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HEAT RECOVERY POTENTIAL OF A CANTEEN

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Abstract

In this work I discuss three heat recovery possibilities in professional kitchens. They are ventilation heat recovery, heat recovery from cooling machines and waste water heat recovery.

First I explain special features of professional kitchen ventilation. Then I go over different types of ventilation heat recovery and their advantages and disadvantages. Also filters are described as very important component of heat recovery in professional kitchens. Then I present measurements in practical case, calculations based on the figures and alternatives.

Then I describe cooling process of vapour compression cycle to explain why it is possible to get heat from it. I go through existing devices and how they utilize heat. Also I estimate possible magnitudes in case under study and compare those with heat from exhaust air.

Also I describe possibility of utilising heat of waste water, advantages and disadvantages of this type of heat recovery and existing devices. Then I make evaluation of practical case and compare it with magnitudes of heat from exhaust air.

As conclusion I give my opinion about validity of different types of heat recovery and existing devices and schemas.

Subject headings, (keywords)
Professional kitchens, ventilation, filters, ventilation heat recovery, waste water heat recovery, heat recovery from refrigerators.

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1 INTRODUCTION

Effectiveness of professional kitchens depends on many things. They include good design and construction of interiors, placing of cooking devices, HVAC-systems, organization of staff activities. All these measures are undertaken to make working more effective. They also contribute to energy savings. Nowadays possibility of recovering waste heat from different sources has also became one of the most important ways of savings.

The main question of this thesis is: How to choose the most efficient heat recovery for a canteen? I answer it by looking at three different types of heat recovery:

- ventilation heat recovery;
- heat recovery from cooling machines;
- waste water heat recovery.

Another significant question is: what type of recovery devices exist and which of them can be used in professional kitchens? This question is important because commercial kitchens have very specific conditions. There are numerous impurities including hardly removable grease, special sanitary conditions and fire protection norms. I will discuss manufacturers' products to evaluate the current situation.

As a practical example case I will tell about heat recovery possibilities of canteens using university canteen/student restaurant AMICA as an example. Its attendance is about 4700 students as well as teachers and staff and it works 8 hours per day 5 days a week. It is situated in an old renovated building which now conforms to modern standards of public buildings in Finland. The canteen is provided with mechanical exhaust and supply ventilation. The air handling unit contains filters, sound absorbers, heat coils and also water-glycol heat recovery. There is no waste water heat recovery and no heat recovery for cooling machines in this building. In this study I will estimate size of catering facilities where those heat recoveries would be feasible.

Measurements about working effectiveness of ventilation heat recovery will be carried out. Also the temperatures and flows of waste water and the energy from cooling machines and storages for food will be found out. Effectiveness of the existing system will be compared with possibilities of recovering from different sources. Contribution of every source will be compared. Advantages and disadvantages of each device will be evaluated.

2 VENTILATION HEAT RECOVERY

Nowadays ventilation heat recovery is the most developed field of heat recovery application. Ventilation is the most heat demanding system of engineering services of non-residential building. On diagram 1 below you can see heat balance for a commercial building with operation hours similar to case under study. The diagram 1 is divided in two vertical parts – operation and non operation hours. The operation hours' part is divided also into three parts – space heating, ventilation heating and cooling demand in summer:

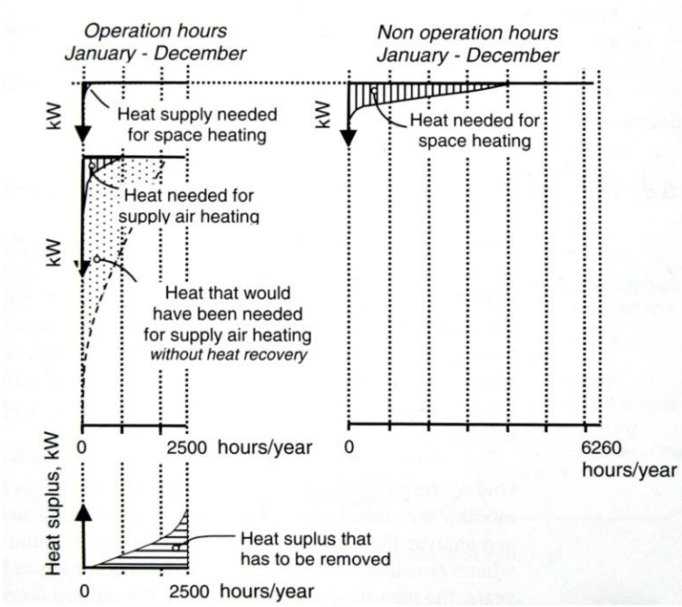


DIAGRAM 1. Complete heat balance of a commercial building /1, p.343/

It's possible to recover heat with ventilation heat recovery from exhaust warm air. On diagram 2 below the part of energy saved thanks to heat recovery is shown. In the studied case temperature efficiency and operation hours are less but anyway diagram 2 clearly represents profitability of ventilation heat recovery.

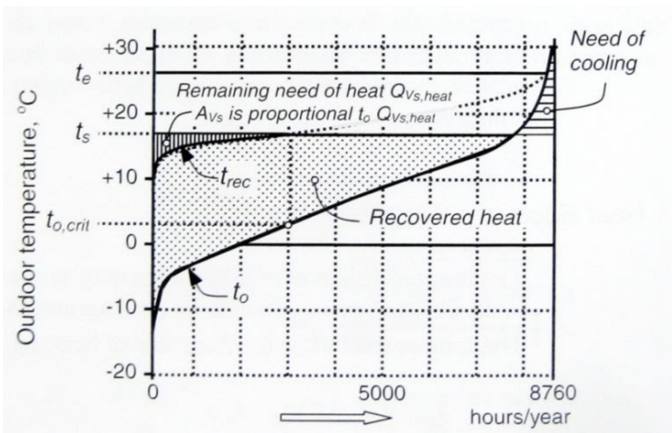


DIAGRAM 2. Need of heat to warm air for the supply /1, p.340/

At first it seems that feasibility of heat recovery depends mostly on temperature efficiency. But that’s not exactly the case. There are different types of ventilation heat recovery, which are possible to choose for each case individually. The type has an influence on temperature efficiency and annual efficiency.

Temperature efficiency describes momentary efficiency of heat recovery device and usually given in manuals for best conditions. Temperature efficiency can be given for supply and exhaust air flow, but they are the same if the flows are equal. Usually the supply efficiency is more important:

$$\eta_t = \frac{t_{supply} - t_{out}}{t_{in} - t_{out}} \qquad (1)$$

Annual efficiency describes relation between amount of recovered heat and total heat demand and can be described by next equation:

$$\eta_a = \frac{Q_{HR}}{Q_{total}} \qquad (2)$$

In cold climates where outside temperature in winter is often much less then 0˚C the minimum extracted air temperature has to be limited to avoid freezing. Freezing is more expectable when humidity of the extracted air is high. So the time of operation with full power is more important than the temperature efficiency itself. Water-glycol heat exchangers are the most convenient type of heat recovery in this respect. It’s possible to regulate the temperature of liquid by three-port valve, thus make impossible condensate to freeze in exhaust duct. So this type of heat recovery has the biggest full power operation time period among all heat recoveries.

2.1 Types of ventilation heat recovery units

There are three main types of ventilation heat recovery units: plate heat exchanger, rotating wheel and water-glycol heat exchanger.

Plate heat exchanger has very simple structure (figure 1). Exhaust warm air and outdoor cold air go through spacings in counter flow. Heat is transferred through metal plates by conduction. Also warm air condensate in dew point and then additional sensitive heat is transferred to outdoor air. This heat recovery has a temperature efficiency about 80%. The main disadvantages of this type are freezing and cross-leakage, which is bad especially in the case of the AMICA kitchen./2, 44.13/

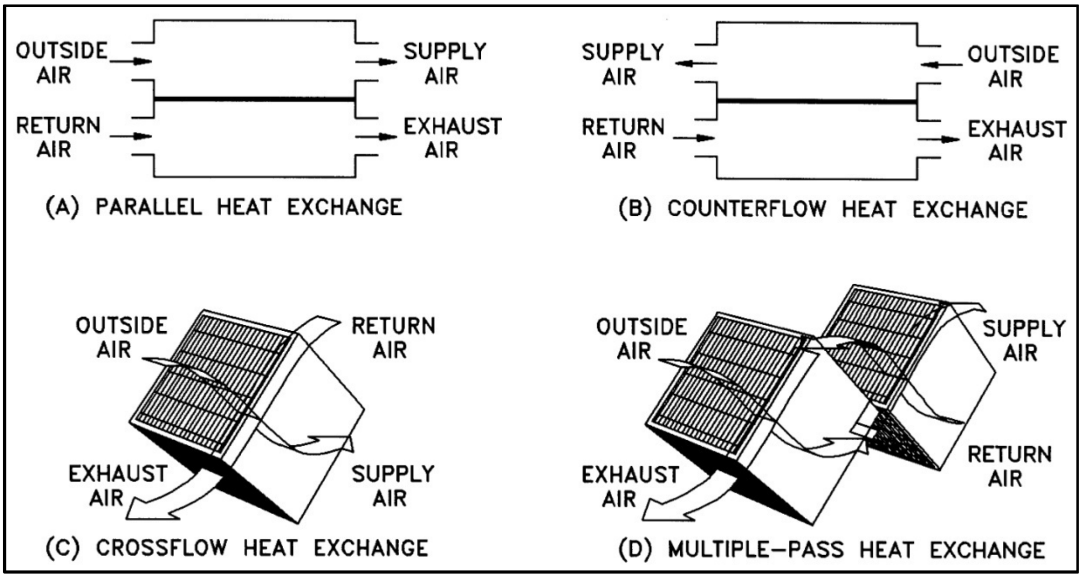


FIGURE 1. Plate heat exchanger/2, 44.7/

Rotating wheel is another type of heat recovery (figure 2), where two air flows – cold supply and warm exhaust pass through metal wheel with many holes. The wheel is warmed up in exhaust part and gives heat to cold air in another part. Latent heat is also transferred while moisture condensates in the air with bigger humidity and then evaporates to dry air. Temperature efficiency of this type is very high – about 80-85% in maximum. But the problem is cross-contamination, which is not allowed in caterinf facilities. /2, 44.13/

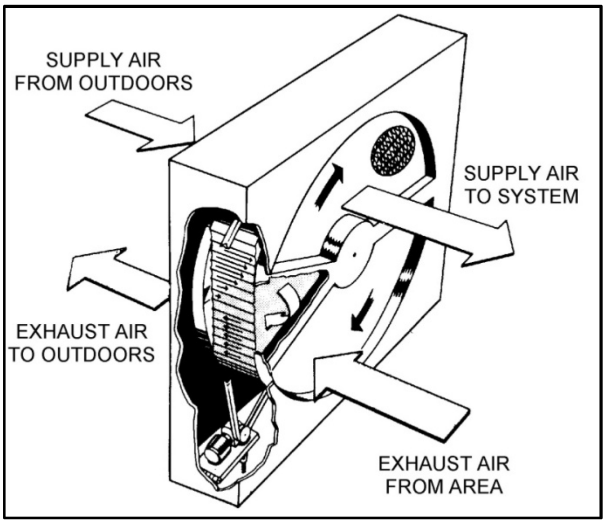


FIGURE 2. Rotating wheel/2, 44.13/

Water-glycol heat exchanger is a coil heat exchanger and it is the best variant for renovation (figure 3). Exhaust and supply coils may be separated if needed. Temperature efficiency of this type is not very high – just 40-60%, but because of good regulation, total savings may be significant/2, 44.15/.

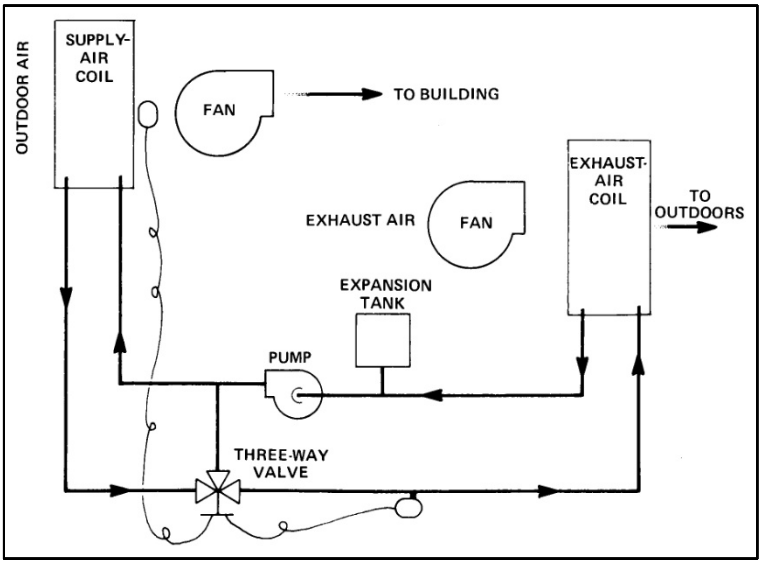


FIGURE 3. Water-glycol heat exchanger/2, 44.15/

In my thesis I'm going to discuss only the last one, although two first ones have better efficiency and they are more popular in most cases. But in professional kitchens it is impossible to use them. The reason is highly probable leakages between supply and exhaust ducts. Because in water-glycol systems these leakages are impossible this system is appropriate for using in places of public catering, which have high hygienic demands. Another advantage of water-glycol systems is the anti-freeze regulation. Thanks to the three-port valve in pipe-system refrigerant regulation can be done exactly. And in contrary to other types of heat recovery it is possible to keep intake temperature of refrigerant in exhaust duct even at -7˚C. The freezing of condensate in exhaust duct will not occur. But of course this temperature depends on moisture level of exhaust air.

2.2 Alternative solution on market

There is another type of water-glycol heat exchanger, which has different form. It's called needle heat exchanger. This technology is patented by Retermia OY. And it has advantages over other types of heat recovery. Supply and exhaust units of needle heat recovery can be installed outside the building on the roof or on the wall (figure 4).

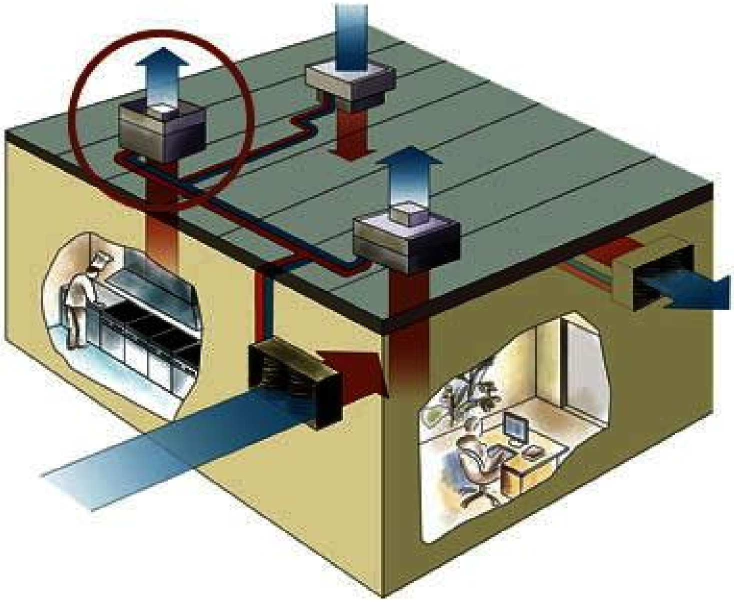


FIGURE 4. Outside installation of air intake and exhaust units/3/

This solution is good for renovation because inside space is often limited. According to manufacturer's brochure efficiency of needle coils is not lowered so much as usually because dirty greasy air so exhaust air from kitchens is not a problem for them. Also these needle heat exchangers solve problems of intake unit freezing in winter. Intake unit which you can see on figure 5 preheats and pre-filters the air. So even during heavy snowfall warm intake coils melts it. Damping of air intake unit is impossible. Also air is pre-filtered in intake unit. Thus make impossible big solid particles and snow to get into main filter.

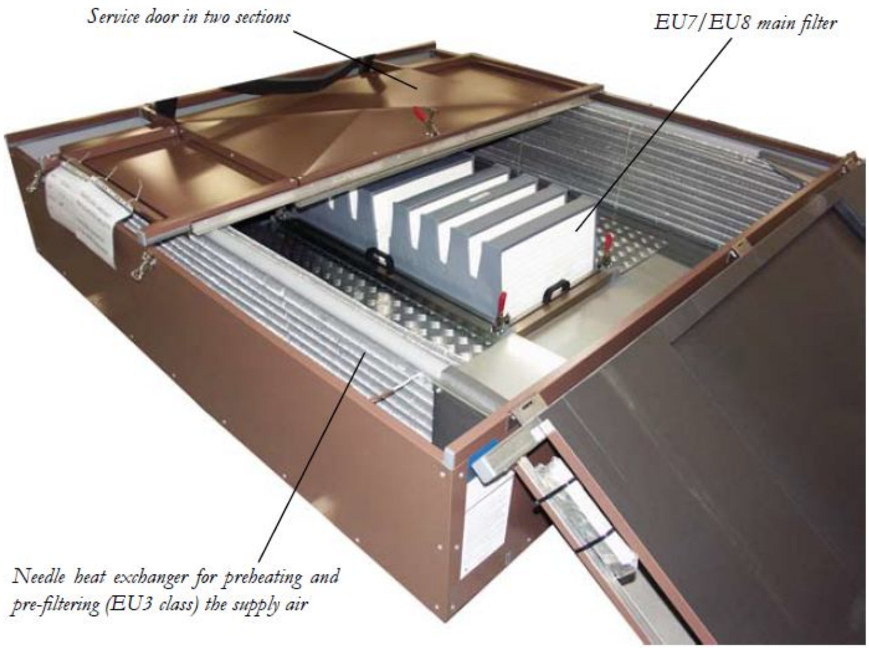


FIGURE 5. Air intake unit of Retermia OY with needle heat exchanger /3/

Intake unit can provide air to different supply air units. Also these units add very little pressure drop (nearly 50 Pa). This pressure drop is equal to pressure drop of inlet outdoor air grill, which are always in ventilation. This positively affects the fan power and SFP-figure (specific fan power), which is lowered together with electricity expenses.

Specific fan power is amount of electric power which is needed to drive fans divided into air flow. Next equation is given by D5:

$$P_{es} = \frac{P_e}{q_v} \qquad (3)$$

where P_{es} is specific electric power of a ventilation machine or blower, P_e is electric power of a ventilation machine or blower, q_v is air flow of a ventilation machine or blower.

This figure describes rightness of chosen air handling unit. It’s limited by standards, particularly by the Finnish standard: for mechanical supply and exhaust ventilation it should not exceed 2,5 kW/(m³/s) and for exhaust ventilation – 1,0 kW/(m³/s). So we can say that Retermia’s system is very economical./4/

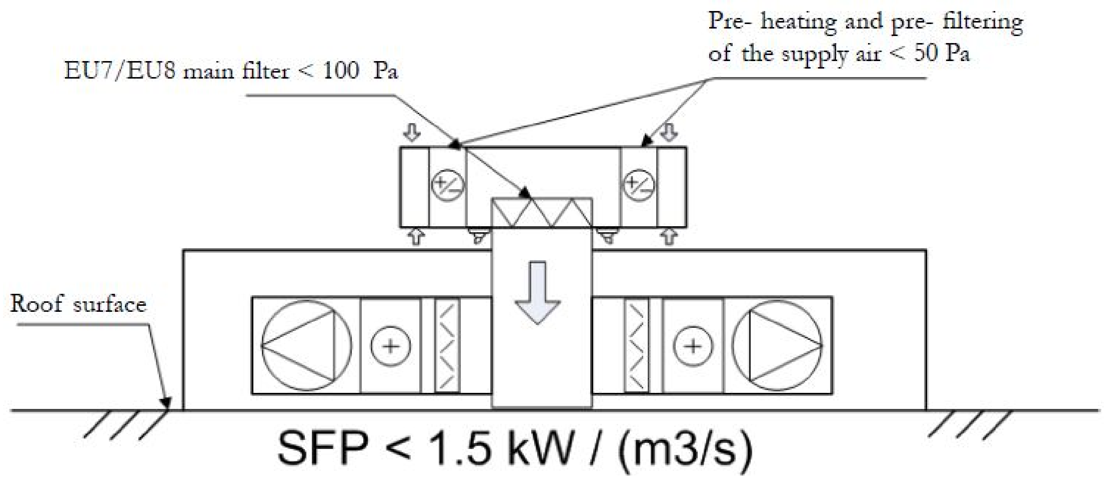


FIGURE 6. Scheme of air intake unit with needle heat exchanger /3/

2.3 Modern filters

Heat recovery for professional kitchens as soon as ventilation in whole is closely associated with fire protection. So in the past it was impossible to use heat recovery in professional kitchens. Pollution of ducts with grease and soot caused a lot of fires.

Also it was impossible to recover heat from such a dirty air even in heat recovery with separate coils. Rapid and intensive pollution of recovery coils would make efficiency of heat transfer too small. Also it would need too frequent cleaning. That makes that type of recovery economically unreasonable. Why is it becoming possible now?

Nowadays different types of extremely effective filters have been developed. And although they are still not perfect it has became much more realistic to install heat recovery in such places as professional kitchens. These filters solve two important problems of heat recovery. The first is fire protection: with new filters risk of fire spreading through the ducts is lowered a lot. Second if that with new filters exhaust air in heat recovery coils is much cleaner than before. And heat recovery units should be cleaned more rarely than before. So air heat recovery is more possible now.

Today some types of grease filters for commercial kitchens exist. They are mesh filters and baffle (or labyrinth filters). Mesh filters are widespread and well-known. There is one example on figure 7.

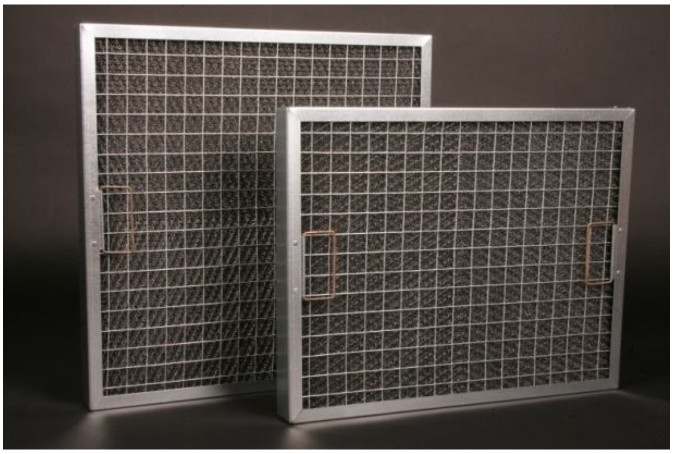


FIGURE 7. Mesh filters /5/

But they become polluted very rapidly and nowadays their using in commercial kitchens is forbidden for example in USA. In other countries either their use is not recommended in kitchens with great grease emission. They require cleaning once a week, otherwise their efficiency is reduced rapidly and this way exhaust air flow is lowered also.

Baffle filters are quite effective and used all over in catering. They have various models. But there are two totally different models. They baffle filter and multi-cyclonic baffle filter. Operating principle of usual baffle filter is based on “speed” of grease. Grease drops couldn’t change direction of moving so rapidly as air do, so they remain on walls of filter.

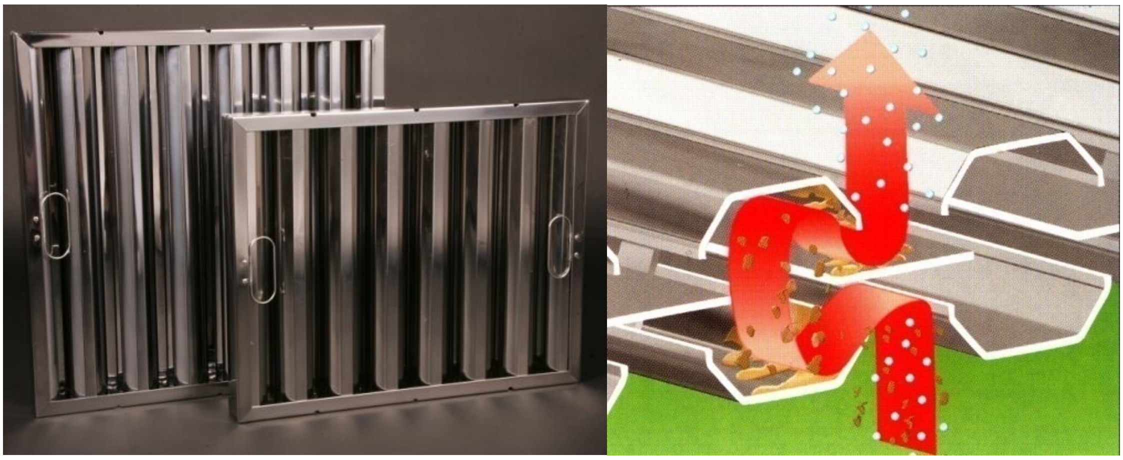


FIGURE 8. Baffle filters and principle of their operation /6/

Figure 9 presents another type of baffle filters – multi-cyclonic filter – is product of Halton company. In this filter air inlet from frontal side spins inside of filter and goes out from the top and from the bottom.

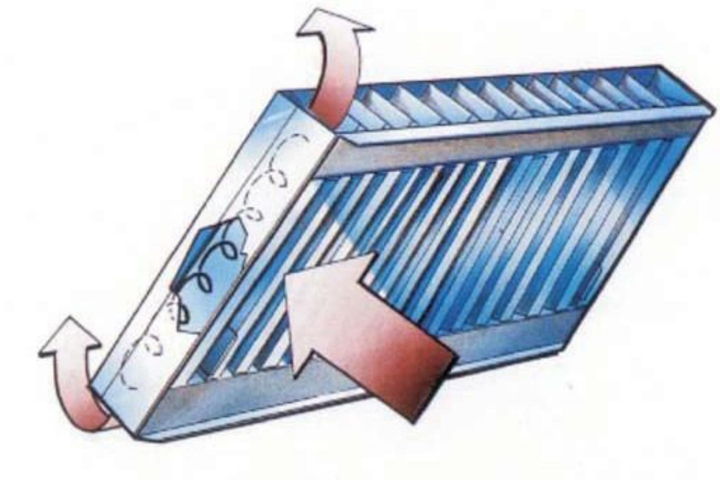


FIGURE 9. Halton’s “multi-cyclone” KSA grease filter /7/

Another grease separating technology is a product of Jeven (figure 10). It is called JCE filter and also based on cyclonic effect, but the design is significantly different from most other filters.

FIGURE 10. Jeven JCE filter /8/

Jeven JCE filter is usually used with UV-filter. In figure 11 you can see working principle of UV-filter Unit: 1) Dirty air enters the filter; 2) Air spins inside and separates grease; 3) Grease settle on the bottom of filter; 4) Cleaned air cooled in mesh filter, become smooth and leave smaller particles on mesh; 5) In UV-filter rest of grease particles and VOCs are decomposed; 6) Clean air enters the duct. /9/

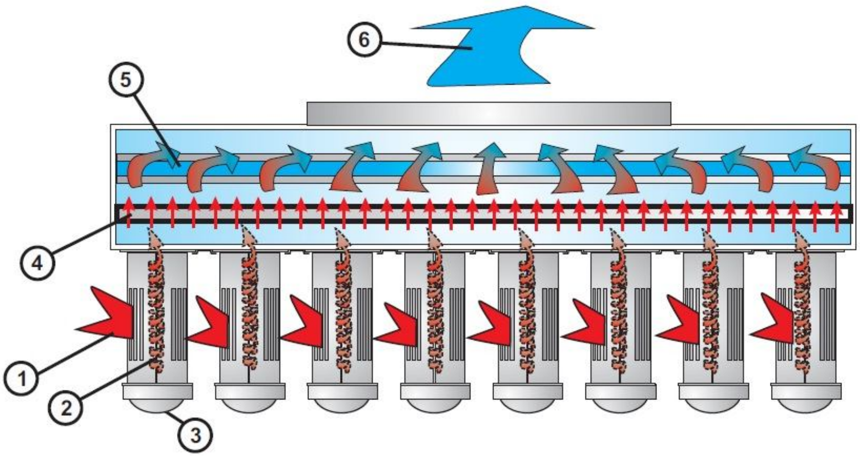


FIGURE 11. Function principle of the UV-filter Unit /9/

Jeven also produces another special type of filter – TurboSwing (figure 12). The operating principle is based on rotary movement. In contrary to usual type of filters this filter is working with help of motor, but its efficiency is very high.

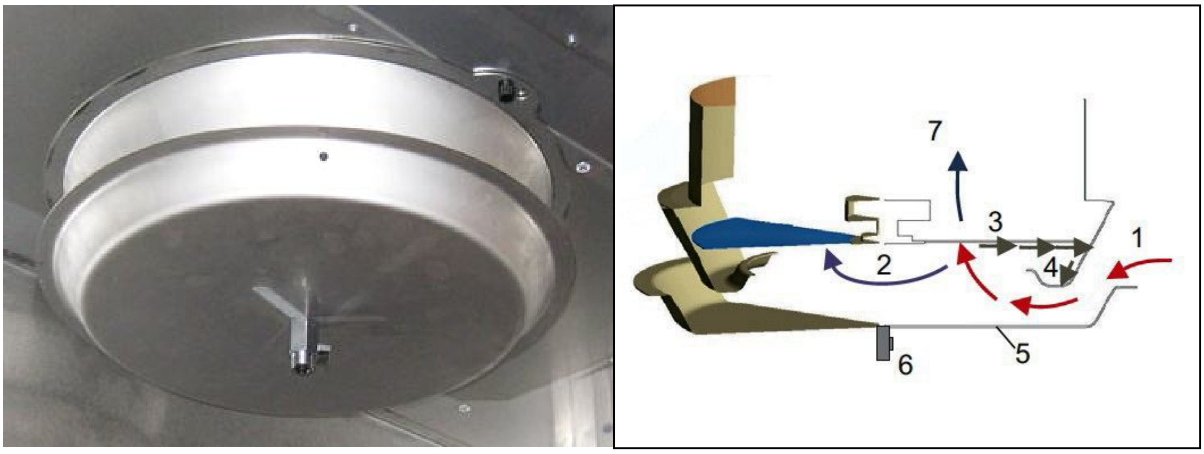


FIGURE 12. TurboSwing filtering solution – photo and schema of operation /10/

> ”Dirty air enters the TurboSwing(1). The separation plate rotates (2), grease and impurities are separated (3) and moved (4) to the edges of the separation chamber from where they drain into the collection basin (5). Liquid grease is removed by turning on the tap (6). Cleansed air exits (7) to ducts.”/10/

2.4 Practical measurements in AMICA

Measurements in air handling unit of university canteen were carried out in spring and in autumn 2011. Temperatures and relative humidity of air in all ducts near the heat recovery unit were measured. They are outdoor, supply (after HR), exhaust, extract, (re)heated, indoor.

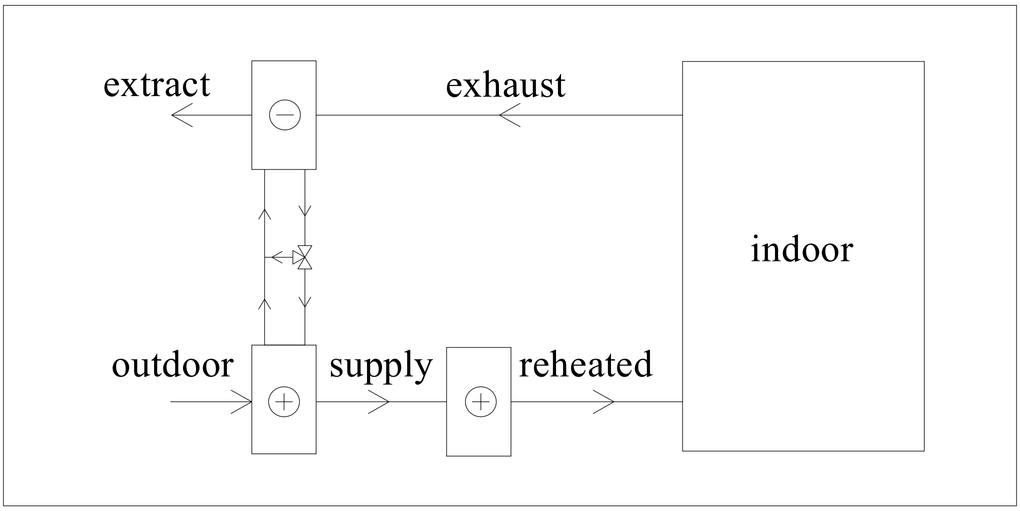


FIGURE 13. Scheme of Air Handling Unit and measured flows

Outside temperatures were still rather low at these times of the year. This factor affected the efficiency of heat recovery. So results should represent the winter situation quite well.

2.4.1 Methods

Measurements were undertaken from 21 to 28 of March and were repeated from 19 to 21 of October 2011. But as all days and relationship between temperatures seem to be quite similar, so only one working day is described.

Graphs of temperatures in different ducts during the working day and hours when heat recovery operates can be seen on the figure 14 below. There is also the temperature efficiency graph of supply air. This graph is just for understanding general view of temperatures in case under study. Here you can see that temperatures outdoor (OUT), supply (HR) and extracted (EXTR) are growing equally. Efficiency of heat recovery is rising a little as well. Temperature of exhaust air is jumping a little (probably in time of biggest heat emissions). Indoor temperature increases by approximately 0,5 degree after heat emission, but returns to normal soon.

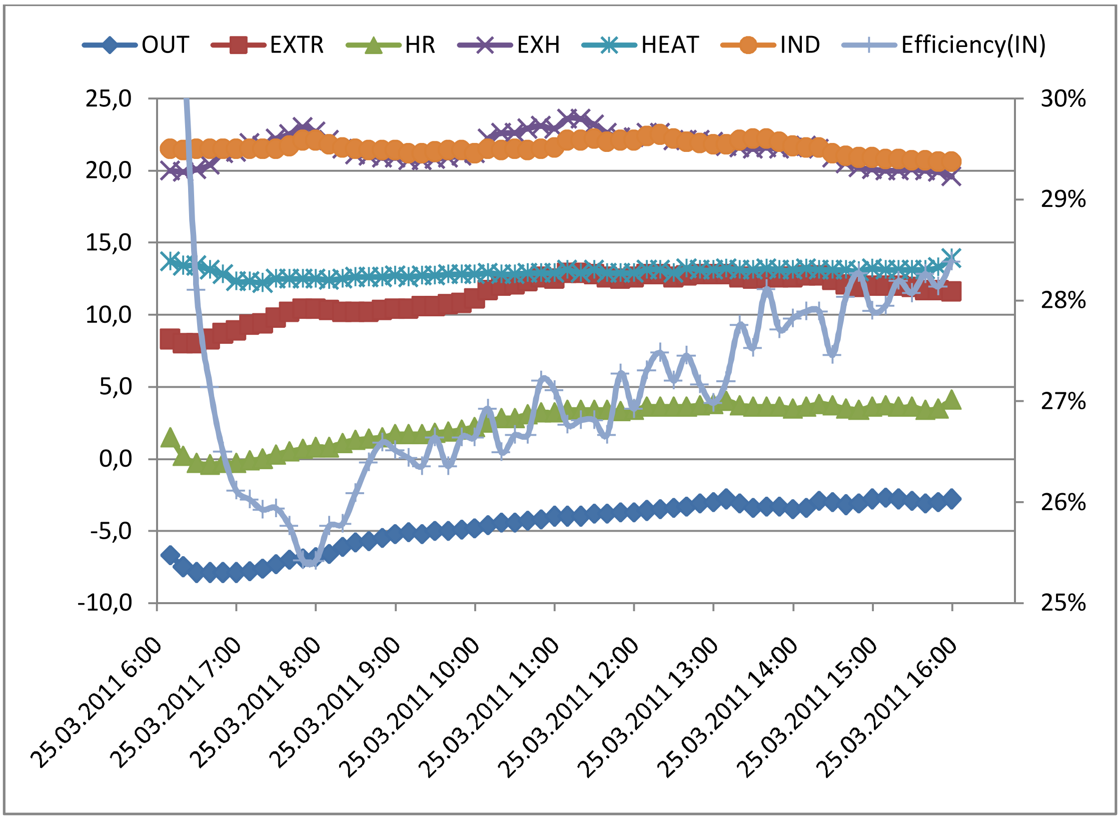


FIGURE 14. Temperatures in ducts and efficiency of heat recovery

2.4.2 Results and discussion

So we can see that in spite of effectiveness of heat recovery our system is working properly: temperatures of supply and indoor air are almost the same all the time. They are 13,2˚C and 21,6˚C respectively on average. Actually supply temperature usually is higher. At first air is a little bit heated in fan (about 1,5˚C). And also it was found that in warmer days it can be higher – about 17˚C.

But the value of extract temperature is still not clear. Efficiency of heat recovery is lower than it could be while extract air temperature is much higher than possible. Usually recommended extract temperatures are 5-7˚C. But in case under study extract air is cooled only to 10-13˚C. And we still need to heat supply air quite a lot: from 4˚C to 9˚C approximately.

In autumn measurements were repeated to check if we make any mistake and to find out inaccuracy. We got almost the same results: temperature efficiency is about 30% and heat recovery provides 40% of heat. But temperatures after heat recovery and after reheating coil were different. And it means that at this time reheating coil didn't work.

So it should be said that both our measurements were not correct. The main problem – is just one measuring point in the bottom of rectangular duct. This leads to inaccuracy, which is even more because air temperatures differ a lot in duct section exactly after heat recovery. Temperature becomes more balanced in duct section after reheating coil so inaccuracy decreases. It can be accepted that temperature after out-of-operation reheating coil is more reliable. Also temperature rises a little after fan because of fan heat emission. But temperatures before fan were measured, so this increase shouldn't be taken into account.

So it's accepted that temperature efficiency of existing heat recovery is about 50-60%. It's clear as according to fixed measurement devices of building automation system so and according to our measurements. That efficiency is acceptable for our water-glycol heat exchanger.

2.4.3 Comparison with estimated values

It was found from manometers on ducts that supply and exhaust air flows are 3,6 m^3/s and 3,4 m^3/s accordingly. From "Calculation of ventilation heat recovery heat loss equalization" /11/ duration of certain temperatures outdoors were taken and hours when certain temperatures occurred were counted. Then it was assumed that extracted air temperature is not less than 0˚C, supply temperature is not more than 16˚C and heat recovery stop to work if outdoor temperature more than 16˚C. It's also known that AHU works 10 hours per day, 5 days a week /12/.

According to these conditions annual demand of heating for ventilation is calculated:

$$\Sigma\Phi_i = \mathrm{q_v} \cdot \rho_a \cdot \mathrm{c_p} \cdot (\mathrm{T_{out}} - \mathrm{T_{supply}}) \cdot \tau_i \qquad (4)$$

where $\Sigma\Phi_i$ is heat demand annually; $\mathrm{q_v}$ is mean supply air flow; ρ_a is density of air, $\mathrm{c_p}$ is specific heat capacity of air; $\mathrm{T_{out}}$, $\mathrm{T_{supply}}$ are outdoor and supply temperatures of air accordingly; τ is hours per year when certain outdoor temperature occur.

$$\Phi_a = \Sigma\Phi_i = 150\frac{MWh}{a}$$

According to layout area of kitchen is approximately. Then we get approximate heat demand for each square meter annually:

$$\Phi_a^{"} = 750\frac{kWh}{m^2 \cdot a}$$

According to measured temperatures we have temperature efficiency about 30%. But we analyzed results, compared them with output of fixed devices and decided that in our case we have real temperature efficiency – about 50%, when usual theoretical values are from 40% to 60%.

There are two types of annual efficiency. According to D2 the annual efficiency is calculated by very simple and strict formula, where annual efficiency is 60% of temperature efficiency of device. But for water-glycol system this formula is not very good, because in spite of low temperature efficiency, thanks to good anti-freeze regulation their annul efficiency is higher. /13/

Also another formula for annual efficiency of ventilation heat recovery exists, which takes into account only heating effect of ventilation without contribution of space heating devices.

It is accepted that temperature efficiency is 50%, and then estimated annual efficiency is 48% if to compare recovered heat with heating air with all heating devices including space heating. Comparing recovered heat with heat, provided by ventilation, we get 68%.

It is accepted that it is right and we get economy:

$$150\frac{MWh}{a}\cdot 68\% = 102\frac{MWh}{a}$$

2.4.4 Analysis of different possibilities

Using the same calculation method as in paragraph 2.5.3 annual efficiencies of ventilation heat recovery relatively to different temperature efficiencies and temperature of extract air can be estimated. Usually minimum temperature of extract air ($t_{ext,min}$) is 5˚C more than minimum temperature of water-glycol on exhaust side. Also water-glycol on supply side should be warmer than outside air at least on 5˚C. There are three cases: real case in AMICA (liquid is about 0˚C) – then $t_{extr,min}$= 5˚C; Flächtwoods says that liquid temperature may be -7˚C – if it's even -5˚C then $t_{extr,min}$= 0˚C; Retermia says that their coils shouldn't be controlled until outside temperature is -15˚C – then without regulation $t_{extr,min}$= -5˚C.

In table of results it can be seen that annual efficiency depends on temperature efficiency much more than on the temperature of the extracted air. With increase of temperature efficiency impact of minimum extract temperature increase also. But still additional benefit is too small for these efficiencies. Bigger efficiencies are not possible for water-glycol heat recovery.

TABLE 1. Influence of temperature efficiency and minimum temperature of extracted air on annual efficiency

Temp. efficiency, η.s, %	Min extract temp., ˚C	Heat recovery energy, kWh/a	Heat demand of ventilation, kWh/a	Total demand of air heating, kWh/a	Annual efficiency, η.a (D2), %	Annual efficiency, η.a, %	Annual efficiency, η.a BOOK, %
40	5	84363	149495	202097	24	0,42	0,56
	0	85034				0,42	0,57
	-5	85043				0,42	0,57
50	5	100930			30	0,50	0,68
	0	104385				0,52	0,70
	-5	105042				0,52	0,70
60	5	113733			36	0,56	0,76
	0	120426				0,60	0,81
	-5	123303				0,61	0,82

Other aspect which influences on annual efficiency of water-glycol heat recovery is moisture content of exhaust air. If moisture content and temperature efficiency are low then we can get just sensible heat from exhaust air. But if air is humid then condensation may occur. In this case efficiency of heat recovery will increase. The reason is a big heat capacity of condensation process.

Average monthly temperatures and relative humidities for Kuopio and standard temperature efficiencies of coil heat exchanger are taken as base for calculations. Air flow rates are the same as in case under study – 3,6 m^3/s (supply) and 3,4 m^3/s (exhaust). Maximum supply temperature is 16˚C and exhaust temperature is 23˚C. /14/

It was found that temperature efficiency increases when condensation occurs. Of course increase of moisture content means increase of condensation. In figure 17 below you can see increasing of annual efficiency according to increasing of additional moisture.

In case under study temperature efficiency – 50%, estimated annual efficiency – 70% and additional moisture content – +2 g/kg of air. So case under study is a black point on figure below. Also such good results as 100% for annual efficiency are hardly reachable because 2g/kg of additional moisture seems to be average increase of humidity for professional kitchens, but how big could it be – difficult to say.

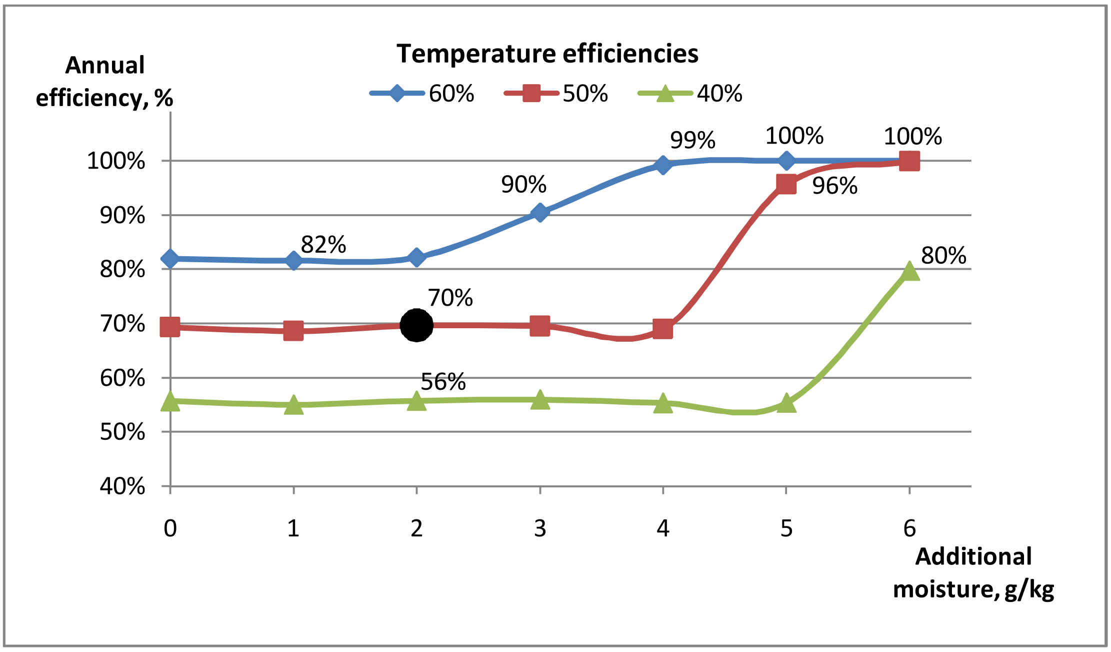


FIGURE 15. Relations between annual efficiency and additional moisture content in extract air in cases with different temperature efficiencies

3 HEAT RECOVERY FROM COOLING MACHINES

As soon as cooling plants in some entertainments provide huge heat output from condensers heat recovery is quite widespread there. But in many facilities which don't use refrigerators a lot people don't even try to utilize heat power of condensers. Still with modern technologies this heat source can be used.

3.1 Heat losses

The best way to understand how much energy is lost during cooling is to draw cooling process on a p-h-diagram. This diagram shows visually magnitudes of lost energy. Thus it shows utility of heat recovery in this case. Often this heat is removed and not used in profitable way. The worst is when condensers are inside the building then during summer period when spaces need cooling condensers add extra demand of cooling power.

At figure 16 it's possible to see that in vapour compression cycle more that 100% of energy that's taken from cooled space wastes in condenser. In past this problem haven't been discussed so much. Heat from condenser went to atmosphere. The only wish was to ensure proper operation of cooling machine. But now we have to think about all the possibilities to save energy.

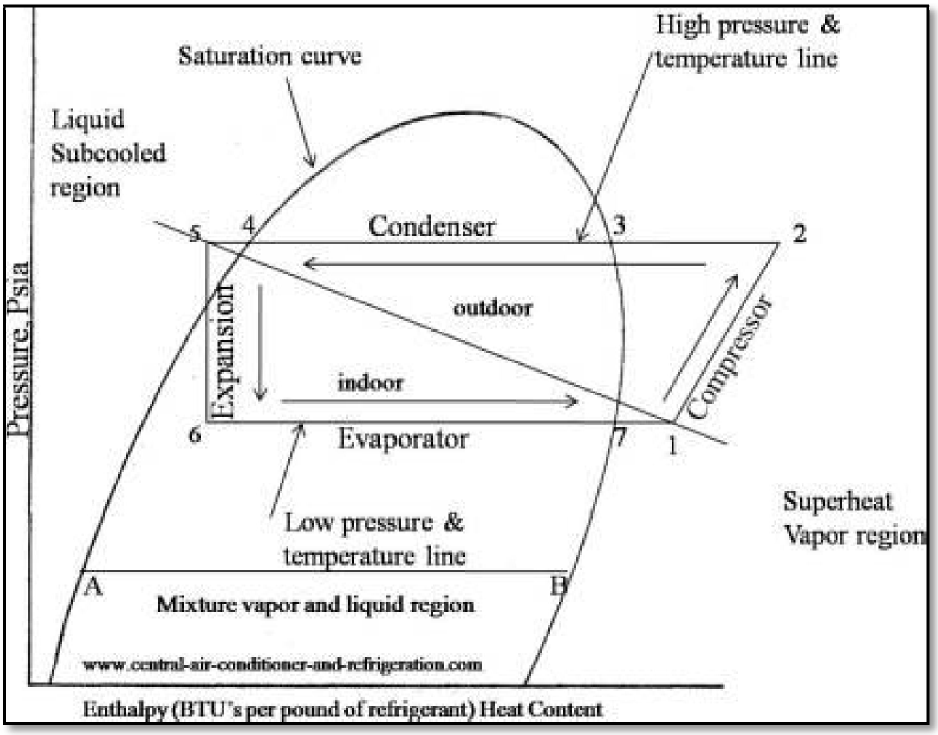


FIGURE 16. The vapour compression cycle on Pressure-Enthalpy diagram /15/

3.2 Possibility to utilize heat of condensers

Heat of condensers is used in different ways. It's possible to preheat potable water, supply air in ventilation or provide space with low-temperature water heating. Let's look at one existing solution, where heat of condensers is used as additional heating source for ventilation in coldest days of the year. It's a solution of Retermia Company, which manufactures designs and installs heat recovery units for ventilation. They propose solution where because of big efficiency of their ventilation heat recovery even in cold climate whole ventilation heat demand is provided with heat recovery.

On figure 17 you can see schema of water-glycol heat recovery. Two exhaust units in upper part and two supply units in bottom part. Also there are two air handling units: for kitchen and for restaurant. There is refrigeration circuit in the middle of the layout where X2 is condenser and X1 is liquid tank. In summer exhaust units can work as additional fans for refrigeration circuit.

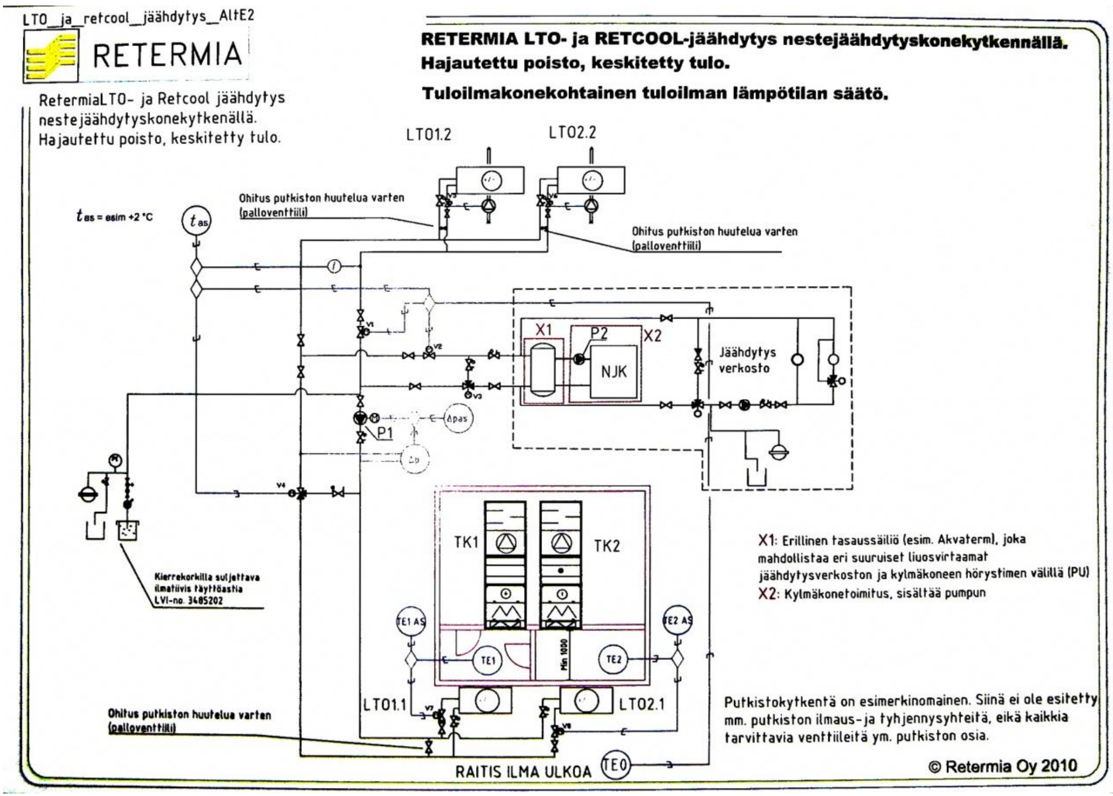


FIGURE 17. Ventilation heat recovery with additional heat recovery from refrigeration system /3/

3.3 Existent devices and their evaluation

One type of refrigeration heat recovery on market is product of German company “Eureka”. It consists of water storage tank with cold and hot water at the same time. After beginning of refrigeration process cold water from the bottom of tank goes through the heat transfer pipes and return to tank. This way the entire tank becomes full of hot water step-by-step. Operational principle of this system consists in two-layer pipe. The inner pipe is for cold water from distribution system and the external layer contain refrigerant from cooling machine. This system enables to get water at 50˚C-60˚C which is approximately 7˚C higher than refrigerant condensing temperature. Technology enables to save 100% of heat. /16/

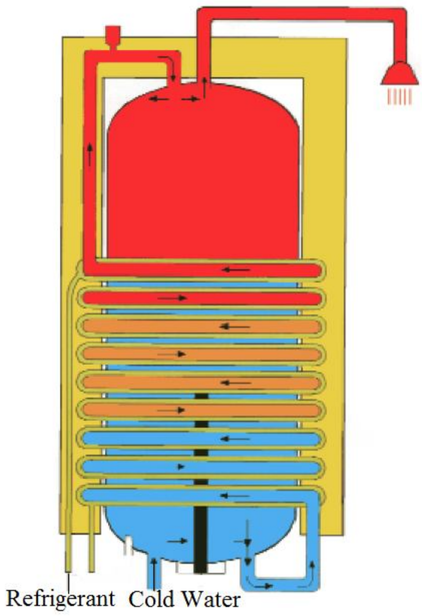


FIGURE 18. Water storage cylinder /16/

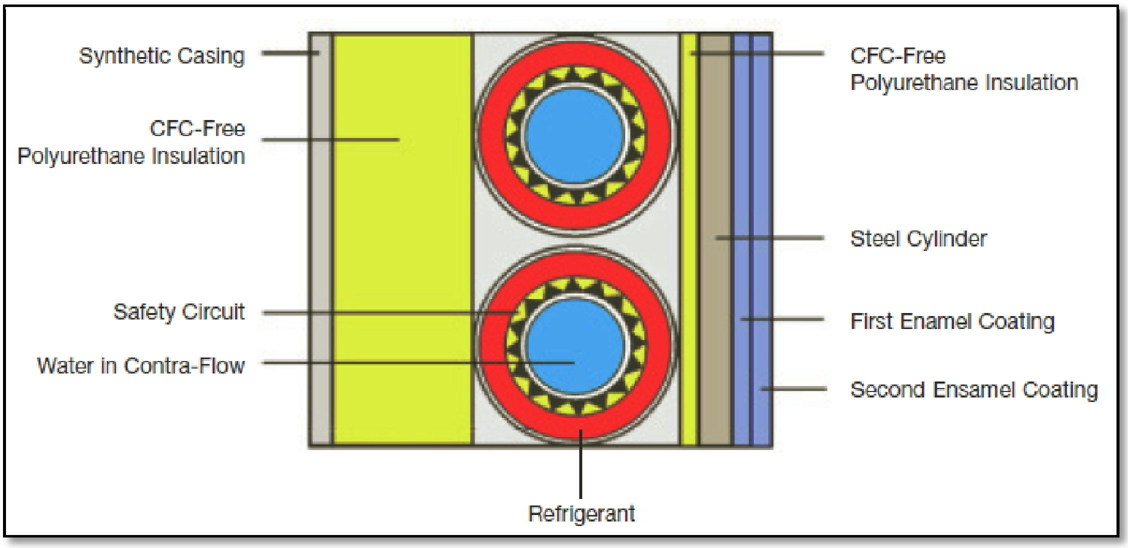


FIGURE 19. Safety circuit incorporated within the insulation jacket /16/

3.4 Magnitudes of heat losses in the studied case

In our case there are no big cooling machines to save great amount of energy. But they are still present.

The main condenser of refrigeration system in AMICA restaurant is situated on the roof of the building. Its capacity is 2,5kW. Service Engineer of Mikkeli University of Applied Science estimated that it works about 10 hours 5 days a week. This condenser takes heat from most refrigerators in AMICA. There are also some smaller units that have condensers inside the building. But their capacity is so small that it's not worthy to take into account. /12/

3.4.1 Results and discussion

Trying to get amount of energy which is lost through the condenser we accept that it's possible to use all wasted heat. Then in our case estimated value is (if to accept that refrigerators work 10 hours per day, but probably it is less):

$$\Phi_a = \Phi \cdot \tau = 2{,}5kW \cdot 1250\frac{h}{a} = 3{,}2\frac{MWh}{a} \qquad (5)$$

where Φ_a is amount of waste heat from condensers annually; τ is operating time annually $\frac{10\frac{h}{d}\cdot 5\frac{d}{w}\cdot 50\frac{w}{a}}{2} = 1250\frac{h}{a}$

With price for district heat about 6,3 euro cents for Finland is about 200 euro annually. Similar calculations are presented in web-page of manufacturer of refrigerator heat recovery “Eureka”. They estimate values for system with higher heat losses and bigger operation time, but with our values estimated profit is similar./16/

So it’s possible technically to save some energy with heat recovery from cooling machines, but figures are much less then heat expenses of ventilation (100MWh/a) and savings of ventilation heat recovery(~50MWh/a). Also probably investment cost of heat recovery for cooling machine will be too big and pay-back period will be too long.

4 WASTE WATER HEAT RECOVERY

Nowadays ventilation heat recovery is widespread all over the world. Energy becomes more expensive every day. So people want to save their money and invest in modern energy efficient technologies. The more so because ventilation heat recovery is rather much popularized by governments and energy institutions of EU, USA and Canada. But due to their wish to spend less money they make a contribution in saving of energy sources and less carbon emissions. In spite of that heat recovery from other energy sources is not so popular at this time. But accordingly to increase of energy costs all possibilities of energy recovery are going to be taken into account.

Waste water heat recovery for residential and commercial buildings is quite widespread in Canada and USA. According to W.Urban, VP Marketing and Business development of the RenewABILITY Energy's ”Waste Water Heat Recovery is a virtually untapped global market that is about to become even larger, given impending changes in energy availability”/17/.

But in Europe waste water heat recovery is being developed for short time period. There is a big project of utilizing waste water heat in Helsinki. It’s the largest in the world district heating and cooling plant that uses heat pumps. It’s situated 25m under the Katri Vala park in Helsinki and uses waste water and sea water to produce energy. /18/

But this project is unique. And in residential houses people don’t use waste water heat recovery. In Finland reason of such a situation is that drain pipes are hidden inside the concrete in floor. But for most waste water heat recovery devices at least 1-3 meters of free space vertically is needed. According to my research waste water heat recovery is also not very popular in other European countries.

Heat losses of warm waste water

During domestic and commercial use of water we lose about 80-90% of the energy, consumed for water heating./19/ In commercial sphere this waste is the more significant the more business use warm water. Due to great amount of water used daily in commercial kitchens it’s possible to save up to 60% of water heating costs. /20/

4.1 Existing devices in market

Trend of waste water heat recovery (DWHR) is being developed a lot nowadays. So it’s possible to bring out different technologies and patents at this field with main manufacturers. At first it is worth saying that waste water heat recovery is better than somewhere else spread in Canada and US. Probably it happens because of great attention given to development of heat efficient technologies in these countries. But anyway there are existing also European manufacturers including Finnish.

4.1.1 Falling-film heat exchangers

A technology is called “The Power-Pipe”. Operating principle of heat recovery devices is based on a so called "falling film" effect. ”Water falling down a vertical waste stack does not run down the middle of that stack, but instead clings to its inside wall. This creates a thin "falling film" from which the all-copper Power-Pipe can readily recover heat energy.” /20/ The manufacturer promise safety of these technology, possibility to use in residential, commercial, industrial and institutional sectors. Also they declare advantages relatively to another type of falling film waste water heat recovery. On figure 20 below you can see the schema with fluid flows and photo of device.

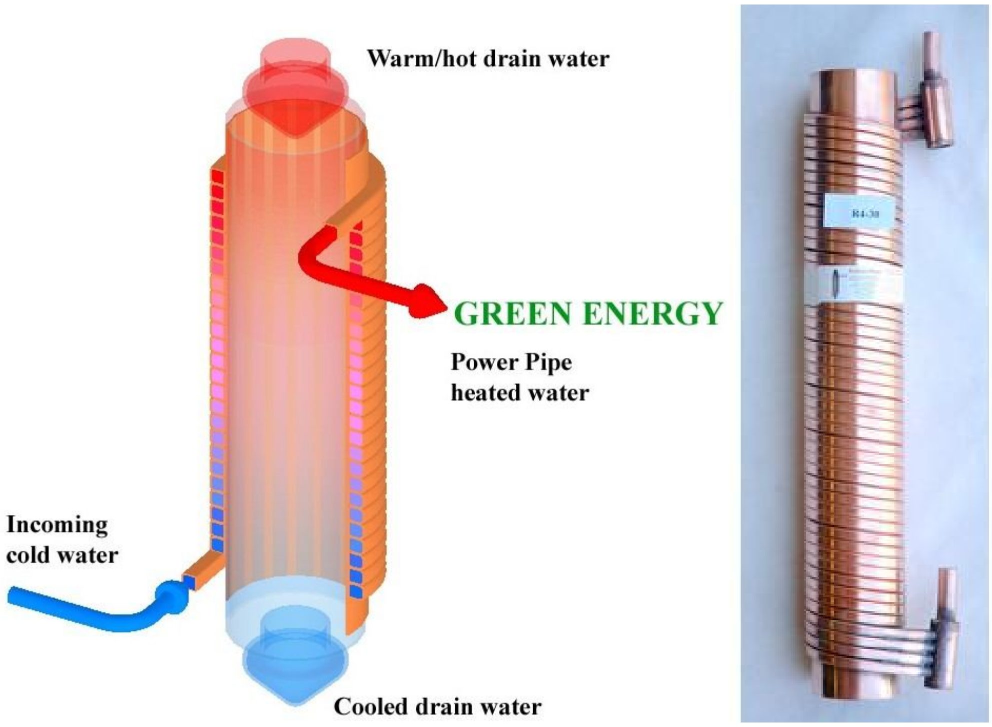


FIGURE 20. Falling film waste water heat recovery (the Power-Pipe patented type) /20/

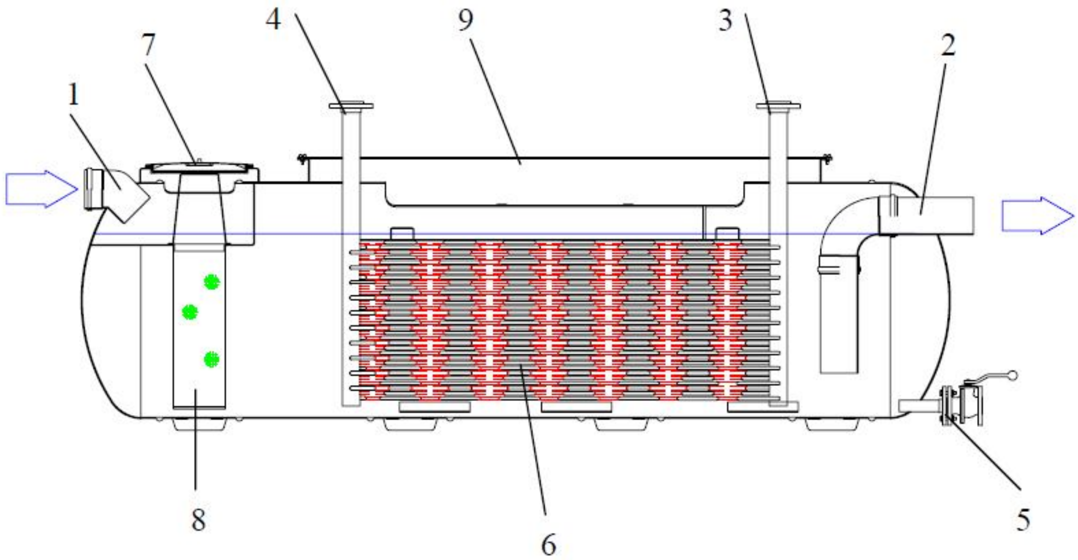
FIGURE 21. Watercycles's WWHR /21/

There are two another types of falling-film heat recovery. One of them has only one coil wrapped around the duct. For example Watercycles energy recovery Inc. produces such type of DWHR. In spite of simplicity of this technology they declare efficiency about 40%. It can be seen in temperature test for 3 inch 29 inches long pipe given in their web-page. Test was done at the 4^{th} of June 2006 at 11 am. According to results average temperatures are t_{cold}=6.3˚C, $t_{preheat}$=18.0˚C, $t_{beforeHR}$=37.0˚C, $t_{afterHR}$=29.6˚C. Cold water temperature increase - 11.7˚C Effectiveness - 38.0% . But this test seems to be not enough valid because from average temperatures we can see that temperature difference of clean water flow is more than in drain: 11.7˚C > 7.4˚C

It means that clean water flow is less than drain flow in one and half times. It's possible only if a part of clean potable water flows through heat exchanger. Usually efficiency of heat recovery is counted with same flows. And supply flow is almost always more than waste water flow. The main problem of Watercycles system is great water resistance and thus additional losses in pump pressure. The main difference of the Power-pipe according to manufacturer's explanations is a presence of more than one coil thus reducing resistance in thin cooper pipes./21/ Another model of same type of DWHR is product of Retherm Energy Systems company. Their device is the same as previous under discussion.

4.1.2 Tank heat exchanger

Another totally different technology of waste water heat recovery is performed by Finnish company "Wavin-Labko". It represents big vessel with coil inside which is called heat recovery centre (HRC). It increases temperature of cold water by 10˚C...15˚C. Advantage of this system for commercial use seems to be in built-in filter for solid impurities. So dirty drain water from dishwasher machines can be at first purified for better heat transfer in coils and less contamination of DWHR unit. But in spite of that manufacturer suggestion to use it in combination with fat separator for better heat transfer. But this additional device makes this DWHR unit more expensive and increase pay-back period.



1-Water inlet; 2-Water outlet; 3-Domestic inlet; 4-Domestic outlet; 5-Draining; 6-Heat transfer piping; 7-Maintanence cover; 8-Lint filter; 9-Service hatch.

FIGURE 22. HRC – hardware components /22/

4.2 Measurements of losses in AMICA

The biggest amount of water used in professional kitchen is water for dishwasher machine. According to Metos OY it is about 80% of all the water used in professional kitchens. In case under study dishwasher WD241E is used. According to catalogue it can wash 210 dishwashing baskets per hour and spends 1,8 liters per each. Also kitchen is equipped with several kettles and almost the same amount of water is used for their cleaning. /23/

So average water flow in dishwasher is $\left(210\frac{baskets}{h}\cdot 1{,}8l\right)\cdot 2 = 750\frac{l}{h}$. Dish- and kettles- washers work about 5 hours a day, 5 days a week. So we get annual consumption of 1000 m^3/a. It accords with data from water meter collected at 2008, 2009 years. Cold water consumption in those years is approximately 1500 m^3/a in each. So value in case under study is just 67%, but this can be explained by water consumed in toilets of canteen, which is not taken into account when accepted that dishwasher consume 80% from whole kitchen expense.

Usually manufacturers of waste water heat recovery accept that temperature of outlet water is about 37˚C and from 20˚C to 27˚C after heat recovery. This way they count efficiency of their devices. In case under study temperature of outlet waste water is 33-35˚C according to measurements. It is accepted that temperature difference between inlet and outlet of waste water heat exchanger is 10˚C, then annually potential of waste water recovery:

$$\Phi_a = \mathrm{q_v} \cdot \rho_w \cdot \mathrm{c_{p,w}} \cdot (\mathrm{T_{exh}} - \mathrm{T_{extr}}) \qquad (6)$$

$$\Phi_a = 1000\frac{m^3}{a} \cdot 1000\frac{kg}{m^3} \cdot 4{,}2\frac{kJ}{kg\cdot K} \cdot (34-24)K = 42000\ \frac{MJ}{a}$$

$$\Phi_a = 11{,}7\frac{MWh}{a}$$

In this case supply temperature efficiency of waste water heat recovery is accepted as 42%.

$$\eta_s = \frac{t_{preheat}-t_{cold}}{t_{outlet}-t_{cold}} \qquad (7)$$

$$\eta_s = \frac{20^\circ\mathrm{C} - 10^\circ\mathrm{C}}{34^\circ\mathrm{C} - 10^\circ\mathrm{C}}$$

$$\eta_s = 42\%$$

It means that we have cold water temperature 10˚C and temperature of preheated water at 20˚C.

But in canteen under study so much hot water not needed to be used (usually dishwashers use cold water and heat it inside), so we should use this preheated water another way. Good possibility for water in that temperature is preheating supply air in ventilation. In this case there should be closed circulating system between drain pipe and ventilation duct. But there are still some problems: the first is that dishwasher starts to work 3-4 hours later than AHU, so this additional heat can be used only part of time; the second is that temperature of water is almost the same as temperature of exhaust air in ventilation and it’s not easy to decide where to put it. The second problem can be solved also: as soon as climate in example is quite cold (temperature can be -20˚C...-30˚C), it’s possible to preheat cold supply air before ventilation heat recovery coil. In this case temperature of water glycol in circulating circle can be lowered to increase heat transfer from waste water.

5 CONCLUSION

In this work I analyzed the possibilities of different Heat Recovery systems and tried to choose the most efficient heat recovery for a canteen. I've looked through existing design solutions which provide good indoor climate. In these projects heat of exhaust air, waste water and heating power of condensers is utilized in different combinations to provide the most efficient solution for each case.

I've found out that in the canteen under study the most reliable source of energy is ventilation. And ventilation heat recovery is installed in case building. I've found that efficiency of that heat recovery is probably not as big as possible but still good.

Other potential sources of heat recovery are not so big in comparison with ventilation. But still warm waste water could be used as additional pre-heating source for supply air for example or to preheat water before inlet in dishwasher machine. Magnitude of waste water potential heat capacity is $1/15^{th}$ of that we need to preheat supply air and $1/10^{th}$ of that we get from ventilation heat recovery. It's rather low, but it can be used anyway.

Heat potential of compressors is too low to be economically reasonable in case study. But this heat source should be taken into account when new projects for canteens are designed. In our case size of the canteen is rather low. But if it would be the canteen for big plant, which sometimes works even in three shifts, then it could happen, that according to bigger working times and bigger storage spaces this heat source will be useful.

Another significant question of this thesis was to find and to evaluate existing heat recovery devices and possibility to use them in professional kitchens.

In ventilation heat recovery for professional kitchens the only possible to use is water-glycol heat exchanger and its variations. It's totally sanitary safe. Also exact regulation of extract air temperature to avoid freezing is important advantage of this system. Specific type of water-glycol heat exchanger is needle heat exchanger. Air intake units with warm fluid are installed outside so they prevent freezing, damping by snow, also they pre-filter air. Exhaust units also prevent freezing and enable system to work with highest efficiency until outside temperatures is -15˚C.

In waste water heat recovery there are two main types of devices which can be used in professional kitchens. One is film heat exchanger with different variations of design. Another is tank heat exchanger. They are water-to-water heat exchangers and they are designed to carry portable water without risk of its contamination. Another good possibility for recovering heat of waste water is presented on example of combined district heating and district cooling plant in Helsinki which is working on heat pumps and uses residual heat of waste water and sea water. This project could be somehow adapted to Mikkeli new waste water plant in future, because need of using wasted energy is growing every day.

For heat recovery of cooling machines there is also special device. It's very simple technology – just a tank with heat exchange coils around. Other schemas of heat recovery from cooling machines exist but this technology is the most simple for using as for low-capacity refrigerators so and for big storages.

So I can say that ventilation heat recovery is the most reliable waste heat source in canteen. With the exception of special situation where expenses of water or refrigeration need are great.

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