Journal of Engineering Science | *Vol. XXVII, no. 3 (2020), pp. 65 - 75*
Fascicle *Industrial Engineering* *ISSN 2587-3474*
Topic *Applied Engineering Sciences and Management* *eISSN 2587-3482*

DOI: 10.5281/zenodo.3949666
UDC 004.9:621.565:637

COMBINED AUTOMATED INSTALLATION DEPLOYMENT FOR MILK COOLING

Anatolie Daicu*, ORCID ID: 0000-0002-9968-8444,
Augustin Volconovici, ORCID ID: 0000-0002-0346-5423,
Ala Chirsanova, ORCID ID: 0000-0001-6541-5678,
Onorin Volconovici, ORCID ID: 0000-0003-1623-2028,
Victorin Slipenchi, ORCID ID: 0000-0003-2253-5324,
Ina Volconovici, ORCID ID: 0000-0002-4907-7944

State Agrarian University of Moldova, 44 Mircesti Street, Chisinau, Republic of Moldova
*Corresponding author: Anatolie Daicu, *a.daicu@uasm.md*

Received: 05. 19.2020
Accepted: 07.23.2020

Abstract. The work was aimed to develop the structural and functional diagram, automatic graphs and operating algorithms of the natural and artificial cooling receiver/accumulator for milk chilling in the capacitive cooler with low energy consumption. The automated natural and artificial cooling installation was developed and the control parameters for milk and water chilling in the accumulator were selected. The use of the natural cooling installation in the cold season and of the combined installation (refrigeration installation and natural cooling installation) in the warm season was substantiated from energy saving point of view. The automatic graphs presented in the paper and the operating algorithms developed on their base may be used to solve further engineering tasks related to efficiency functioning of milk cooling system.

Keywords: *automated installation, artificial cold, automatic graphs, milk cooling, natural cold, operating algorithms.*

Introduction

The environmental issues and those of low energy consumption are key issues in the cooling process of milk that is one of the most indispensable, responsible and decisive in the quality of final product [1].

In the conditions of a modern market economy and the constant increase in the cost of energy, the use of natural cold is becoming more and more efficient and cost-effective [2]. The non-traditional technique of natural cooling is ecofriendly, because it excludes the use of freons, has a low energy consumption due to its limited consumption when accumulating cold and it does not require additional refrigeration rooms, and this contributes to improve economic indicators [3, 4].

The problem of using natural cooling to chill milk is urgent for Republic of Moldova, since it imports over 90% of energy resources. A complex analysis to operate structural, energetic, technological and economic effects confirms the appropriateness of using natural and artificial cooling for milk chilling [5].

The sources of economic effect are [6, 7].

• reduction of energy consumption when chilling milk;
• reduction of electric power of the milk chilling system;
• improvement of the production quality by enhancing the operational reliability of natural cooling installations;
• reduction of raw materials consumption for manufacturing.

The most appropriate milk cooling technology or system depends on the location, the availability of electricity and water, capacity requirements; and the capital and operating costs [8].

The purpose of research is to develop an automated installation with natural and artificial cold using automatic graphs and operating algorithms.

The proposed natural and artificial cold system can only be competitive if the process of water and milk cooling is automated. In this case, automatic graphs are used to automate the nominated installation.

Materials and methods

The operating algorithms of the automated natural and artificial cooling installation were developed based on automatic graphs and logical algebra.

The study was conducted based on experimental data obtained at the training and experimental complex of SAUM, where a combined installation was implemented.

It included a refrigeration installation and a natural cooling installation for milk chilling [9].

a)

b)

Figure 1. Combined refrigeration system for milk chilling with natural (a) and artificial cold (b).

Results and discussions

In Republic of Moldova natural and artificial cooling installations (of combined action) are the most effective ones.

The structural and functional diagram of the natural and artificial cooling installation for milk chilling in a capacitive cooler is presented in Figure 1.

The structural and functional diagram of refrigeration installation and water accumulator for milk chilling presented in Figure 2 differs since instead of a flow-through cooler, a capacitive cooler is used, in which both cooling and storage of milk take place.

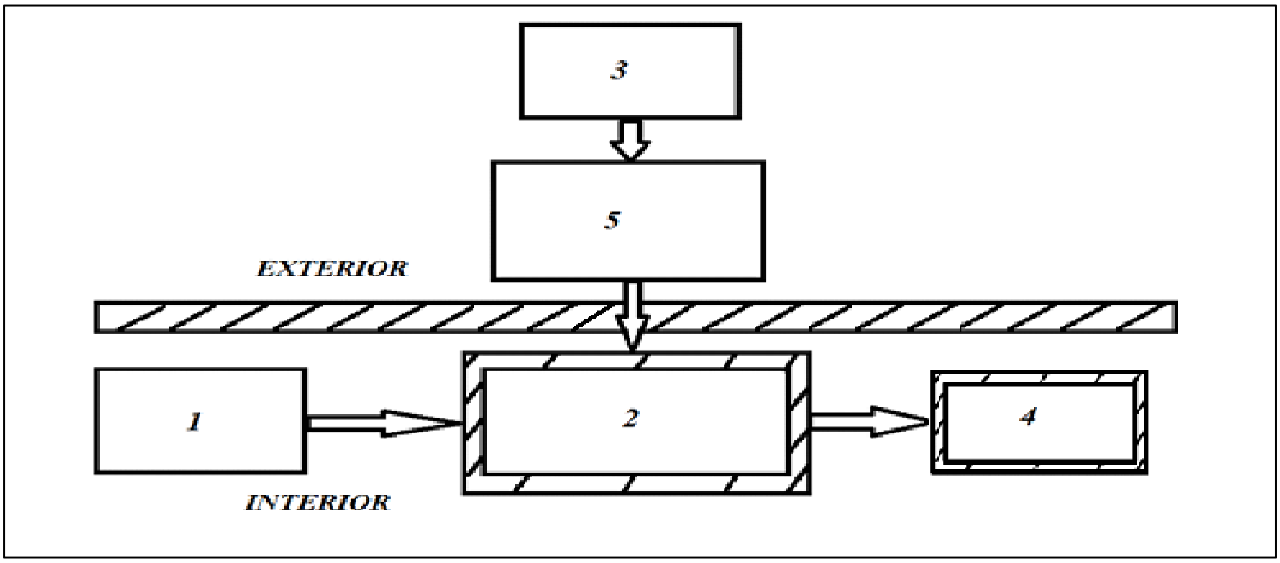

Figure 2. Structural and functional diagram of the refrigeration installation and the water accumulator for milk chilling in the capacitive cooler by using natural and artificial cooling.
1 – refrigeration installation; 2 – insulated water accumulator installed inside the farm;
3 – sprayer; 4 – capacitive cooler for milk chilling;
5 – water accumulator installed outside the farm.

The combined action installation for milk chilling in the capacitive cooler with natural self-regulation is presented in Figure 3.

The installation (Figure 3) includes an accumulating vessel made in the form of a lower and upper accumulating tank. The upper accumulating tank *1* is placed in the open air and it has some supports *2* and a pipe *3*, joined with a pump *4*, at the end of which there is a rotating support *5* with spray pipes *6* and aerodynamic plates *7*, which are placed inside a cylinder *8* with a flat screen *9* at the top and a conical screen *10* at the bottom. In the lower part of the storage tank, on the axial bearing there is a tube *11* placed vertically, whose horizontal cut is located in the upper part of the storage tank *1*.

Parallel to the tube *11* there is a screen *12*, the lower part of which forms a space with the lower part of the accumulating tank *1*. In the lower storage tank there is an evaporator *14*, connected by pipes *15* with a rechargeable refrigerating machine *16*.

In the discharge tube at the bottom of the storage tank there is a hole *17*, below which on the opposite side of the lower storage tank there is a drain cavity *18*, which is connected by a drain tube *19* with a heat exchanger tank for milk *21*, which is connected with the pump *4* by a pipe, connected with the rotating support *5* and the spray tubes *6* by the tube *3*.

In the lower accumulating tank *13* and the drain cavity *18* there are placed temperature sensors *22*, connected to a control unit *23* and the water pump *4*. A valve *24* is installed on the delivery pipe from the pump.

The installation works as follow:

During the cold season, the refrigerant cools or freezes due to natural cold. While cooling milk in the heat exchanger tank *21*, the water from the vessel *20* enters the tube *3* through the discharge tube through the pump *4* and goes further into the spray pipes *6*, which come into rotary motion from the reactive jets. The aerodynamic plates *7* are also set in motion, and they form an air flow, directed towards the sprayed refrigerant, which cools it intensively.

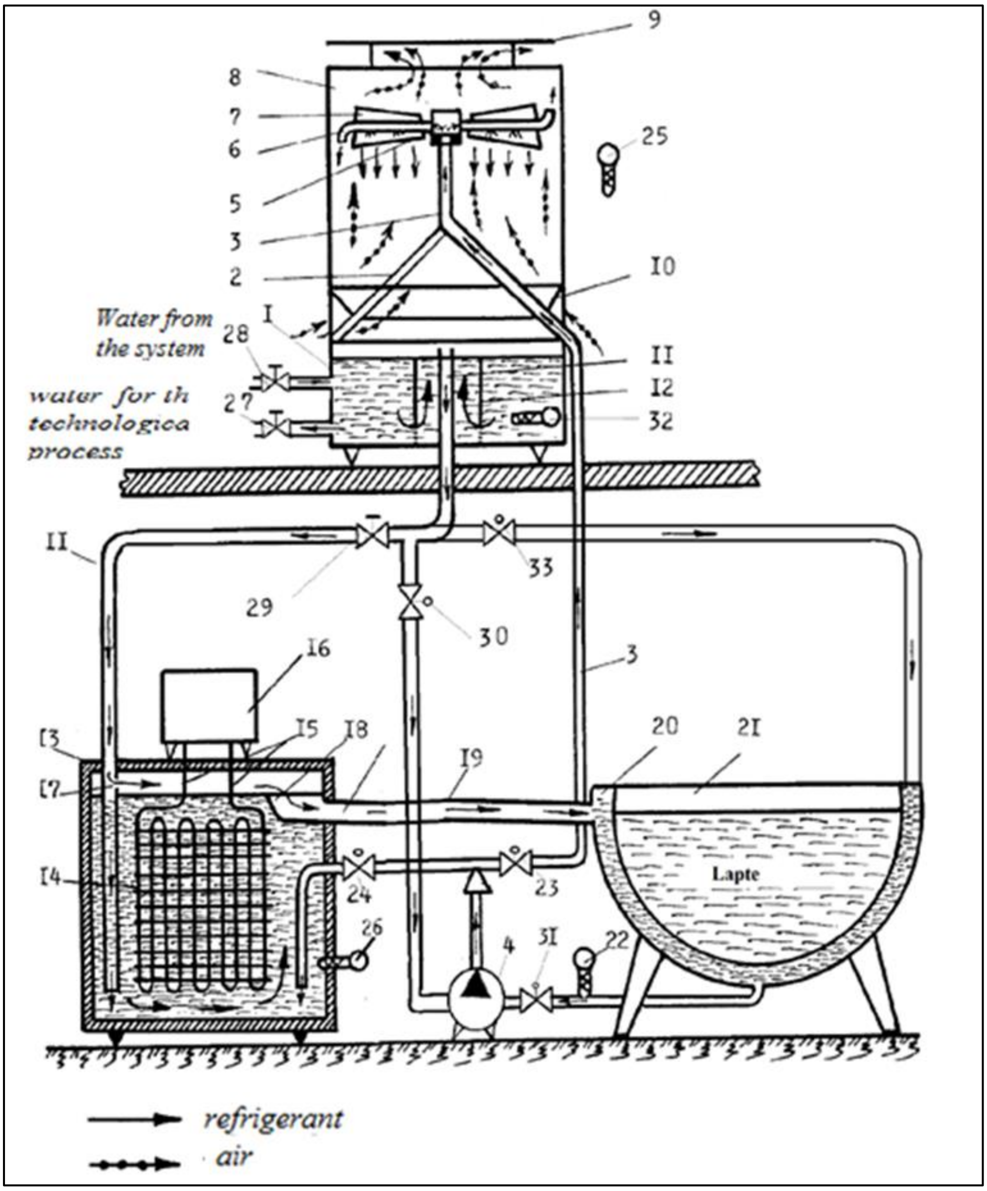

Figure 3. Refrigeration installation and water accumulator for milk chilling in the capacitive cooler by using natural and artificial cooling [6].

The cold air flow further cools the water in the accumulating tank *1*. The cooled and sprayed water, flowing on the conical screen *10* and hitting the upper accumulating tank *1*, mixes with the cooled water, passes through the hole between the screen *12* and the lower part of the accumulating tank *1* and reaches the bottom of the lower accumulating tank *13* through the discharge tube. If the water in the upper accumulating tank *1* has frozen, then the water flowing on the ice surface, while cooling and flowing over the edge of the screen *12*, also enters the bottom of the lower accumulating tank *13* through the discharge tube, Figure 3. If the temperature of the refrigerant (water) drops below the required temperature (2-3^{0}C), then the control unit *23* activates the rechargeable refrigeration installation *16*. The evaporator *14*, connected by pipes *15* with the rechargeable refrigeration installation *16*, begins to cool the refrigerant, which flows over the edges of the drain cavity *18*, enters the heat exchanger tank *21* through the drain tube *19* and cools the milk.

If the refrigerant in the lower accumulating tank *13* freezes, then the refrigerant flows through the hole *17* on the ice surface and through the drain tube *19* flows further according to the cycle described above. During the warm season, when cooling of the refrigerant sprayed in the upper accumulating tank *1* may become ineffective, the refrigerant flows from the pump *4* through the valve *24* and goes to the bottom of the lower accumulating tank *13* and further cooling of milk takes place according to the procedure described above.

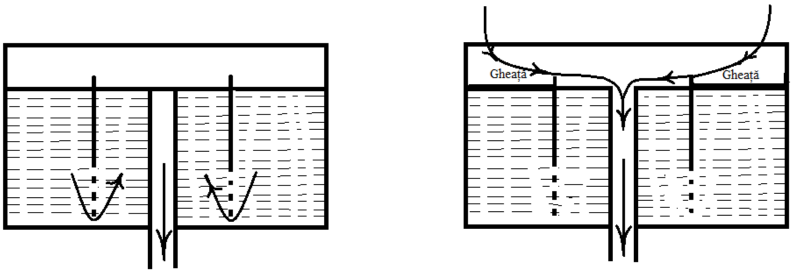

Figure 4. Directing water in the accumulator - 1, when the atmospheric temperature is t> 0^0C (a) and t ⩽ 0^0C (b).

The control parameters of the milk chilling process in the capacitive cooler by using natural and artificial cooling are:

- water temperature in the water accumulator installed outside the farm;
- water temperature in the insulated water accumulator installed inside the farm;
- atmospheric air temperature;
- temperature of cooled milk.

These temperatures are fixed by the temperature transducers 22, 25, 26, and 32, Figure 3.

Next, we have developed automatic graphs and operating algorithms of the refrigeration installation and the water accumulator for milk cooling in the capacitive cooler by using natural and artificial cooling.

The automatic graph of the M_{16} refrigeration installation in the milk chilling mode is presented in Figure 5.

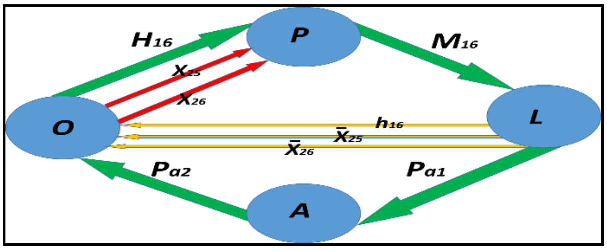

Figure 5. Automatic graph of the M_{16} refrigeration installation.

where: O; P; L; A – operating conditions of the M_{16} refrigeration installation, stop, start, operation, and fault, respectively

M_{16} – refrigeration installation (compressor 1);

H_{16} and h_{16} – start and stop command, respectively;

$\bar{h}_{16}$ - lack of signal from the stop button;

x_{25} and x_{26} - presence of signals from the transducers 25 and 26;

$\bar{x}_{25}$ and $\bar{x}_{26}$ - lack of signals from the transducers 25 and 26;

Pa_1 and Pa_2 - presence of fault signals;

$\bar{Pa}_1$ and $\bar{Pa}_2$ - lack of fault signals.

The operating algorithm of the refrigeration installation developed based on the automatic graph presented in Figure 5 has the form:

$$Y_{16} = (x_{25} \cdot x_{26} + H_{16}) \cdot \overline{h_{16}} \cdot \overline{Pa_1} \cdot \overline{Pa_2} \cdot M_{16} \quad (1)$$

The automatic graph of the water pump in the milk cooling mode is shown in Figure 6.

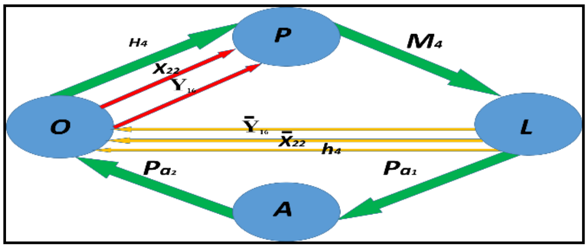

Figure 6. Automatic graph of the M_4 water pump.

where M_4 - water pump; H_4 and h_4 - start and stop command, respectively; $\bar{h}_4$ - lack of signal from the stop button;

Pa_1 and Pa_2 - presence of fault signals; $\overline{Pa}_1$ and $\overline{Pa}_2$ - lack of fault signals.

The operating algorithm of the M_4 water pump developed based on the automatic graph presented in Figure 6 has the form:

$$Y_4 = (Y_{16} \cdot x_{22} + H_4) \cdot \overline{h_4} \cdot \overline{Pa_1} \cdot \overline{Pa_2} \cdot M_4 \quad (2)$$

The automatic graph of the valve 24 in the milk chilling mode is presented in Figure 7.

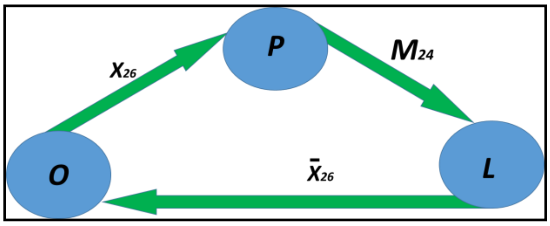

Figure 7. Automatic graph of the valve 24.

where: V_{24}- valve 24

X_{26} - presence of signal from the water temperature transducer 26

$\bar{x}_{26}$ – lack of signal from the water temperature transducer 26

The operating algorithm of the valve 24 developed based on the automatic graph presented in Figure 7 has the form:

$$Y_{24} = x_{26} \cdot V_{24} \quad (3)$$

The automatic graph of the valve 30 in the milk chilling mode is presented in Figure 8.

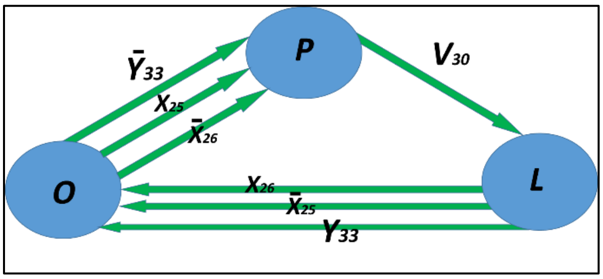

Figure 8. Automatic graph of the valve 24.

where:

V_{30} - valve 30

x_{26} - presence of signal from the water temperature transducer 26

$\bar{x}_{26}$ - lack of signal from the water temperature transducer 26
x_{25} - presence of signal from the atmospheric transducer 25
$\bar{x}_{25}$ - lack of signal from the atmospheric transducer 25
Y_{33} - presence of signal from the valve 33
$\overline{Y_{33}}$ - lack of signal from the valve 33

The operating algorithm of the valve 30 developed based on the automatic graph presented in Figure 8 has the form:

$$Y_{30} = \overline{Y_{33}} \cdot x_{25} \cdot \overline{x_{26}} \cdot V_{30} \tag{4}$$

The automatic graph of the valve 31 in the milk chilling mode is presented in Figure 9.

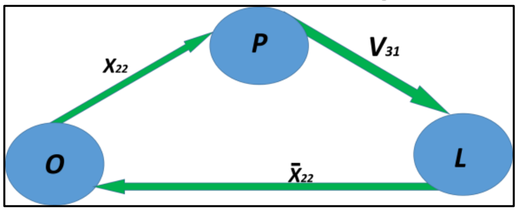

Figure 9. Automatic graph of the valve 31

where:
V_{31}-valve 31
x_{22} - presence of signal from the water temperature transducer 22
$\bar{x}_{22}$ - lack of signal from the water temperature transducer 22.

The operating algorithm of the valve 31 developed based on the automatic graph presented in Figure 9 has the form:

$$Y_{31} = x_{25} \cdot V_{31} \tag{5}$$

The automatic graph of the valve 33 in the milk chilling mode is presented in Figure 10.

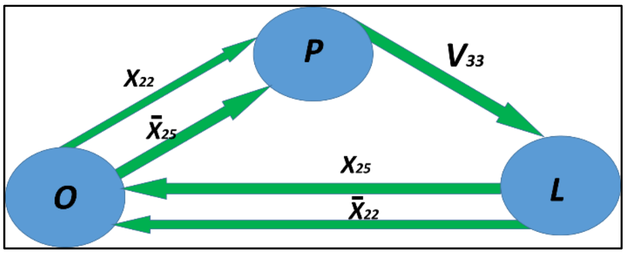

Figure 10. Automatic graph of the valve 33.

where:
V_{33}- valve 33
x_{22} - presence of signal from the water temperature transducer 22
$\bar{x}_{22}$ - lack of signal from the water temperature transducer 22
x_{25} - presence of signal from the atmospheric transducer 25
$\bar{x}_{25}$ - lack of signal from the atmospheric transducer 25.

The operating algorithm of the valve 33 developed based on the automatic graph presented in Figure 10 has the form:

$$Y_{33} = x_{22} \cdot \overline{x_{25}} \cdot V_{33} \tag{6}$$

The automatic graph of the valve 23 in the milk chilling mode is presented in Figure 11.

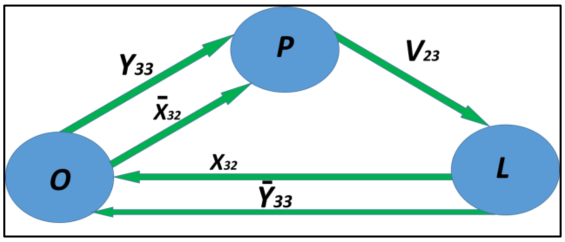

Figure 11. Automatic graph of the valve 23 in the milk chilling mode.

where:
V_{23} - valve 23
x_{32} - presence of signal from the water temperature transducer 32
$\bar{x}_{32}$ - lack of signal from the water temperature transducer 32
x_{25} - presence of signal from the atmospheric transducer 25
$\bar{x}_{25}$ - lack of signal from the atmospheric transducer 25
Y_{33} - presence of signal from the valve 33
$\bar{Y}_{33}$ - lack of signal from the valve 33

The operating algorithm of the valve 23 developed based on the automatic graph presented in Fig. 11 has the form:

$$Y_{23} = \overline{x_{32}} \cdot Y_{33} \cdot V_{23} \tag{7}$$

The automatic graph of the valve 23 in the mode of water chilling in the tank 1 is presented in Figure 12.

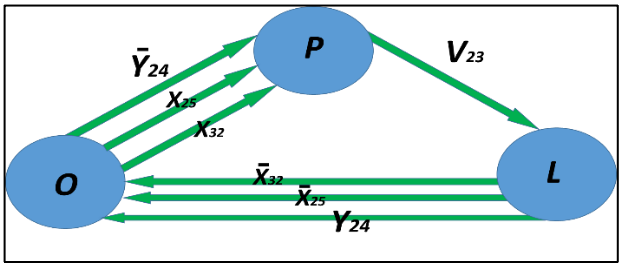

Figure 12. Automatic graph of the valve 23 in the mode of water chilling in the tank 1.

where:
V_{23} - valve 23
x_{32} - presence of signal from the water temperature transducer 32
$\bar{x}_{32}$ - lack of signal from the water temperature transducer 32
x_{25} - presence of signal from the atmospheric transducer 25
$\bar{x}_{25}$ - lack of signal from the atmospheric transducer 25
Y_{24} - presence of signal from the valve 24
$\bar{Y}_{24}$ - lack of signal from the valve 24

The operating algorithm of the valve 23 developed based on the automatic graph presented in Figure 12 has the form:

$$Y_{23} = x_{25} \cdot \overline{Y_{24}} \cdot x_{32} \cdot V_{23} \tag{8}$$

The refrigeration installation and the water accumulator for milk chilling in the capacitive cooler Figure 3 by using natural and artificial cooling allow ensuring both the chilling of milk up to 6⁰C and the heating of water in accumulator during the warm season up to 25-30⁰C (without water spraying) and up to 30-35⁰C with water spraying [10, 11].

Water chilling in the natural cooling installation (water accumulator A) Figure 13 (a) takes place only at low atmospheric temperatures from $t \leq 4^0C$, without using the refrigeration installation. The specific energy consumption for milk chilling is at the level of 0.3 kWh/t compared to 30-35kWh/t when using refrigeration installations [12].

The use of the water accumulator also in the warm season (for $t > 4^0C$) for water chilling in the accumulator from the refrigeration installation Figure 13 (b) allows reducing the electric power of the refrigeration installation by about 1.6-1.7 times [13, 14].

At the same time, the chilling of water in the accumulator at night according to the National Agency for Energy Regulation of Republic of Moldova (ANRE) allows reducing the electric power bills by 40%, Figure 14 [15].

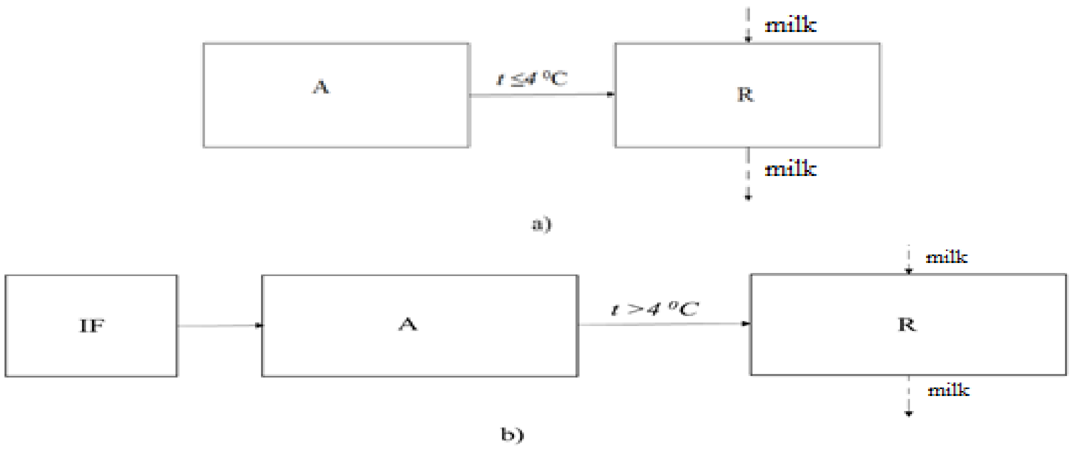

Figure 13. Milk chilling by using natural (a) and artificial cold (b).

A – water accumulator;
R – cooler;
IF – refrigeration installation.

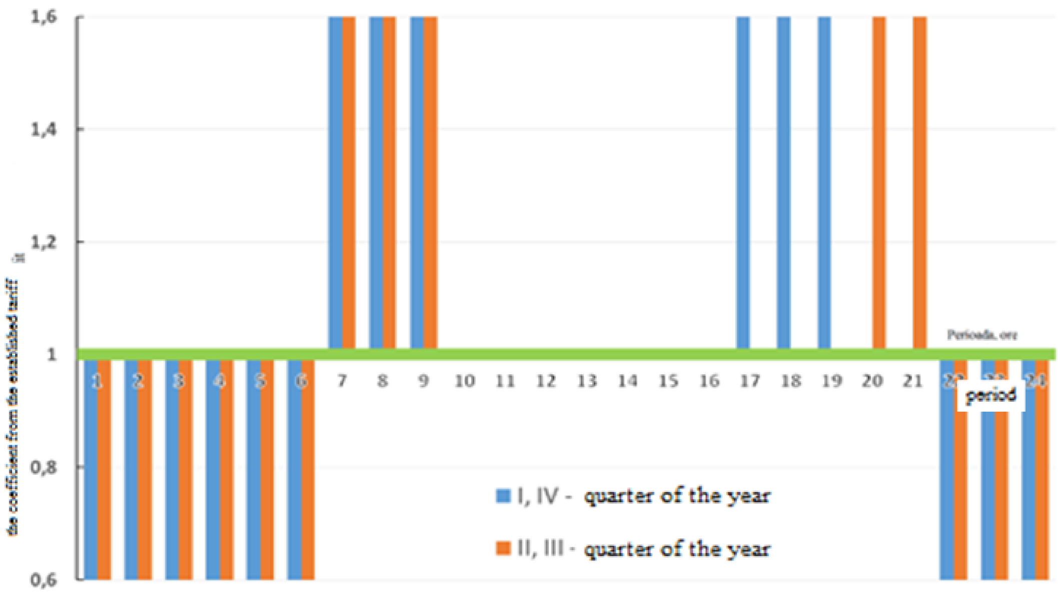

Figure 14. Cost of electricity according to differentiated rates depending on the consumption period.

Conclusions

An automated natural and artificial cooling installation was developed at the training and experimental complex of the State Agrarian University of Moldova and the control parameters for milk and water chilling in the accumulator were selected.

The structural and functional diagram, automatic graphs and operating algorithms of the natural and artificial cooling receiver/accumulator for milk chilling with low energy consumption were developed.

The main advantages of using water accumulators together with refrigeration installations are:

- saving energy and water;
- ensuring a high operating reliability of cooling systems as a result of cold accumulation in accumulators with simple maintenance and repair;
- possibility to use a lower night tariff for energy consumption;
- lower cost price for cold accumulation;
- improving the ecological situation by reducing the amount of freons and freon oils used.

It has been established that:

- the specific energy consumption for milk chilling when using the proposed installation is 0.3 kW h/t in the cold season, compared to 30-35 kW h/t when using typical refrigeration installations;
- the use of water accumulator also in the warm season (for t> 4^0C) for water chilling in the accumulator from the refrigeration installation allows reducing the electric power of the refrigeration installation by about 1.6-1.7 times;
- chilling of water in the accumulator during off-peak hours of energy consumption according to the National Agency for Energy Regulation of the Republic of Moldova (ANRE) allows reducing the electric power bills by 40%;
- refrigeration installation and water accumulator allow to ensure both the chilling of milk up to 6^0C and the heating of water in the accumulator during the warm season up to 25-30^0C (without water spraying) and up to 30-35^0C with water spraying.

References

1. Murphy M., Upton J., O'Mahony M. J. Rapid milk cooling control with varying water and energy consumption. In: *Biosystems Engineering*, 2013, vol. 116, pp. 15-22.
2. Kozlovtsev A.P. & Korovin G.S. Natural cold milk cooling system. In: *IOP Conference Series: Materials Science and Engineering*, Vol. 666: Quality Management and Reliability of Technical Systems 20–21 June 2019, St Petersburg, Russian Federation. Available: https://iopscience.iop.org/article/10.1088 /1757-899X/666/1/012070/meta
3. Коршунов Б.П. Учеваткин А.И., Марьяхин Ф.Г. et al. Повышение эффективности систем охлаждения и хранения молока на фермах [Improving the efficiency of cooling and storage systems for milk on dairy farms]. В: *Техника в сельском хозяйстве*, 2010, № 2, с. 6-8.
4. Фокин А.И., Цой Ю.А. Зиганшин Б.Г. et al. Комбинированная установка для охлаждения молока с использованием искусственного и естественного холода [Combined installation for cooling milk using artificial and natural cold]. В: *Техника и оборудования для села*, 2015, № 10, с. 11-12.
5. Коршунов Б.П. Учеваткин А.И., Марьяхин Ф.Г. et al. Энергосберегающее оборудование для охлаждения молока на семейных фермах [Low energy consumption equipment for cooling milk on family dairy farms. В: *Механизация и электрификация сельского хозяйства*, 2012, с. 21-23.
6. Волконович Л., Черней М., Волконович А. et al. *Применение холода для охлаждения молока и хранения плодоовощной продукции* [The use of cold for cooling milk and storing fruits and vegetables]: Монография. Chișinău: UASM, 2019. ISBN: 978-9975-56-625-4.

7. Cușnir M., Ucevatchin A., Slipenchi V., Daicu A. Analiza complexă a proceselor technologice automatizate derăcire a laptelui, eficiente din punct de vedere energetic. In: *Lucrări științifice, vol. 51, Inginerie agrară și transport auto*, Universitatea Agrară de Stat din Moldova. Chișinău, 2018. pp. 374-381. ISBN 978-9975-64-300-9.
8. Moffat F., Khanal S., Bennett A., Thapa T.B. & Malakaran George S. *Technical and investment guidelines for milk cooling centres*. Rome: FAO, 2016. ISBN 978-92-5-109300-9.
9. Патент РФ № 2314681. Энергосберегающая установка для охлаждения молока на фермах с использованием природного холода [Energy-saving unit for cooling milk on farms using natural cold] / Ф.Г. Марьяхин, Б.П. Коршунов, А.Б. Коршунов, Ю.Б. Пржетишевский, Ю.В.Челницев. БИ № 36. 2008.
10. Кушнир М. Г., Попа А. Г., Слипенки В. Е., Кушнир Н. А. Анализ структурных схем энергосберегающего процесса хранения фруктов и овощей с применением естественного и искусственного холода. Инновации в сельском хозяйстве, 2017. 1 (22)/2017.
11. Creţu V., Volconovici L. *Răcirea laptelui cu aplicarea frigului natural și artificial* [Milk cooling with natural and artificial cold application]. Chișinău: Tehnica Info. 2009. 245 p. ISBN978-9975-63-301-7.
12. Volconovici L., Creţu V., Cușnir M. Mathematical model of the ecological system with electricity consumption for milk cooling in the Republic of Moldova. In: *SIELMEN 2011: proceedings of the 8-th Intern. Conf. on Electromechanical and Power Systems*, Chisinău, 13-15 oct. 2011.
13. Creţu V., Volconovici L., Cușnir M. Experimental researches of the ecological system for cooling of milk with low energy consumption. In: *SIELMEN 2011: proceedings of the 8-th Intern. Conf. on Electromechanical and Power Systems*, Chişinău, 13-15 oct. 2011.
14. Шилин В.А., Герасимова О.А., Лобачев А.В. Охлаждение молока на фермерских хозяйствах с применением естественного холода. В: *Научное обеспечение развития АПК в условиях реформирования*. Санкт-Петербург, 2012. с. 303-305. ISSN 0136-5169.
15. National Agency for Energy Regulation of Republic of Moldova [online]. Accessed: 12 May 2020. Available: http://www.anre.md/tarife-in-vigoare-3-204.