Installation of absorption refrigerating machines for the needs of conditioning of the Armada Mall

V Y Sokolov and T Y Sokolova

Department of Electrical and Heat Power Engineering, Orenburg state University, Shevchenko St., 28, Orenburg, 460005, Russia

E-mail: teploosu@mail.ru, sokolova_25@mail.ru

Abstract. The energy strategy of Russia for the period up to 2020 noted that in order to ensure energy security it is necessary to solve two priority issues: firstly, the modernization of the obsolete and physically worn out technological base of the fuel and energy complex using the best domestic and relevant foreign technologies for our conditions; secondly, it requires a change in the consumption pattern and distribution of production of fuel and energy resources. The work analyzed the state and considered the characteristics of the energy source. The concept of increasing the efficiency of the thermal power plant has been developed. As a result of analysis of existing plants for additional generation of cold from a more heated power generator, a scheme and theoretical cycle of absorption bromide of a lithium refrigerating machine is made. The results were obtained on the expected annual savings of the Armada Mall operating costs at the application of lithium refrigeration machine absorb bromide for the annual cold demand of 3,4 million kWh.

1. Introduction

Currently, steam compression chillers (steam compression chillers) are used in the air conditioning system of the Armada Mall, which cool water directed to the fan coil system [1, 2].

As a systemic source of electricity, CHP plants play a significant role in the structure of generating capacities and electricity production in most of the country's regional and combined energy systems. Of course, having played a large positive role in the previous development of power systems, the existing thermal power plants are seriously outdated, and now a significant part of their equipment needs to be dismantled, modernized or replaced with more modern equipment [3, 7].

The economic efficiency of further use of the accumulated capacity of existing thermal power plants strongly depends on such «systemic» factors as the growth rate of electricity and heat consumption in the respective regions and the rate of aging of the capacity of existing thermal power plants in these regions. At the same time, the efficiency of heating both in the local context and at the system level is highly dependent on external factors, such as fuel prices, technical and economic indicators of all types of existing and new sources of heat and electricity production and transportation, as well as the amount of CO₂ emissions charges [4].

All researchers agree that heating systems should be seriously modernized. The changes being developed today in the model of heat and electricity markets and in the methodology for planning energy development should create the right incentives for market participants to create reliable, balanced energy resources for all types of flexible and economical systems.
Steam compressors use electric energy to produce cold. In contrast, absorption refrigeration machines use heat energy (in hot water or steam) to produce cold, and electric energy primarily for the operation of circulation pumps. According to the estimates of the manufacturers of refrigerating machines with the same refrigerating capacity, the electric energy consumption of absorption refrigerating machines is 21% of the electric power consumption of vapor compression refrigerating machines [5, 6, 8]. In the middle years of the last century, the introduction of a high-quality method of regulation was not facilitated by low prices for fuel and energy resources and the lack of an urgent need for energy conservation in the energy industry. In addition, the implementation of quantitative and qualitative-quantitative methods for regulating thermal load was hindered by the absence or imperfection of automatic control devices.

Therefore, these methods of regulating the thermal load of energy sources are not widely used in domestic heat supply. At present, due to radically changed economic conditions and new technical capabilities, the introduction of these methods of regulation in heating systems allows to achieve a significant energy saving effect and improve the quality of energy supply [6-8]. Thus, the efficiency of most domestic heating systems continues to remain at a rather low level, however, CHPs allow the city to produce electricity and other energy carriers with specific fuel costs that are not achievable outside the heating cycles, and in the amount necessary to meet all urban needs. It is only necessary to develop a set of measures for the modernization of urban heating systems and correctly select their structure, composition of the CHP equipment corresponding to thermal and electrical loads. This problem has become particularly urgent in recent decades due to the transition to a non-volatile economy and the constant increase in energy prices. The analysis of the state of domestic urban thermal systems and experience in their improvement make it possible to formulate the following main conclusions on the concept of increasing their efficiency due to structural and technological modernization.

2. Materials and Methods
When replacing the chillers of steam compression chillers with absorptive chillers, the win-win principle between Armada Mall and PJSC «T Plus» is achieved by:[8-10]

- increase in sales of heat energy in the summer season from the Sakmarskaya CHPP (increase in branch revenue, increase in the base load of the Sakmarskaya CHPP and, as a result, improvement in the equipment economic indicators) - PROFIT for PJSC «T Plus»;
- reduction of the annual operating costs of the air conditioning system - PROFIT for Armada Group of Companies.

Armada Mall is connected to the water heating network from the Sakmarskaya CHPP (M1 highway with a jumper to M3), and currently consumes heat energy only for heating needs in the winter season (the hot water supply of the complex is provided by electric water heaters). In order to reduce capital expenditures, this leads to the use of hot-water absorption chillers with the supply of thermal energy in hot water in the summer season through the existing heating network. Since the calculated temperature of hot water supplied to absorption refrigeration machines (120 °C) differs from the water temperature in summer in the supply lines from the Sakmarskaya CHPP (75 °C), it is planned to build a one-pipe section of the heating network from collector power station to rack № 126 (branch to the Armada Mall) with a length of 1 500 m and a nominal diameter of 150 mm along the existing corridors, supports and racks to the former Silk weaving factory. In the part of the return pipeline, it is supposed to use the existing line [9-12].

The circuit diagram of the connection is shown in Figure 1.
Figure 1. Connection diagram of the Armada Mall to the Sakmarskaya CHPP.

Monthly estimated heat consumption for the generation of cold absorption hot-water refrigeration machines for the needs of the Armada Mall air conditioning and ventilation systems (calculated based on the actual energy consumption provided by the mall for air conditioning and ventilation for 2018) are given in table 1.

Information about the chillers used in the Armada Mall are shown in table 2.

Table 1. Heat consumption for the production of cold Armada Mall.

| Indicator | May    | June   | July   | August  | September | TOTAL for the summer period: |
|-----------|--------|--------|--------|---------|-----------|-------------------------------|
| Heat consumption for cold production, Armada Mall, Gcal | 240.96 | 696.31 | 1024.63 | 971.41 | 316.23 | 3249.54 |
| Estimated average hourly heat load, Armada Mall, Gcal / h | 0.98 | | | | | |
| Estimated maximum achieved hourly heat load of hard currency of the Armada Mall, Gcal / h | 4.77 | | | | | |

Table 2. Information from refrigeration machines used in the Armada Mall.

| Type, brand of refrigeration machine (chiller) | The number of chillers, pieces. | Cooling power, kW | Total refrigerating power, kW | Serviced air-conditioned area, m² |
|----------------------------------------------|-------------------------------|------------------|-------------------------------|----------------------------------|
| MBC-07182                                    | 12                            | 554              | 6648.0                        | 102183.40                       |
| EWLDI-SS 600                                 | 1                             | 595              | 596.0                         | 46926.00                        |
| EWLDI-SS C60                                 | 3                             | 1033             | 3099.0                        | 46926.00                        |
| Total:                                       |                               |                  |                               | 149109.40                       |

The estimated capital costs for replacing the chillers of steam compression chillers with absorption chillers with the supply of thermal energy in hot water from the Sakmarskaya CHPP are given in table 3 and table 4.
Table 3. Activities on heating networks (costs of PJSC «T Plus»).

| Name | Amount | Unit of measurement | Cost, thousand rubles without VAT | Note |
|------|--------|---------------------|----------------------------------|------|
| Construction of a heating network section 1Du150, overhead laying in mineral wool insulation with a cover layer of galvanized steel using existing supports | 1.5 km | 5500.00 | 9817.50 | According to the estimated cost of the construction (re-construction) of heating networks of BE Engineering PJSC «T Plus», taking into account the conversion coefficient from the prices of 2015 to the prices of the 1st quarter of 2018 |
| Other unaccounted expenses | – | – | 981.75 | Accepted at a rate of 10% of the cost of building a heat network section |
| TOTAL | | | 10799.25 | |

3. Results

Armada Mall here is considered as a collector consumer with the sale of thermal energy in hot water at the collector rate. In order to assess the economic efficiency of connecting the refrigeration load of the Armada Mall to the Sakmarskaya CHPP, the following options were calculated:

1. The entire heat load of the hard drive of the Armada Mall is connected to the Sakmarskaya CHPP at a time. In this case, the annual net supply of heat energy in hot water increases by the amount indicated in table 1.

2. The thermal load of the hard drive of the Armada Mall is connected to the Sakmarskaya CHPP 2 in equal turns for 2 years. At the same time, during the connection period, the useful supply of thermal energy in hot water from the Sakmarskaya CHPP annually increases by 1/2 the value indicated in Table 1.

3. The heat load of the hard drive of the Armada Mall is connected to the Sakmarskaya CHPP in 3 equal stages for 3 years. At the same time, during the connection period, the net supply of thermal energy in hot water from the Sakmarskaya CHPP increases annually by 1/3 of the value indicated in Table 1.

4. The heat load of the hard drive of the Armada Mall is connected to the Sakmarskaya CHPP 4 in equal bursts for 4 years. At the same time, during the connection period, the useful supply of thermal energy in hot water from the Sakmarskaya CHPP annually increases by 1/4 of the value indicated in table 1.

At the same time, the capital costs of PJSC «T Plus» for all options are shown in section 1 of tables 3 and 4.

Indicators of economic efficiency options are shown in table 5.

The results of the analysis of the annual savings in operating costs of Armada Mall when using absorption refrigerating machines of vapor compression machines for the annual need for cold in the amount of 3.4 million kW/h are shown in table 6.
Table 4. Activities on the client side (costs Armada Mall).

| Name                                                                 | Cost, thousand rubles without VAT | Note                                                                                                                                 |
|---------------------------------------------------------------------|-----------------------------------|-------------------------------------------------------------------------------------------------------------------------------------|
|                                                                     | one unit of measure, at initial   |                                                                                                                                     |
|                                                                     | prices in prices of the 1st       |                                                                                                                                     |
|                                                                     | quarter of 2017                   |                                                                                                                                     |
|                                                                     | Note                              |                                                                                                                                     |
| Acquisition of absorption bromistolytic refrigeration machine in hot water (5000 kW) | 16.00 80010.00 10.00             | Based on the data of ARM suppliers, the specific cost of ARM on hot water was accepted in the amount of 254 $ per 1 kW of cold production, the dollar exchange rate in the first quarter of 2018 was assumed to be 63 rubles. |
| Purchase of a cooling tower for absorption bromistolytic refrigeration machine | 2660.00 2793.00                   | According to ARM suppliers at prices in 2019, taking into account the conversion coefficient from prices in 2018 to prices in the first quarter of 2018 |
| Delivery and storage costs absorption bromistolytic refrigeration machine | 321.12 321.12                     | Accepted at a rate of 12% of the cost of equipment                                                                              |
| The cost of design survey works absorption bromistolytic refrigeration machine | 299.71 299.71                     | Accepted at a rate of 10% of the cost of equipment with delivery                                                                |
| Construction installation costs absorption bromistolytic refrigeration machine | 899.14 899.14                     | Accepted at a rate of 30% of the cost of equipment with delivery                                                                |
| The cost of commissioning absorption bromistolytic refrigeration machine | 630.00 630.00                     | Accepted in the amount of 10 000 $ according to suppliers, the dollar exchange rate in the first quarter of 2018 is assumed to be 63 rubles. |
| Other and unaccounted expenses on the client side                   | – 8495.30                         | Accepted in the amount of 10% of the total cost of equipment, delivery, the cost of design survey works, construction installation costs , the cost of commissioning absorption bromistolytic refrigeration machine |
| TOTAL                                                               | 93448.27                          |                                                                                                                                     |

Table 5. Indicators of economic efficiency.

| Index                                               | Option 1 | Option 2 | Option 3 | Option 4 |
|-----------------------------------------------------|----------|----------|----------|----------|
| Capital expenditures of PJSC «T Plus», mil.rub.     | 10.80    | 10.80    | 10.80    | 10.80    |
| Net present value, NPV, mil.rub.                    | 2.38     | 0.89     | 0.09     | -0.64    |
| Internal rate of return, IRR, %                     | 21.09    | 17.44    | 15.62    | 14.03    |
| Payback period is simple, PP, years                 | 2.37     | 3.14     | 3.63     | 4.13     |
| Discount payback period, DPP, years                 | 5.66     | 7.99     | 9.76     | >14      |
Table 6. Analysis of annual savings when using ARM instead of VRM.

| Index                                                   | VRM         | ARM          |
|---------------------------------------------------------|-------------|--------------|
| Annual energy costs, thousand rubles                     | 14985.00    | 3146.85      |
| Annual costs of thermal energy, thousand rubles         | 0.00        | 3058.50      |
| Annual savings from the use of ARM, million rubles      |             | 8779.65      |
| Capital investments, million rubles                      |             | 93448.27     |
| Simple payback period due to savings, years              |             | 10.6         |

Note
1. With an estimated electricity tariff of 4.5 rubles / kW·h without VAT.
2. With an estimated collector tariff for thermal energy in hot water from Sakmarskaya CHPP, 941.077 rubles/Gcal, excluding VAT.
3. According to section 2 of tables 3 and 4.

4. Conclusion

The greatest effect for PJSC «T Plus» is achieved by connecting the entire heat load of the hard drive of Armada Mall at a time, while the costs of activities on heating networks are borne by T Plus and the costs of acquisition, installation and commissioning of absorption refrigeration machines - at Armada Group of Companies.

The payback period of absorption chillers for Armada Group due to energy savings is 10 years, and this is subject to the installation of 1 absorption chiller with an installed capacity of 5 MW. By installing several absorption refrigeration machines (and putting the refrigeration load in stages), the costs will increase, and accordingly, the payback period will increase, which can frighten off a potential client.

All researchers agree that heating systems should be seriously modernized. Changes in the model of heat and electricity markets and in the energy planning methodology being developed today should provide market participants with the right incentives to create reliable, balanced energy resources for all types, maneuverable and economical systems.

A significant package of measures to increase the efficiency of the existing CHPP is proposed:
- switching to the CHPP, loads of own and municipal boiler houses, including combining most of the city load of the WAN with jumpers of small diameters (reduction of specific fuel consumption for heat and electricity, increase in the utilization factor of installed capacity);
- formation of favorable proposals on the cost of steam and hot water for enterprises that have their own production boilers, for example, for the price of the fuel component in the production of heat in their own boilers;
- attracting, in cooperation with municipalities, investors for the construction of energy-intensive means (steam production, refrigerators with absorption machines, production with drying processes), primarily to increase the demand for heat in the summer;
- legal division of CHPP with low power generation into the CHP itself and boiler house for accounting in tariffs for heat of real fuel costs;
- transfer of CHPP to operation according to thermal schedule, up to removal of blades in LPC of steam turbines and liquidation of cooling towers (elimination of loss-making modes of equipment operation);
- reduction of the heating network temperature schedule, switching to quantitative control;
- decommissioning or preservation of excessive worst power equipment, including those involved in heating modes, but used less than 1000-2000 hours per year, with compensation of thermal peaks by peak boilers or boilers put into peak mode (significant reduction of operating costs for unloaded equipment);
- superstructure of CHPP with gas turbines (reduction of specific fuel consumption, significant increase in the profitability of summer regimes, additional revenues from the sale of electricity and participation in the coverage of consumption peaks) [13-15].
Most residential urban thermal systems use central heat load quality control on heat sources, which involves changing the temperature of the refrigerant depending on the temperature of the outside air with a constant flow of refrigerant [16].

The main advantage of quality control of heat load is stable hydrocyclic mode of heat supply system. Thus, the efficiency of most domestic heating systems continues to remain at a rather low level, however, CHPs allow the city to produce electricity and other energy carriers with specific fuel costs that are not achievable outside the heating cycles, and in the amount necessary to meet all urban needs. It is only necessary to develop a set of measures for the modernization of urban heating systems and correctly select their structure, composition of the CPH equipment corresponding to thermal and electrical loads.

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