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T662KA

SYSTEMS BASED ON
MAISOTSENKO CYCLE
Coolerado Coolers

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DESCRIPTION

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Abstract <p>A large part of the world's energy is consumed by ventilation and air-conditioning. One of the most energy-intensive processes in the ventilation and air-conditioning is the process of air cooling. Traditional systems based on the compressor cycle consume a lot of energy. Refrigerants contained in compressor circuits are often very harmful to the environment. These factors led to the active development of evaporative coolers. And the former soviet scientist Valery Maisotsenko improved evaporative cooling technology and called the resulting cycle as Maisotsenko-cycle (=M-cycle). He also patented a series of devices based on the M-cycle. Some of the devices based on the M-cycle are Coolerado air conditioners. These air conditioners have very low power consumption and the ability to cool the air below the wet bulb temperature.</p> <p>The aims of this work are: to get acquainted and understand principles of the M-cycle and review the systems from different areas based on the M-cycle; to figure out the advantages of the Coolerado air-conditioners compared to traditional evaporation and compressor systems and to calculate the possibility of using Coolerado air conditioners in Scandinavian climate.</p> <p>In order to reach specified aims the following methods are applied: literature review, analysis of differences between traditional adiabatic cooling systems and evaporative systems based on M-cycle and calculation of the possible use of this system in Scandinavian climate.</p> <p>This thesis describes principles of the M-cycle and systems based on it. In this work advantages and disadvantages of the Coolerado coolers are figured out and compared to the traditional cooling systems. Also the possibility of use of Coolerado coolers in Northern climate is estimated.</p>			
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1 INTRODUCTION

1.1 General overview

Nowadays, great attention is paid to the environment, energy saving and energy efficiency. Energy production often adversely affects the environment and increases greenhouse gas emissions. Despite this, the global energy consumption grows from year to year. That is why the question of the development of new, cleaner and more efficient technologies has been raised acutely in recent years.

A large part of the world's energy is consumed by ventilation and air-conditioning. Practically in each modern building ventilation and air-conditioning systems are installed. Even many of the old buildings where possible, are equipped with modern ventilation systems. Many of building facilities, such as hospitals and industrial buildings, have specific requirements for ventilation and air conditioning systems.

One of the most energy-intensive processes in the ventilation and air-conditioning is the process of cooling. Traditional systems based on the compressor cycle consume a lot of energy. Refrigerants contained in compressor circuits are often very harmful to the environment.

These factors led to the active development of evaporative coolers. Air coolers based on evaporative cooling of the air consume far less energy compared to traditional compressor systems. They are also more ecological and environmental-friendly systems.

However, the efficiency of evaporative air cooling systems is strongly dependent on the state of the air. The most suitable conditions for these systems are the areas with a hot and dry climate. Determining factor in this case is the air wet bulb temperature. This is the theoretical minimum temperature to which air can be cooled.

However, this was not the limit, and the former soviet scientist Valery Maisotsenko improved evaporative cooling technology and called the resulting cycle as Maisotsenko-cycle (M-cycle). He also patented a series of devices based on the M-cycle. The

application of this cycle improves the efficiency of the existing devices, and allows create new devices with better performance than their analogues.

Some of the devices based on the M-cycle are Coolerado air conditioners. These air conditioners have very low power consumption and the ability to cool the air below the wet bulb temperature. The determining factor for these conditioners is the dew point temperature - theoretically the lowest temperature to which air can be cooled using this technology.

Coolerado air conditioners are increasingly used throughout the world. Due to a greater range of cooling, these systems can be used in many parts of the world. And due to the low power consumption, they can greatly reduce the energy consumption for ventilation and air conditioning.

1.2 Aims

This work has following aims. The first aim is to get acquainted and understand principles of the M-cycle. This is an innovative and versatile technology that can improve the effectiveness of many technological areas.

The second aim is to review the systems from different areas based on the M-cycle. Perhaps in the near future the use of these systems may change a lot in many fields.

The next aim is to figure out the advantages of the Coolerado air-conditioners compared to traditional evaporation and compressor systems.

The final aim is to calculate the possibility of using Coolerado air conditioners in Scandinavian climate, for instance in Finland.

1.3 Methods

In order to reach specified aims the following methods are applied. The first method is the literature review. There is not much information about the topic of this thesis, because it is a pretty new and innovative system. The first area in which this invention was applied is ventilation and air conditioning. Since the equipment based on the new

technology was successful, the active implementation of this technology is going in other fields. So the main literature resources for this thesis work are patents of these systems, magazine articles and information given by the manufacturer.

The second method is analysis of differences between traditional adiabatic cooling systems and evaporative systems based on M-cycle. The main advantages and disadvantages of these systems will be figured out.

The next method is the comparison. The main points and differences will be compared. Advantages and disadvantages of one system relative to another will be shown.

The last method is calculation of the possible use of this system in Scandinavian climate. Data obtained during the independent testing of these systems will be used to assess their performance. By using climatic data for Finland and tested data of the performance of these systems, conclusion about the applicability of these systems in the Scandinavian climate will be drawn.

2 ADIABATIC COOLING

Maisotsenko cycle (M-cycle) is a particular case of indirect adiabatic (evaporative) cooling (IAC) in air conditioning systems. Interest in using the technology of adiabatic cooling in air conditioning systems is caused by a number of advantages, the most important of which is a radical reduction of energy consumption. Systems based on the M-cycle allow to achieve even greater efficiency than ordinary adiabatic cooling.

2.1 Adiabatic cooling

For the first time the method for indirect adiabatic cooling was patented by Valery S. Maisotsenko and Alexandr N. Gershuni in 1987 in Soviet Union. After that they patented it in the United States of America in 1990 as “Method for indirect-evaporative air cooling”. “The present invention relates to methods for air cooling with the use of heat-exchangers of the indirect evaporative type and can find most utility when applied for air cooling in those premises or accommodations which must be isolate from the surrounding atmosphere either for technological reasons or on account of labor protection condition, etc.”. /1, p.3./

The traditional source of cooling power in air conditioning systems is a thermodynamic process in refrigerating circuit. In systems with adiabatic cooling technology, the source of cooling power is an adiabatic process - a special case of the thermodynamic process. This approach allows you to completely or partially abandon compressor in cooling, where the compressor is the main consumer of electricity.

In the recent past adiabatic cooling systems were primarily used in areas with dry and hot climate. But the latest development of HVAC equipment manufacturers has demonstrated great potential for the use of adiabatic cooling systems in European temperature regions. Determining factor in the use of adiabatic cooling systems is the outdoor wet bulb temperature in the summer time. /2./

Adiabatic cooling process occurs as a result of contact between the evaporating water particles with air flow. Potential cooling effect can be estimated from the difference

between the outdoor temperature and its wet bulb temperature. The greater this temperature difference, the greater the potential effect of cooling.

The process is called adiabatic, because it goes without heat exchange with the environment. Cooling is achieved by the fact that the particles of water take heat from the air during the evaporation process.

2.2 The process of adiabatic cooling

When the water evaporates into the air, it takes heat from the air. This heat is usually called latent heat. It consists of two parts. The first part is the heat, which is needed to vaporize water from liquid to vapour (phase transition from liquid phase to gas phase). The second part is the heat, which is needed to superheat water vapour to the air temperature.

The main idea of the adiabatic cooling is shown in the Mollier chart in the Figure 1.

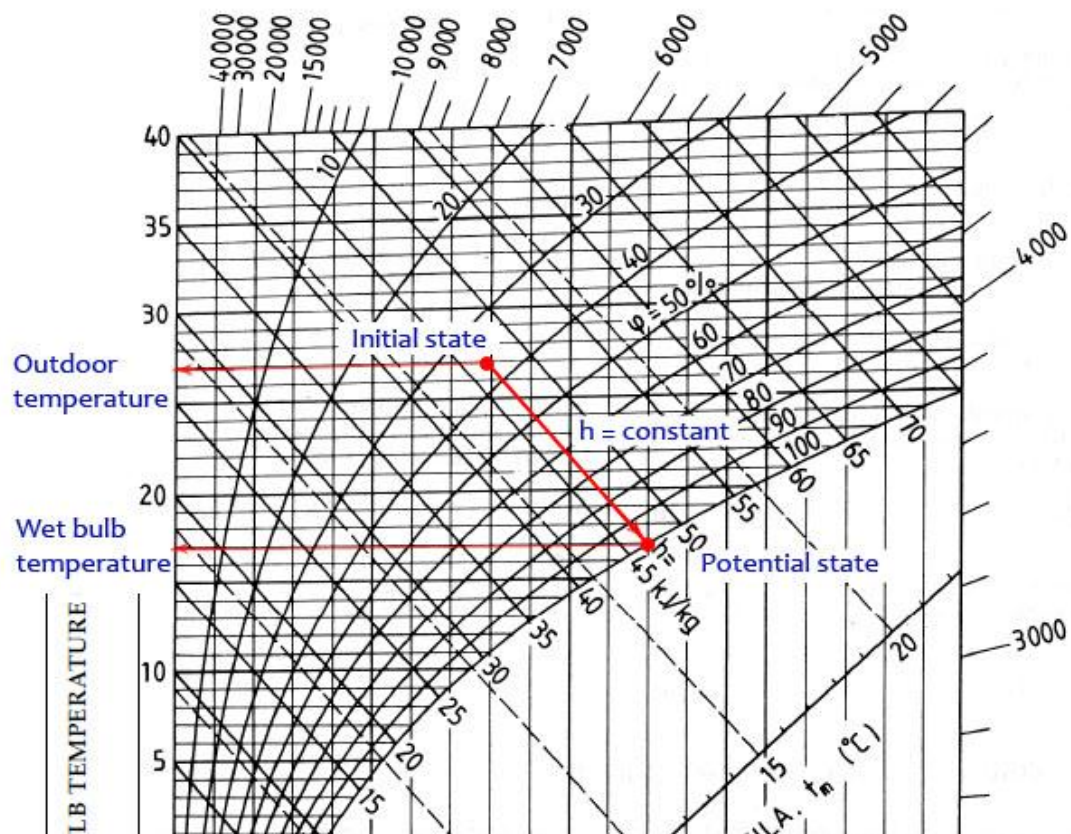


FIGURE 1. Adiabatic cooling process

The air with initial characteristics comes to the adiabatic cooler, where the particles of water are sprayed into the incoming air stream. Water particles evaporate in the air stream and take the latent heat from it. The process goes with the constant enthalpy. The temperature of the air decreases, but the moisture content increases. The minimum possible temperature is the wet bulb temperature. The potential air state is the point on the saturation curve on the line with constant enthalpy.

The figure shows that the lower the relative humidity and higher temperature of the air, the greater the potential effect of cooling. That is why dry and hot climate is the most suitable for the adiabatic cooling systems.

2.3 Indirect adiabatic cooling

In adiabatic cooling of the air with decreasing of the temperature, increases humidity. The higher the cooling effect, the more humid the air becomes.

High humidity can cause discomfort. The most comfortable humidity level in the room varies from 40 % to 60 %. Humidity levels below 30 % and over 70 % are uncomfortable. Decrease in temperature with a simultaneous increase of humidity, using a direct evaporative cooling in a confined space, impairs the comfort especially in regions where the climate is hot and dry. /3./

High level of humidity can cause growth of microbes or microorganisms, health hazards, emissions from building materials, moisture damage and so on. Indirect adiabatic cooling helps to avoid problems associated with changes in moisture content of the incoming air. /4, p.10./

It is often so, that recirculation water is used in evaporative cooler. It may cause some problems. In systems with water recirculation there is always stagnant water. Therefore, there is high probability of formation of microorganisms. Only a regular cleaning with disinfectants (at least once a month) and regular draining (once a day) can prevent problems with hygiene. There could be also activities, which include ultraviolet disinfection of water for the humidifier or use antibacterial environments. But all of these activities lead to increased costs and interruption of the operating cycle.

Schematic diagram of the indirect evaporative cooling is shown in the Figure 2.

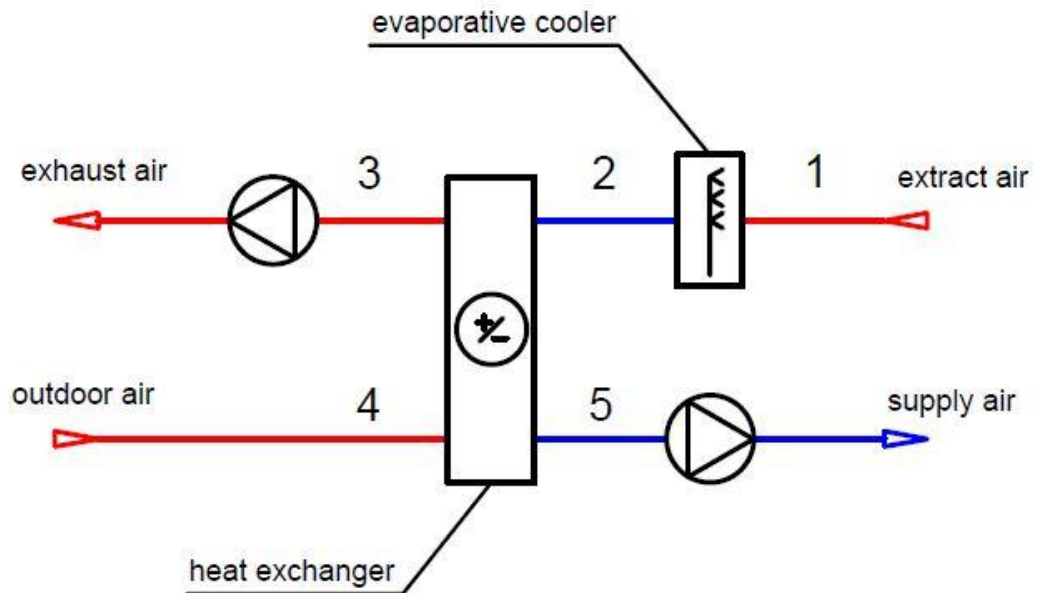


FIGURE 2. Schematic diagram of the indirect evaporative cooling

Warm extract air from rooms (1) comes to the evaporative cooler. There because of the evaporation the air cools down and becomes more humid (2). After that the air comes to the heat exchanger, where it takes heat from the incoming outdoor air (3). On the other hand, the outdoor air comes to the heat exchanger (4), where it is cooled by the exhaust air flow without increasing of the moisture content (5).

The process can also be followed in the Mollier chart in the Figure 3.

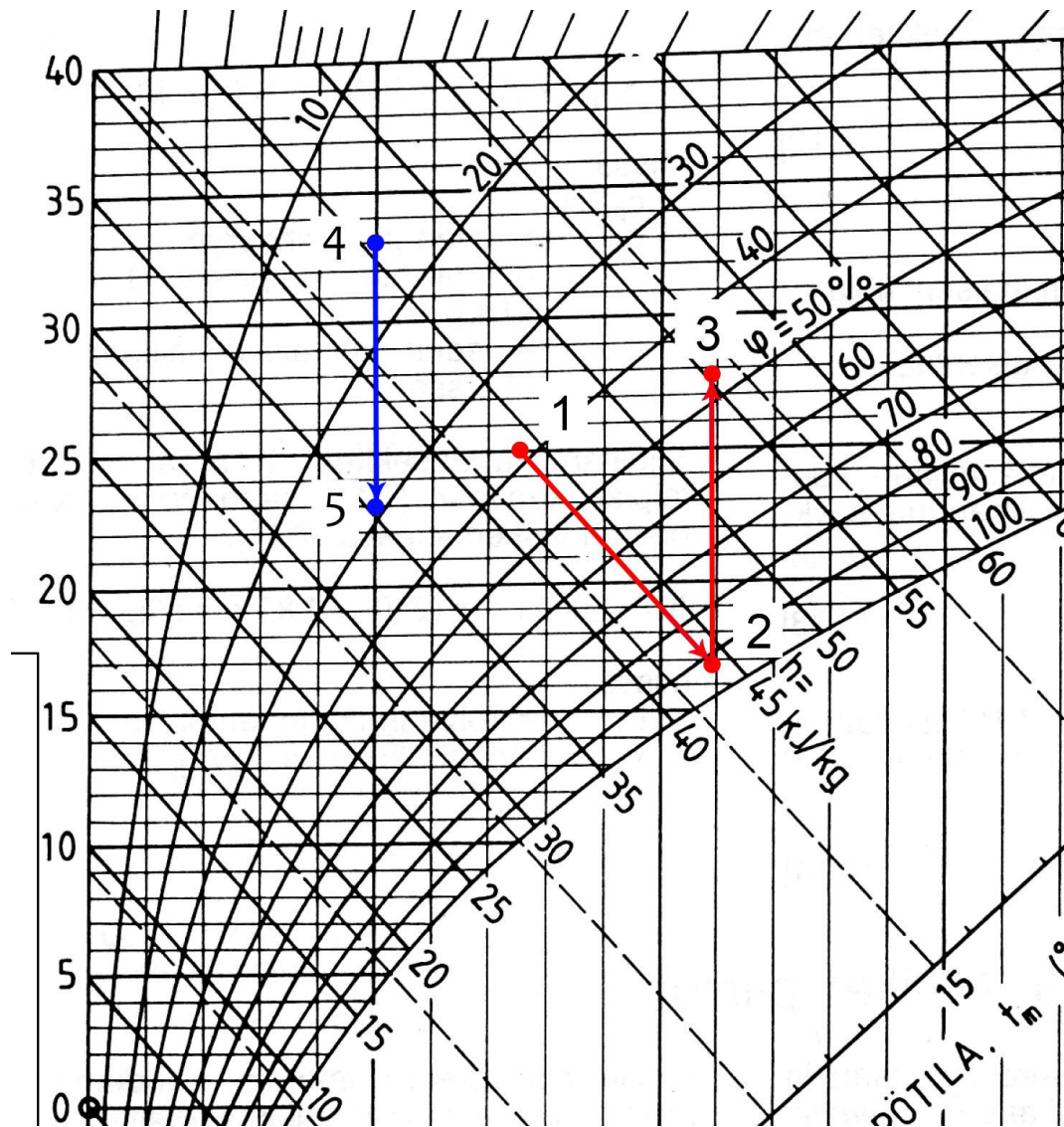


FIGURE 3. Schematic diagram of indirect evaporative cooling on the Mollier chart

2.4 Heat exchangers in traditional indirect adiabatic cooling

Indirect evaporative cooling efficiency depends not only on the state of the air, but also on the efficiency of the heat exchanger. The main types of the heat exchangers are plate heat exchangers, rotating heat exchangers and air-fluid-air heat exchangers.

System with the use of plate heat exchangers is simple in design, reliable in operation and has minimal maintenance costs. The heat exchanger is made of metal plates, which create a system of canals, where are two flows of air. The main advantage of the plate heat exchangers is that air flows do not mix, so the system can be used in

"clean" areas (medicine, pharmaceuticals, microelectronics, etc.). While the main drawback of the system is the probability of freezing of the exchangers exhaust line.

The main types of plate heat exchangers are shown in the Figure 4 /5/.

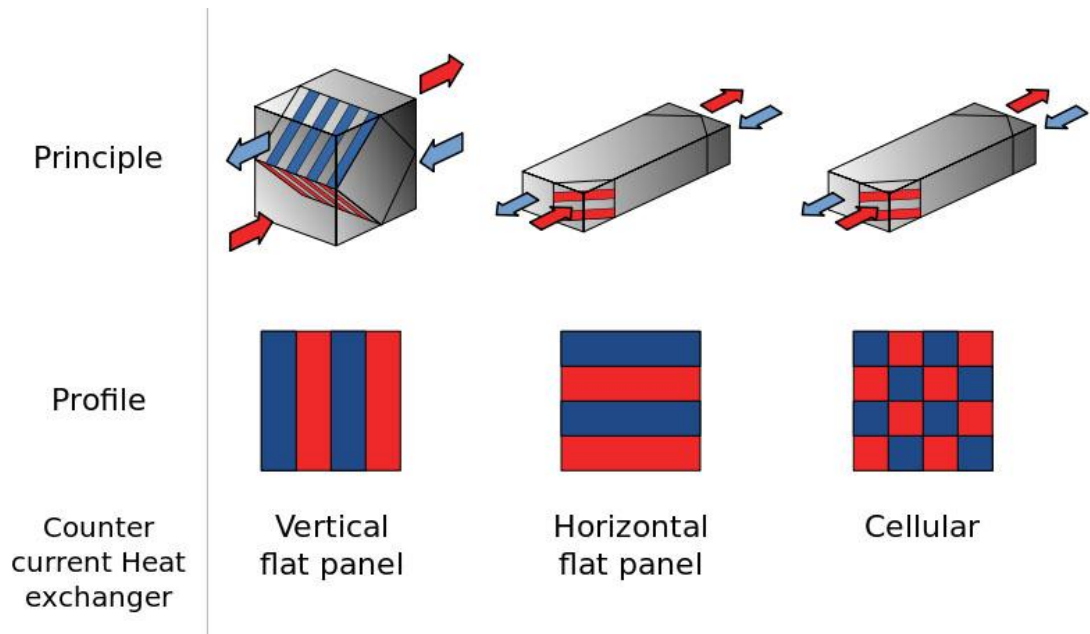


FIGURE 4. Different types of plate heat exchangers /5/

According to the Figure 4, from left to right are shown: cross flow heat exchanger, counter flow heat exchanger and cellular counter flow heat exchanger. The most common at this time is a cross flow heat exchanger, but it has smallest efficiency among other types (50 – 70 %). The efficiency of the counter flow heat exchanger is about 70 – 80 %. And the efficiency of the counter flow cellular heat exchanger can reach 95 %. /6./

Rotating heat exchanger is a device in which heat transfer is the result of accumulation of heat in rotating wheel (corrugated steel sheet, folded so as to get channels for horizontal air flow). The advantage of rotary heat exchangers is very high efficiency of heat recovery. The disadvantage is the mixture of air streams so these exchangers are not applicable in places where is needed full separation of supply and exhaust air. The schematic diagram of the rotating heat exchanger is shown in the Figure 5 /5/.

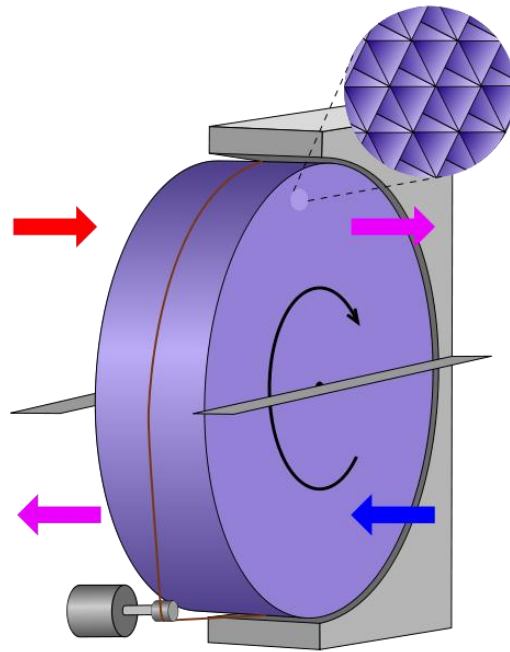


FIGURE 5. The schematic diagram of the rotating heat exchanger /5/

The air-fluid-air heat exchangers are used in cases, when the distance between the supply and exhaust units is large enough and mixing of air streams is unacceptable. This system consists of two heat exchangers which are located in the supply and exhaust ducts and connected with the piping system filled with heat transfer agent. One of the main advantages of the system is that the heat transfer agent is a nonfreezing fluid, which ensures stable operation without freezing of agent. But because there are two intermediate heat exchangers, heat transfer efficiency is reduced by 40 - 50 % . /6./

3 SYSTEMS BASED ON MAISOTSENKO CYCLE

The first area, in which was successfully applied the M-cycle is ventilation and air conditioning. However, M-cycle can be used not only in ventilation and air conditioning systems. Large density difference between the cooled and heated air is the potential, which can be used as a driving force (potential difference) in the energy and heat and mass transfer technologies.

The main advantages of systems based on the M-cycle are the environmental safety, high efficiency, low unit cost (design has no complex assemblies), low operating costs. Because all the processes occur at atmospheric conditions, there is no problem of sealing the installation. An important advantage is the absence of expensive compressor and refrigerant.

According to the report of the United States Department of Energy, Energy Efficiency and Renewable Energy, the energy derived from the air through the M-Cycle is 10 times cheaper than the energy obtained from traditional sources /7, p.10/.

3.1 Maisotsenko exergy tower

Potential interest for alternative energy is Maisotsenko exergy tower. It can be used to generate electricity, cold air and cold water. Exergy tower scheme based on M-cycle is shown in the Figure 6.

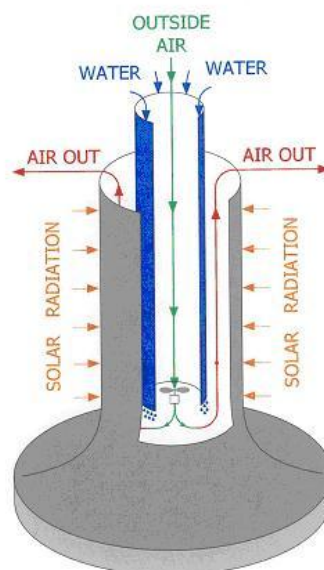


FIGURE 6. Maisotsenko exergy tower /8/

Maisotsenko exergy tower consists of two cylinders. The outer part of the inner cylinder is covered with a capillary-porous material and is irrigated with water. As is known, water vapor has a lower molar mass than dry air. Hence, the mixture of dry air with water vapour has lower density, than dry air. Because the outer part of the inner cylinder is wet, the water will evaporate in to the air. Since humid air has a lower density, it will go up. The air, which is going upwards, creates under pressure in the wet channel, which increases the overall flow of air in the system.

On the other hand, evaporating water takes heat from the walls of the inner cylinder. The wall of the inner cylinder is made from thin, heat conductive material. So the heat for evaporation of water is taken from the internal air flow. The inner cooled air goes downwards. Due to the evaporation of water in the annular channel mass flow output significantly exceeds mass flow of the incoming air, which increases the velocity of the air in the tower.

Tower can also be affected by the sun. The air in the outer channel of the tower can be heated by solar radiation. The warmer the air, the lower its density, and the better is the flow through the exergy tower.

With the appropriate height of the tower and a sufficiently high flow rate, wind turbine can be installed in the lower part of the tower which allows electricity production. The operation of such installation occurs day and night and does not depend on the wind speed in the ambient atmosphere.

Calculations show that the exergy tower with height of 10 meters is able to produce up to 25 kilowatt-hours of electricity per day. In fact, almost any industrial pipe, fitted with a device based on the M-cycle can be used to generate electricity. The lowest temperature of the air and water in the tower is reached in the bottom of the tower. This can be used for the production of cold air and cold water. /8./

3.2 Maisotsenko combustion turbine cycle

Gas turbines are widely used in energy, aviation, shipbuilding, as well as mechanical drive in various systems. Despite a high rate of thermodynamic perfection, the coeffi-

cient of performance (COP) of powerful gas turbines is not more than 40% (GTP SGT5-800H; 375 MW; «Siemens», Germany). To improve the COP of gas turbines a variety of methods is used, the main of which are: increase in temperature of the combustion products before the turbine and increase of compression of air in the compressor.

Maisotsenko Combustion Turbine Cycle (MCTC) aims to increase the power output and broaden the power range while sustaining high system efficiency by supplying added mass (moist air) to the turbine with no additional work of the compressor. MCTC recovers turbine exhaust heat by putting it back to the cycle. Also by supplying moist air into the combustion chamber lower emissions are achieved. /9, p.2./

The scheme of the MCTC is shown in the Figure 7.

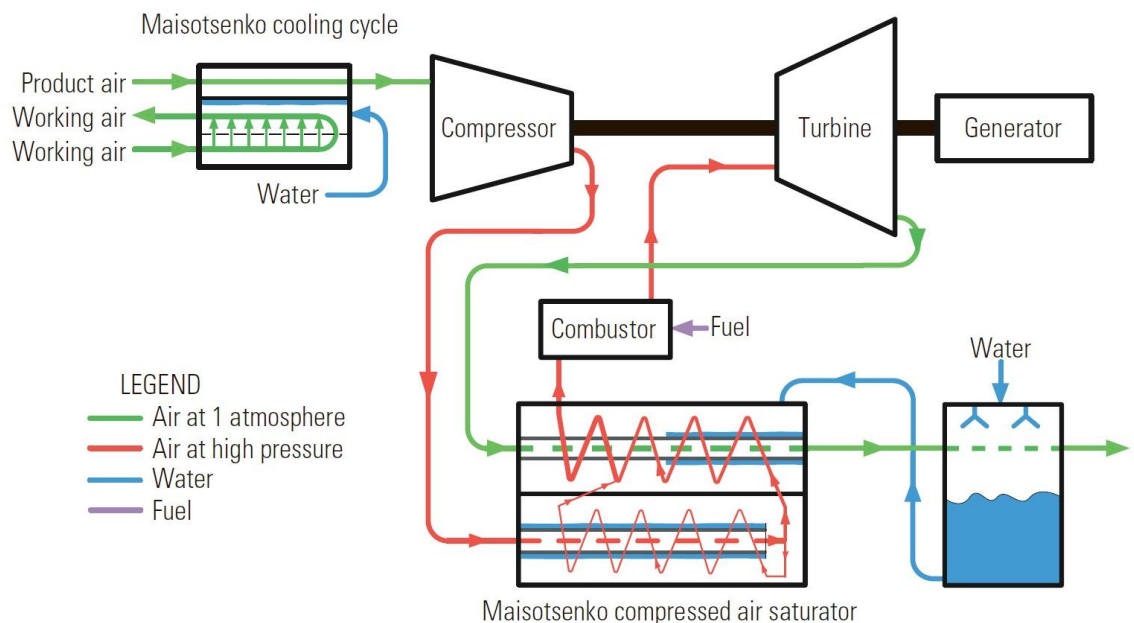


FIGURE 7. Maisotsenko Combustion Turbine Cycle (MCTC) /9/.

Decrease in temperature without adding moisture in the air can increase efficiency of the compressor. The colder the air, the easier it is to compress. Based on this, there is the Maisotsenko cooling cycle before the compressor. It allows cool the air flow without high increase in energy consumption. /9, p.2./

After compressor, dry and cold air comes to the Maisotsenko compressed air saturator/turbine exhaust cooler. Detailed diagram of the Maisotsenko compressed air saturator is shown in the Figure 8.

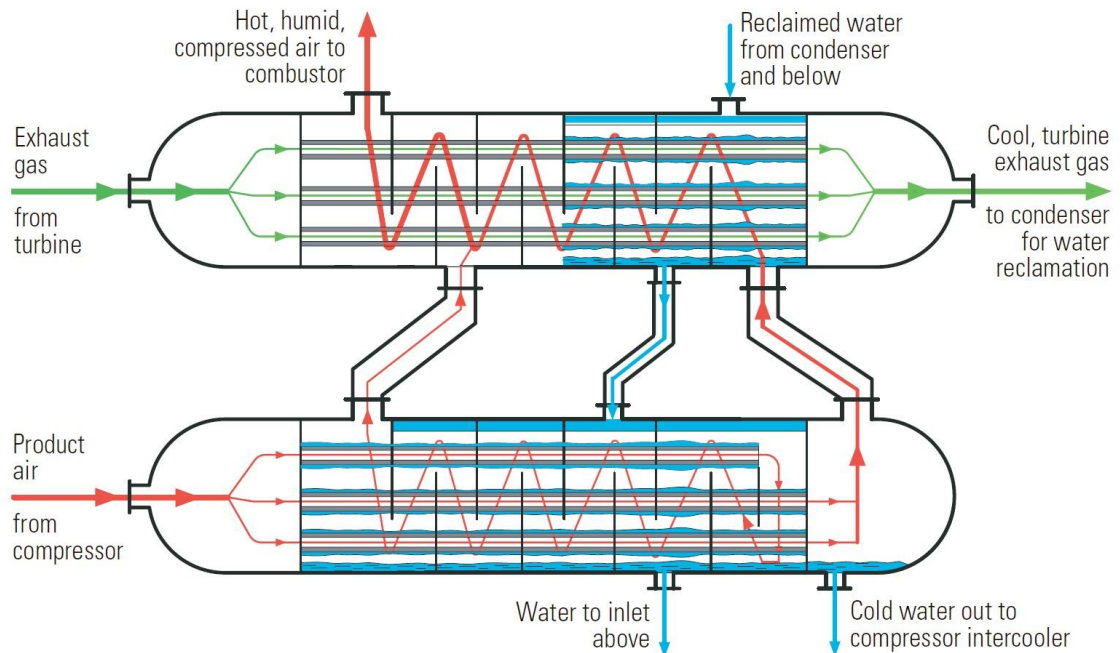


FIGURE 8. Maisotsenko compressed air saturator/turbine exhaust cooler /9/.

Compressed cold and dry air comes to the Maisotsenko compressed air saturator, where it is divided into 2 streams. One of the streams goes through the narrow channel, where it is cooled. After exiting this channel the flow of air gets into the wet channel that surrounds the other narrow channels. There, because of the evaporation it is cooled and humidified. This air flow goes around narrow channels in counter direction and cools air flows inside them.

The other air stream goes through their channels, where they are cooled by the first air stream. After that, they enter into the wet channel, where they are cooled and saturated with water due to evaporation. Before leaving the Maisotsenko compressed air saturator the first stream is mixed with the second. After that, the flow of moist air enters the combustor.

On the other hand, exhaust gas from the turbine comes to the Maisotsenko compressed air saturator. There it goes through the narrow channels in counter flow with the hu-

mid air from the compressor. The heat from the hot exhaust gas goes to the cold air from the compressor.

Maisotsenko compressed air saturator allows achieve a very high degree of humidification - 30% or more. With use of the air with high humidity, improves the fuel consumption, the level of harmful emissions into the atmosphere reduces by several times, increases power of the gas turbine. However, the moist air requires more fuel, because of the higher specific heat capacity. On the other hand, more fuel means bigger temperature of the turbine exhaust gases, which could be recovered in the Maisotsenko compressed air saturator/turbine exhaust cooler. /9, p.1-3./

3.3 Other systems

M-cycle can be used in various fields. On the basis of the M-cycle many different devices are patented, e.g. refrigerant condenser for air conditioners, refrigerators and freezers, new construction of cooler tower packing, units for production of fresh water from industrial fluids and seawater and so on /10, p.5/.

In the short term, the M-cycle can be used in internal combustion engines, gas turbines, fuel burners, condensers for various purposes, car air-conditioning systems, boilers and water heaters, industrial furnaces, thermo-chemical fuel recovery systems /10, p.8/.

For instance, installation of ceramic recuperator with indirect evaporative cooling at the exit of the engine, where the temperature is from 540 °C up to 980°C, will not only utilize the exhaust heat and water vapor contained in the flue gas, but also the heat of the engine cooling system /10, p.8/.

Minor changes in the design of cooler tower packing, in accordance with the M-cycle, reduce the consumption of water by 30% and more (Figure 9). However, at a relative humidity of over 60% water consumption will be the same as in conventional cooling towers. /10, p.8-10./

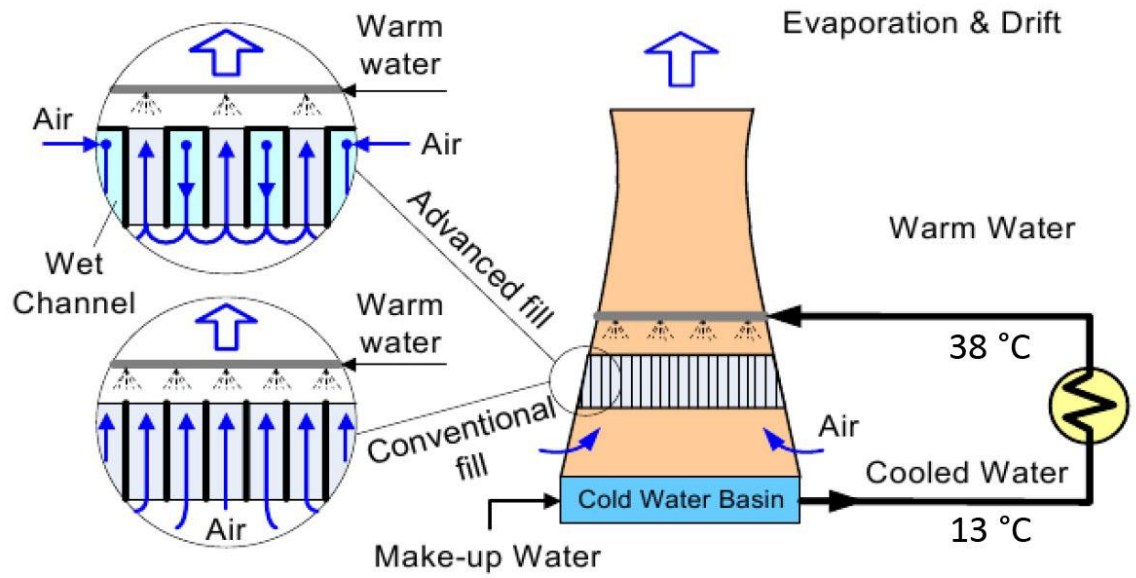


FIGURE 9. The construction of cooling tower packing /10/.

4 COOLERADO COOLERS

As can be seen, the M-cycle can be used in many fields. The first area in which the M-cycle has been applied is the ventilation and air conditioning.

Coolerado company was founded in 2004 by Valery Maisotsenko and Gillan brothers. The first units were installed at Mount St. Vincent's Children's Home and Bradford Publishing. At once Coolerado coolers received the prestigious R&D 100 award for the successful operation of the systems.

At the moment there are installed more than 1300 Coolerado air conditioners in 26 countries. /11./

4.1 Operation principle

As is known the traditional adiabatic cooling does not allow cooling the air below the wet bulb temperature. However, the use of the M-cycle allows cooling air to lower temperatures. Because of that Coolerado air conditioners, which are based on the M-cycle, were created.

To understand the principle of the M-cycle we consider a simple adiabatic model (Figure 11) /12/.

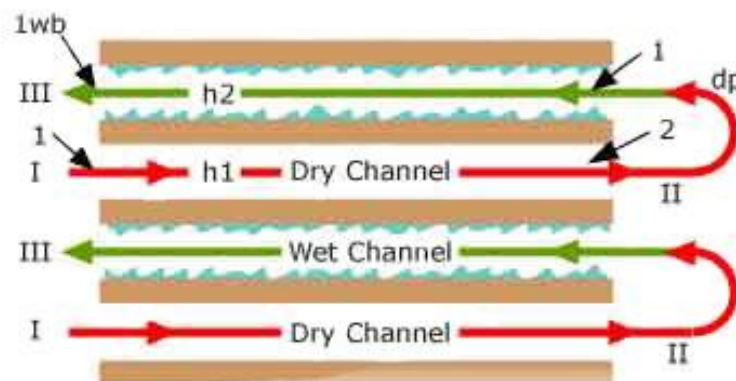


FIGURE 11. Heat and mass exchanger based on M-cycle /12/

The incoming air comes to the dry channel, where it is cooled by the air flow from adjacent wet channels. In theory, the air in state II is cooled to the dew point temperature of the incoming air I. After that the air stream comes to the wet channel, where due to evaporation it takes heat from the air in dry channels. At the exit of the wet channel the air is saturated and its temperature is equal to the wet bulb temperature. This process can be followed on the Mollier chart in the Figure 12. /12./

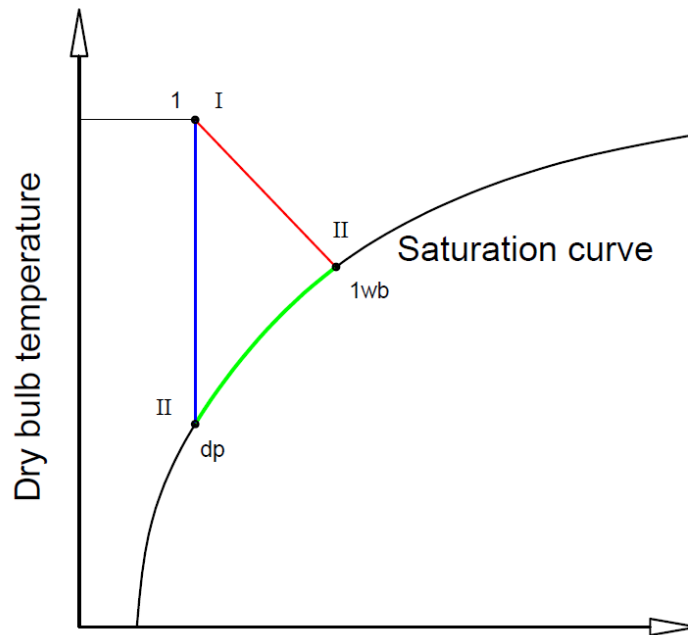


FIGURE 12. Adiabatic heat and mass exchange on the Mollier chart /12/

These theoretical results have been achieved in the real prototypes. The air at the outlet of the second channel reached the dew point temperature. But the cooling capacity of this unit equals to zero, because there is no product stream, supply air goes to the outside.

Based on this another scheme was developed for the real air conditioner. Now there are dry channels for the product air and perforation in working channels. This principle was applied in Coolerado air conditioners. M-cycle diagram is shown in the Figure 13 /12/.

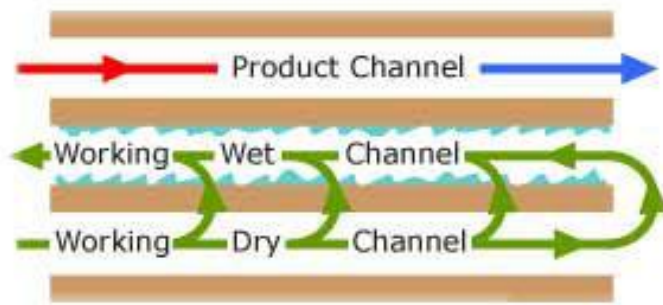


FIGURE 13. Perforated cross flow heat and mass exchanger /12/

The incoming air is divided in two streams. The working stream comes to the dry working channel, where it is cooled by adjacent wet working channel. There are also perforations between working channels. They are needed to significantly reduce the pressure drop. Because product channel is isolated from other channels, the air is cooled without changing of the moisture content. Due to this scheme, the product air can be cooled almost to the dew point temperature, which is the theoretical minimum achievable temperature. /12./

4.2 Coolerado coolers

Coolerado cooler has a rather simple design. It consists of a fan, filters, Heat and Mass Exchanger (HMX), air and water connections. Schematic illustration of the Coolerado cooler is shown in Figure 14.

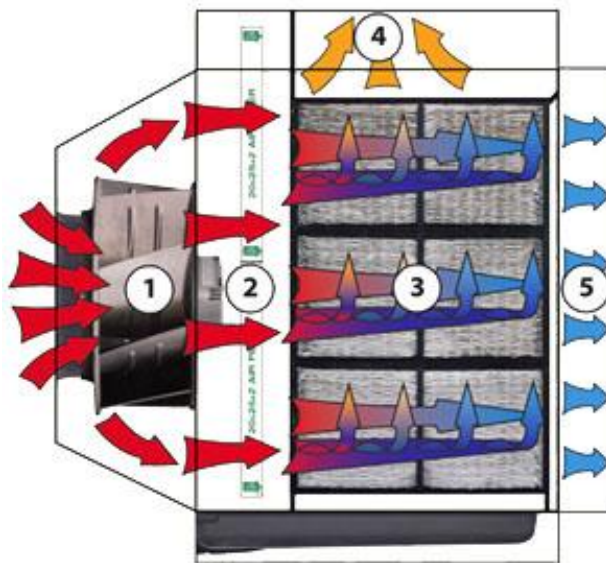


FIGURE 14. Schematic diagram of the Coolerado cooler /13/

At first, fresh air enters the system (1). After that, it goes through the filter (2) and enters the Heat and Mass Exchanger (3). There the air flow is divided into two streams. One of them, which is called working stream, takes heat from the other stream, which is called product stream. Humid working air is released back into the atmosphere (4). Chilled fresh air with no added humidity is supplied to the premises (5). /13./

The main part of Coolerado air conditioners is patented Heat and Mass Exchanger (HMX). HMX consists of plates made of a plastic-coated, cellulose blend fiber. This plastic is designed to wick water evenly on one side and and pass well the heat in the transverse direction without mixing of air flows. The plates are stacked on top of each other, and a series of channels are formed between them. The diagram of the HMX is shown in the Figure 15. /12./

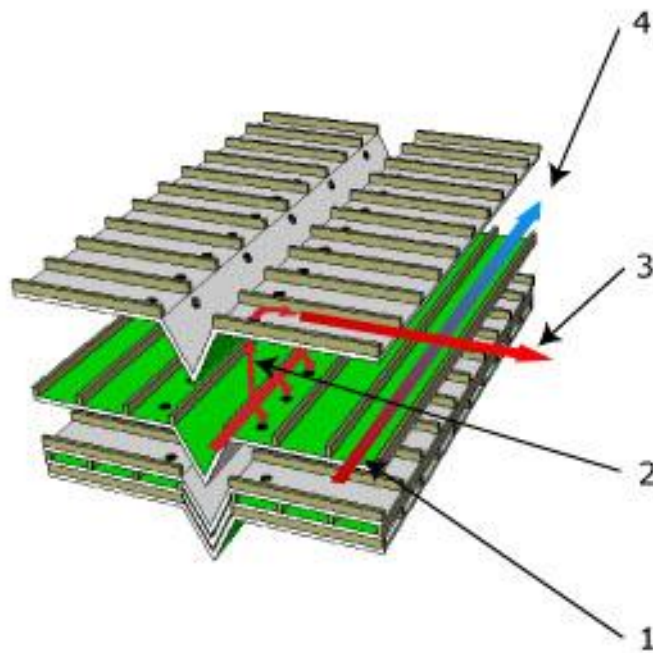


FIGURE 15. Design of the Heat and Mass Exchanger /12/.

The air which enters the HMX is divided in two streams. One stream is called working air and another is called product air. Working air comes to the dry channel, where it is cooled by adjacent wet channels. In the dry channel it is splitted into streams which

are coming to the wet channels (2). In wet channels the water evaporates and cools air flows of working air. The humid working air is exhausted to the atmosphere (4). The stream of product air enters the dry channel (1), where it is cooled by adjacent wet channels. /12./

Coolerado air conditioners have a modular design. To meet cooling requirements buildings, they may be combined with each other. Capacities in that case are just simply summed. Coolerado coolers can be used as independent air conditioners and as precooling systems. Also in places, where specific requirements take place, Coolerado hybrid system could be applied. /7, p.2./

4.3 Comparison with traditional adiabatic and compressor cooling systems

The maximum achievable temperature for the traditional adiabatic coolers is the wet bulb temperature. The larger cooling limit of the Coolerado cooler allows using it in areas and climates where traditional adiabatic coolers are not suitable. In Coolerado cooler there is no change of moisture content in product air. Whereas direct evaporative coolers increase change in moisture content proportionally to the temperature decrease of the product air. Indirect evaporative coolers have some losses in heat exchanger. These losses make the wet bulb temperature unachievable for indirect adiabatic coolers.

After direct evaporative cooler the air has increased moisture content and is almost saturated. But the relative humidity higher than 70 % feels uncomfortable /3/. This fact limits the use of direct evaporative cooling in the occupied places. On the other hand Coolerado coolers have its HMX, where working and product air channels are separated. And also the fact that the Coolerado air conditioners have a larger cooling range than other evaporative systems.

The HMX, which is installed in Coolerado coolers, has much better performance than the most common in indirect adiabatic coolers cross flow heat exchangers (Figure 16).

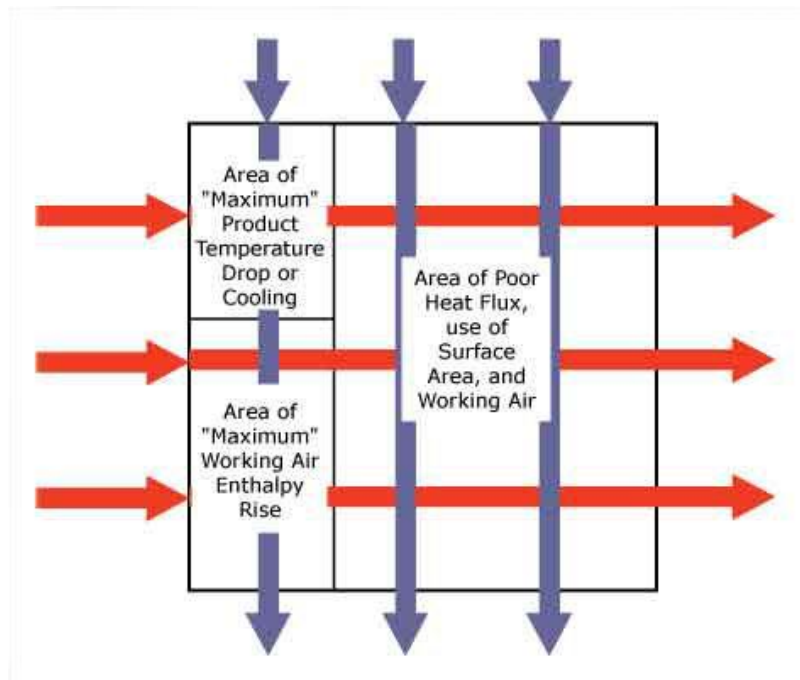


FIGURE 16. The scheme of the traditional cross flow indirect evaporative cooler /12/

As can be seen from the Figure 16, the highest heat flux occurs at the point where the streams entering the heat exchanger cross with each other. That is the area of the maximum cooling. Area adjacent to the incoming warm air is characterized by the largest increase of the enthalpy of the working air. On the other hand area adjacent to the incoming cold air is characterized by the largest decrease of the enthalpy of the product air. The further the flow of air passes through the heat exchanger, the less heat is transferred from one stream to another. This means that about 70 percent of the cooling is performed by about 10 percent of the working air and 10 percent of the surface area. /12./

Traditional compressor coolers consume a lot of energy. The use of the evaporative cooling systems helps to reduce the energy consumption. Coolerado coolers use up to 90 % less energy than the compressor coolers /14/. This significantly reduces expenses for electricity. But evaporative coolers consume water for cooling purposes. In hot weather, the water consumption increases, which can be very important in areas where water prices are high. The average water use for 21,1 kW unit, the Coolerado C60, is about 12 to 15 liters per hour depending on climate and water quality /15/.

4.4 Products

Since 2004 Coolerado Company has developed several products. At this moment they have pre-cooling, stand alone and hybrid systems. /16./

4.4.1 Pre-cooling systems

For pre-cooling system Coolerado Company has RF100. This unit is engineered to connect Coolerado M50's cooler to the existing rooftop unit. It has two modes: free-cooling mode and pre-cooling mode. When the weather conditions are favorable it works in free-cooling mode and supplies fresh air to the building. It handles the entire cooling load of the building. The existing rooftop unit is bypassed.

When the humidity of the ambient air is high RF100 works in pre-cooling mode. It reduces the cooling load on the main air conditioning system. This solution helps to reduce energy consumption of the air conditioning system. RF100 unit is shown in the Figure 17. /16./

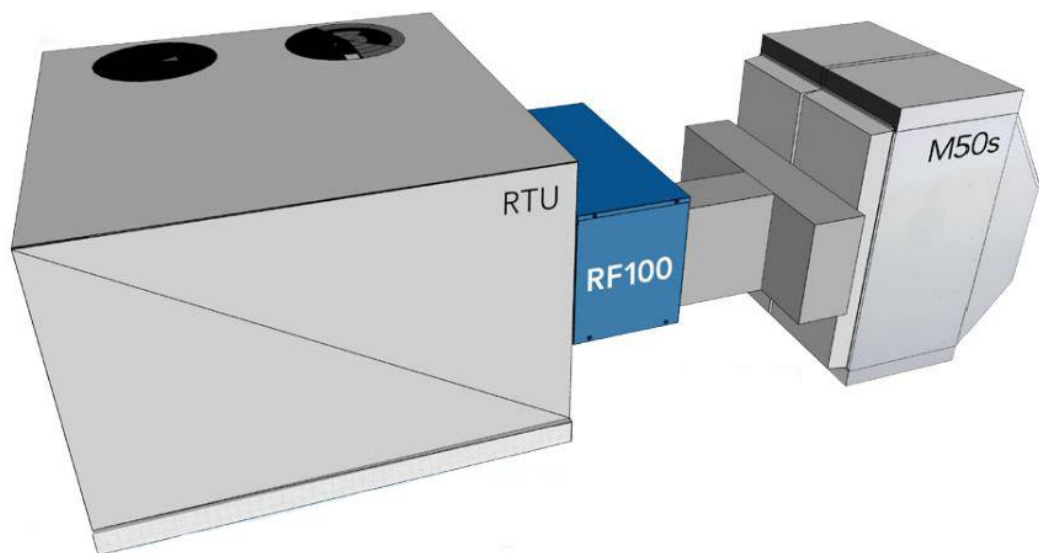


FIGURE 17. RF100 pre-cooling system /16/

4.4.2 Stand alone systems

For stand alone coolers at this moment Coolerado has three units. They are M30, M50 and C60 (Figure 18). All of them have a modular design. That means that they could be stacked side by side with each other to increase the total cooling power.



FIGURE 18. Coolerado cooling units M30, M50, C60 /16/

These three units which differ by the maximum air flow rate and thus by power. Characteristics of those units are shown in the Table 1.

TABLE 1. Technical information of M30, M50 and C60 units /16/

Unit model	M30	M50	C60
Full speed product air flow, l/s	425	684	788
Full speed working air flow, l/s	335	557	622
Full speed intake air flow, l/s	760	1241	1410
Product air wet bulb approach, %	93 – 117	94 – 120	94 –120
Minimum dimensioning water flow, l/s	0,063	0,088	0,107
Energy efficiency ratio (EER)	40+	40+	40+
Maximum electricity consumption, W	450	710	710

Those units are not very different from each other. They differ mainly in flow rates and therefore in cooling capacity. But the wet bulb temperature approach is almost the same. Energy efficiency ratio (EER) of these units is very high. EER means the declared capacity for cooling [kW] divided by the rated power input for cooling [kW] of

a unit when providing cooling at standard rating conditions /16, p.5/. For comparison, an EER class A corresponds to the value more than 3.2, but in case of Coolerado coolers it could reach values more than 40. /17, p.9/.

4.4.3 Hybrid systems

For special cases Coolerado Company has hybrid system H80. It has two stage compressor with R-410A refrigerant system. This air handling unit offers the possibility to heat the air flow. It is also high-efficient solution for the locations, where the Coolerado air conditioner cannot take the full cooling load. The maximum cooling capacity of this unit is 17,6 kW and the maximum heating capacity of the refrigeration circuit is 44 kW. The flow rate of the supply air in the H80 is about 940 l/s. The scheme of the H80 unit is shown in the Figure 19. /16./

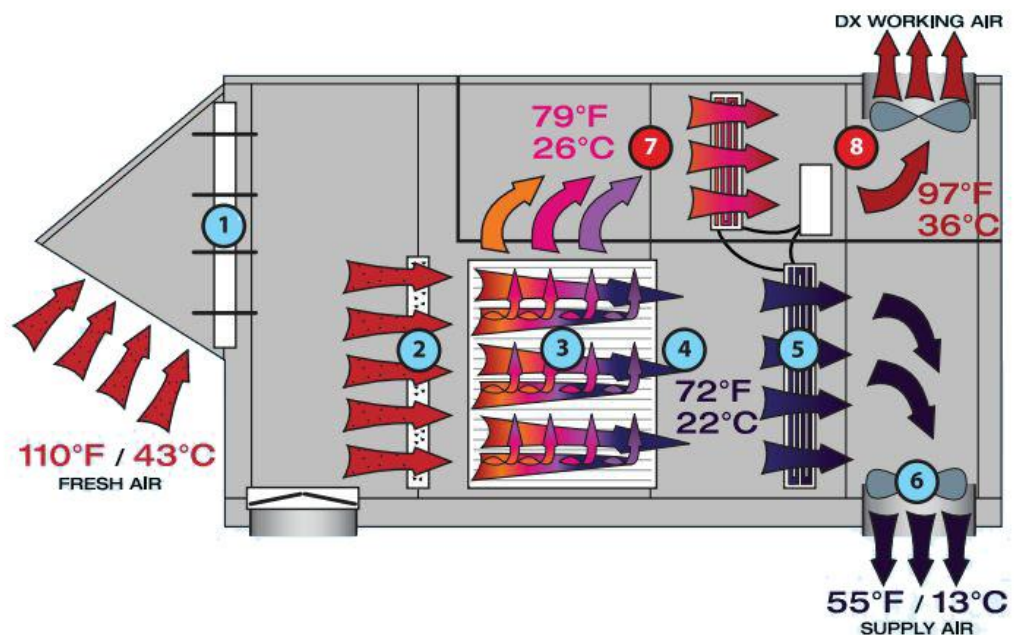


FIGURE 19. Coolerado H80 hybrid system /16/

The outside fresh air comes through the outside damper (1). For instance its temperature is 43°C . Then it goes to the filters (2) and enters the HRW (3), where it is divided into two flows. The product air, which is cooled by the working air, leaves the HRW with the temperature about 22°C and with no change in humidity (4). After that the air stream enters the refrigerant coils (5) and with the fan is distributed to the rooms (6). The temperature of the distribution air is about 13°C which is approximately 30°C less than the outside air. The working air takes heat from heat exchangers and is

exhausted to the outside (7,8). The temperature of the saturated air after the HMX will be about 26 °C and after hot coils about 36 °C. /16./

If there is only a traditional cooling system with compressor, then the temperature of condensation should be more than 43 °C and the temperature of evaporator less than 13 °C. That means temperature difference between evaporation and condensation temperatures more than 30 °C. On the other hand in hybrid system the air flow at first goes through the HMX and comes to the condenser with the temperature about 26 °C and to the evaporator about 22 °C. That means much less temperature difference between condensation and evaporation in comparison with stand-alone compressor system. Higher temperature difference means more work for the compressor and therefore less COP and higher energy consumption. So that the HMX in the hybrid system makes the work of compressor cooling system more efficient.

5 APPLICABILITY IN NORTHERN CLIMATE

To evaluate the applicability of Coolerado air conditioners in northern climates summertime is considered.

5.1 Initial data

Northern climate in summer is characterized by temperatures below 30 °C and relative humidity from moderate to high. At temperatures of about 30 °C relative humidity rarely exceeds 50%. At lower temperatures, relative humidity can reach values close to saturation.

A step change in temperature is taken as 1 °C and step change in the relative humidity is taken as 10%. Considered values of temperature and relative humidity are shown in Table 2.

TABLE 2. Initial weather data

Dry bulb temperature, °C	Relative humidity, %
21	50 – 90
22	50 – 80
23	50 – 80
24	50 – 70
25	50 – 70
26	50 – 60
27	40 – 60
28	40 – 50

Peak temperatures exceeding 28 °C are not taken into account. Supply air design temperatures are taken as 17 °C and 19 °C. As the considered unit Coolerado M30 is taken. Atmospheric air pressure is taken on the sea level and equals 101 325 Pa.

5.2 Method of calculation

To get the characteristics of the air obtained after Coolerado cooler, calculation offered by the Coolerado Company was used. Obtained values depend on air flow rate

through the cooler and on combination of dry bulb air temperature and relative humidity.

For calculation of properties of the air after Coolerado cooler, Coolerado Company offers a table. Calculation values for Coolerado M30 are shown in the Table 3.

TABLE 3. Coolerado M30 performance /18/

External static pressure	Full speed product air flow	Full speed working air flow	Full speed intake air flow	Product air wet bulb approach
Pa	l/s	l/s	l/s	%
0	425	335	760	93
25	401	320	721	94
50	376	302	678	95
75	354	288	642	96
100	335	274	609	98
125	311	255	566	100
150	288	241	529	103
175	264	222	486	107
200	241	203	444	110
225	217	184	401	113
250	198	170	368	117

For the estimation two cases are taken. The first one is a case of the lowest external static pressure losses, which means maximum air flow through the unit and minimum drop in temperature. The second one is a case of the highest external pressure losses, which means minimum air flow through the unit and maximum drop in temperature.

From the initial weather data from Table 2 wet bulb temperature is calculated using the PsychroGen 2.0 software (Figure 20) /19/.

<input checked="" type="radio"/> S.I Units <input type="radio"/> I.P. Units		S.I
Atmospheric pressure (kPa)	101,3249	101
Altitude of Location (m)	0	0
<input checked="" type="checkbox"/> Dry Bulb Temperature (deg.C)	21	21
<input type="checkbox"/> Moisture (kg/kg dry air)	0,007733	0
<input type="checkbox"/> Wet Bulb Temperature (deg.C)	14,03	14
<input checked="" type="checkbox"/> Relative Humidity (%)	50	50
<input type="checkbox"/> Percentage Saturation (%)	49,3782	49
<input type="checkbox"/> Specific Volume (cu.m/kg)	0,843692	0
<input type="checkbox"/> Specific Enthalpy(kJ/kg)	40,6703	40
<input type="checkbox"/> Dew Point (deg. C)	10,1801	10
<input type="checkbox"/> Vapour Pressure (kPa)	1,2444	1
Saturation Pressure (kPa)	2,4888	2,4888
Reset		0

FIGURE 20. PsychroGen 2.0 calculations /19/

Wet bulb performance is calculated according to the formula 1.

$$E_{wb} = \frac{t_1 - t_2}{t_1 - t_{wb}} \cdot 100\% \quad (1)$$

where E_{wb} is the wet bulb performance, t_1 and t_2 are dry bulb temperatures of the entering and leaving air respectively [$^{\circ}\text{C}$] and t_{wb} is the wet bulb temperature of the entering air [$^{\circ}\text{C}$].


From the wet bulb temperature and according to the wet bulb performance of the unit the temperatures after Coolerado cooler are calculated.


5.3 Results and analysis

After the calculations, temperature data was obtained. There are values of the supply air for the maximum flow and for maximum drop in temperature for the Coolerado M30. So the actual value most likely will be somewhere between these values. The results of the calculations are shown in the Table 4.

TABLE 4. Calculation results

Dry bulb temperature, °C	Relative humidity, %	Wet bulb temperature, °C	93% wet bulb approach temperature, °C	117% wet bulb approach temperature, °C
21	90	19,7	19,8	19,5
	80	18,3	18,5	17,8
	70	16,9	17,1	16,2
	60	15,4	15,8	14,5
	50	14,0	14,5	12,8
22	80	19,3	19,5	18,9
	70	17,8	18,1	17,1
	60	16,3	16,7	15,3
	50	14,8	15,3	13,6
23	80	20,3	20,5	19,8
	70	18,8	19,1	18,1
	60	17,2	17,6	16,2
	50	15,6	16,1	14,3
24	70	19,8	20,1	19,1
	60	18,1	18,6	17,1
	50	16,5	17,0	15,2
25	70	20,6	20,9	19,9
	60	19,1	19,5	18,1
	50	17,3	17,9	16,0
26	60	20,2	20,6	19,2
	50	18,3	18,8	16,9
27	60	20,8	21,3	19,8
	50	19,2	19,8	17,9
	40	17,2	17,9	15,5
28	50	20,2	20,8	18,9
	40	18,1	18,8	16,4

 - Supply temperature less than 17 °C

 - Supply temperature less than 19 °C

As it is seen from the Table 4 not all the temperatures are lower than the designed supply temperatures. Although if we appreciate the lowest air flow and the supply air temperature 19 °C, almost for all designed weather conditions Coolerado cooler is suitable.

The lowest temperature values are obtained with the lowest air flow rate. In spite of this there are values which do not satisfy supply air temperature 17 °C. But if we consider for instance the reference climate data for Helsinki-Vantaa (Finland) of the 2012 year that is not so critical /20/. The supply air temperatures which refer to the 19 °C correspond to a very rare weather conditions. Amount of hours for the difficult weather conditions (referred to the 19 °C supply air temperature and lowest air flow) is shown in the Table 5. From the known data for each hour with the help of the spreadsheet the number of hours with the certain weather conditions was calculated. Share of the time in a year was obtained by dividing the calculated number of hours by 8765.

TABLE 5. Amount of hours for the difficult weather conditions (referred to the 19 °C supply air temperature and lowest air flow) for Helsinki-Vantaa (Finland)

Dry bulb temperature, °C	Relative humidity, %	Amount of hours per year	Share of the time in a year, %
>28	-	5	0.057
>27	>50	3	0.034
>25	>60	2	0.023
>26	>50	6	0.068
>24	>60	3	0.034
>23	>70	3	0.034
>21	>80	1	0.011

As it is seen from Table 5 these difficult weather conditions are so rare that they may not be taken into account. Also the values which are difficult for case of 17 °C supply air could be considered. Amount of hours for the difficult weather conditions (referred to the 17 °C supply air temperature and lowest air flow) is shown in the Table 6.

TABLE 6. Amount of hours for the difficult weather conditions (referred to the 17 °C supply air temperature and lowest air flow) for Helsinki-Vantaa (Finland)

Dry bulb temperature, °C	Relative humidity, %	Amount of hours per year	Share of the time in a year, %
>28	>40	5	0.057
>27	>40	8	0.091
>26	>50	6	0.068
>25	>50	13	0,148
>24	>50	20	0.228
>23	>60	11	0.125
>22	>60	22	0.251
>21	>70	12	0.114

As it seen from the Table 6 the durations of the difficult weather conditions are longer, but the percentage against the year is still low. This makes it possible to neglect these values.

6 CONCLUSIONS

This work was devoted to the evolution of evaporation systems from direct adiabatic coolers up to ultra coolers such as Coolerado coolers. Thanks to the patented M-cycle, evaporative systems have reached a new stage of its evolution. Now the limit of evaporative cooling is not the wet bulb temperature but almost the dew point temperature.

Compared to the traditional compressor cooling systems Coolerado coolers have one significant advantage which is very low power consumption. EER value of these systems could exceed the value of 40. This is an incredible index, because the A-class of energy consumption corresponds to the $EER > 3,2$. Performance of the Coolerado air conditioners increases with the increase of the temperature difference, which is not typical for traditional systems.

However, Coolerado coolers require a constant supply of water, which can cause problems in places with lack of water or high prices for water. Also their performance is highly dependent on the climate and may not be suitable for all weather conditions.

Based on the M-cycle there are already multiple devices patented which could improve the energy efficiency of many fields in the near future. These systems have many advantages in comparison with existing analogues. The main advantages of systems based on the M-cycle are the environmental safety, high efficiency, low unit cost (design has no complex assemblies), low operating costs.

According to the results Coolerado coolers can be used in a Northern climate. This is not the best suitable climate for this type of system, which prefer hot and dry climate. In this regard, the use of these systems may impose some restrictions and each case must be considered individually. These systems do not have specific requirements for water quality and consume much less electricity than traditional compressor systems. So their use can be a great solution for improving energy efficiency of the air conditioning.

If there are special requirements to the indoor climate of the premises, these systems can be used as pre-cooling systems in conjunction with compressor systems. Howev-

er, initial costs, energy and water consumption for each individual case should be estimated to assess the usefulness of such systems.

Also the Coolerado Company has a hybrid system that can be used in almost any weather conditions. The hybrid system is more efficient, not only due to the use patented Heat and Mass Exchanger (HMX), but also due to more efficient operation of the compressor, which operates at a lower temperature difference between evaporation and condensation.

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