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ECONOMIZERS IN CHILLER SYSTEMS

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DESCRIPTION

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Economizers in Chiller Systems

Abstract

There are many buildings that have cooling demands for different purposes. They can be hospitals, administrative and office buildings, shopping centers, data centers and also industrial buildings. Cooling of processes and products, cool rooms, ice halls, and air-conditioning systems require chiller system application. Chiller system is usually the substantial part of energy consumption of the building. That's why different ways of increasing of the chiller systems efficiency began to be used more often.

Due to the widespread use a lot of schemes to optimize and improve the effectiveness of chiller systems have been developed. One possibility is the installation of an additional low-cost equipment like the economizer systems. They may be applied in the refrigeration cycle of the chiller or in the rest chiller system.

In the theoretical part of the thesis measures and methods of the chiller systems efficiency increasing and different types of economizers were described. Influencing on the economizers efficiency factors were noted.

Study case contains the simulation of the office building in different modes with IDA Indoor Climate and Energy software. Some results of the simulations are presented in the tables. The benefit from the economizer operation is calculated as compared with traditional chiller system. Also influence of the economizer set-point temperature on its benefits was evaluated. The relationship between equipment cost and benefits from the system operation must be precisely evaluated in every individual case.

Subject headings, (keywords)

Chiller system, Economizer, Efficiensy, Free-cooling

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CONTENTS

1 INTRODUCTION

1.1 Background

In the modern world, energy conservation and resource conservation is a critical issue. The key task is to ensure that the required conditions for minimum energy consumption in the design of various buildings are followed. Despite this the world consumes a very large amount of energy and the consumption grows every year.

Thus, there are many buildings that have cooling demands for different purposes. Cooling of processes and products, cool rooms, ice halls, and air-conditioning systems require chiller system application. The air-conditioning in the rooms is more relevant for different types of buildings. Chiller systems are widely used in multi-zone air conditioning systems of buildings. These systems are installed in public and in industrial buildings.

Due to the widespread use a lot of schemes to optimize and improve the effectiveness of these systems have been developed. One possibility is the installation of an additional low-cost equipment. It makes good economic advantage in the operation of the system and increases its effectiveness.

A chiller system consists of a cooling unit itself and its service units. Thus there is the possibility of increasing the efficiency of both the chiller, and various parts of the system. One possibility is the installation of the so-called economizer systems. Economizer systems are widely used in chillers of the most reputable manufacturers who are working to improve them.

In this thesis economizer systems are divided into two main types. The first type is external economizers, which increase the efficiency of the cooling unit of the chiller. The second type is internal economizers that improve thermodynamic circuit of the chiller. Both types have their application conditions, which are discussed in this thesis.

For more detail view and understanding the real application conditions of the external economizer systems simulation of indoor climate and energy of office building were done in IDA Indoor Climate and Energy software. The operation of the chiller system and the economizer system were studied in the different working conditions and benefits of economizer application were determined.

1.2 Aims

Nowadays chiller systems have become very popular particularly in Russia. They are installed in different types of buildings and have some advantages compared with other systems. That's why it was decided to learn this theme more deeply.

There are many ways increasing the efficiency of chiller systems. One of them is use of economizers. It is the way of system improving with additional equipment. Economizer systems are contained in chiller system or in construction of chiller itself. They are designed to save energy and used by different chiller manufacturers. Also there is no clear classification of such systems.

So one objective of my work is to classify the economizer systems and to describe them, to see how the use of economizer will affects on chiller system efficiency and what economic benefits it can brings.

Also in my thesis it will be shown how economizer systems may be applied on practice and how the efficiency of chiller system may be increased. What savings, depending on the application conditions may be obtained with selected type of economizer system.

1.3 Methods

My thesis consists of several parts. In theoretical part operating principle of the chiller systems will be described, the economizer systems will be classified and described using library and researching materials, patents of the best known manufacturers. Different measures of the chiller system efficiency will be listed for understanding the economizers benefits evaluation methods.

Then case of application of the chiller system with economizer will be researched. In the IDA Indoor Climate and Energy program the example building will be modeled and cooling and energy systems simulations will be carried out. The example building is the two-storage office building 1080 m^2 by the area with constructions and loads according to standard D3 /1/. It is placed in Helsinki and the climate of this town will be used for simulation. Then different cases and conditions of the chiller system operation will be modeled.

Based on it economizer efficiency of this study case can be calculated. Advantages and disadvantages of the economizer application will be discussed in last chapter of the thesis.

2 CHILLER SYSTEMS

2.1 Definition

There are many types of buildings that have cooling demands during some part of the year. They can be hospitals, administrative and office buildings, shopping centers, data centers and also industrial buildings. Quite profitable and modern way is the use of chilled water for cooling of buildings or industrial purposes. Chiller is the refrigeration unit that is applied for water cooling in conditioning and cooling systems using the vapor compression cycle. It is mostly used when cooling is needed for a quite large area of the building. Also it is able to maintain the temperature required for continuous operation of the equipment for instance in data centers.

Chiller systems consist of refrigeration unit and another equipment serving for its operation. So, chiller itself uses the principle of vapor compression cycle and contains condenser, expansion device, evaporator, compressor and refrigerant circulated between them. For proper operation of refrigeration unit it should be served by condenser cooling system. For this purposes ambient air is usually used. This system, in turn, contains a number of equipment like circulation pumps, pipes or ducts, cooler and other depending on developed requirements. Through the various configuration and different types of its components chillers system can be classified according to various criteria /2./

2.2 Classification of chiller systems

The first division is concerned to the way of heat rejection out of the condenser. Based on this there are two types of chiller systems: with air-cooled condenser (direct condensing) and with liquid-cooled condenser. Chillers with air-cooled condenser are more common. The heat is taken by the air, usually it is outdoor air. This way of heat transfer requires installing the condenser outside of the building. Also special functions are required for implementation of this method.

Chillers with air-cooled condenser are also divided due to the way of the chiller configuration. It can be monoblock design when all chiller parts are in the same block. Another type is system with remote condenser. In this case main unit is installed inside the building and condenser is placed outside, for example on the roof. The main unit is connected to the condenser by the copper refrigerant tubes.

Monoblock air-cooled chillers are equipped with the fans. Based on fan types there are systems with axial and centrifugal fans. Axial fans can’t be included in the ventilation network. That’s why chillers with axial fans may be installed only outside of the building. Nothing must prevent the airflow to the condenser and out of it by the fans. Chillers with centrifugal fans are designed for installation inside the building. The main requirements are small size and low noise level due to the internal placing. With such configuration it is needed to provide the flow of the cool air to the condenser and outflow of warmed air from condenser. For this purpose suction and discharge ducts are used. Together with the fan they form the ventilation network. So fan must be selected according to pressure losses in the net /2./

The units without condenser are installed inside the building and connected with the remote condenser. The inside installation makes the use and maintenance of such systems easier. Water may be used as coolant and emptying of the system in cold weather is not needed. Also it has lower pumping cost compared to non-freezing liquids. However, the length of refrigerant tubes in such systems is limited because of too high pressure losses.

Liquid-cooled chillers have higher initial cost. It is needed to create a liquid loop of condenser cooling with required equipment. Such system may be divided by the type of condenser cooler. It can be open or closed cooling loop. Traditional way of removal heat from condenser is evaporative cooling tower. Water from the condenser is sprayed through the injectors in the stream of ambient air and directly cooled near to the wet bulb outdoor temperature. Such equipment is rather big and special maintenance and additional equipment like a pump is needed. It is open or direct system. Closed systems don't have an direct contact with air. Nowadays dry coolers become more popular. It is surface water-to-air type heat exchanger with axial fans. Warm water circulates through the heat exchanger and fans blows it with outside air. Water is cooled by the convection heat transfer. Another case of the closed system is closed circuit cooling tower or liquid cooler. It is a combination of two previous systems. It is close to the dry cooler construction but the water from the local water supply network is additionally sprayed to the coil pipe of the heat exchanger. So blown by the fans the water evaporates and takes the heat from the condenser cooling water. Closed systems require installation of appropriate equipment like circulation pump, expansion tank, check valve and shut-off valves. For freezing prevention in cold weather closed circuit is filled with antifreeze like mixture of water and glycol /2./

Depending on capacity chillers are equipped with three types of compressors. So based on it chillers with scroll, screw and piston compressors may be distinguished. Scroll and sealed piston compressors are applied with small capacity chillers, single-screw compressors are for medium and high capacity chillers, twin-screw and non-sealed piston compressors are for medium capacity /2./

Also chillers may be divided on units with integrated hydronic module or without it. Usually it is small capacity chillers. Integrated hydronic module may include circulation pump on return line, expansion tank, check valve, discharge valve, water filling block, manometer and differential pressure relay or other additional equipment /2./

2.3 Principles of chiller operation

Chiller as it was described consists of compressor with electric motor, condenser, evaporator, expansion device and controller. Principle scheme of chiller with air cooled condenser is presented in the Figure 1.

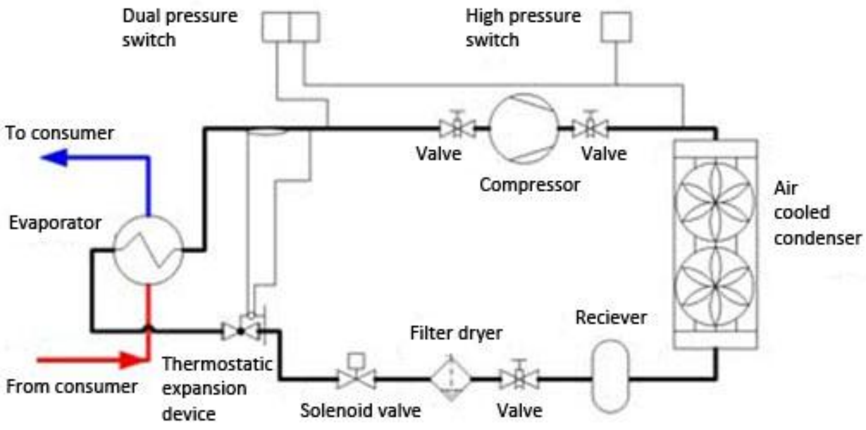

FIGURE 1. The principle scheme of chiller system /3/

A warm return water is cooled in evaporator by boiling of refrigerant. As a result of heat transfer refrigerant evaporates to the gaseous form and goes to the compressor. Here it is compressed to the condensation pressure. Vapor with high pressure becomes liquid with high pressure in condenser. Heat from the gas is rejected to the atmosphere with evaporator cooling system, here it is air-cooled condenser. Liquid is collected in receiver and then passes through desiccating filter, solenoid valve and thermostatic expansion valve where pressure decreases to the evaporation pressure and refrigerant goes to the evaporator. The receiver, desiccating filter, shut-off valves provide reliable operation of the system. Also solenoid valve and high pressure and low pressure relay are necessary for the safe work.

Log(p)-h diagram of vapor-compression cycle shows changes of refrigerant phases and parameters during the operation cycle. Example of the vapour compression cycle is shown in the Figure 2. Every point on the diagram shows certain conditions of working substance. Every line is the process of change the thermodynamic parameters. The length of the line shows amount of output energy in the condenser, input energy in the evaporator and amount of compressor work.

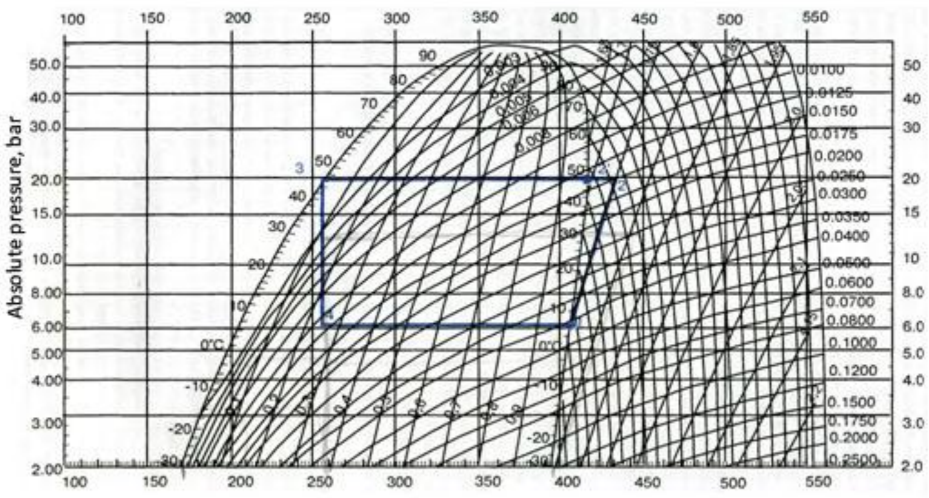

FIGURE 2. Theoretical vapor-compression cycle on lgP-h diagram

In the example theoretical cycle with suction of the saturated vapor is shown. Saturated vapor of the point (1) is sucked and adiabatic compressed in the compressor to the point (2) conditions with the constant enthalpy. Further superheated gas becomes saturated vapor in the process (2-2’). Process of condensation (2’-3) goes with constant condensation pressure. In the throttling device the pressure is reduced from the condensation pressure to the evaporation pressure (process 3-4). Through the expansion there is strong pressure and temperature decrease but no heat exchange with the environment, that’s why the enthalpy is constant. Real cycle differs from the theoretical one. It contains subcooling in condenser and throttling device connection pipes, superheating in suction line, real compression process, associated with heat transfer between the compressor and environment and pressure losses in the suction and discharge lines.

Compressor is the main element of a chiller. It provides compression of the refrigerant vapour from the evaporation pressure to the condensing pressure. Chillers are equipped with either piston, scroll or screw compressors. In the piston compressor piston is moved by a crank mechanism. These compressors may be one- or two-stage and have one or several cylinders depending on power. Rotary compressor parts require lubrication, so special system with lube pump, oil filter and pipes is needed. Advantages of piston compressors are: easy regulation, no congestion with serial commissioning of each compressor, reliable operation /3./

Screw compressors may have one or two screws. Operation process in compressor consists of three phases – suction, compression and pumping. Also it can be dry, oil-fill or wet compression. For the cycle performance and efficiency increasing intermediate suction and two-stage expansion like economizer system may be used. Intermediate pressure must be the same as pressure in closed cavities of compressor chamber in the place of special port. Increase in power is lower than increase in capacity, so coefficient of performance of the system becomes higher. Such cycles are beneficial when pressure ratio is higher than 3,5. Advantages of such compressors are: smaller size, high efficiency coefficient, reliable operation, minimal wearing of main parts, smooth regulation, high pressure ratio and lower temperatures at the end of compression process /3./

A scroll compressor contains two spiral plates like one in another. Upper spiral doesn't move, lower spiral rotates on its axis. The main problem is the power regulation. For small power changes frequency oscillation can be used. Advantages of scroll compressors are: high energy efficiency, reliable work dealing with lower amount of moving parts, volumetric coefficient is close to 1, lower pressure losses, no connection of gas with the hot parts of the compressor /3./

Evaporator is the heat exchanger where liquid evaporates and becomes gas in low pressure by means of absorption of the heat from chilled water. It can be plate, shell-and-tube, and capacitive evaporator. Plate evaporator is the most compact. It can have a heater for freezing protection. Capacitive evaporator is the tank with coil pipe. It is applied in small capacity chillers with hydronic module and can play the role of accumulation tank of chilled water /2./

Condenser is the heat exchanger where gas of refrigerant becomes liquid by means of rejection of heat to the atmosphere. It can be air- and water-cooled. Surface heat exchangers are used with air cooling by fans. Also water-cooled condenser plate, water-to-water or shell-and-tube heat exchangers can be used /3./

Also different refrigerants are used in the system. They have different thermodynamic characteristics and influence on efficiency, maintenance and construction of the system. Also temperature ratio and field of application influence on choice of refrigerant.

More over some refrigerants are very toxic and may have a bad effect on the environment. That's why some refrigerants are forbidden in modern countries /2./

3 EFFICIENCY OF CHILLER SYSTEMS

Chiller systems are used for industry or for air conditioning of quite big buildings and therefore have high value of initial and maintenance cost and require a lot of space. So efficient operation decreases maintenance and energy cost. The problem of efficiency increasing is very popular and there are many ways to solve it. But it should be noted that in some cases the price of efficiency increasing may negate their subsequent benefits. Feasibility must be assessed in each individual case.

To create an effective system, it is needed to know in which ways it can be achieved, and which performance benchmarks are implemented. This will be discussed in the following chapter.

3.1 Measuring of the chiller systems efficiency

System efficiency is defined as the efficiency of each part of the system and operation mode of the whole system. Chiller is the main part and there are few parameters of its efficiency. The first is coefficient of performance (COP). It is the ratio between cooling power and input energy expended in the compressor. The COP is defined by the formula /1/.

$$COP = \frac{W_{cooling\ output}}{W_{power\ input}} \qquad (1)$$

Where

$W_{cooling\ output}$ is cooling power, kW

$W_{power\ input}$ is input energy expended in the compressor, kW

In ASHRAE Std 90.1 chiller performance table is represented /4/. It shows minimum efficiency requirements and gives values of COP and Integrated Part Load Value (IPLV) for different types of chillers. The higher COP value means the better efficiency. Also it can be Energy Efficiency Ratio (EER). The difference is that output cooling is measured in Btu/hr. Btu shows how much kW of energy we must spend on heating of one pound of water. EER is defined by the formula /2/ /3/.

$$EER = \frac{Tonsx12}{kW_{input}} \tag{2}$$

Where

Tons is amount of water, tons

kW_{input} is energy for water heating, kW

The COP is more common, than EER. The EER can be converted to COP by multiplying by 3,412 what deals with Btu/hr to kW conversion /4/.

The next value is Full Load Efficiency (FLE). The unit is kW/ton. It shows how much energy W_{input} is needed to cool 1 ton of water. The lower FLE value means the better chiller efficiency.

But in normal case chiller doesn't work at the full load all the time. Its capacity is varied depending on outdoor conditions, so the choice of the most efficient chiller based on FLE doesn't mean the best efficiency around the year. For more real evaluation of work of the chiller Integrated Part Load Value (IPLV) is used. It shows average value of chiller efficiency based on part-loads and hours that chiller operates on these loads. The conditions of work are determined by ARI 550/590 /5/. The unit is kW/ton. Standard gives next values of loads and hours: 1% of operating hours with 100% load, 42% operating hours with 75% load, 45% operating hours with 50% load, 12% operating hours with 25% load. Based on it IPLV is defined by the formula /3/ /6./

$$IPLV = \frac{1}{\frac{0{,}01}{A} + \frac{0{,}42}{B} + \frac{0{,}45}{C} + \frac{0{,}12}{D}} \tag{3}$$

Where

A is chiller efficiency at 100% capacity, kW/ton

B is chiller efficiency at 75% capacity, kW/ton

C is chiller efficiency at 50% capacity, kW/ton

D is chiller efficiency at 25% capacity, kW/ton

In case when the chiller cannot operate with the values given in the ARI standard, the Non-Standard Load Value (NPLV) is used. The NPLV is defined at the same formula as IPLV, but efficiency is calculated with another more appropriate rating conditions. The unit is also kW/ton /6./

There is one more value that was eliminated already from ARI Standard. It is Application Part Load Value (APLV) that was calculated as IPLV but with another chilled water and condenser water temperatures. This value was replaced with NPLV /6./

Besides the chiller other equipment influences on the system. So energy conversion efficiency η of such equipment as circulation pumps and coolers of condenser must be taken into account in evaluating of energy efficiency of the system.

3.2 Methods of efficiency increasing

Often chiller system is the main electricity consumer in building. There are three basic components of the system that use electric power: chiller itself, pumps and system that cools the condenser. With efficient design of chiller system electricity consumption may be reduced from 30 to 50% than Standard 90.1 requires /6/. Based on it ways of efficiency increasing will be discussed.

Usually when chiller systems are designed the efficiency at 100% load are used. But as it is given in Standard 90.1 the system operates only 1% of all operating time with this load /4/. So it is more important to know the efficiency at 10-100% loads because the most time chiller works at these conditions. For this IPLV or NPLV are used.

The first possibility to improve the chiller efficiency is decrease in temperature of water that cools the condenser. It gives rapid efficiency increasing but may cause some problems in system operation like problem with oil pressure control. The most manufacturers don't recommend use of their chillers at such conditions, but some of them make specially designed chillers with possibility of operating at low temperatures of water that cools the condenser /6/. Also the possibility to vary the compressor speed can improve the efficiency by changing capacity according to the current conditions /6/. But this option is often applied with centrifugal compressors and match rarer with other types. Besides there are many construction improvements for efficiency increasing like two-stage compressor systems or internal economizers application. Depending on operation conditions it is important to use suitable number and size of chillers. For example when multistorey building has working hours from 8 to 18 but one storage requires 24 hours of work it makes sense to install two chillers, one big and one small for that additional load. Also the right mode of the chiller operation may help to save a lot of electricity. The operation with the external economizer mode helps sufficiently reduce the number of operating hours.

The second energy consumer in the chiller system is the pumping system. Pumps are used for water circulation between the condenser and cooling equipment, and in the evaporator-cooling load loop. There are few ways to decrease their consumption. First of all pumping system shouldn’t be oversized. Increased designed pump head leads to choice of bigger pumps with higher initial cost and energy consumption. Then velocities of fluids in the system affect on pressure losses and thereby on pumps head. So right sized pipes correspond low velocities and low frictional pressure losses. Also the flow rate in the system depends on the temperature difference. Selection of coils with bigger temperature difference may reduce the required flow rate and by this the size of whole system. Proper configuration of the pipe system reduces length of pipes and lower pressure losses and corresponds to the lower pump head. Any valves or control devices also increase pressure losses. That’s why they must be used only if it is really necessary. The right flow control may decrease power consumption according to the loads. The system of variable pump speed helps to regulate the flow rate and avoid unnecessary energy wastes. And of course the energy conversion efficiency of pumps and motors must be very high for the efficient system /6./

The process of cooling of the condenser is the third energy consuming part of the chiller system. Often designers have a problem with the sizing of cooling towers. It is rather big equipment and takes a lot of space. Also cooling towers are sized in tons, but actually it must be flow rate to keep the required temperature. That’s why sometimes it is undersized and this doesn’t allow the chiller to work with the full load. The outdoor conditions must be properly set from the nearest weather station. It will allow to select the right-size tower. According to the weather conditions the speed of fans or the amount of the working fans may vary. It saves their consumption of the electricity /6./

Measuring and controlling operations help to select the most efficient mode according to the actual conditions. Electronic control systems measure the outdoor conditions and cooling loads and determine the best parameters for the operation of the system. Also collecting data may help to identify the ways of the system improving.

Even if the efficient system is designed, there is a number of factors that may not allow it to work with the desired efficiency. Not proper installation, bad control system, inadequate working conditions may give lower efficiency values. That's why commissioning of the system must be carried out properly. The system must be tested with all operation modes.

4 ECONOMIZERS

4.1 Definition

Economizer is the system or unit allowing to reduce energy consumption and improve the efficiency of chiller system. It is modification of chiller system or chiller itself whose initial cost is covered by significant economic benefits from the further operation. Thus with the application of economizers their expediency should be assessed in each case.

4.2 Main types

There are a lot of different modifications of the economizer systems. Generally they could be divided in two main types, which are internal and external economizer systems.

The possibility of energy savings exists both in the chiller itself and in the rest of the chiller system. Because of that modifications of the chiller which are connected with the changes in the vapour compressed cycle are referred to the internal economizers. Whereas the changes in configuration of the chiller system, which helps to save the energy by using cold outside air, are referred to the external economizer systems. Possible configurations of internal and external economizers will be considered in the following parts.

4.2.1 External economizer systems

Sometimes with the certain weather conditions the cool of outdoor air can be used to cover the cooling loads. The heat transfer between outdoor and indoor air may be carried out directly like a direct air-side economizers or indirectly like water-side with the help of water and indirect air-side economizers with air. The main feature is the use of the cooling power of outdoor air instead of the mechanical cooling for the decrease of power consumption of the chiller system.

4.2.1.1 Water-side economizers

There are conditions, when air-side economizers are less effective or ineffective at all. In those cases it is advisable to apply water-side economizers. Those conditions can be conditions of the inside air. For example, if the ambient air is too dry, the additional humidification is needed. Also limited space for air ducts and air equipment may preclude the application of air-side economizers. One more reason is that the air-side economizers usually serve only needs of ventilation.

"Water-side economizer is a system by which the supply air of a cooling system is cooled indirectly with water that is itself cooled by heat or mass transfer to the environment without the use of mechanical cooling" /7/.

Economizer system must provide the total amount of cold for cooling system in certain conditions. Also it can operate simultaneously with mechanical cooling and reduce chiller load /7./

Water-side economizers are divided into several types:

- Dry coolers
- Evaporative heat rejection
    - Direct systems
        - Strainer cycle
    - Indirect systems
        - Plate and frame heat exchanger
        - Load-shaving with plate heat exchanger
        - Closed-circuit cooling tower

- Thermosyphon systems

Principle scheme of strainer cycle is presented in the Figure 3. In normal mechanical cooling return chilled water is cooled in evaporator and condenser removes heat from the circuit. But if the outside temperature is cold enough, return chilled water is cooled by condenser cooler in bypass of the chiller. After the cooling tower the water passes through the strainer and goes to the cooling load.

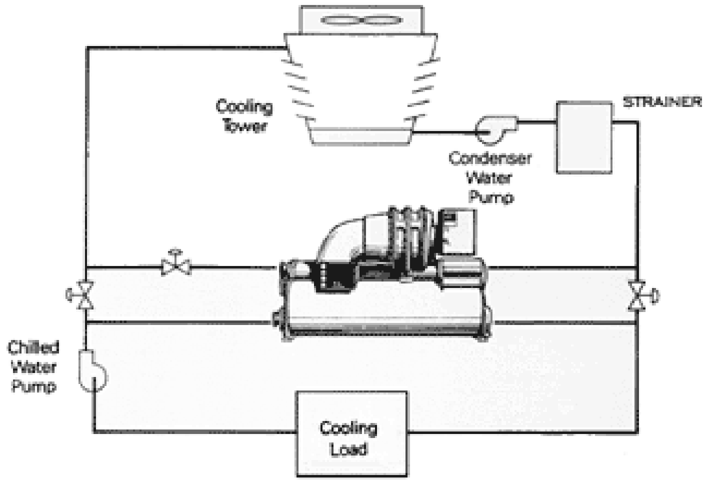

FIGURE 3. The principle scheme of strainer cycle /8/

The chiller doesn’t operate and it is not using energy for compressor. Water is cooled directly and in this way the heat exchange with ambient is rather fast and simple. These are the main benefits of such systems /8./

But quite a lot disadvantages exist. First of all is contact of chilled water with the atmosphere in cooling tower. It increases the possibility of chilled water pollution and pipes corrosion. Only expensive water treatment can solve the problem. Water passes through a strainer. Also the application of the system is limited. It can operate only when cooling tower may provide total cooling load of the system. Also cooling tower must reliably operate in low temperatures. All of this makes strainer cycles unpopular. They were common in the beginning of 80-th. But they are very rarely installed nowadays /7./

Indirect water-side economizer systems solve the problem of fouling. A system with plate-and-frame heat exchanger is one of them. Here water of cooling tower loop and chilled water loop are not mixed. It is shown in the Figure 4. If the temperature of outdoor air is less than about 13 °C, chiller valves are shut off, and condenser cooling loop enlarges and becomes the main cooling loop /7/. It cools warm water from the load by means of the heat transfer in plate heat exchanger.

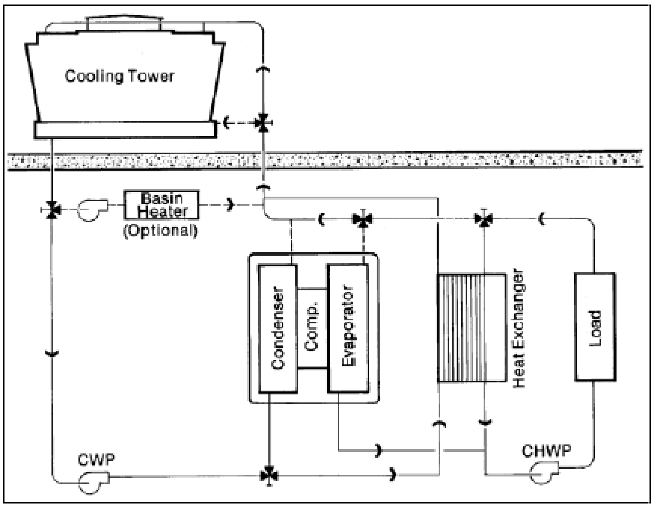

FIGURE 4. Indirect economizer cycle with the heat exchanger /9/

However, the fact that the way of heat transfer between cooling load and ambient becomes longer and more difficult must be taken into account /10/. The temperature of cooling tower loop must be lower because of heat gain in heat exchanger. It decreases possibility of free cooling. Also the installation of such systems leads to additional expenses for equipment like heat exchanger, pipes and valves. Energy consumption of pumps becomes bigger, both Cold Water Pump (CWP) and Chilled Water Pump (CHWP) must have an additional pump head for compensating of heat exchanger pressure losses. Cooling tower must reliably operate in low temperatures like in previous case /9./

The expediency of such systems in comparison with direct cooling must be evaluated based on these facts. But now maintenance problems and fouling possibility of direct systems are leading to indirect systems widespread /7/.

Systems with the heat exchanger may be designed in another way. It is load-shaving with the plate heat exchanger. Here heat exchanger and chiller work simultaneously. It is shown in the Figure 5. Heat exchanger is installed before the evaporator. Cold water from cooling tower pre-cools warm water from the load. This temperature decrease before the evaporator makes chiller cooling power lower and accordingly reduces the energy consumption. Such systems have all disadvantages of previous one. Besides it is very important to control cooling temperature of the condenser and provide proper chiller work. Such systems are applied to operate only when outside temperature is lower than temperature of chilled water on 5,5 °C /8/. If outside temperature is low enough, the chiller may be switched off and the system works like the previous one, but the water flows through chiller's heat exchangers anyway.

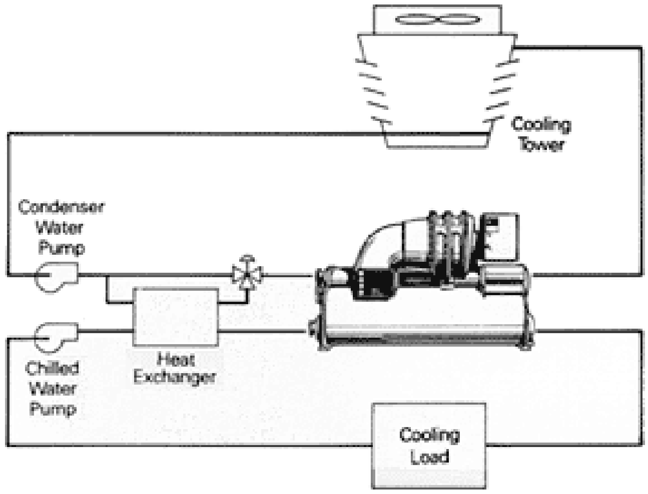

FIGURE 5. Indirect load-shaving economizer with plate heat exchanger /8/

The next type is water-side economizer with closed circuit cooling tower. It is used as pre-cooling together with the air-cooled chiller. In fluid cooler working liquid doesn't have a contact with the ambient air. Heat transfer takes place in the heat exchanger like coil. The water is sprayed on the coil and evaporates in the ambient air. So there are two loops: loop of chilled water inside the coil and loop of clean water which moistens the coil and has a contact with air. Heat from the coil rejects to the atmosphere through the evaporation of sprayed water. Fans are used to improve the evaporation process. Chiller starts to operate when the cooling power of the cooling tower is not enough to fulfill the cooling loads. Main disadvantages are: additional cost associated with loop of sprayed water and dependence on humidity of the outdoor air /10./

Another alternative is the dry cooler. It is also closed loop, but water is cooled by air with heat convection rather than previous case when evaporation process was used. Chilled water doesn't have a contact with the outside air. Fans blow on the heat exchanger coil and temperature of the inside water decreases by means of the convection heat transfer. Fans have adjustable rotating speed. It helps to carry out fine control of the cooling power. However dry coolers sometimes cannot fulfill cooling loads of the system. They are not enough when temperatures are 10/7,2 or 7,2/4,4 °C /7./

And one more type of indirect economizer is rarely used so-called free cooling chiller method. In another way it is called thermosyphon or refrigerant migration. It is applied in centrifugal chillers. The scheme of thermosyphon system is presented in the Figure 6.

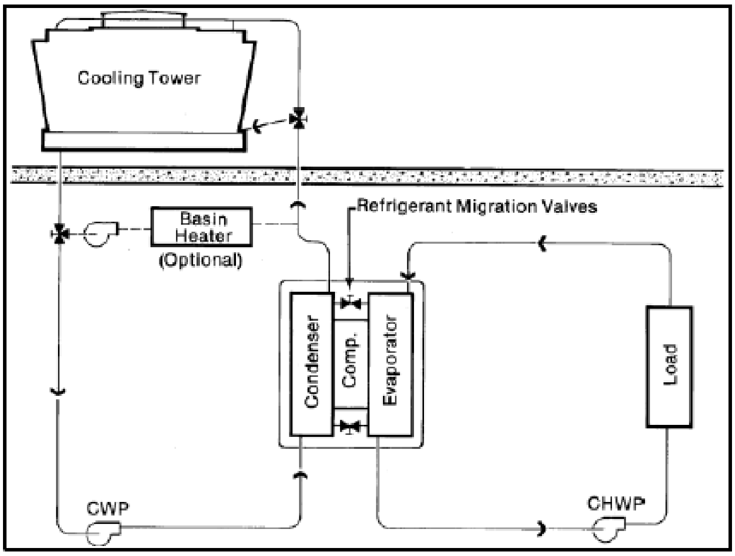

FIGURE 6. Thermosyphon economizer system /9/

The system consists of the chiller with the possibility of the thermosyphon, of the dry cooler, of pumps and of valves. Arrangement of the thermosyphon allows the chiller to play the role of the heat exchanger under certain conditions. When the temperature of the water coming from the cooling tower is lower than the desired temperature of the chilled water, refrigerant in a gaseous form moves into the low temperature zone. The hot refrigerant vapor enters the condenser where it is cooled and condensed /9./

After that the fluid enters the evaporator by gravity. In the evaporator refrigerant fluid takes heat from the chilled water, which has sufficiently high temperature. Because of the gained heat the refrigerant boils and evaporates. Pressure difference between condenser and evaporator leads to the fact that the gas is moved toward the condenser. For this transition bypass connection is used. In this way refrigerant circulates bypassing the compressor. This fact eliminates the need for the compressor in this situation.

However, this method is applicable not to all systems. In free cooling mode it provides not more than 30% of the rated chiller capacity /7/. This percentage depends on the chiller selection and temperatures in the cycle. As well to the disadvantage is that the system can not work in a mixed mode. Because of that the most common way for collaboration of the chiller with the thermosyphon is connection of the free cooling chill-er in series with a conventional chiller.

The advantage of the system is the absence of fouling, because cooling is carried out in indirect way in the condenser. The system does not require additional cleaning. Also the system does not need to install a heat exchanger and therefore additional pumps and pipes. This reduces the initial costs. Because there are no transfer devices in the system, the system is more reliable and durable, it has less maintenance costs and noise level /7/.

4.2.1.2 Air-side economizers

Air-side economizers is one of the ways to use the cold of the environment for cooling the premises. The main point is that the heat goes from the inside air to the outside air. Thereby two ways of such heat transfer are distinguished and accordingly two types of air-side economizers are differentiated. These types are direct and indirect (recirculating). In direct air-side economizers the air from the outside directly comes to the room and cools it. In indirect systems the heat transfer is performed with air-to-air heat exchanger.

Operating principle of the direct economizers can be compared with the opening of the window. This is quite natural idea when the room temperature is higher than the outside temperature. In such a way, letting more air than is needed, the use of mechanical cooling can reduced or even turned off. According to the ASHRAE standard 90.1-2004 air-side economizer can achieve this through a system of channels, dampers and automatic control sensors /4/. The scheme of such system is shown in Figure 7.

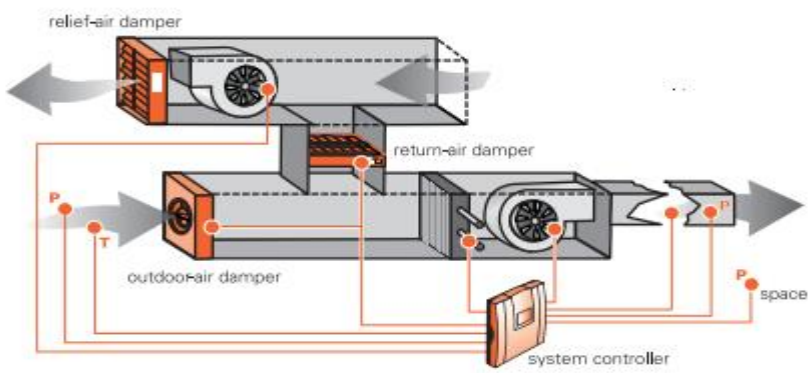

FIGURE 7. Direct air-side economizer /11/

As it is it seen from the Figure 7 this system consists of outdoor air, relief-air, return air dampers, circulating pumps and automation system. The automation system controls indoor and outdoor states of the air, work of the dampers and work of the pumps. In such a way the control system via sensors depending on weather conditions can regulate inflow of the outside air. By these regulations it may reduce the work of the chiller or completely shut it down. Relief-air damper is used to prevent the overpressure in premises /11./

If the outdoor temperature is minimal, the mechanical cooling is turned off. The economizer system delivers the smallest possible amount of outside air required by regulations. This air is mixed with the exhaust air. There is also a possibility of heating air mixture to achieve the desired supply air temperature.

When the outside temperature rises and is in the range of from about 0 to 14 °C, the system begins to vary the flow of outside and return air. By using outdoor and return dampers control system determines the flow of air, which needed to reach the desired temperature. In this mode the mechanical cooling is also switched off. With an increase of the outdoor temperature, the outdoor damper opens more and more, until it is fully opened.

Further, when the temperature of the outdoor air rises up to approximately 25 °C, economizer is used together with mechanical cooling. With further increase in temperature, it is used less and less until it shuts down completely upon reaching certain conditions. After that the system proceeds to only mechanical cooling.

There are several parameters by which control system can determine the time of shutting down the the economizer system. This may be a certain outdoor temperature or condition, when the outdoor temperature is higher than the temperature the return air. Another principle is the enthalpy. The sensor can also respond to the specific enthalpy of the outside air, or to determine when the outside air enthalpy is higher than the return air enthalpy. Electronic mode allows to disable the economizer when the outdoor enthalpy reaches the saturation curve.

Another method is the availability of two conditions. The economizer is turned off when the outside air temperature reaches a certain dry bulb temperature or another certain wet bulb temperature. These types are used depending on the location. They have a different initial costs, but also have different operating costs.

The principle of turning off the economizer system affect humidity of the indoor air. In addition, depending on the climate, some adjustment systems are not allowed to be used, as they can give erroneous results.

Although it is the most effective method of saving energy, it has some drawbacks that may affect against the use of such systems. This is the possibility of contamination from the outside, the problem of moisture control and the cost of additional equipment. The problem can be solved by installing humidifiers or dehumidifiers, but it will affect the initial costs /11./

This problem can be solved by the use of systems of indirect air-side economizers that uses air-to-air heat exchanger like in the Figure 8. Fans are required to run the cold air through the heat exchanger, which on the other hand interact with the air from the premises. This mode can also be supplemented by evaporative cooling, which means the irrigation of the heat exchanger surface from the outdoor air side. This moisture does not affect the indoor humidity /12./

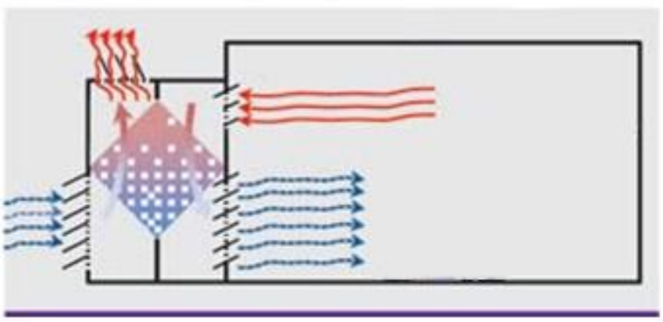

FIGURE 8. Indirect air-side economizer with heat exchanger /12/

Also it is possible to use a rotary heat exchanger. Adding a rotary heat exchanger is appropriate when the temperature difference between wet and dry bulb temperature is over 5,6 °C. This system is less efficient than the previous one, but still has some advantages. This is also decrease in the quality of filters, as the strong filtration of the outside air is not needed. This entails a reduction in fan power and in maintenance costs. In addition there is no negative effect of humidity and pressure. In this system, humidity control is simplified due to relatively constant humidity indoors. However, heat loss in the heat exchanger should be taken into account. For example, a 50% efficient heat exchanger can fully meet the needs of the data center starting from 9.2 °C. Therefore, very efficient heat exchanger is needed for the best performance /12/.

Also in contrast to the direct system there is no need for the relief- and return dampers. There the temperature is controlled by the varying the fan speed. These systems are also presented as systems suitable for use even in a warm climate.

4.2.2 Internal economizer systems

In the simple systems there is no separation of liquid or gas in the circuit. Also the flow of working fluid has no division. The system has ordinary composition and all volume of the refrigerant passes through all parts like evaporator, compressor, condenser and throttling device. But there is another way, when the system is designed so, that possibility of phase separation or flow division exists. In the first case, the part of gas or liquid may be separated in two-phase part of circuit. According to this, the phase ratio and properties of working flow changes. In other case the flow of the refrigerant divides and then there is a place where flows with different temperatures are mixed. Both cases have an effect on the efficiency of the system. On these two principles the internal economizer systems are based. So such systems have better efficiency and lower energy consumption compared to simple systems.

Basically, there are three main types of economizer systems: with the flash tank, with internal heat exchanger and both with flash tank and heat exchanger /13/. In this chapter these different variations of economizer systems, their schemes, principles of work, efficiency and application conditions will be described.

4.2.2.1 Economizer system with flash tank

The economizer system with flash tank is one of three main types of economizer systems. It was designed by Carrier Corporation in 1997. York International Corporation also carried out some researches for improving this system. Both well known companies actively apply the system in their chillers.

The aims of the system are: improving of the system work, increasing of the system performance and efficiency. According to this a simple system was changed and additional equipment such as flash tank and return line were included to the cycle. This compact system improves thermodynamic cycle without size increasing and expanding the boundaries of the compressor working pressure. /14./

Principle scheme of economizer system with flash tank is presented in the Figure 9

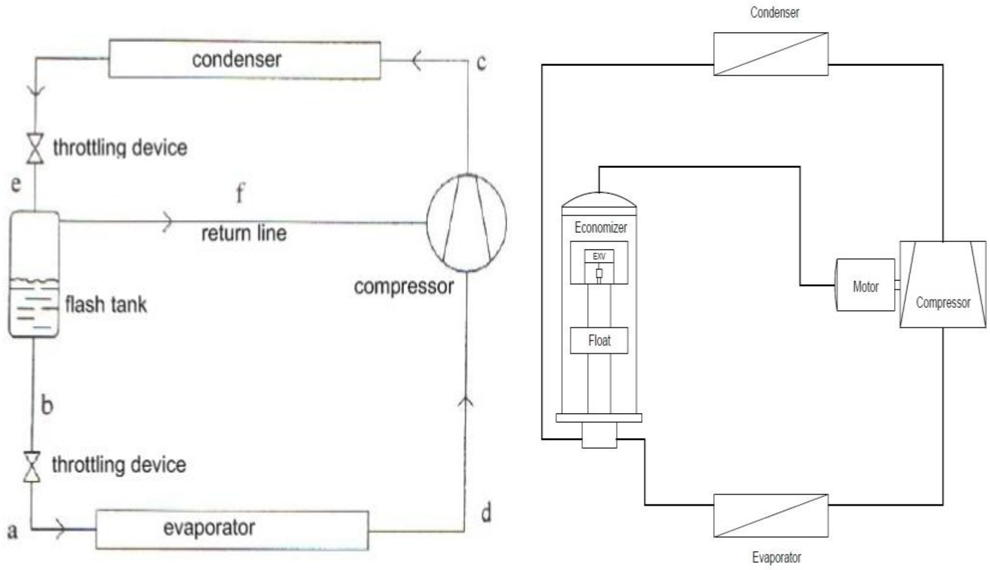

FIGURE 9. The principle scheme of economizer system with flash tank

The principle of such system work can be described as following. The mixture of liquid and gas of refrigerant goes through the heat exchanger (evaporator), where it takes heat from the secondary media. It is heated, evaporated and becomes a vapour. The evaporator's construction may be different. In that case it is cooled by the water as secondary media.

After that the vapour with low pressure enters the compressor. In the best case it can be screw compressor, but it can be also centrifugal. The vapour is compressed to medium pressure where it is mixed with the vapour from separator. Then all vapour is compressed to the high pressure and refrigerant enters the heat exchanger (condenser) /14./

High pressure vapour goes through the condenser, where it rejects the heat to the secondary media. The refrigerant is cooled and condensed. The received liquid enters the flash tank of the economizer, where it is expanded twice. First, high pressure liquid is expanded with the expansion valve to the medium pressure. It is approximately a half of the highest system pressure. Expended work media passes through the septum and the vapour is separated from the liquid. Flash vapour is collected in the upper part of the separator and goes to the compressor through the return line. It enters in place of the compressor chamber where pressure is equal to separated vapour pressure /14./

The liquid is separated from the vapour in the chamber of flash tank. Then it is collected to the tray and expanded again in the expansion chamber. Temperature and pressure are decreased to the evaporator conditions. Construction of the flash tank is shown in the Figure 10.

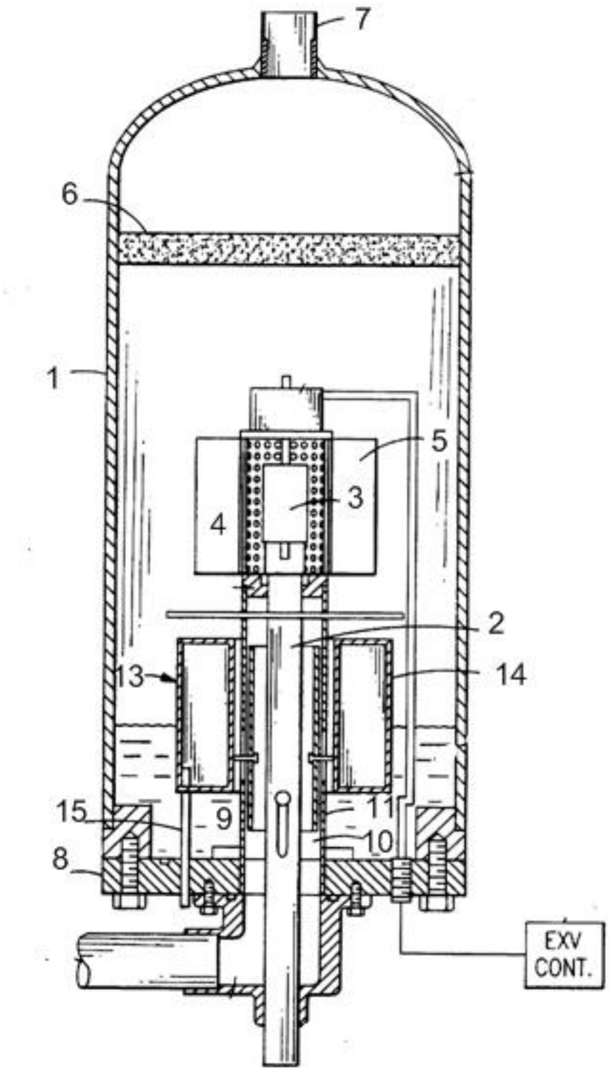

FIGURE 10. The construction of the flash tank /14/

The liquid refrigerant enters the body of flash tank (1) by the vertical tube (2). Then it expands to the medium pressure by the electronic expansion valve (3) inside the wire screen pipe (4) which is placed on the top of inlet pipe (2). Last part of the liquid passes through wire screen (4) and separates from the vapour in baffle separator (5). This flash vapour rises to the top of flash tank passing through a demister (6), where it is collected and goes to the compressor by return line through the outlet (7).

The separated liquid falls down on the bottom of the tank (8) and is collected there. Then through the regulated openings (9) it enters the expansion chamber (10) that is placed in the space between inlet tube (2) and encircling it bigger pipe (11). The pressure here is lower than in the sump (8), thus liquid expands with the lowest pressure, and the mixture of the liquid and gas goes to the evaporator through the inlet pipe (12). Because the temperature in the expansion chamber (10) is lower than in inlet tube the low pressure mixture subcools the liquid, which incomes by inlet (2).

Flash tank is equipped with the float controlled device (13). It regulates the size of the openings (9) and accordingly the volume flow to the camber (10) depending on the level of the liquid in the tank. The high pressure vapour from the separator is delivered to the floats (14) by the tube (15). It helps them to stay afloat at the varying conditions /14./

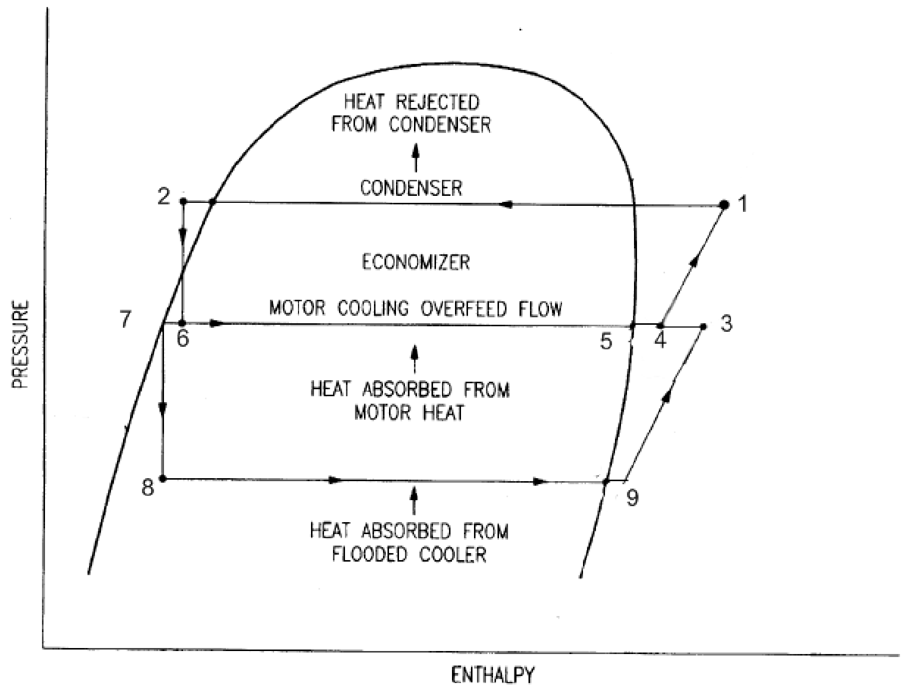

FIGURE 11. The thermodynamic cycle diagram /14/

The Figure 11 is presented as log(p)-h diagram, which shows all thermodynamic processes in the cycle. So, the process (1-2) describes temperature decrease in the heat exchanger (condenser). The vapour cools to the temperature of the point (2) and becomes liquid. Then liquid is expanded by electronic expansion valve to medium pressure of the point (6). Here the vapour is separated in the flash tank and goes to the compressor through the motor, where it is heated by cooling of the motor itself to the conditions at point (5).

Liquid of the point (6) cools to temperature (7) by the partial evaporation in the flash tank. Then it is expanded by a throttling device according to the fluid level in the flash tank. Low pressure refrigerant enters the heat exchanger (evaporator) in conditions of the point (8), where it is heated to the conditions of the point (9) and enters the compressor. It is compressed to the medium pressure of the point (3) and mixed with the flash vapour. This mixing of two gases gives a little drop of energy to the point (4) and that gas is compressed to high pressure of the point (1) /14./

Such system is equipped with a large number of automatic. It regulates the operation of valves and vessels, mass flows of refrigerant depending on work conditions of the system. The controller receives parameters of different points of the system and calculates the optimal conditions of the throttling devices. For example the opening size of the secondary expansion throttling device corresponds to the liquid level in flash tank separator. This is through the flow control system.

Such gas delivery system directly into the compressor increases compressor performance without growth of the compressor pressure difference. Researches of this system have shown that such two-stage expansion increases compressor shaft power approximately to 15-20% /14/. Principles of screw compressor were described earlier.

Also counter flows of refrigerant with low and high pressure in flash tank promote to the subcooling of high pressure mixture and improve the processes in the expansion valve.

So that the compact system that has simple and relatively inexpensive structure helps to improve the system performance and to increase system efficiency by 5-10% /14/.

These advantages were taken into account by the most famous chiller system manufacturers.

4.2.2.2 Economizer system with heat exchanger

The second economizer system is the system with the heat exchanger. It has no hold-ups of any phases and the main idea is driving the whole flow of working media. The aim is to increase the compressor work efficiency by the refrigerant subcooling /13/. Such systems work with scroll or screw compressors. They are not as common as systems with the flash tank.

The principle scheme is presented in the Figure 12. It contains heat exchanger (evaporator), compressor, heat exchanger (condenser), heat exchanger of economizer circuit, expansion valve of economizer circuit, throttling device of primary circuit, return line of the gas from economizer circuit to the primary circuit.

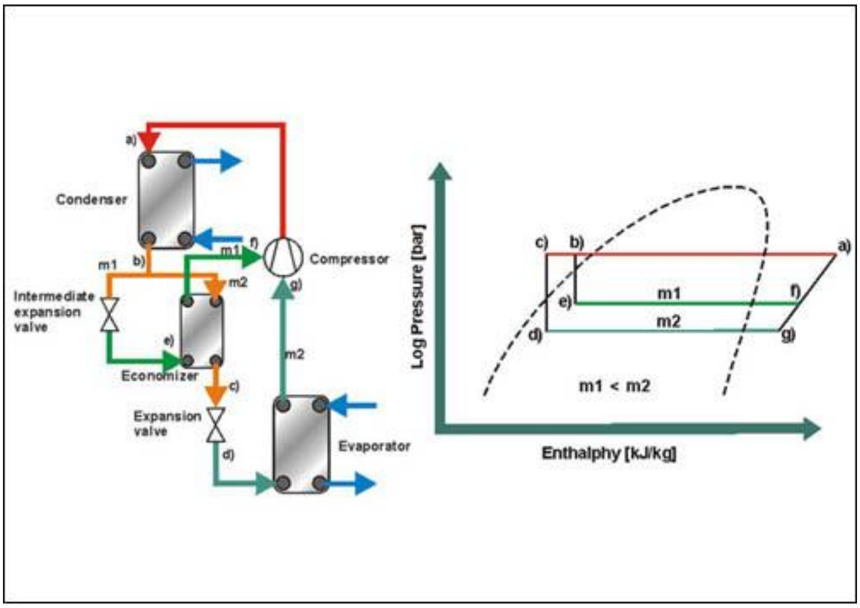

FIGURE 12. Principle scheme of economizer system with heat exchanger and log(p)-h diagram of the process /15/

The system consists of primary and secondary circuits. In primary circuit high pressure gas enters the condenser, cools and becomes liquid. Then the liquid after the condenser is divided in two flows. One part goes to the secondary circuit of the economizer. It passes through the expansion valve of the secondary circuit, the pressure drops to the medium value and cooling refrigerant goes through the economizer heat exchanger. Here it subcools the liquid of the primary circuit – the other part of divided flow. After subcooling the liquid goes to the evaporator while the heated vapor enters the compressor. In the primary circuit liquid passes through the evaporator and becomes gas after heating. Primary circuit gas enters to the compressor where it is compressed to the medium pressure and in that moment mixed with the economizer circuit gas. The compositions of the two gases are the same. Then all gas flow is compressed to the high pressure /16./

The subcooling of the refrigerant impairs the quality of the vapour which is coming to the evaporator. It increases the cooling capacity of the evaporator. The efficient operation of the economizer makes lower the required temperature difference between the sub-cooling and evaporating flows which means higher efficiency of the system. Economizer system needs additional equipment such as piping and compressor with an entrance for economizer pipes. These additional costs make this economizer solution appropriate only for large air conditioning systems /15./

There are many variations of this basic scheme. They are designed to improve the system and make it more reliable. So for expansion in economizer circuit different devices can be used. For example expanders are installed in Carrier chillers. They help to increase the system performance and control the temperature of the process successfully /17/.

Also a check valve may be installed in the economizer return line. It is designed to prevent the refrigerant back flow from the compressor to the economizer heat exchanger. Pressure in the compressor chamber may fluctuate in part where economizer port is placed. According to this, pressure lower than pressure in economizer heat exchanger may occur. In that case refrigerant may flow back. The check valve excludes this possibility. The highest efficiency of such system is achieved with scroll compressor /18./

Another case is when the system is equipped with multiple economizer circuits. It increases the capacity and the efficiency of the system. Such system has two secondary economizer circuits. After each circuit refrigerant goes to the compressor by two parallel return lines. The subcooling of the liquid which goes in two stages becomes deeper and the capacity of the refrigeration circuit increases. The subcooling range becomes bigger than 8,3 °C of the normal system. The multi-stage economizer system has the best application in case with the big pressure difference in suction and downstream line. This scheme became possible only with new modification of screw compressor. Earlier two rotors in compressor didn't give sufficient conditions for certain medium pressures retaining in economizer return flow inlet /19./

4.2.2.3 Economizer system with flash tank and heat exchanger

This system is a combination of the two previous systems. It is designed with applying of three-rotor screw compressor. So, there are two economizer systems, one with the high pressure and one with the low pressure. The system can be applied for the cooling of rooms, where chilled water circulates and delivers cold to the cooling loads. It can be such buildings as laboratories, office buildings, hospitals, industrial buildings, data centers, etc.

The principle scheme is presented in Figure 13. The system consists of following parts: condenser; high pressure economizer circuit with heat exchanger, expansion device and control valve; low pressure economizer circuit with flash tank, expansion device and control valve; expansion device of primary circuit; evaporator; three-rotor screw compressor with two economizer ports of high and low pressure /20./

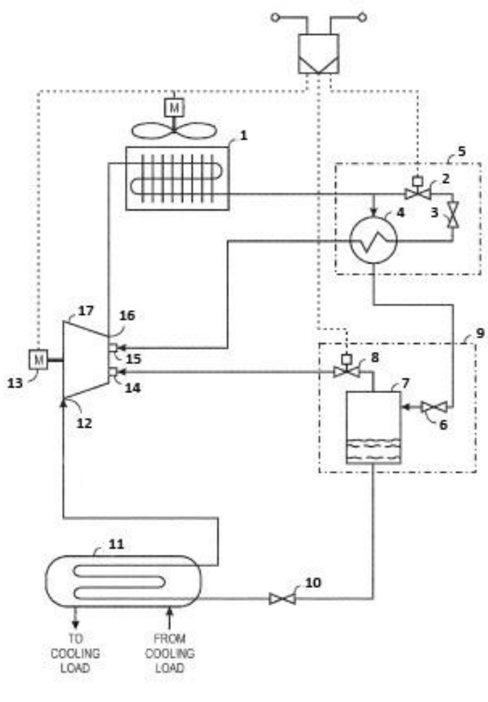

FIGURE 13. The principle scheme of economizer system with flash tank and heat exchanger /20/

The liquid from the condenser (1) is divided into two parts. One part goes to the high pressure economizer loop (5) where it passes through the expansion device (3), cools down and goes to the heat exchanger (4). Another part goes through the same heat exchanger (4). Here cooled refrigerant from the first part subcools the second part of liquid, becomes warmer and enters to high pressure economizer port of compressor (15), while subcooled liquid goes to the low pressure economizer loop (9). Further this liquid is expanded (6) and enters the flash tank (7). There the gas is separated from the liquid and goes to the low pressure economizer port of the compressor (14). At the same time separated liquid is expanded again (10) and enters the evaporator (11), from where the low pressure gas goes to the compressor (12). Here it is compressed and at first mixed with the low pressure gas in compressor's chamber sector that is coincided with the low pressure economizer port. Then it is mixed with the high pressure gas in compressor's chamber sector that is coincided with high pressure economizer port. After that the whole amount of gas is compressed to the condenser conditions (16) /20./

This scheme has several variations. For example, the flash tank may be presented as high pressure economizer and the heat exchanger as low pressure economizer. In other way flash tank may be both high and low pressure economizers. Also the flow control valves are installed in the system. They can shut off one of the economizer loops or both together if it is necessary.

Both high and low pressure economizer systems give some advantages. By additional subcooling they improve the work of the expansion valve and thereby increase the chiller efficiency. The flow division in both cases provides the portion gas intake to the compressor. It means that the compressor must compress smaller amount of gas at the low pressures. As a consequence, compressor load becomes less and energy consumption is reduced.

4.2.2.4 Economizer system with internal heat exchanger

Another name of such systems is liquid-suction heat exchangers. They are applied in cooling systems, increase reliability and coefficient of performance of the system. In this case the flow is not divided and only heat transfer from one part of cycle to another happens. Internal heat exchanger is one of the subcooling methods. Also the type of refrigerant is very important for the system effectiveness. The best results are shown with nonazeothropic mixtures /21./

In the Figure 14 the principle scheme is presented. The heat exchanger is included in the simple refrigeration circuit. The heat transfer is realized between the refrigerant after the condenser and the gas from the evaporator. Liquid refrigerant down flow the condenser passes through the liquid-suction heat exchanger and is subcooled by the cool gas. After that subcooled liquid is expanded by the expansion valve and goes to the evaporator. After the evaporator the low temperature gas passes through the heat exchanger, is superheated and goes to the compressor which compresses it to the high pressure level. Interaction of the high pressure side and the low pressure side occurs in the heat exchanger. The subcooling is on the high pressure side and superheating is on the low pressure side. The heat exchanger is also used as accumulator. If there is non-evaporated part of the liquid in the evaporator, it is collected as accumulation part and then evaporated by the energy from the high temperature liquid /22./

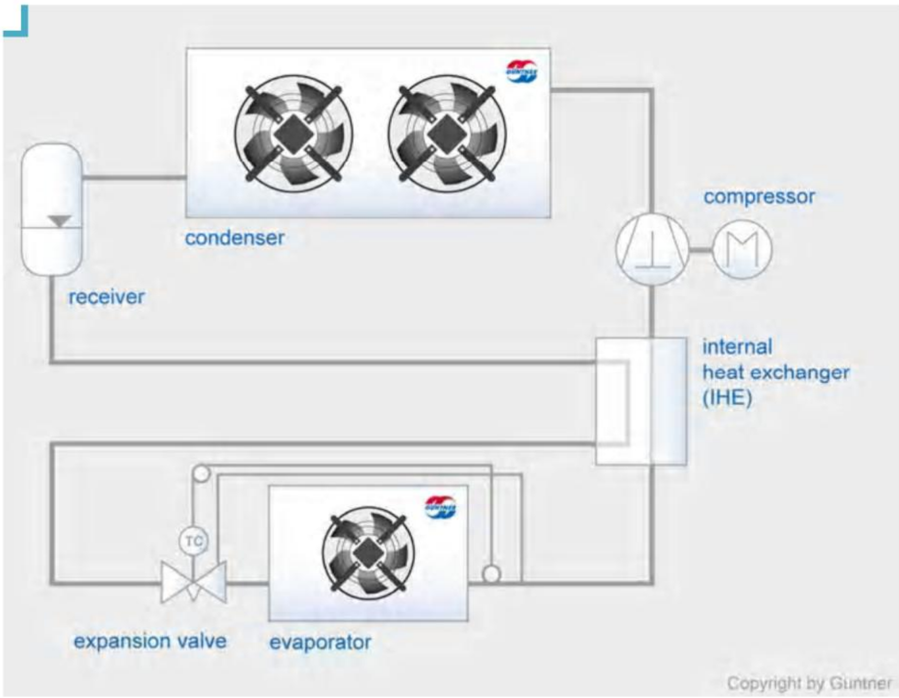

FIGURE 14. The principle scheme of economizer system with liquid-suction heat exchanger /22/

In some cases the heat exchanger is installed close to the cooling point. It decreases heat losses in the suction line. So, the suction line will absorb less heat from the ambient air.

The economizer system has several special conditions and may have positive and negative effect on the whole system performance. The advantages of the economizer are following. In general it increases the COP of the system /22/. Also the subcooling improves expansion valve work and prevents the appearance of flash gas. Besides, the heat exchanger provides total refrigerant evaporation after the evaporator and protects the compressor from non-evaporated liquid intake and damages. Such liquid may occur for several reasons. It can be wrong operation of the expansion device or sensors, or strong load fluctuations. In addition the cost of the additional equipment is rather low.

However, such system has many special conditions and disadvantages. First of all they are pressure losses. They are evaluated depending on type of the heat exchanger. Also the internal heat exchanger increases temperature and decreases pressure of the gas at the compressor inlet. It means that the gas density becomes lower and the volumetric efficiency and the mass flow rate decrease as a result. This is especially for low-temperature system. That is why systems with the high temperature lifts have best results with this type of economizer /22./

One more disadvantage is no opportunity to control the subcooling temperature of the liquid refrigerant. However, it can be determined for the certain operating point. Also the liquid-suction heat exchanger has more difficult installation than other economizer systems. Moreover, the system has different effectiveness with various refrigerants. The economizer has the best performance and the lowest pressure losses with R 134A and R 407C. It depends on the isentropic coefficient. The economizer has negative influence on the system effectiveness with refrigerants that has low isentropic coefficient value, for instance R 717 or R 22 /21./

Nevertheless, economizers with internal heat exchanger should be evaluated as successful in the efficiency increasing.

5 STUDY CASE

In previous chapters different types of economizers were described and it was determined that they are serving for energy economy. Study case was modelled to estimate approximate profit from economizer system. In this chapter the model of the building and simulation methods will be described, cooling loads and energy consumption of the building in different cooling modes will be determined, and the expected benefits of the economizer system will be marked. Also predicted cost saved by the economizer will be estimated according to the electricity traffic.

5.1 Building model and simulations

To determine power consumption of the cooling system of the building it is needed to know cooling loads. For cooling loads and energy simulations the model of building was developed in IDA Indoor Climate and Energy software. It is two-storage office building 18 m by the width, 30 m by the length in plan and 5,4 m by the high (internal floor is 0,2 m), with total area 1080 m^2. 3D model of the building is presented on the Figure 15.

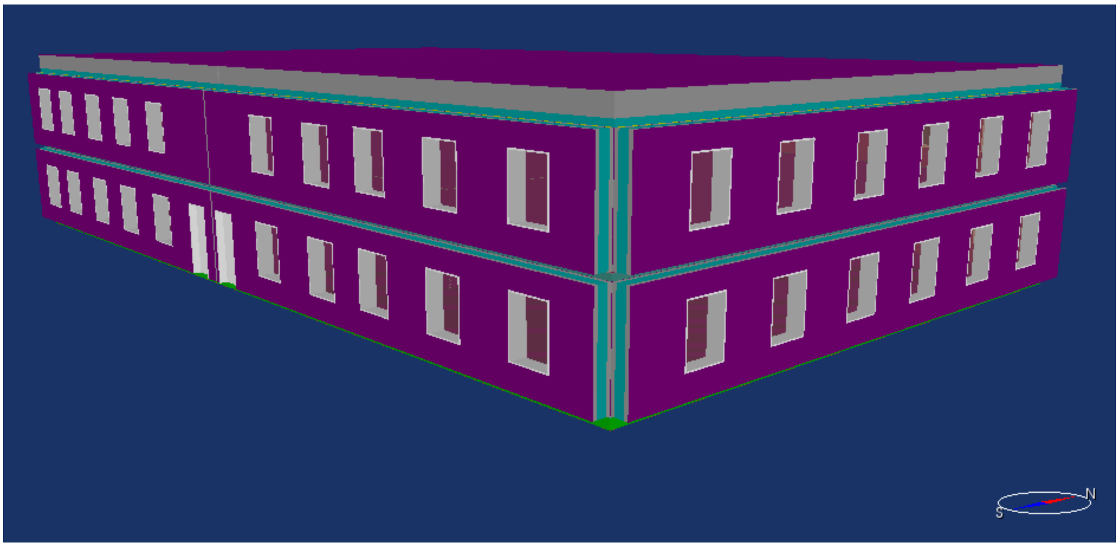

FIGURE 15. 3D model of the study case office building in IDA ICE Software.

All building elements were designed according to D3 and C4. External walls, floor and roof is made from concrete, windows are with the internal blinds. The leakage air value q_{50} = 1.0 $m^3/h\ m^2$. Values of thermal bridges are from D3 in according to materials. U-values of building constructions were taken according to D3 /1/. U-values and areas of the building constructions are shown in the Table 1.

TABLE 1. U-values and areas of the building constructions

Construction	Area m^2	U-value, $W/m^2/K$
Wall	219,6	0,17
Roof	540	0,09
Floor	540	0,16
Windows and doors	123,6	1

The building is placed in Helsinki. It has four zones for simulation. On the first floor it has two office zones with the time of work from 07 to 18 and data center with the aria of 100 m^2 that works always. On the second floor this is only one office zone that works from 07 to 18. The plan of zones on the first floor is on the Figure 16.

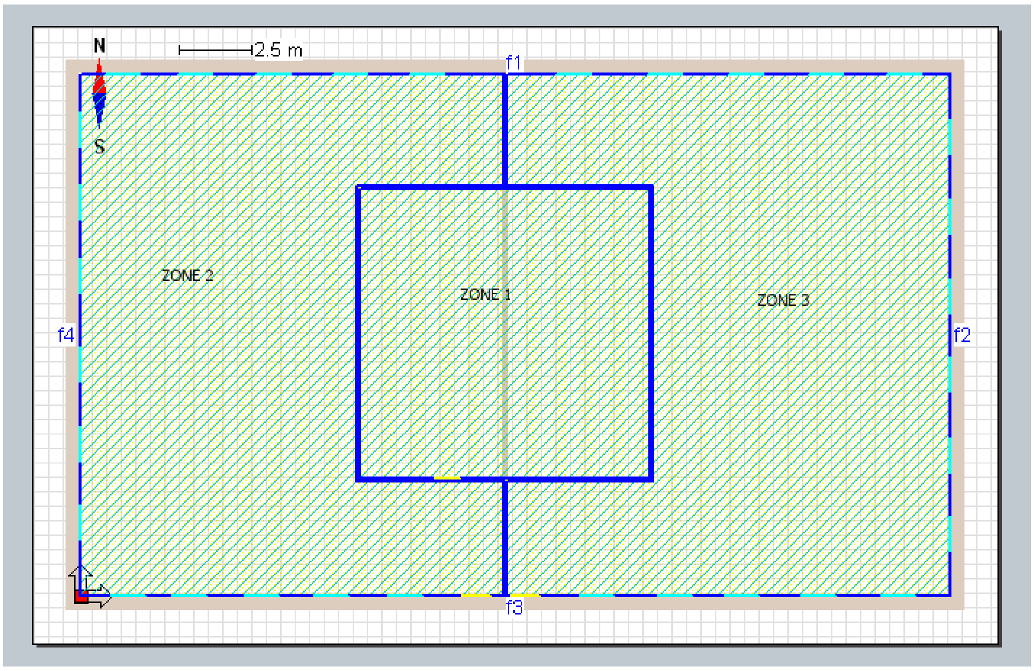

FIGURE 16. Plan of zones on the first floor

There are two separated air handling units for office zones 2, 3, 4 and for data center zone 1. Values of room temperatures and volumes of ventilation are according to Table 2 of D3 /1/. The time of ventilation system operation in office zones is from the Table 3 /1/. Air handling unit is began it work 1 hour before time of the building use and switched 1 hour after the time of building use /1/. Degree of use and thermal loads of lighting, equipment and persons in office zones are according to Table 3 D3 /1/.

In data center zone air handling unit is always on. There is 1 person from 07 to 18, lighting has the same schedule. Thermal load from the equipment is 40 W/m^2. Ventilation in all zones has the constant air flow rates. Both AHUs have constant 18 °C of supply air temperature and 1°C of the temperature rising in AHU's cooling coil. The scheme of air handling unit from IDA ACE is presented on the Figure 17.

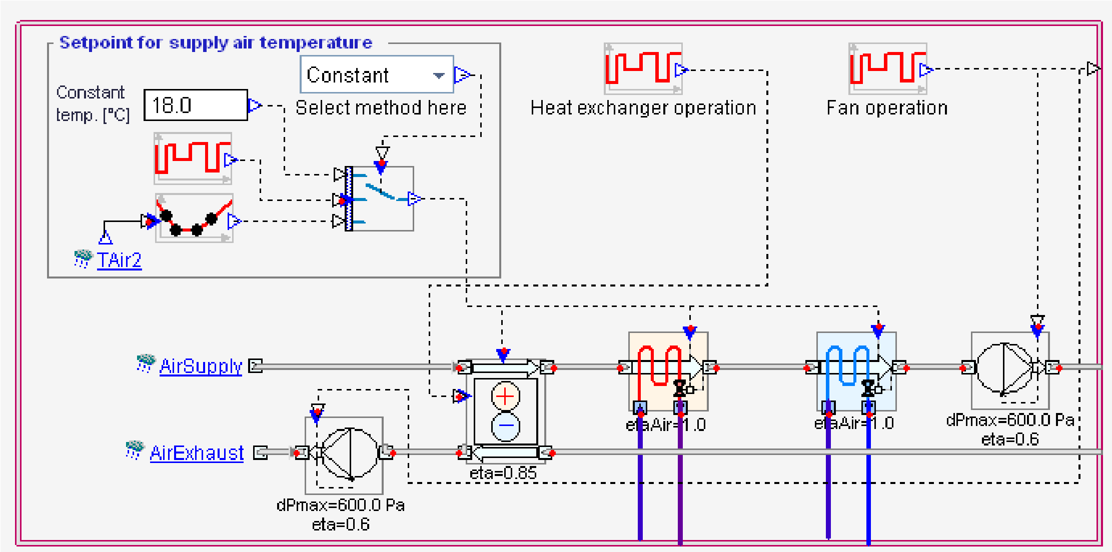

FIGURE 17. Air Handling Unit from the IDA ICE Software

In each zones ideal heaters and ideal coolers are installed besides air handling unit. Heat to the zones is supplied from the district heating network. Cooling for AHU's cooling coils and cooling units are from the chiller. Temperature of ideal coolers in zones is 15 °C.

There were planned two simulation cases: the first one when only chiller works and the second one includes economizer operation besides the chiller. But because of the software cannot set two cooling systems at the same time, there were made two simulations in different modes. One is the only-chiller mode and another is only economizer mode. Then the hours of the economizer possibility were calculated according to set pointtemperature. It is switched on when outdoor temperature is lower than 6 °C. In such case chiller is switched off. This working value was set in the study case.

To see how different set-point temperatures affect on the economizer benefits, also 4°C and 8°C were taken as temperatures when the chiller stops the economizer switched on.

The chiller has indirect air cooling of the condenser. COP of the chiller was taken as 3, COP of indirect air-side economizer is 10 /23/. According to these values energy consumption of cooling systems was calculated.

5.2 Results

As results of simulation in IDA ICE and calculations cooling loads and energy consumption in both cases were determined. Systems energy demand values are shown in the Table 2.

TABLE 2. Systems energy in kWh

Month	Zone heating	Zone cooling	AHU heating	AHU cooling	AHU heat recovery	AHU cold recovery	Fans	Pumps	Dom. hot water
1	988.8	4536.0	2328.3	0.0	16057.0	0.0	0.0	1316.8	1.7
2	565.0	4314.0	3040.9	0.0	15378.0	0.0	0.0	1252.0	2.2
3	99.7	4886.0	1521.0	0.0	15444.0	0.0	0.0	1318.1	1.1
4	0.0	6372.0	321.1	2.0	10020.0	0.0	0.0	1274.7	0.2
5	0.0	8651.0	55.4	138.1	6189.0	0.2	0.0	1393.0	0.4
6	-0.0	9249.0	7.0	338.4	2997.7	0.0	0.0	1292.2	0.9
7	-0.0	10448.0	0.4	2025.0	1247.7	65.7	0.0	1355.9	5.8
8	-0.0	9432.0	2.9	1292.0	2337.3	11.8	0.0	1403.5	3.7
9	-0.0	6980.0	52.5	22.3	5461.0	0.0	0.0	1235.9	0.1
10	0.7	5396.0	226.4	0.0	10241.0	0.0	0.0	1382.8	0.2
11	231.4	4575.0	1614.6	0.0	13849.0	0.0	0.0	1314.8	1.2
12	700.6	4551.0	1687.0	0.0	15260.0	0.0	0.0	1268.1	1.2
Total	2586.2	79390.0	10857.6	3817.8	114481.7	77.8	0.0	15807.8	18.7

According to this total cooling energy demand is calculated with the formula /4/:

$$W_{cooling} = W_{zone\ cooling} + W_{AHU\ cooling} \quad (4)$$

Where

W_{zone} cooling is energy demand for zone cooling, kW

$W_{AHU\ cooling}$ is energy demand for AHU's cooling coil, kW

$W_{cooling}$=79390,0 kWh + 3817,8 kWh =83207,8 kWh

The most part of cooling load of the building is from the data center zone 1. Energy demands for this zone are presented in the Table 3.

TABLE 3. Zone 1 energy demands in kWh

Month	Envelope & Thermal bridges	Internal Walls and Masses	External Window & Solar	Mech. supply air	Infiltration & Openings	Occu-pants	Equip-ment	Lighting	Local heating units	Local cooling units	Net losses
1	-150.0	-547.5	0.0	-1087.0	0.0	16.6	5952.0	289.7	0.0	-4536.0	62.9
2	-145.1	-442.3	0.0	-1017.0	0.0	15.8	5568.0	276.6	0.0	-4314.0	58.8
3	-152.4	-292.8	0.0	-1087.0	0.0	16.3	5952.0	289.9	0.0	-4788.0	62.9
4	-139.1	-16.5	0.0	-1052.0	0.0	15.3	5760.0	276.9	0.0	-4905.0	60.8
5	-122.7	86.3	0.0	-1087.0	0.0	16.6	5952.0	303.0	0.0	-5210.0	62.9
6	-106.3	117.3	0.0	-1052.0	0.0	15.3	5760.0	276.6	0.0	-5072.0	60.8
7	-98.0	132.0	0.0	-1086.0	0.0	16.1	5952.0	289.9	0.0	-5268.0	62.9
8	-90.7	102.8	0.0	-1086.0	0.0	16.8	5952.0	303.0	0.0	-5260.0	62.9
9	-96.3	32.7	0.0	-1052.0	0.0	14.6	5760.0	263.4	0.0	-4983.0	60.8
10	-112.3	-153.7	0.0	-1088.0	0.0	17.0	5952.0	302.9	0.0	-4981.0	62.9
11	-121.5	-377.4	0.0	-1052.0	0.0	16.4	5760.0	289.7	0.0	-4575.0	60.8
12	-142.4	-526.7	0.0	-1087.0	0.0	15.8	5952.0	276.6	0.0	-4551.0	62.9
Total	-1476.8	-1885.8	0.0	-12833.0	0.0	192.6	70272.0	3438.2	0.0	-58443.0	742.1
During heating	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
During cooling	-1476.9	-1885.8	0.0	-12836.1	0.0	192.6	70277.8	3438.9	0.0	-58444.4	742.2
Rest of time	0.1	-0.0	0.0	3.1	0.0	-0.0	-5.8	-0.7	0.0	1.4	-0.1

The first case is when only chiller works. The results of the electrical energy calculations are presented in the Table 4.

TABLE 4. Electrical energy of cooling by chiller in kWh

Month	Facility electric								Facility district			
	Lighting, facility		Equipment, facility		Cooling		HVAC aux		Heating		Domestic hot water	
	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)
1	3113.0	5292.1	8776.0	14919.2	1512.0	2570.4	1319.0	2242.3	3530.0	2471.0	2020.0	1414.0
2	2973.0	5054.1	8265.0	14050.5	1438.0	2444.6	1254.0	2131.8	3837.0	2685.9	1890.0	1323.0
3	3116.0	5297.2	8778.0	14922.6	1629.0	2769.3	1320.0	2244.0	1724.0	1206.8	2020.0	1414.0
4	2976.0	5059.2	8459.0	14380.3	2125.0	3612.5	1275.0	2167.5	341.6	239.1	1955.0	1368.5
5	3256.0	5535.2	8905.0	15138.5	2930.0	4981.0	1394.0	2369.8	59.0	41.3	2020.0	1414.0
6	2973.0	5054.1	8456.0	14375.2	3196.0	5433.2	1294.0	2199.8	7.4	5.2	1955.0	1368.5
7	3115.0	5295.5	8778.0	14922.6	4158.0	7068.6	1362.0	2315.4	0.5	0.3	2020.0	1414.0
8	3256.0	5535.2	8905.0	15138.5	3575.0	6077.5	1407.0	2391.9	3.1	2.2	2020.0	1414.0
9	2831.0	4812.7	8327.0	14155.9	2334.0	3967.8	1236.0	2101.2	55.9	39.1	1955.0	1368.5
10	3256.0	5535.2	8905.0	15138.5	1799.0	3058.3	1383.0	2351.1	241.6	169.1	2020.0	1414.0
11	3114.0	5293.8	8584.0	14592.8	1525.0	2592.5	1316.0	2237.2	1964.0	1374.8	1955.0	1368.5
12	2973.0	5054.1	8649.0	14703.3	1517.0	2578.9	1270.0	2159.0	2540.0	1778.0	2020.0	1414.0
Total	36952.0	62818.4	103787.0	176437.9	27738.0	47154.6	15830.0	26911.0	14304.0	10012.8	23850.0	16695.0

In the case when only chiller works the biggest cooling power demands are occurred 31.07.2012 at 11 o'clock. Simulation data of this hour is shown on the Table 5. Cooling power for AHU is $W_{AHU\ cooling}$ = 31465,8 W and for zone cooling is $W_{zone\ cooling}$ = 42925,5 W. It means that chiller cooling capacity is calculated by the formula /4/

$$W_{cooling} = 31465{,}8\ W + 42925{,}5\ W = 74391{,}3\ W = 74{,}4\ kW$$

TABLE 5. Systems energy at 31.07.2012 in W

Time	Outside air dry-bulb temperature, Deg-C	AHU cooling coil power, W	Water based cooling power to zones, W	AHU heating coil power, W	Water based heating power to zones, W	Ideal cooler power to zones, W	Ideal heater power to zones, W	Domestic hot water use, W
31.07.2012 11:00	26,10	42925,50	0,00	0,00	0,00	31465,80	0,00	2552,10

In the second case economizer is switched on and chiller is stopped when outdoor temperature is lower than +6°C. Systems energy values are the same as in previous case, but primary energy calculations are presented in the Table 6.

TABLE 6. Electrical energy of cooling by chiller and economizer in kWh

Month	Facility electric								Facility district			
	Lighting, facility		Equipment, facility		Cooling		HVAC aux		Heating		Domestic hot water	
	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)
1	3113.0	5292.1	8776.0	14919.2	453,0	770,1	1319.0	2242.3	3530.0	2471.0	2020.0	1414.0
2	2973.0	5054.1	8265.0	14050.5	443,5	753,9	1254.0	2131.8	3837.0	2685.9	1890.0	1323.0
3	3116.0	5297.2	8778.0	14922.6	495,8	842,8	1320.0	2244.0	1724.0	1206.8	2020.0	1414.0
4	2976.0	5059.2	8459.0	14380.3	1232,7	2095,7	1275.0	2167.5	341.6	239.1	1955.0	1368.5
5	3256.0	5535.2	8905.0	15138.5	2775,4	4718,2	1394.0	2369.8	59.0	41.3	2020.0	1414.0
6	2973.0	5054.1	8456.0	14375.2	3176,9	5400,7	1294.0	2199.8	7.4	5.2	1955.0	1368.5
7	3115.0	5295.5	8778.0	14922.6	4158.0	7068.6	1362.0	2315.4	0.5	0.3	2020.0	1414.0
8	3256.0	5535.2	8905.0	15138.5	3575.0	6077.5	1407.0	2391.9	3.1	2.2	2020.0	1414.0
9	2831.0	4812.7	8327.0	14155.9	2189,3	3721,8	1236.0	2101.2	55.9	39.1	1955.0	1368.5
10	3256.0	5535.2	8905.0	15138.5	1185,2	2014,8	1383.0	2351.1	241.6	169.1	2020.0	1414.0
11	3114.0	5293.8	8584.0	14592.8	644,0	1094,8	1316.0	2237.2	1964.0	1374.8	1955.0	1368.5
12	2973.0	5054.1	8649.0	14703.3	455,7	774,6	1270.0	2159.0	2540.0	1778.0	2020.0	1414.0
Total	36952.0	62818.4	103787.0	176437.9	20784,5	35333,7	15830.0	26911.0	14304.0	10012.8	23850.0	16695.0

In the time of the economizer operation when the outside temperature is lower than 6°C the biggest cooling power demands are occurred 20.04.2012 at 16 o'clock. Simulation data of this hour is shown on the Table 7. Cooling power for AHU is $W_{AHU\ cooling}$ = 0 W and for zone cooling is $W_{zone\ cooling}$ = 21148,0 W. It means that heat exchanger capacity is calculated by the formula /4/

$$W_{cooling} = 0\ W + 21148{,}0\ W = 21148{,}0\ W = 21{,}1\ kW$$

TABLE 7. Systems energy at 20.04.2012 in W

Time	Outside air dry-bulb temperature, Deg-C	AHU cooling coil power, W	Water based cooling power to zones, W	AHU heating coil power, W	Water based heating power to zones, W	Ideal cooler power to zones, W	Ideal heater power to zones, W	Domestic hot water use, W
20.04.2012 16:00	4,90	0,00	0,00	324,00	0,00	21148,00	0,00	2552,10

The electrical energy for cooling if the economizer switches on with the outside temperature lower than +8°C is shown in the Table 8.

TABLE 8. Electrical energy of cooling by chiller and economizer in kWh

Month	Facility electric								Facility district			
	Lighting, facility		Equipment, facility		Cooling		HVAC aux		Heating		Domestic hot water	
	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)
1	3113.0	5292.1	8776.0	14919.2	453,0	770,1	1319.0	2242.3	3530.0	2471.0	2020.0	1414.0
2	2973.0	5054.1	8265.0	14050.5	431,4	733,4	1254.0	2131.8	3837.0	2685.9	1890.0	1323.0
3	3116.0	5297.2	8778.0	14922.6	487,9	829,4	1320.0	2244.0	1724.0	1206.8	2020.0	1414.0
4	2976.0	5059.2	8459.0	14380.3	1099,8	1869,6	1275.0	2167.5	341.6	239.1	1955.0	1368.5
5	3256.0	5535.2	8905.0	15138.5	2485,2	4224,9	1394.0	2369.8	59.0	41.3	2020.0	1414.0
6	2973.0	5054.1	8456.0	14375.2	3148,8	5352,9	1294.0	2199.8	7.4	5.2	1955.0	1368.5
7	3115.0	5295.5	8778.0	14922.6	4152,8	7059,8	1362.0	2315.4	0.5	0.3	2020.0	1414.0
8	3256.0	5535.2	8905.0	15138.5	3556,6	6046,3	1407.0	2391.9	3.1	2.2	2020.0	1414.0
9	2831.0	4812.7	8327.0	14155.9	1997,4	3395,5	1236.0	2101.2	55.9	39.1	1955.0	1368.5
10	3256.0	5535.2	8905.0	15138.5	970,6	1650,0	1383.0	2351.1	241.6	169.1	2020.0	1414.0
11	3114.0	5293.8	8584.0	14592.8	508,0	863,6	1316.0	2237.2	1964.0	1374.8	1955.0	1368.5
12	2973.0	5054.1	8649.0	14703.3	455,7	774,6	1270.0	2159.0	2540.0	1778.0	2020.0	1414.0
Total	36952.0	62818.4	103787.0	176437.9	19747,2	33570,2	15830.0	26911.0	14304.0	10012.8	23850.0	16695.0

In the time of the economizer operation when the outside temperature is lower than +8°C the biggest cooling power demands are occurred 25.05.2012 at 17 o'clock. Simulation data of this hour is shown on the Table 9. Cooling power for AHU is

$W_{AHU\ cooling}$ = 0 W and for zone cooling is $W_{zone\ cooling}$ = 21937,0 W. It means that heat exchanger capacity is calculated by the formula /4/

$W_{cooling}$ = 0 W + 21937,0 W = 21937,0 W = 21,9 kW

TABLE 9. Systems energy at 20.04.2012 in W

Time	Outside air dry-bulb temperature, Deg-C	AHU cooling coil power, W	Water based cooling power to zones, W	AHU heating coil power, W	Water based heating power to zones, W	Ideal cooler power to zones, W	Ideal heater power to zones, W	Domestic hot water use, W
15.05.2012 17:00	7,60	0,00	0,00	0,00	0,00	21937,00	0,00	2552,10

The electrical energy for cooling if the economizer switches on with the outside temperature lower than +4°C is shown in the Table 10.

TABLE 10. Electrical energy of cooling by chiller and economizer in kWh

Month	Facility electric								Facility district			
	Lighting, facility		Equipment, facility		Cooling		HVAC aux		Heating		Domestic hot water	
	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)
1	3113.0	5292.1	8776.0	14919.2	453,0	770,1	1319.0	2242.3	3530.0	2471.0	2020.0	1414.0
2	2973.0	5054.1	8265.0	14050.5	487,5	828,8	1254.0	2131.8	3837.0	2685.9	1890.0	1323.0
3	3116.0	5297.2	8778.0	14922.6	533,3	906,6	1320.0	2244.0	1724.0	1206.8	2020.0	1414.0
4	2976.0	5059.2	8459.0	14380.3	1428,8	2428,9	1275.0	2167.5	341.6	239.1	1955.0	1368.5
5	3256.0	5535.2	8905.0	15138.5	2870,8	4880,3	1394.0	2369.8	59.0	41.3	2020.0	1414.0
6	2973.0	5054.1	8456.0	14375.2	3176,9	5400,7	1294.0	2199.8	7.4	5.2	1955.0	1368.5
7	3115.0	5295.5	8778.0	14922.6	4158.0	7068.6	1362.0	2315.4	0.5	0.3	2020.0	1414.0
8	3256.0	5535.2	8905.0	15138.5	3575.0	6077.5	1407.0	2391.9	3.1	2.2	2020.0	1414.0
9	2831.0	4812.7	8327.0	14155.9	2280,6	3876,9	1236.0	2101.2	55.9	39.1	1955.0	1368.5
10	3256.0	5535.2	8905.0	15138.5	1433,8	2437,5	1383.0	2351.1	241.6	169.1	2020.0	1414.0
11	3114.0	5293.8	8584.0	14592.8	851,4	1447,4	1316.0	2237.2	1964.0	1374.8	1955.0	1368.5
12	2973.0	5054.1	8649.0	14703.3	485,7	825,6	1270.0	2159.0	2540.0	1778.0	2020.0	1414.0
Total	36952.0	62818.4	103787.0	176437.9	21751,2	36977,0	15830.0	26911.0	14304.0	10012.8	23850.0	16695.0

In the time of the economizer operation when the outside temperature is lower than +4°C the biggest cooling power demands are occurred 20.04.2012 at 14 o'clock. Simulation data of this hour is shown on the Table 11. Cooling power for AHU is $W_{AHU\ cooling}$ = 0 W and for zone cooling is $W_{zone\ cooling}$ = 19002,4 W. It means that heat exchanger capacity is calculated by the formula /4/

$W_{cooling}$ = 0 W + 19002,4 W = 19002,4 W = 19,0 kW

TABLE 11. Systems energy at 20.04.2012 in W

Time	Outside air dry-bulb temperature, Deg-C	AHU cooling coil power, W	Water based cooling power to zones, W	AHU heating coil power, W	Water based heating power to zones, W	Ideal cooler power to zones, W	Ideal heater power to zones, W	Domestic hot water use, W
20.04.2012 14:00	3,60	0,00	0,00	454,30	0,00	19002,40	0,00	2552,10

5.3 Analysis and discussion

In data center zone of the building there is constant cooling load that requires mechanical cooling during whole year and as shown in the Table 3 it is about 5000 kWh per month. And the comparison of the Table 2 and Table 3 says that in the winter time all or almost all cooling load of the building is from the zone 1. That's why there is economizer possibility during winter time. In economizer mode chiller compressor will be switched off and saved by this energy will give profit to economizer mode.

Energy demands of the cooling system of the building in only chiller case is 27,74 MWh annual (25,68 kWh/m^2) from the Table 4 and in chiller and economizer case is 20,78 MWh (19,24 kWh/m^2) from the Table 6. According to energy form coefficient for electricity that is equal 1,7, primary energy demand is 47,2 MWh annual and 35,3 MWh annual. It means that annual energy economy is 27,74 MWh – 20,78 MWh = 6,98 MWh and economizer allows to reduce the annual energy demand of cooling system on 25,2 %. This value is not big because of the economimzer works only with low outdoor temperature when cooling loads is on minimum and maximum summer values are referred to chiller operation anyway. And we can consume that bigger constant cooling loads in winter time corresponds better value of annual energy economy of economizer.

For estimation of the operational cost of the cooling system the price 100 € per MWh of electricity is assumed. The price of chiller system operation in only chiller case may be calculated with multiplying of the delivered energy to energy price per MWh. 27,74 MWh *100 € = 2774 €. The price of the chiller system operation in chiller and economizer case is equal to 20,78 MWh *100 € = 2078 €. The price of the energy economy is 2774 € - 2078 € = 698 €.

Set-point temperature of the economizer has a significant influence on its benefits. That's why +4°C and +8°C were taken as the set-point temperatures besides +6°C for comparison of economies. Energy demands of the cooling system of the building in chiller and economizer case with +8°C set-point temperature of the economizer is 19,75 MWh annual from the Table 8 and it reduces the annual energy demand of cooling system on 28,8 %. It is bigger than with +6°C but the capacity of the heat exchanger also rises and becomes 21,9 kW. With +4°C set-point temperature of the economizer energy demands is 21,75 MWh annual from the Table 10. It reduces cooling system energy consumption on 21,6%. But with lower benefit heat exchanger capacity is lower also and equal to 19,0 kW. In the building with bigger cooling loads the difference between heat exchanger capacities will be much more significant. It means that in every individual case it it needed to evatuale the benefits from the economizer in comparison with capacity of the heat exchanger for the pay-back calculations.

6 CONCLUSION

In this thesis the theme of energy efficiency was touched upon. Chiller systems are used for different cooling purposes. If they are applied for the air conditioning, they are the substantial part of energy consumption of the building. That's why different types of economizers began to be used more often. They serve to reduce the energy for cooling. This is done by increasing coefficient of performance of the system by using the additional equipment. Also another methods of energy efficiency estimating were described.

There are two types of the economizers in chiller systems – internal and external. Internal economizers are applied in the refrigeration cycle of the chiller. They improve performance of the cycle by the different ways. It may be flash tank, heat exchanger, both of them or internal heat exchanger.

External economizers are related to supporting chillers equipment like coolers of the condensers. They are divided by the type of liquid cooler – water-side or air-side. These systems have different modifications but all of them reduce energy consumption of the chiller system by means of switching on the compressor with suitable outdoor air conditions and providing the cooling loads through the cooler of condenser. It allows to use the cold of outdoor air and doesn't require the installation of the large number of additional equipment.

In case study the two-storage office building in Helsinki 1080 m^2 by the area with constructions and internal loads according to D3 /1/ was modeled in IDA Indoor Climate and Energy software. Simulations of two general cases were carried out for comparison and evaluation of economizer effect. The first one if only chiller provides cooling loads from cooling units and from AHU whole year. COP of such system was 3. The second one if chiller system with COP 3 works in summer time and when the outdoor temperature is cold enough chiller is stopped and indirect air-side economizer mode with COP 10 is started. Different energy consumptions were simulated and as a result the benefit of economizer system was determined. With the set-point temperature of economizer system +6°C the benefit is 25,2%.

But the different conditions influence on the economizer benefits. In study case two bigger set-point temperatures +4°C and +8°C were set. They reduce cooling system energy consumption on 21,6% and 28,8% accordingly. But the capacity of the heat exchanger in the first case was lower than in the second. It corresponds to lower equipment cost in the first case and higher in the second case. The relationship between equipment cost and benefits from the system operational must be precisely evaluated in every individual case. The economizer systems may be implemented only if they give substantial operation economy in comparison with their initial cost.

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