RIGA TECHNICAL UNIVERSITY

Faculty of Civil Engineering

Institute of Heat, Gas and Water Technology

Kaspars GRĪNBERGS

Doctorate student in Doctor's Study Programme „Heat, Gas and Water Technology"

CONDENSER COOLING
IN ABSORPTION-BASED COLD SUPPLY SYSTEMS

Doctorate Thesis Outline

Scientific adviser

Academician , Dr. habil. sc. ing., professor

P.ŠIPKOVS

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DOCTORATE THESIS

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In order to secure a doctorate degree, the Doctorate Thesis is being defended publicly on 20 December 2013, at 16.00, at the Riga Technical University Faculty of Civil Engineering in Riga, at Āzenes iela 16/20, in the Faculty of Civil Engineering Session Room.

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DECLARATION

I confirm that I have developed this doctorate thesis, submitted to the Riga Technical University for receiving a doctorate degree. The doctorate thesis has not been submitted to any other university for the purpose of receiving a scientific degree.

Kaspars Grīnbergs ……………………………. (signature)

Date: ………………………

The Doctorate Thesis has been written in Latvian and contains an introduction, 6 chapters, a summary or conclusions, a bibliography, 47 figures and illustrations, for a total of 107 pages. The bibliography contains 79 titles.

ABSTRACT

Since the collapse of the Soviet Union, regional heat supply in Latvia has been only partially able to re-orient itself, reducing the percentage of facilities in operation since that age. Boiler houses and heating networks built in the 80s, considering their assembly technology, have been operating past their designed service life. Deficiencies in the heating network assembly technology are highlighted particularly by the great increase in fuel costs. The potential of using thermal energy should now be considered from a broader perspective. Solutions should be devised that allow heat to be consumed year-round. In this regard, a major role could be played by thermal energy absorption, or cold supply systems, which allow thermal energy to be used at a competitive price in order to cool down indoor spaces in summer.

The goal of this doctorate thesis was to develop a condensation cooling device for absorption/cold supply systems as an alternative to a cooling tower.

A research stand was constructed to achieve this goal, used as a basis for studying heat exchange processes. The device is intended for low-potential heat removal, radiating the thermal energy extracted from the coolant into the environment. The paper studied convective, evaporative and condensation-based heat exchange processes in order to determine the link between the efficiency of the device's operation to changes in ambient air parameters. The study analysed correlations between the changes in the capacity of the device under study and the factors that affect it. Based on the mathematical model developed for the study, conclusions were drawn regarding the practical applications of this device.

The research conducted within the framework of the doctorate thesis is based on the author's practical experience and knowledge about the specifics of regional heat supply, having worked in the industry using available resources. A regional boiler house and the connected infrastructural network and related territory were used, both to collect local ambient air measurements and fluctuations, and to apply the mathematical model for measuring equipment efficiency developed by the author. The scientific novelty of the doctorate thesis lies in a condensation cooling device for absorption cooling systems, to be used for cooling local buildings or complexes of buildings with absorption cycle facilities.

During the study, experiments produced a prototype device that can be considered an alternative to a cooling tower, and a methodology was developed; the conclusions are practically applicable to designing similar structures within existing heat supply systems.

Earlier in this sector were employed number of Russian scientists such as Margulova T, Labedevs P. In Latvia evaporative processes were studied by Janis Nagla, Peteris Sipkovs, Rudolfs Ciemins, Daniels Turlajs, Andris Kreslins, Egils Dzelzitis, Peteris Saveljevs etc.

6 publications have been made based on the results of the paper, published in compendia of articles for international conferences. Various stages of execution of the study were reported at 7 international conferences.

The author has developed and coordinated with the Public Utilities Commission a number of thermal energy tariffs and performed a careful analysis of regional heat supply systems, developing technical and economical justifications for renovation of the heat supply system in various administrative divisions throughout Latvia.

The paper consists of an introduction, eight chapters, and conclusions. It includes 101 pages in Latvian, 47 figures, and 15 tables. The bibliography includes 79 sources of literature.

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INTRODUCTION

A modern regional boiler house contains facilities intended for generating energy in a number of modes. Usually, there are two modes at the regional level, consisting of simultaneous generation of thermal energy and electricity. Following adequate refitting of heating networks for output of thermal energy, another mode might be added, to be used for cooling purposes. This way, the power of cogeneration equipment might be increased, expanding the hours in operation of boiler facilities, as well as enhancing the energy efficiency of supply networks and reducing the ratio of thermal energy losses. However, there are many obstacles to this technological solution.

Within the framework of the doctorate thesis, a number of potential obstacles have been considered, paying particular attention to the use of absorption-based heating systems and their component devices in order to increase the energy efficiency of centralised heating.

The first chapter of the doctorate thesis offers a technological solution for adapting the heating network to the use of cooling systems. Particular attention has been paid to a condenser cooling device in the absorption system, with a prototype developed during implementation of the paper, intended as an alternative to cooling towers in a decentralised cooling network. The purpose of the study was to verify the efficiency of a low-potential heat removal system regardless of changes in ambient air temperature parameters. The following enabling objectives were specified for achieving the goal:

- Construct and study an absorption-based condenser cooling, substantiating its potential application as an alternative to cooling towers;
- Conduct experiments during the study in order to identify changes in the facility's cooling properties given the influence of ambient air parameters;
- Study the facility's specific evaporation and convective heat dispersal capacity;
- Analyse processes which take place in the heat exchange layer between the facility and the external environment;
- Prepare a technical solution for constructing a similar structure.

Further, the doctorate thesis seeks a justification for adjusting the heating network to decentralised cooling systems. Changes in the energy efficiency of the heating network and self-cost of energy generation were analysed with increased sales of thermal energy.

The concluding part of the doctorate thesis analyses the regional heating system and the conditions that affect its energy efficiency indicators. Real data were used in the analysis to reflect the efficiency of the system, and they have been used as the basis for calculating thermal energy tariffs.

1. ENERGY EFFICIENT GENERATION CYCLE

Traditional energy producers consume fuel, such as fuel oil, diesel or natural gas, and transform it into electricity, although this is inefficient: the generation process produces heat that can be put to use. In cogeneration facilities, the heat is supplied to nearby consumers for operational or generation purposes.

Cogeneration denotes simultaneous generation of electricity and thermal energy at one facility in a thermodynamic cycle, with a ratio of electricity to thermal energy output that is characteristic for the facility. The energy ratio is equal to total (gross) electricity generated divided by (net) thermal energy delivered to the consumer. The energy ratio is generally noted as *a,* the quality indicator of a cogeneration system that describes how many kWh of electricity can be produced per kWh of thermal energy delivered to the consumer. This parameter describes the ability of thermal engines to generate electricity in a cogeneration system, and depends on a number of factors, including:

- heat consumption;
- load;
- type of heat carrier (steam, water);
- heat carrier parameters (temperature, pressure).

With cogeneration, there is a choice between a longer period of operation in cogeneration mode and greater capacity, although these values are inversely proportional. With 8760 hours in a year, the best-case scenario for operation during the heating season might approach 5500h, provided that wintertime consumption is very good. In the case of trigeneration, there is a choice in diverting heat to specific facilities depending on ambient air temperature. At the end of the heating season, as ambient air temperature increases, thermal energy might be directed to absorption-based cooling systems without reducing the capacity of generation facilities. Such a solution would allow a choice of facilities with considerably greater thermal energy capacity and therefore higher electricity capacity. This would allow uninterrupted generation of electricity.

Centralised cooling is based on supplying cooled water to the consumer, similarly to centralised heating. Water is cooled at a single location in large amounts and pumped to buildings, office complexes, hospitals, industrial consumers, and all sorts of consumers that require indoor cooling.

In the case of a decentralised cooling network, the necessary indoor cooling facilities are installed by the service recipient. Thermal energy is delivered from the thermal energy producer's boiler house to the thermal energy absorption facilities installed on the consumer's property. After the absorption device (chiller), cooling networks – including cooling of the chiller – are handled by the consumer.

Transformation of heat into cold energy takes place in absorption cooling devices (chillers). A principal scheme of an absorption facility is provided in fig. 1.1.

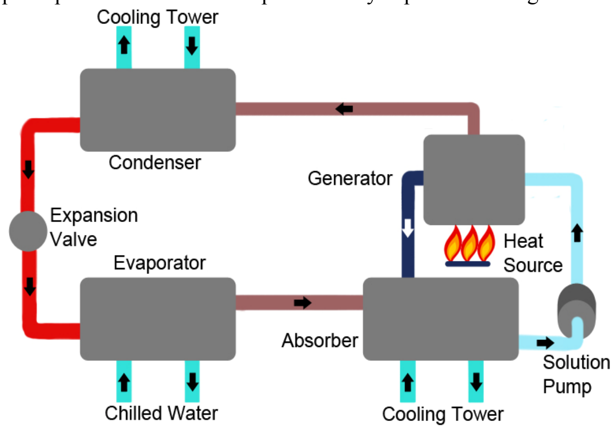

Fig. 1.1. Principal scheme of a heat absorption facility.

The generator evaporates a weak water solution of ammonia, with heat supplied in the form of either hot water or steam. The produced ammonia vapour flows to a condenser (Chiller) under pressure, where it condenses and gives off heat to the cooling water. From the condenser, the coolant flows to the evaporator is condensed, giving off heat to the cooling water. From the condenser, the coolant flows to the evaporator via a throttle valve. Via throttling, the pressure of the condensate reduces until partial evaporation is achieved, thereby lowering its temperature. In the evaporator, the coolant boils by accepting the heat necessary for evaporation from the cooled environment. The resulting ammonia vapour is diverted to an absorber. In the absorber, ammonia is dissolved in water, dispersing the heat it carries. In the absorber, the solution of ammonia in water becomes more concentrated. A circulation pump fills up the weakly concentrated ammonia fluid in the generator with the concentrated ammonia solution. Though a regulating valve, weakly concentrated fluid flows into the absorber from the generator.

In the condenser, in order to increase the heat removal intensity as fluid vapours condense, low-potential heat should be supplied in what is called a supercooling cycle. The heat carrier's temperature graph in this cycle is within 35-29 ^{o}C. This complicates assembly and operation of the system; to the temperature graph for this cycle, the manufacturer generally recommends construction of water evaporation towers (cooling towers) to remove heat. Construction of cooling towers is expensive and often does not fit into the landscape.

2. CONDENSER COOLING IN ABSORPTION-BASED COLD SUPPLY SYSTEMS

Initially, centralised energy generation and supply were based on studying and effectively using various properties of water. By boiling water, steam was obtained, which would power an electric generator. Water was used to cool the electric generator and steam condenser, and the cooling fluid would then be delivered either to centralised heating networks or to a heat dispersal circuit, which was often a large body of water such as a river, lake or pond. A cooling tower would be used where water bodies were not available.

Open-type cooling towers also exist, which might be more correctly named evaporation pools. These devices are highly suitable for the needs of small cogeneration plants and for cooling of absorption facilities. Condenser cooling in absorption-based cold supply systems has certain specifics related both to the peculiar heat carrier temperature graph and to the potential location of the cooling systems. In the case of a combined heat and power plant, the heat carrier in the cooling circuit exceeds the ambient air temperature considerably; besides, a cooling tower is an open system that increases cooling capacity. The heat carrier temperature graphs for condenser cooling in absorption-based cold supply systems are close to ambient air temperatures; the system also needs to be enclosed because it is to be installed at locations that are freely accessible.

2.1. Alternative cooling device for absorption-based facility condensers

Referring to the aforementioned, the research project entailed construction of a pool with a water sprinkling device for the purposes of condenser cooling in absorption-based systems. During operation of the facility at appropriate ambient air temperature, pressure and relative humidity, heat output and its fluctuations are measured. The goal of the study is to conduct an experiment using the constructed study stand to determine the possibility of practically using the condenser cooling device, as well as to develop a complete prototype that might be used as the basis for designing similar structures.

An absorption facility condenser cooling pool (hereinafter referred to as a cooling pool) is a heat engineering structure whose advantages compared to a heat carrier cooling tower (hereinafter referred to as a cooling tower) are:

- a heat carrier cooling pool is considerably less expensive to construct compared to a cooling tower;
- a cooling pool is an enclosed system, it can be placed in public areas;
- a cooling pool is a considerably more compact structure compared to a tower;
- in a residential area, a cooling pool is a visually more appealing and fitting structure compared to a cooling tower.

A heater is placed in the pool which is connected to the heat source and ensures a constant heat carrier temperature. The lower part of the pool includes a suction pump connection to a circulation pump, delivering water from the pool to water sprinklers located above the air/water interface. Water in the pool receives the heat supplied from the heater and is sprinkled above the pool, at a rate dependent on circulation pump/sprinkler capacity. Most of the sprinkled water returns to the surface of the pool in the form of fine droplets under the influence of gravity. Part of the sprinkled water returns to the surface of the pool under the influence of condensation processes and some of the droplets are released into the environment, briefly increasing cooling capacity; however, the mass of water lost by the pool must be recovered. Unlike an evaporation tower, which is an open system, a pool is a closed system, meaning that the heat carrier that is being cooled flows from condensers to the heater at the cooling facility, with no risk of atmospheric pollution. For this reason, cooling pools may be installed in inhabited areas – inside cities, parks, parking lots – without worrying about the possibility of mechanical damage to absorption equipment.

Thermometers are placed inside the pool on three levels, measuring fluctuations in temperature on different levels. The first thermometer is located above the heater, the other about 0.4 m below the air/water interface. The third thermometer is located above the air/water interface. Measurements from underwater thermometers are very similar; the above-water thermometer gives a different reading. The reading from this thermometer may be used to forecast changes in the intensity of heat flow.

The pool's cooling capacity, the throughput, temperature and pressure of heat carrier and water were measured using an Elkora B-34 thermal energy measurement device.

The facility's cooling properties are analysed in conjunction with changes in ambient air parameters, therefore an EasyWeather weather monitoring station was placed in the vicinity of the pool. The device is used to monitor ambient air temperature, wind direction and speed, since changes in any of these parameters affect the operation of the cooling pool.

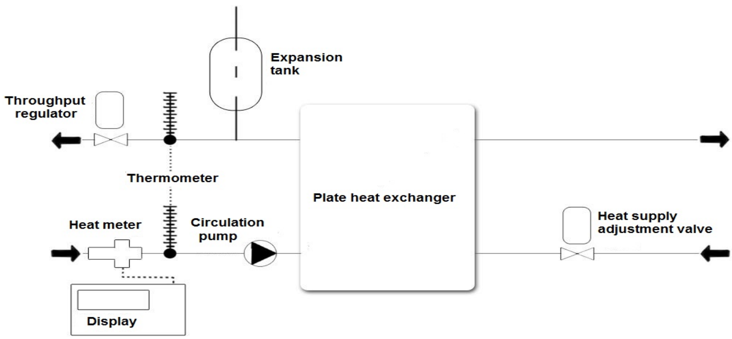

Fig. 2.1. Principal scheme of a heat carrier cooling pool for a heat source.

Heat is supplied to the pool from a boiler house, the connection scheme is seen in fig. 2.1. It was essential to place the cooling device as close as possible to the heat source, near flow meters. The necessary temperature schedule was achieved using a heat supply adjustment valve. Throughout the experiment, the pool's temperature graphs were adjusted until the optimal values were achieved for studying the selected processes.

2.2. Technical parameters of the research stand

Measurements intended for the duration of the experiment took place in several stages, with different sets of pool measurement devices and heater configurations. At different stages of the experiment, with improved equipment, the number of measurement devices was increased, additional pressure and temperature measurement devices were included; the heater circuit was also replaced.

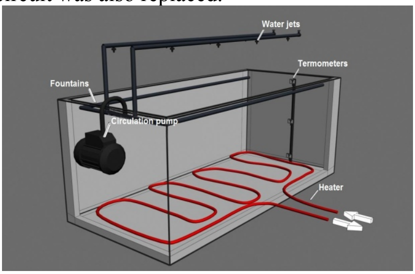

Fig. 2.2. *Pool with tube heater.*

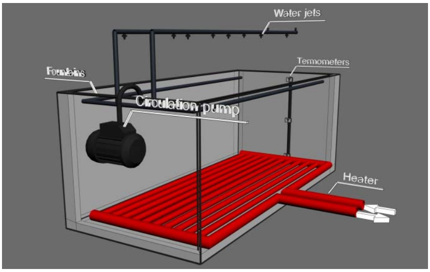

Fig. 2.3. *Pool with plate heater*

The shaped-circuit heater shown in fig. 2.2 had a high piping diameter and few curves, reducing local resistances. The amount of heat supplied for the purposes of the experiment was sufficient but a considerably higher heater surface area would be necessary for removing the necessary amount of heat during operation of the facility. In order to reduce the heater's surface area and increase local resistances (and therefore the amount of heat removed), a heater with a plate-based circuit was used. The updated heater configuration scheme is provided in fig. 2.3.

2.3. Analysis of changes in cooling pool capacity

The study of absorption-based condenser cooling was based on experiments using a previously constructed experimental stand, i.e. cooling pool. Using data obtained experimentally, the facility's cooling properties were determined with fluctuating ambient air parameters. The pool was placed as close as possible to the heat source to minimise heating network losses and precisely determine the importance of the pool's cooling properties in cooling the supplied substance. Changes in the pool's cooling capacity during the experiment were measured hourly. The throughput of heat carrier supplied to the pool heater was maintained constant over time, and the cooling capacity changed depending on ambient air parameters only. Fluctuations in incoming and outgoing cooled heat carrier temperature within the heater circuit are acceptable within a small range. The flow of heat in the pool was calculated based on the formula:

$$Q_{silt} = M \cdot c \cdot (T_1 - T_2) \text{ J,} \tag{2.1}$$

where: M – throughput, kg/s;

c – heat capacity, J/kg·K;

T_1, T_2 – heat carrier incoming, outgoing temperature, K.

The pool's cooling properties fluctuate depending on the surface area of the heater: the larger the area, the greater the cooling capacity. The pool's heat transfer ratio was calculated based on the following formula:

$$Ktr = \frac{Q}{S} \cdot \Delta t \quad \mathrm{W/(m^2 \cdot K)}, \qquad (2.2)$$

where: Q_{silt} – heat flow, J;
S – pool surface area, m^2;
Δt – temperature difference, K.

The cooling properties of the pool are affected by sprinkler output, which depends on the pressure generated in supply piping by the circulation pump. As sprinkler output increases, the pool's cooling capacity is increased. During the experiment, sprinkler output was kept constant in order to identify the effect of fluctuations in ambient air parameters on cooling capacity. The volume of sprinkled water was determined using the formula:

$$Vspr = \eta \cdot F \cdot \sqrt{2g \cdot \frac{\Delta P}{\alpha_p}} \quad \mathrm{m^3}, \qquad (2.3)$$

where: η – sprinkler output ratio, (0.6 – 0.75);
F – sprinkler diameter 0.01, m;
g – gravity, 9.8, m/s;
ΔP – nozzle pressure drop, kg/m^2;
α_p – relative weight of water 1 kg/m^3.

Removal of heat received by the pool partially takes place through evaporation. To calculate the ratio of convective heat transfer, a formula for nuclear evaporation was used where water was in free convection. The specific heat evaporation transfer ratio is specified using the formula:

$$\alpha_{evr} = 6{,}02 p^{0,20} q^{0,67} \quad J, \qquad (2.4)$$

where: q- thickness of heat flow from the surface of the pool, W/m^2;
p – absolute pressure of ambient air, Pa.

TO specify the specific heat flow of evaporation from the surface of the cooling pool, the following formula was used:

$$Q_{evr.} = \alpha \cdot S(t_v - t_s) \cdot \tau \quad J, \qquad (2.5)$$

where: t_v – surface temperature of dispersed droplets, ^oC;
t_s – ambient air saturation temperature, ^oC;
τ - duration of the evaporative heat exchange process, s.

The specific condensation heat transfer ratio was calculated at average ambient air temperature during the expert, selecting characteristic ambient air parameters based on a table of water properties: saturation curve and dry saturated water vapour properties. The temperature difference was calculated between the readings of dew point and pool water surface temperature readings. Condensation heat transfer ratio for the horizontal surface area was calculated using the following formula:

$$\alpha_{kond} = 0.725 \left(\frac{g \lambda^3 \rho r}{\nu \Delta t l}\right)^{0.25} \varepsilon_t \quad W/(m^2 \cdot K), \qquad (2.6)$$

where: g - gravity acceleration, m/s^2;
λ - heat transfer ratio of the medium (fluid or gas), W/(m·K);
ρ - density, kg/m^3;
r – evaporation heat, kJ/kg;
ν - kinematic viscosity of the medium, m^2/s;
t – pool water surface and ambient air saturation temperature difference, K;
l – characteristic geometric dimension, m.

The thermal energy received by the pool as a result of the condensation process was calculated using the following formula:

$$Q_{kond} = \alpha \cdot S(t_s - t_v) \cdot \tau \qquad J, \qquad (2.7)$$

where: t_s – pool water surface temperature, ^oC;
t_v – temperature of dispersed water droplets above the air/water interface, ^oC;
τ - duration of the condensation heat exchange process, s.

The convective heat transfer ratio was calculated by determining the ambient air temperature during the experiment. With this temperature, using a table of fiscal values for water and dry air, the characteristic air parameters were determined, calculating the Grashof and Nusselt criteria. Length was used as a characteristic geometric value for the pool. The pool surface temperature was measured using thermometer 2; ambient medium temperature was measured using an ambient air parameter measurement station. The convective heat transfer ratio for the horizontal surface area was calculated using the following formula:

$$\alpha_k = \frac{Nu \cdot \lambda}{l} \qquad W/(m^2 \cdot K), \qquad (2.8)$$

where: Nu – Nusselt criterion, number;
l – characteristic geometric dimension, m.
λ - heat transfer ratio of the medium (fluid or gas), W/(m·K).

The flow of heat transferred via convection was calculated using the following formula:

$$Q_k = \alpha_k \cdot S(t_s - t_v)\tau \qquad J, \qquad (2.9)$$

where: t_s – pool water surface temperature, ^oC;
t_v – ambient air temperature, ^oC;
τ - duration of the convective heat exchange process, s.

Total of transferred thermal energy components:

$$Q = Q_{evr} + Q_k - Q_{kond} \qquad J \qquad (2.10)$$

2.4. Experimental study of the cooling pool

The experimental measurement part on the devised research stand (pool) took place in three stages. An analysis of obtained data from the 3rd stage of measurement was used as the basis for developing a prototype device.

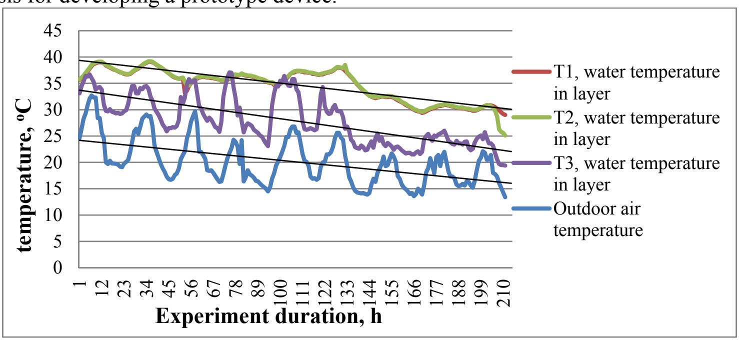

Fig. 2.4. Impact of ambient air temperature on the temperature of cooling water, in different layers within the pool.

The temperature distribution by pool water layers is provided in the graph in fig. 2.4. In layers one (T1) and two (T2), no temperature changes are observed, which is explained by uniform convective heat flow in the water. Unlike in the second part of the experiment, a sharp distinction between temperatures in different layers is observed. The active exchange zone is between the (T3) and ambient air temperature curves. In this (interface) layer, a micro-environment is created where a temperature is higher than ambient air temperature and lower than pool whereas surface temperature. In this interface layer, heat exchange processes take place, affecting the pool's cooling capacity parameters: convective heat exchange, evaporation and condensation of moisture.

Changes in temperature also affect relative humidity of the ambient air, with a day/night cycle inferred from the fluctuations in these parameters. Increased relative humidity is due to a drop in temperature during the night, while decreased relative humidity is observed during daytime heat. Relative humidity parameters affect the pool's specific evaporative heat flow intensity; the fluctuations are shown in fig. 2.5. The first stage of the experiment took place with very high relative humidity, which is considered normal; during the second stage of the experiment, relative humidity also increased during the day, reducing evaporative heat flow intensity.

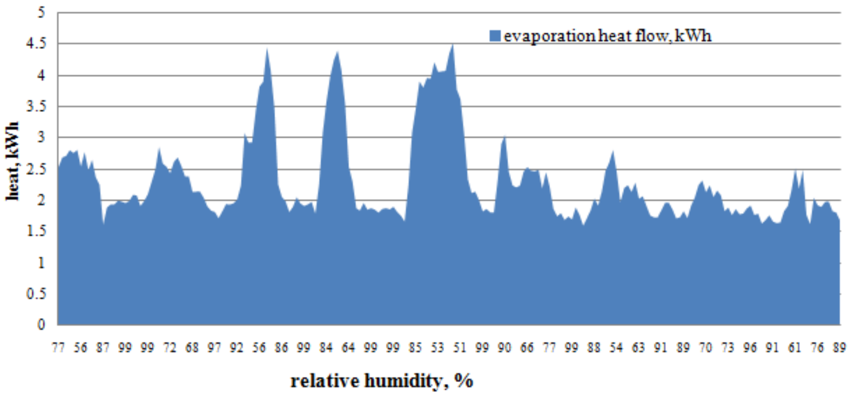

Fig. 2.5. Effect of ambient air moisture on evaporative heat flow intensity.

There is a process that is the opposite of moisture evaporation in the pool interface layer – condensation. The interaction between these processes is as follows: droplets sprinkled above the water give off heat through evaporation of moisture into the environment; however, because the temperature in the interface layer is lower than that of the environment, evaporated moisture reaches its saturation temperature quicker and part of it condenses, heating the pool. The process is intensified when ambient air and saturation temperatures are closer because relative humidity parameters increase and partial pressure rises. Air and air saturation temperatures during the experiment are provided in the graph in fig. 2.6. Critical locations where condensation risks arise are where the curves come closer together, air and saturation temperatures reaching a difference of just $0.1^{o}C$. This process is considered undesirable because it reduces the pool's potential cooling capacity. It is impossible to eliminate these processes altogether using technology; considering the negligible amount of supplied heat, it is not necessary. Changes in the condensation heat flow intensity depending on the relative humidity during the experiment are displayed in the graph in fig. 2.7. A comparison of the graphs in fig. 2.5 and fig. 2.7 shows that heat evaporation processes take place with considerably higher heat flow intensity compared to moisture condensation; condensation values are considered negligible.

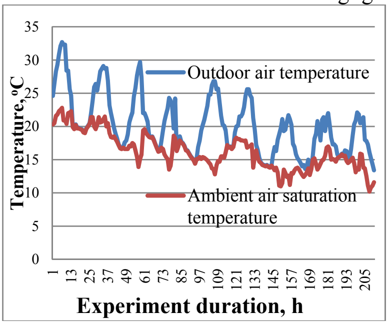

Fig. 2.6. Air temperature and air saturation temperature.

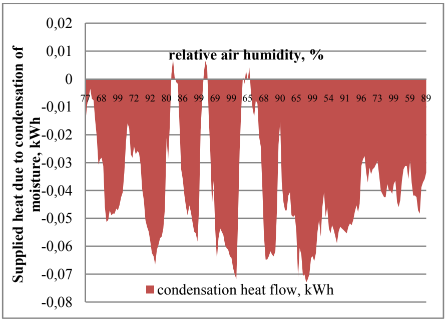

Fig. 2.7. Condensation heat flow changes depending on air humidity.

The moisture condensation process is not considered a troublesome phenomenon for any other reason because it is mostly observed during the night, when air temperature is reduced, improving heat transfer from the pool via convection. The effect of ambient air temperature on convective heat exchange values is shown in fig. 2.8. If the different measurement units and their relative scale are ignored, the curves are evidently mirrored. Convective heat exchange processes are also markedly cyclical in nature, as evident from the graph in fig. 2.9, except in this case heat flow intensity increases during the night. This means that the two main heat transfer processes within the pool are complementary: when the amount of heat transferred through convection is reduced, the amount of heat transfer through evaporation is increased.

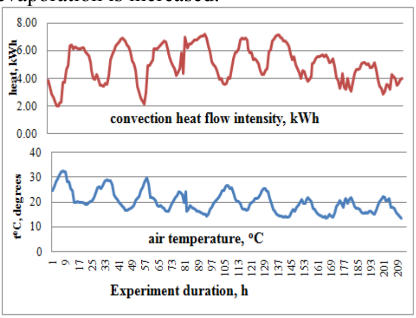

Fig. 2.8. Impact of external air temperature on convective heat exchange

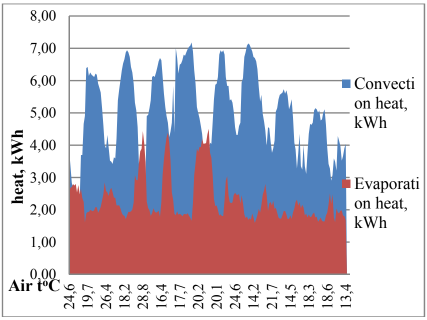

Fig. 2.9 components of heat transferred from the pool during the day/night cycle

The heat exchange processes observed during the experiment in the interface layer affect the amount of heat transferred but their fluctuations complement each other, maintaining the pool's cooling properties regardless of changes in ambient air parameters.

The total of transferred thermal energy components (red curve) and actual pools heat consumption (blue curve) during the third stage of the project are displayed the graph in fig. 2.10. Values on the red curve were higher than values on the blue curve for almost the entire duration of the experiment. This is explained by the fact that the pool takes up some heat from the environment through solar radiation, effectively reducing the pool's cooling properties.

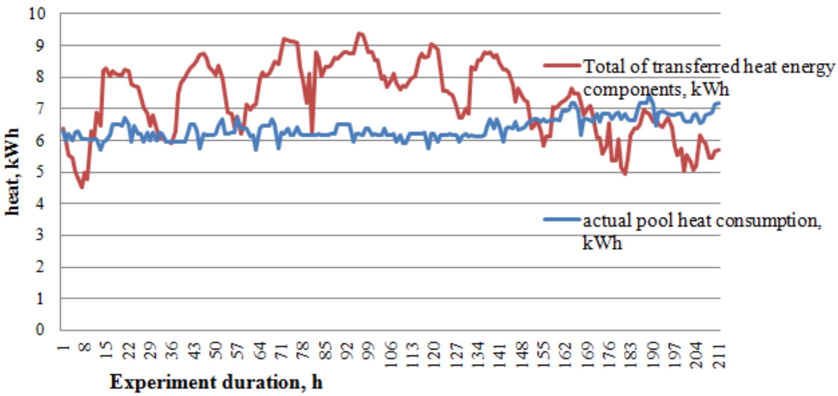

Fig. 2.10. The actual heat consumption on heat flow components amount.

From the graph in fig. 2.10, it is evident that the pool's cooling potential is higher; however, in spite of it, the amount of heat received from solar radiation is not considered a determining factor in maintaining the pool's cooling properties.

3. ADVANTAGES OF A DECENTRALISED ABSORPTION COOLING NETWORK

Thermal energy consumption, and therefore demand, is seasonal and directly related to heating. If thermal energy sales were successfully increased during the summer months thanks to the use of absorption-based cooling facilities, this would considerably improve the energy efficiency of a boiler house and allow more attractive thermal energy pricing. A calculation model has been devised in order to analyse potential gains from operating a decentralised absorption-based cooling network, with parameters that allow one to study the effect of increased thermal energy sales on tariffs. To make the analysis comprehensive, the calculation is based on the current thermal energy tariff calculation methodology, which subdivides expenses into a number of items.

Fixed expenses remain unchanged. Variable expenses increase with higher sales, since there is a direct relation to increased thermal energy demand.

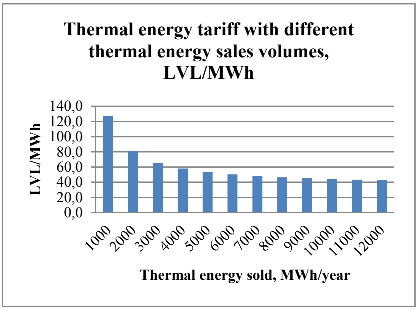

Fig. 3.1. Effect of thermal energy demand on pricing.

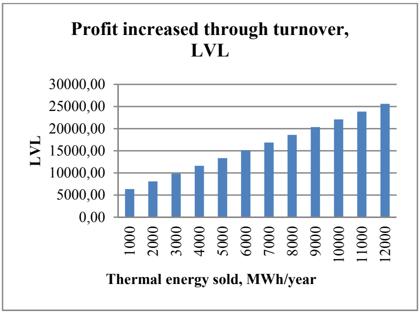

Fig. 3.2. Changes in the profit component given increased demand for thermal energy.

The graph in fig. 3.1 reflects thermal energy tariffs with increased thermal energy demand during a reporting year. It shows how much thermal energy tariffs might be reduced if sales increase. As turnover increases, the intensity of constant expenses is reduced: this is a goal for any thermal energy producer. Variable expenses, mostly representing fuel consumption, are very difficult to alter (besides the choice of fuel itself); the fixed expense items can be reduced significantly.

Reduced thermal energy prices are an insufficient motivator for the producer, but increased profits are. As evident from the graph in fig. 3.1, increased thermal energy tariffs might reduce thermal energy tariffs, but what would happen to the profit component? Profit is defined as 5% of the price per MWh. Profit intensity at a given thermal energy tariff is calculated using the formula:

$$P = T * (5\%), \text{Ls/MWh} \qquad (3.1)$$

How a company's profits might increase through higher thermal energy sales is reflected in the graph in fig. 3.2. Despite potential reductions in thermal energy tariffs, as turnover increases, profit from higher total thermal energy sales increases as well.

By optimising heating networks and adjusting them to consumption, allowing use of thermal energy for indoor cooling needs, one may increase the energy efficiency of the heat production and supply system, thereby reducing tariffs. In the long term, such a solution might be interesting both to the producer and to the user.

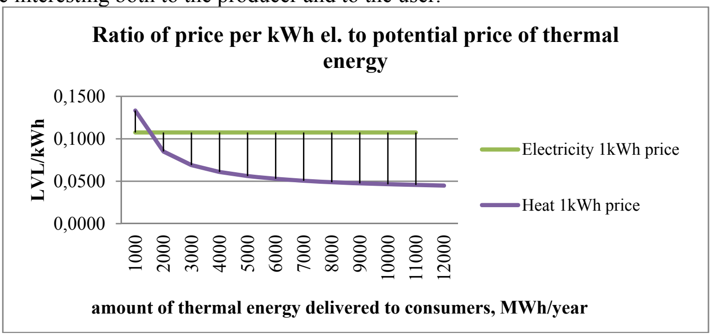

Fig. 3.3. Changes in thermal energy pricing

The graph in fig. 3.3 reflects the potential price difference given specific increases in thermal energy consumption. In this example, greater consumption of thermal energy thanks to the use of absorption-based facilities for indoor cooling would be 2.4 times cheaper than compression-cycle facilities operated with electricity.

4. ANALYSIS OF OPERATION OF AN EXISTING REGIONAL HEATING SYSTEM

Classical centralised heating is so far the best known means of heating. Its advantages no longer need proof because it has been verified by years of practice and research in European Energy Charter documentation. In countries whose climate requires particular attention to heating, centralised heating is the dominant means of heat supply for urban purposes.

For Latvia, keeping heating centralised in its regions is a priority: it is the only way towards reducing energy expenses. However, at many new sites, particularly with detached and low-rise residential buildings, local heating systems are installed instead. As technology develops and the availability of financial instruments increases, thermal energy consumption goes down, the number of winterised buildings increases, where, with low heat load during the summer, heat load is also reduced during heating periods; the number of consumers who wish to install individual heating systems is increasing, however, as a result of which the energy efficiency of the heating system is going down. These circumstances demand caution with modernising existing boiler houses according to contemporary standards, as the costs take longer to recoup once thermal energy consumption is reduced.

Currently, regional heating systems in various municipalities throughout Latvia operate in a somewhat impaired fashion, comparing to a classical heating system. Deviations observed in heating systems are mostly the following:

1) high expenses on producing and transmitting heat, mostly due to high losses in transmission networks;
2) low efficiency of fuel consumption, due to the use of worn-down, obsolete facilities to generate heat;
3) insufficient reliability of heating supply, due not to technical properties of the systems but to outstanding debt in payments for heating supply at certain sites;
4) inadequate level of service, expressed primarily as deviations from the temperature schedule, lack of automatic regulation equipment and manual regulation (in certain periods leading to excessive heating of spaces), improperly adjusted internal heating systems inside homes (lack of riser pipe balancers, leading to excessive heating of one section of a building while another section is not sufficiently heated), lack of circulation in the hot water supply system; lack of data registration journals and maintenance instructions at heating nodes; lack of house energy management services (public supervision institution maintained by the inhabitants of a building) etc.

In order to analyse the situation given current operation of the regional centralised heating system, a heating company was selected that exhibited issues representative of the local heating system - INP SIA „Ikšķiles māja”. The company’s core business activities are heating and management of residential buildings and structures owned by legal entities within the town of Ikšķile, extraction and delivery of potable water to consumers.

The heating system is compact, the total length of heating networks is 1.8 km, with a heat capacity of 5.7 MW, produced by 4 boiler houses. Individual heating nodes are installed inside all multi-apartment consumer buildings; 1.44 km of heating networks have been replaced, representing 80% of the total length of heating mains, including part of distribution networks inside building blocks, up to building inlets; the town's larges boiler house has been fully reconstructed. The repair works improved the quality of the heating service at the generation and transmission sections. However, the thermal energy tariff within the town of Ikšķile remains high.

A summary of efficiency parameters for boiler houses within the city of Ikšķile is provided in fig. 4.1. The summary shows that the boiler houses operate at high efficiency but with obvious impact from the typical climate conditions of Latvia: once the heating season ends, the amount of thermal energy sales decreases sharply. The figure demonstrates that the range of changes in thermal energy losses is considerably narrower. For instance, in February, 1 MWh per 7 MWh delivered to the consumer have to be spent to overcome the inertia of heating networks (thermal energy losses); in July, this ratio constitutes 1.5:1 MWh.

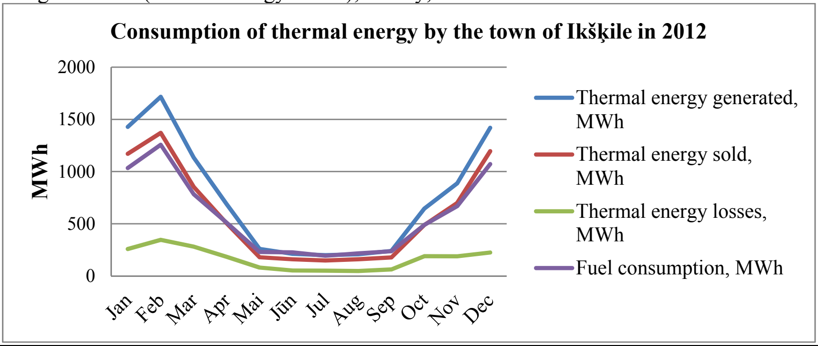

Fig. 4.1. Heat load graph for the town of Ikšķile

To analyse the circumstances that lead to high thermal energy pricing, the energy efficiency parameters of the two largest boiler houses and their respective heating networks should be considered separately. The other two boiler houses are local and do not generate thermal energy losses in heating networks.

Boiler house at Dainu iela 4a – the town's largest boiler house with a total capacity of 4.18MW and vastly higher output compared to the other boiler houses. The boiler house generates about 75% of the total generated within the town of Ikšķile. The total length of connected heating networks is 1.4 km.

Table 4.1.

Thermal energy generated and sold by the boiler house on Dainu iela 4a in 2012.

Month	Thermal energy generated, MWh	Thermal energy sold, MWh	Thermal energy losses, MWh	Fuel consumption, MWh	Fuel consumption efficiency, %	Thermal energy losses, %
Jan	1141.64	921.34	220.3	1033.73	110.44	23.91
Feb	1367.93	1066.15	301.78	1256.91	108.83	28.31
Mar	912.91	674.54	238.35	783.18	116.56	35.34
Apr	549.82	404.29	145.53	510.98	107.6	36.00
May	206.27	156.79	49.48	229.02	90.07	31.56
Jun	191.6	143.02	48.58	225.94	84.8	33.97

Jul	175.68	130.62	45.06	192.91	91.07	34.50
Aug	193.44	148.59	44.85	217.3	89.02	30.18
Sep	199.34	156.52	42.82	236.2	84.39	27.36
Oct	523.46	398.73	124.73	488.54	107.15	31.28
Nov	709.99	551.53	158.64	668.91	106.14	28.73
Dec	1131.12	939.81	191.31	1071.87	105.53	20.36
Total:	***7303.2***	***5691.93***	***1611.43***	***6915.49***	***105.61***	***22.06***

As evident from the data in table 4.1, the amount of thermal energy generated varies depending on the calendar month. Thermal energy is generated with high fuel efficiency, thanks to the use of gas boilers and flue gas economisers. Costs are increased considerably by high thermal energy losses through networks, which remain high despite renovation of all but some networks within individual blocks. In a centralised heating system with relatively low amounts of thermal energy generated and the ratio of energy losses reaching 20%, this becomes a factor that increases thermal energy generation costs considerably. One explanation is inaccurate specification of the consumer-supplier borderline, leading to incorrect placement of thermal energy metering devices and transferring part of the consumer's thermal energy losses to the supplier's side.

Boiler house at Skolas iela 2b – the town's second largest boiler house with a total capacity of 1.3MW. The total length of connected heating networks is 0.4 km.

Table 4.2.

Thermal energy generated and sold by the boiler house on Skolas iela 2b in 2012.

Month	**Thermal energy generated, MWh**	**Thermal energy sold, MWh**	**Thermal energy losses, MWh**	**Fuel consumption, MWh**	**Fuel consumption efficiency, %**	**Therma l energy losses, %**
Jan	234.41	196.56	37.85	250.65	93.52	19.26
Feb	286.97	242.85	44.12	303.18	94.65	18.17
Mar	181.55	138.54	43.01	188.8	96.16	31.05
Apr	112.47	74.31	38.16	117.89	95.4	51.35
May	40.82	9.73	31.09	44.23	92.29	319.53
Jun	8.45	4.67	3.78	29.38	28.76	80.94
Jul	7.9	2.38	5.52	13.33	59.26	231.93
Aug	3.01	1.06	1.95	15.01	20.05	183.96
Sep	29.54	9.83	19.71	33.9	87.14	200.51
Oct	96.95	64.51	32.44	106.57	90.97	50.29
Nov	142.48	113.37	29.11	156.06	91.3	25.68
Dec	231.62	198.83	32.79	242.92	95.35	16.49
Total:	***1376.17***	***1056.64***	***319.53***	***1501.92***	***91.62***	***23.22***

The data in table 4.2 indicate that the efficiency ratio of the second boiler house is lower. Efficiency slumps during the summer because public sites and private homes do not consume heat during the summer period. The only consumer is an 18-apartment residential building that requires heat to produce hot water.

This reflects prevalent issues with regional heating, where a local thermal energy producer would profit much more from not supplying thermal energy to the consumer in summer, than from supplying it. Thermal energy losses affect tariff calculations, so all consumers suffer from the structuring of heating networks. To increase the energy efficiency of regional infrastructure, it is not sufficient to just reconstruct heating networks and boiler houses because, although it will increase the reliability of energy supply and reduce losses, it will not solve problems related to consumer structure and configuration of heating networks. Unorthodox solutions should be sought that maintain high heating network energy efficiency and increase thermal energy demand during the summer period.

5. IMPACT OF SELECTED BOILER HOUSE CAPACITY ON THERMAL ENERGY TARIFFS

Generation of thermal energy at industrial boiler houses is exceedingly variable. The weather changes very sharply each year; the ambient air temperature in Latvia ranges from over +30°C in summer to -30°C in winter. These provisions are essential in designing centralised heating systems, particularly in selecting the capacity of a boiler house. High variation of ambient air temperature often makes engineers cautious, designing high reserve capacities in order to cover peak loads during the winter period. Failure to consider sufficient capacities for the cold winter months would be inexcusable; however, the caution of engineers has an effect on heat consumers.

Natural gas, a traditionally more expensive fuel, was taken as an example. The situation with an existing regional Ikšķile town boiler house was analysed, evaluating expenses related to building and operating such a boiler house. Two other variants were considered – in one case, the capacity of the aforementioned boiler house was reduced to the amount necessary for a given year; in the other, capacity was selected without accommodating a given year's peak loads. The purpose was to evaluate how much thermal energy the consumer overpays daily for "excess" capacity within centralised heating networks, based on expense items that affect the thermal energy tariff. Following an evaluation of the cost data for the existing boiler house, similar parameters were selected for reduced-capacity boiler houses. Thermal energy tariffs were calculated in accordance with the "Thermal Energy Supply Service Tariff Calculation Methodology".

An example thermal energy tariff calculation was devised to establish the effect of a boiler house's thermal energy generation facilities and their constituent devices on thermal energy prices. Boiler house output data were reflected in table 5.1 and grouped as follows:

1. Current capacity of the boiler house under study;
2. Calculated capacity of the boiler house that would be sufficient for the 2011 heating system in accordance with PUC methodology;
2. Calculated capacity of the boiler house that would be sufficient if capacity was not required to cover peak loads in 2011.

Table 5.1 lists a summary of potential expense items for boiler houses with different capacities, which can be divided by the expected amount of thermal energy to be sold to determine the price per MWh. Boiler house output data were kept identical in order to evaluate the impact of peak load capacity increases.

Table 5.1

Expense items constituting the thermal energy tariff.

Boiler house capacity, MW	**4.2 MW**	**3.12MW**	**1.6MW**
Amount of thermal energy delivered to consumers, MWh	6233	6233	6233
Thermal energy supply network losses, MWh	1030	1030	1030
Amount of thermal energy generated, MWh	7263	7263	7263
Thermal energy supply and distribution losses, %	14	14	14
Number of hours in operation of equipment, h	1729	2327	4539
Fixed expenses, LVL	43659	41514	38375
Labour costs, LVL	35000	35000	35000
Fixed asset depreciation, LVL	7149	6014.08	3234.58
Equipment maintenance and repair costs, LVL	1510	500.00	140.00
Variable expenses, LVL	255220.3	252827.7	249623.6
Fuel expenses, Ls (assuming the price of natural gas at 294.99 LVL /1000m3)	244294.6	244294.6	244294.6
Electricity expenses, Ls	10402.8	8010.14	4806.08
Natural resource tax, Ls	522.9	522.9	522.9
Total expenses, LVL	298880	294342	287998
Thermal energy tariff with different thermal energy sale volumes, LVL/MWh	48.0	47.2	46.2

The difference between the highest and lowest capacities exceeds a factor of 2, although, the cost per MWh diverges by less than 4%. This leads to the conclusion that, by opting for higher-capacity facilities according to the designer's precaution in covering peak heat loads and operating/depreciating it in the long term, cannot increase the consumer's thermal energy tariff by a large amount.

6. INVESTMENT PROJECT EVALUATION METHODS

To determine the profitability of investing in projects that increase thermal energy sales, an analysis of returns on project investment should be conducted. As an example, we will consider the higher possible amount of thermal energy sales as calculated in chapter 3, calculation sample. In this case, the calculated thermal energy tariff was lowest: 42.70 LVL/MWh. We will further assume that the current thermal energy tariff is 52.74 LVL/MWh.

To adjust the current centralised heating system to a decentralised cooling network, reconstruct heating networks and divide the thermal energy circuit depending on consumer needs, the necessary investment is LVL 260,000. To analyse the return on investment in the project, a number of project profitability calculation methods may be applied. The most popular ones are payback period (PB), net present value (NPV) return on investment (ROI). All of these methods provide a comprehensive economic analysis for a financial specialist but lack heating industry specifics.

Modified NPV method – in calculating project profitability, a subjective discount rate is applied. Here, during calculation of cash flow with the selected discount rate, the thermal energy tariff is reduced until the first thermal energy tariff value is achieved in whole santīmi [translator's note: one-hundredth of one Latvian lat, or about 1.4 eurocents], where NPV remains positive over the specified period of time. This way, the thermal energy company has a perception of how investment affects the tariff. It does not mean that tariffs must be reduced immediately, but the precise eventual thermal energy cost is known at which a project would be profitable over a given payback period. The thermal energy supplier defines the amount by which the tariff may be reduced. This way of analysing projects is much easier to perceive because it shows the potential extent of reduction in thermal energy tariffs.

The difference in cash flows for the current and reduced thermal energy tariffs is shown in the graph in fig. 6.1.

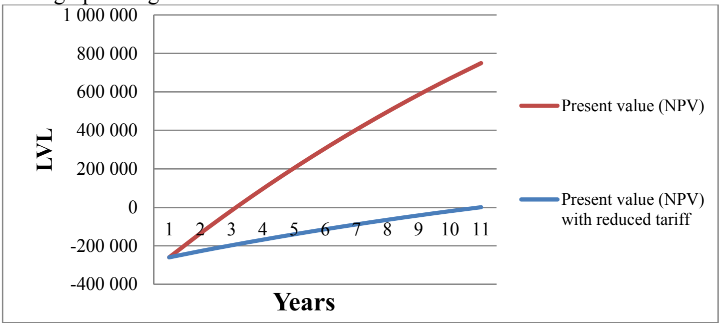

Fig. 6.1. Cash flows with NPV and modified NPV.

Discount ratios are identical for both curves. The red curve increases much faster because the tariff is higher. Although the blue curve is much slower, both projects have positive NPV. This means that investment and adaptation of thermal energy networks to multi-level energy distribution can allow a reduction of thermal energy tariffs by 15.34%.

7. CONCLUSIONS

1. This study is devoted to developing and improving a prototype cooling pool that may be used for condenser cooling of absorption-based facilities. The facility is intended for removing low-potential heat, primarily as an alternative to cooling towers. A cooling pool with a plate-shaped heater circuit is an adequate alternative to a cooling tower given specific provisions: available area, moistening radius of sprinkled droplets, temperature schedule for the absorption-based cooling supply system, heating agent throughput.
2. The paper develops a methodology for calculating the thermodynamic parameters of a cooling device based on intensive research and analysis of climatological data.
3. The dominant parameter affecting a pool's cooling properties is ambient air temperature, which reflects changes in other factors that affect the pool's performance through changes in the air/water interface thermodynamics. As ambient air temperature increases, the amount of heat removed through evaporation increases; as it goes down, more heat is removed by means of convection. The complementary action of these processes allows constant cooling performance to be maintained.

4. Changes in a pool's cooling performance are cyclical; this, in combination with heat accumulation properties, ensures stable and predictable cooling by mitigating the impact of ambient air temperature fluctuations. As air temperature increases and convective heat transfer decreases, the pool accumulates heat generated by the heater, maintaining its cooling capacity. When ambient air temperature decreases, convective heat transfer increases and heat accumulated by the pool is removed into the environment.
5. A correct temperature gradient has the greatest effect on maintaining the cooling performance of a cooling pool. This can be achieved by ensuring a separation of temperature layers in the pool and above the air/water interface. Temperature in the sprinkler zone should be lower than that of the heater layer but higher than the ambient air temperature; otherwise, cooling capacity will depend solely on the pool's heat accumulation properties.
6. An effective way to increase thermal energy sales and keep consumption more steady similar year-round is to use thermal energy for cooling indoor spaces in summer. Such a solution is possible through creation of a cooling supply system: it would increase the efficiency of the thermal energy system at the production and supply stages by reducing the impact of heat losses.
7. Diversified use of thermal energy is a niche for municipalities with small areas and concentrated infrastructure networks. Absorption-based cold supply systems have potential to reduce thermal energy prices in the long term, becoming a competitive alternative to electrically-operated compression-cycle cooling systems. The most important decision is from which side the initiative will come – whether the service would be offered in a centralised manner by the thermal energy producer or individually by the consumer, installing specialised equipment.
8. Given the context of a regional centralised thermal energy supply system and the configuration of heating networks, a decentralised cooling network should be established, maintaining the possibility of supplying hot water as well as ensuring the necessary heat carrier parameters for absorption-based systems during the summer.

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