chilled or frozen goods for customer purchase at food retail and service establishments (supermarkets, convenience stores, commissaries, hospitals, restaurants, cafeterias etc.) [1]. Equipment which is common used can be classified into three main system types: stand-alone or self-contained refrigeration systems, remote condensing unit systems, and multiplex rack systems (i.e., supermarket systems). HFC emissions from commercial refrigeration equipment will account for approximately 26% of global HFC emissions in 2020 [2,3]. HFC refrigerant emissions from

10. Figures indicating that the humidifier and dryer were attached.

11. Information about the time remaining until the end of the test case and the test number that is being performed. If there is no test has been added at this time, the field is empty.

12. Measurement of power.

This system includes a thermosensitive element for measuring ambient temperature, 12 thermosensitive elements for temperature monitoring in the course of experiments, a humidity sensor for measuring humidity. All sensors have a refresh rate of 0.5 seconds, and a measurement error of 0.2°C.

Also, this system includes an additional software "TEST" to output the results to the PC monitor.

To determine the airspeed of air, a thermoanemometer «testo 405i» with two sensitive elements (airspeed and temperature) is used with the additional software for data output «Smart probes».

Measurement diapason

0 ... 15 m / c

(Indication 0 ... 30 m / c)

-20 ... + 50 ° C

Error

± (0,1 m/c + 5% from changing. The data are presented in diapason: 0 ... 2 m/c)

± (0,3 m/c + 5% from changing. The data are presented in diapason: 0 ... 2 m/c)

± (0,3 m/c + 5% from changing. The data are presented in diapason: 2 ... 15 m/c)

For the data collection low-temperature unit is used, M400S+ model. Taking into account commercial refrigeration systems purpose, it should be noted that there is no any difference with other M400 models which can have impact on system performance and will be under consideration.

Low-temperature unit under investigation work on R404A refrigerant, have compressor with a capacity of 240W, steel condenser tube 22 m. length and 4.7 mm in diameter, aluminum tube of evaporator 28.8 m. length and 8 mm diameter, a capillary tube of 3.3m. length and an internal diameter of 0.9 mm, a heat exchanger for removing overheating from a galvanized tube with a 4.7mm diameter and 4.36 m. length, and a recuperative heat exchanger a pipe-in-pipe type. This model is intended to work within third climatic class, at an ambient temperature of 25°C with 60% related humidity.

2.1 Study conditions

Since this class of refrigeration equipment is not stationary, and may be placed in different temperature-humidity conditions, there are nine predetermined climatic classes (environmental parameters). The most widespread climatic classes used in the territory of Ukraine and Europe are Classes No.3 t-25°C; 60% RH, and No. 7 t-35°C; 75% RH.

The temperature in the refrigeration unit corresponds to the product storage temperature. Most form refrigerated display cases are intended for storing a frozen product (ice cream, frozen vegetables and fruits, semi-finished products, etc.) and corresponds to the temperature level -18°C. ... -24°C.

Table 1 – Climatic Classes

Climate Class	Conditions			
	Temperature of dry-bulb thermometer	Related humidity	Dew-point	Mass of water vapor in dry air
№ п/п	°C	%	°C	g/kg
0	20	50	9,3	7,3
1	16	80	12,6	9,1
2	22	65	15,2	10,8
3	25	60	16,7	12
4	30	55	20	14,8
6	27	70	21,1	15,8
5	40	40	23,9	18,8
7	35	75	30	27,3
8	23,9	55	14,3	10,2

3. Results and Discussion

3.1 Temperature data on glass doors of refrigerated display case.

When considering the design of the refrigerated display case and the placement of the container, it was defined that the air volume between the glass and the loading line is “dead” volume (the air volume which is in between loading line to the crown) behave itself as a heat insulating layer, therefore the heat flux will be accepted as heat transfer from the “dead” air volume into the air of the “useful” volume (the volume used for loading products and is determined by the height of the cage from the bottom to the loading line).

Due to the fact that the display case has radial glass doors arranged at an angle, it was decided to determine the temperature change as a function of the height of the glass and determine the average temperature, place 12 temperature sensors on the area of the doors.

Taking in to account above features, for conducted research in laboratory the following temperatures in the refrigerated display case is defined (Figure 2 and Figure 3):

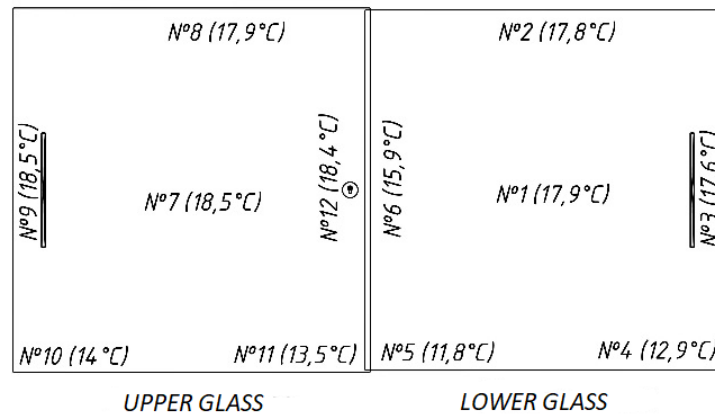


Figure 2 – The placement of thermometers and temperature indicators on glass doors

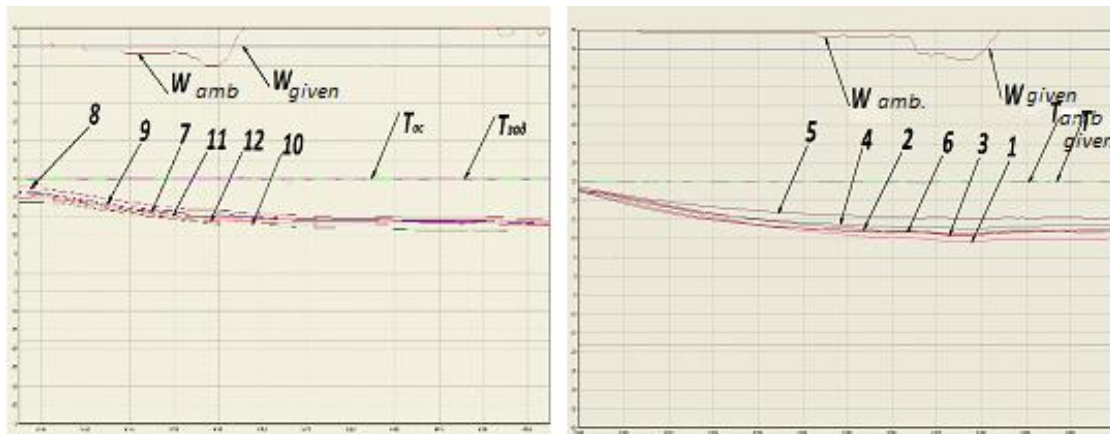


Figure 3 – Schedule of time indications on glass sections

W_{amb} – related humidity; W_{given} – given related humidity; T_{amb} – ambient temperature; T_{given} – given ambient temperature; 1;2;3;4;5;6;7;8;9;10;11;12 - the numbering of the graphs according to the placement on the glass doors

The results of the analysis are shown a maximum temperature drop up to 6.7°C. This indicates the temperature dependence on the height of the sensitive element location on the glass with the natural air movement in the pilot plant.

3.2 Temperatures in the shell in the condenser zone and in the compressor compartment

When considering the heat inflow, you must note the specifics of the particular unit design. Since the condenser is located in the interior of the machine, the wall temperature in the condenser

zone is equal to the condensing temperature; part of the outer shell will heat the condenser, and therefore, in these zones, the temperature will be close to the arithmetic mean between the ambient temperature and the condensing temperature, and the temperature from the side the compressor compartment will be 2-5 °S higher than the temperatures on other walls due to the temperature of the compressor and pre-condenser (Fig. 4., Fig.5).

And since the compressor compartment contains an electric motor with a damper to remove heat from the pre-condenser and cooling the compressor, the temperature in this volume will be significantly higher.

Taking into consideration the design of the refrigerated display case and the site of the winding condenser coil, the logical conclusion is that in the zone of condenser placement on the shell, temperature will be significantly higher than the ambient temperature, and assumed the thermophysical properties of the material, the temperature will spread over the shell.

In zones distant from the condenser, due to a significant difference between the temperature at the interior of the examined object and temperature in the cooled volume, taking into account the insulation thickness, the temperature may fall below the ambient temperature.

Considering the location of the refrigerating system elements in the compressor compartment, it can be concluded that due to the heat inflow from the heat exchanger to remove the overheating of the compressor, in the volume of the compressor compartment the temperature will be significantly higher, and due to the dynamic air movement the temperature is equal to all areas.

During the investigation, temperature sensors were installed in height ribs fixed with aluminum tape HPX ALU / PET50100 at a distance of 100 mm and was insulated from external heat inflow by the insulating tape Insul 50*3mm.

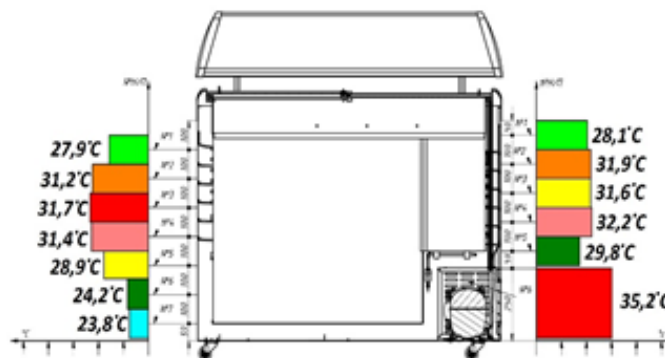


Figure 4 – Temperature reading in the shell of the refrigerated display case.

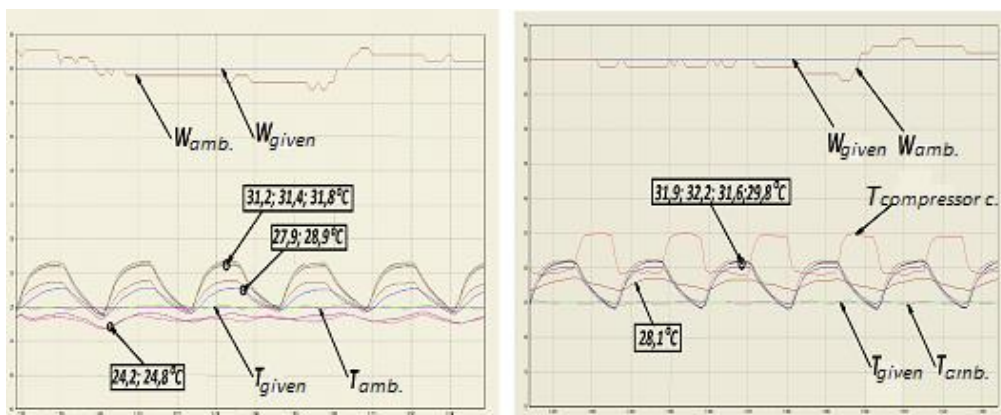


Figure 5 – Graph of temperature reading versus time in the shell of the low-temperature refrigerated case and in the compressor compartment: $W_{amb.RH}$ – related humidity; $W_{givenRH}$ – given related humidity; $T_{amb.}$ – ambient temperature; T_{given} – given ambient temperature; $T_{compressor com.}$ – temperature at te compressor compartiment. $T_{compressor c.} = 35.2^{\circ}C$

Since the compressor compartment contains a motor with propeller for heat removing from a pre-condenser and cooling the compressor, the temperature in this volume will be significantly higher.

In this regard, it is decided to investigate to determine the air speed for the following calculation of heat inflow and heat exchanger for the overheating removal.

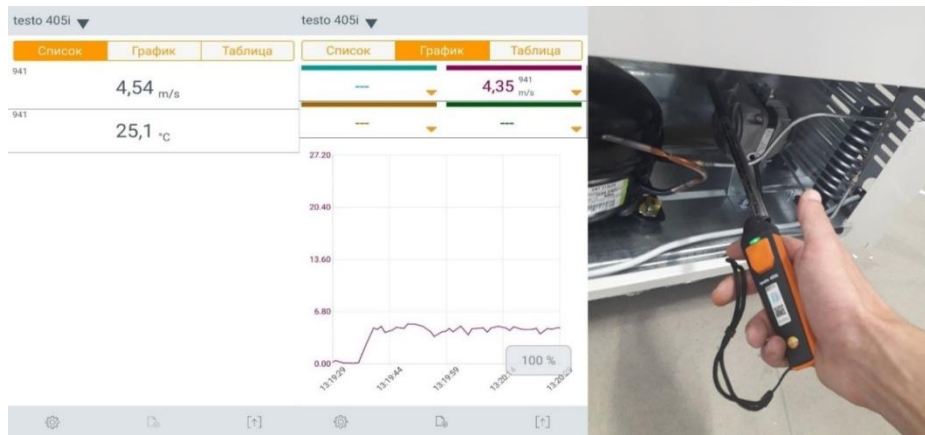


Figure 6 – Air speed measuring at the compressor compartment

The experiment was conducted using the thermoanemometer "testo 405i" (Fig. 6).

The target of this experiment is to confirm the additional heat load on the cooling volume from the condenser and the compressor compartment, and the heat removal through the insulation of the shell.

3.3 Heat inflow through the bottom

Taking into account the design of the compressor compartment and the intense movement of air, the temperature of the outer part of the bottom will be irregular and will decrease in length of the pilot plant (Fig. 7).

When reviewing the design of the investigated object, it should be noted that whetsets or support legs are installed on the each from these type units. Given this feature, and the possibility of air circulation between the compressor compartment and the volume of air under the investigated object, it is possible to predict the temperature of the outer part of the bottom will be irregular and will decrease by the length of the refrigerated display case. The investigation is done in the same way as measuring the thermal load on the shell.

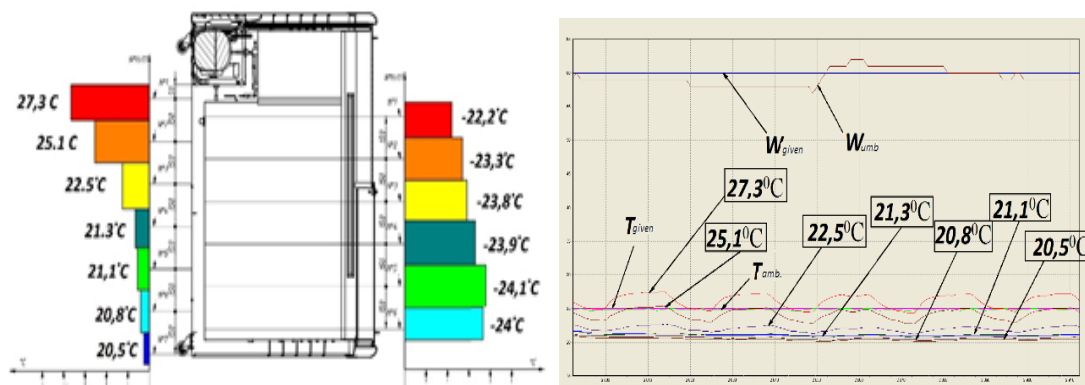


Figure 7 – Graphs of temperature dependence on time at the bottom of the pilot plant: $W_{amb.}$ – related humidity; W_{given} – given related humidity; $T_{amb.}$ – ambient temperature; T_{given} – given ambient temperature

For the demonstrative part of the thermal load, at the bottom of the cooled volume, the sensors are located in parallel.

3.4 Temperature investigation for evaporator

Taking into account the specification of the evaporator (leaf tube), a decision was made to do temperature measurements in the area of the given heat exchanger and graphically depicts the temperature difference along the height of the evaporator (Fig. 8).

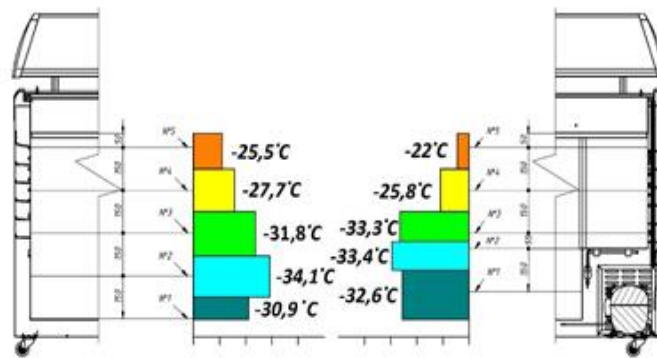


Figure 8 – Temperature reading from evaporator (leaf tube)

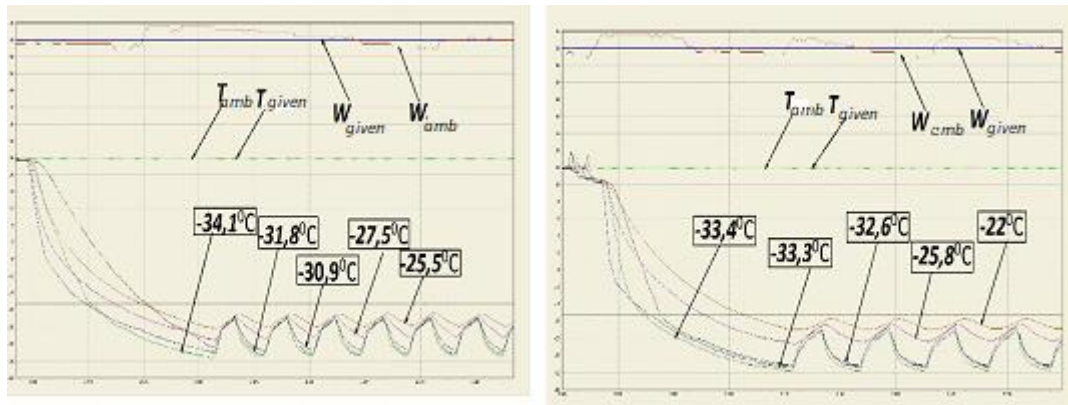


Figure 9 – Graphs of temperature dependence on time:

W_{amb} . – related humidity; W_{given} – given related humidity; T_{amb} . – ambient temperature; T_{given} – given ambient temperature

3.5 Temperatures in the refrigerated volumes

Temperatures in the refrigerated volume are read and depend on thermocouple elements placement according to the height of loaded product stored of the investigated object is shown in Figure 10.

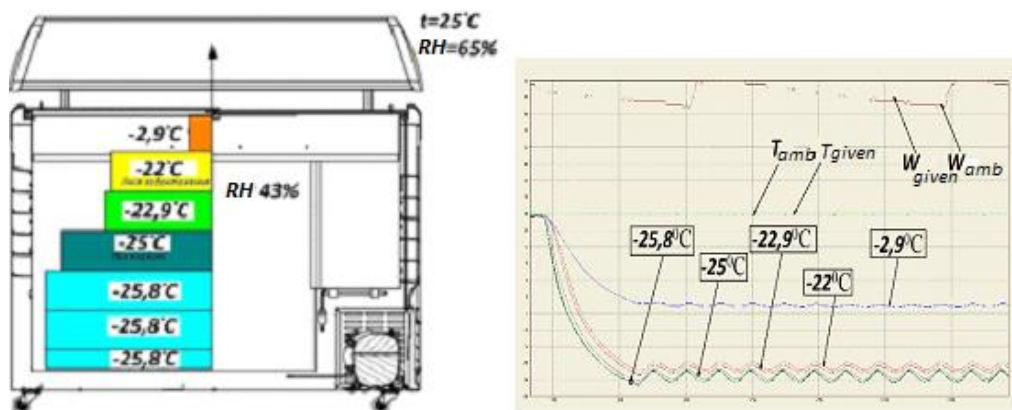


Figure 10 – Temperature reading and graph of temperature dependence on time in the refrigerated volume: W_{amb} . – related humidity; W_{given} – given related humidity; T_{amb} . – ambient temperature; T_{given} – given ambient temperature

The lower temperature is the temperature read from the lower part, and this issues is validated by natural environment (gravity) air movement in the middle of the chamber. The higher temperature is defined in the location product stored is validated by additional heat leakage from the "baskets". The highest temperature reading under the "crown" confirms that "dead volume" behaves as a heat-insulating layer.

The obtained results of experiments done confirm heat load distribution irregularity across all refrigerated unit areas due to the design features of the unit and allow calculating the heat load on the evaporator by the zonal method. ‘

The temperatures correspond to the height in the refrigerated volume and allow graphically to display the filling of the refrigerated volume with cold air.

The graphic representation of the temperatures in height from the outside and the inside of the insulated walls reflects zones of increased heat loads. The major result of experiments enables to develop and calculate the total heat transfer to the refrigerated volume of the pilot plant.

Conclusions

Growing demand for frozen food, and other bakery products stored under low temperature is driving the demand for commercial refrigeration equipment. In a straggle to reduce carbon footprints, the manufacturers develop commercial refrigeration equipment with less or limited energy consumption. In global scale Department of Energy and Environmental Protection Agency are bring together new regulations as well as standards for commercial refrigeration. They have emphasis on energy efficiency improving and as much as possible minimizing environmental impact. To fulfill with the new regulations and strict requirements, companies are capitalizing development costs to new refrigeration system with innovative technology or to redesigning in order to meet standards. Supermarkets are one from the most energy-intensive retail businesses.

To hold one’s finger on the market dynamic pulse is tedious and strenuous work both for research institutes and for manufactory laboratories. "JUKA-Invest” LTD together with Refrigeration and Air-Conditioning Department, ONAFT are conducted experiments give an idea of the temperature fields of the pilot plant as a low-temperature unit compartment M400S+ taking into account the features of the its design, close-fitting the disadvantages and advantages of investigated unit.

The obtained results of experiments make it possible to determine the thermal fields of commercial refrigeration equipment, to determine the places of excessive heat load and the ability to collect the input data to begin the development of a single model for calculating the commercial refrigeration equipment of this class.

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