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Recovering Heat from Condenser Unit Produced Refrigerant System in Food Processing Facility

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Abstract

The object of this research was to investigate of the energy performance of a national chicken slaughterhouse in order to achieve condenser heat utilization generated by the operation of the existing, refrigerant systems. The paper focuses also for the technical realization of condenser heat utilization by concept plans and payback time calculations. The utilizing heat of a cooling circle's condenser is a quite quickly returnable investment. The time of payback is around 330 days by heat utilizing for hot water preheating and also air heating.

Keywords

heat recovery, condenser heat utilization, refrigerant system, energy design, energy consumption, energy saving

1 Introduction

It's essential how we treat the cut-off livestock from the aspect of breeding infections. There are several kinds of contaminations, microorganisms on the surface of a carcass, or it's likely that they settle down from the ambience. They can be bacterias, viruses, mushrooms or mould. First as a microorganism occurs on the surface, it does breed slightly, or even doesn't breed. In this stage the microorganism must adapt itself to the new ambience. After it, if successful, comes the exponential growth period during which the population of microorganisms can double two or more times every hour under favourable conditions. As the number of the microorganisms multiplied, the depletion of nutrients and the accumulation of toxins slow down the growth and start the death period. The rate they settle down depends on the quality of the meat and the environment. Since it's not possible to change the parameters of meat, or we don't really want to change, only the properties of the environment is what we can manipulate with [1-7]. The properties of air, as temperature, humidity, air flow velocity, and oxygen concentration. According to these variable parameters, we can pasteurize, chill down, humidify, dehumidify, ventilate, or change oxygen level, from the side of applied HVAC technology [8-12].

The investigated facility in this research is a slaughterhouse, established specifically to process poultry. The rate of process is about 3000 poultries each hour. During the procedure high cooling and heating energy demand occurs. Viktor Zicho MSc. student [13] has been a huge help in the realization of the project with his assist work and effort. To perform the energy calculations and evaluate the results, Microsoft Excel 2010 software was used in this research. As the livestock arrives at the facility, the following treatment steps are applied:

1. Livestock cleaning with pipe-water
2. Veterinary examination
3. Stunning
4. Killing, bleeding
5. Scalding: during this step, the entire feathering is removed. This removal is facilitated by hot water, which is injected on the body of poultries. Thus feathers loosen up, which makes scalding more effective. The injected hot water's temperature is 65°C and the mass flow rate is 1kg/h.
6. Water bath
7. Feet removal
8. Gutting
9. Pre-chiller, cold-air blast: this step is also called shocking, since the carcasses temperature is decreased very quickly, herewith making the adaptation of microorganisms more difficult. The

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temperature of chickens is 43 °C as they enter the chilling rooms. The aim is to decrease the temperature of the poultry to the level of 3 °C in each point of the carcass.

2 Heat-and moisture load calculations of the conditioned spaces

Heat- and moisture load of the examined building is quite complex: transmission heat flow, heat flow of technology, human moisture- and heat load, evaporating water surfaces and lighting compose it. The slaughterhouse is located at Hajdúböszörmény, Hungary. The design external temperature is T_e = -15 °C, the average soil temperature during heating season is $T_{m,e}$ = 4 °C.

The heated (or likely heated) space: 1566 m^2. Expediently we should divide the building to zones with different temperatures, according to the assigned room's function. Each zone is set out in Table 1.

According to standard No. EN12831 the heat loss of each room can be computed from six components: transmission heat loss, heat radiation of warm surfaces, heat load of evaporating water surfaces, heat load of people, machines and lighting (Eq. (1)).

$$\dot{Q} = \dot{Q}_{tr} + \dot{Q}_{hs} + \dot{Q}_{ew} + \dot{Q}_{p} + \dot{Q}_{m} + \dot{Q}_{l} \tag{1}$$

Since this method is a routine algorithm in building technology profession, we won't negotiate it thoroughly. Conclusions and upshots are unfolded in the next chapter.

Among the rooms, the scalding room and its ambience might have the highest heat load. We considered it important to examine this area of building from the aspect of heat load. The 3000 chickens transiting every hour and the sprayed 1 l hot water per chicken means high amount of generated steam. In addition, a scalding machine is also in service, which generates about 3 kW heat flow.

Value of steam were calculated by Eq. (2).

$$\dot{Q}_{ew} = \dot{m} \cdot h_S = A \cdot \beta \cdot \left(p_{Ss} - p_{S|ti,\varphi}\right) \cdot \left(c_{p,S} \cdot t_v + r_0\right) \tag{2}$$

One poultry stays about twenty minutes in the room, consequently water evaporates from about 1000 chicken body coincidentally. Thus evaporation surface can be estimated with 1000 sphere's surface (Eq. (3)).

$$A = 1000 \cdot 4r^2\pi = 3000 \cdot 4 \cdot \left(0.07816\right)^2 \cdot \pi = 76.7 \text{ m}^2 \tag{3}$$

Mass flow rate of evaporation aware of air velocity (1 m/s) among hanged meat pieces (Eq. (4)).

Table 1 Design temperature room-by-room

Room	Design indoor temperature (°C)
Scalding room and its ambience	25
Residential areas	20
Work zone	16
Store, garage, etc.	12
Refrigerator store	0
Freezer, fore-cooler	-20
Shock freezer room	-35

$$\begin{aligned}\beta &= \left(4.581 + 3.39 \cdot v_{air}\right) \cdot 10^{-8} = \left(4.581 + 3.39 \cdot 1\right) \cdot 10^{-8} \\ &= 7.971 \cdot 10^{-8} \ \frac{\text{kg}}{\text{sN}}\end{aligned} \tag{4}$$

Pressure of saturated water at 25 and 65 °C: 3170 Pa, 25041 Pa. Maximal relative humidity is 85 %. Partial steam pressure in the room (Eq. (5)).

$$p_{S|ti,\varphi} = p_{Ss,ti} \cdot \varphi_i = 3170 \text{ Pa} * 0.85 = 2695 \text{ Pa} \tag{5}$$

Moisture load from generated steam (Eq. (6)-(8)).

$$\dot{m}_{ew} = A \cdot \beta \cdot \left(p_{Ss} - p_{S|ti,\varphi}\right) \tag{6}$$

$$\dot{m}_{ew} = 76.7 \cdot 7{,}971 \cdot 10^{-8} \cdot \left(25041 - 2695\right) \tag{7}$$

$$\dot{m}_{ew} = 0.1366 \ \text{kg/s} \tag{8}$$

Heat load from generated steam (Eq. (9)-(10)).

$$\dot{Q}_{ew} = 76.7 \cdot 7.971 \cdot 10^{-8} \cdot \left(25041 - 2695\right) \cdot \left(1.86 \cdot 65 + 2500 \frac{\text{kJ}}{\text{kg}}\right) \tag{9}$$

$$\dot{Q}_{ew} = 358.1 \text{ kW} \tag{10}$$

Besides this, the heat load given by the scalding machine (3 kW) and the lighting (0.7784 kW) is not significant. Processes performed in this room are entirely automated, there is no staff working here constantly. The scalding room loses 3.51 kW heat flow through the walls. Summarizing these values, total heat load in the scalding room is 358.3 kW, which is leaded off by a ventilation system. The upshot is a value far over my expectations, actually it is greater than the heat flow ejected from the shocker's condenser. This means, there are two possible concepts for heat supply from wasteheat: with condenser heat recovery, negotiated before, or recovering energy from the ejected air diverted from the scalding room. Considering these opportunities, we analyse two constructions in the following.

Performing the computation in case of each heated room, heat demand of the building is $\sum \dot{Q} = 41.65$ kW regarding winter design circumstances. This outgoing heat flow must be in equilibrium with the performance provided by the heat supply system.

In winter design conditions there is a great performance need, in order to warm up the external air to the requested temperature. W calculated the mass flow rate of inlet air for the existing four temperature-zones (Eq. (11)).

$$\dot{m}_{air} = \frac{\dot{Q}_{zone}}{c_{air} \cdot \Delta T_{temp.differential}} = \frac{\dot{Q}_{zone}}{c_{air} \cdot \left(T_{in} - T_{out}\right)} \tag{11}$$

Performance of air heaters depend on the specific temperature differential and the mass flow rate coming through them (Eq. (12)).

$$\dot{Q}_{air\ heater} = c_{air} \cdot \dot{m}_{air} \cdot \Delta T_{air\ heater} \tag{12}$$

External air is let in the scalding room without any treatment and heating. The other rooms get air supply from a common air duct, then it forks into two ducts: Air heater No. 1 heats up to 15 °C, No.2 to 19 °C appropriately for zones 12 °C and 16 °C, since temperature differential is 6 °C between ventilated and exhaust air in each room. After air heater No. 2 air can flow directly to zone 16 °C or it air handler of zone 20 °C. The latter is equipped with an adiabatic air moisturizer and a post-heater. The calculated heating energy demand of the air heaters can be seen in Table 2.

After air heater air of zone 20 °C flows through the adiabatic moisturizer, where moisture gains up to 95 % relative humidity, its temperature drops to 7 °C. Task of post-heater is to heat it up to 23 °C. Considering it, performance of air heater No. 3 can be calculated by Eq. (13).

$$\dot{Q}_{\text{air heater No. 3}} = \dot{m}_{\text{zone 20 °C}} \cdot c \cdot \Delta T \tag{13}$$

The calculated mass flow rates for air heaters can be seen in Table 3.

3 Development of heating energy utilization system

Let it be a standard or any kind of heat recovery equipped system, the three air heater must provide these above summarized performances. Thus total heat flow is 303 kW. Regarding this value, the condenser heat flow can't cover the building's demands entirely. However, this system or scalding room heat recovery can function perfectly, because design heat losses occur only few days long a year. Thus air heaters must provide the maximal performance only rarely.

Table 2 HVAC technology data of zones and heat performance of air heaters

Zone	Heat demand of zone (kW)	Air mass flow rate (kg/s)	Volumetric flow rate (m^3/s)	Heat performance of air heater (kW)
20°C	25.72	4.287	3.133	223.8
16°C	13.77	2.295	1.678	
12°C	2.16	0.360	0.263	10.8

Table 3 Mass flow rate and performance of air heaters

Air heater	Mass flow rate through air heater (kg/s)	Air heater performance (kW)
1	0.36	10.8
2	6.582	223.8
3	4.287	68.6

Investment costs might let us decide between the two available systems. One thing is already known: from heat recovery constructions it is preferable to use construction B), because air heating has a great demand, exceeding the 210 kW supplied limit. As written before, the optional concepts are condenser heat recovery, utilized coincidentally for air heating and DHW preheating, or scalding room heat recovery with cross flow plate-type heat recovery appliances, combined with condenser heat recovery utilized for DHW preheating. Let us denominate the former as construction A) and the latter as construction B). These formations should be compared from aspect of energetics and economy, too. This comparison is performed in the following chapter. Let us assume that formation without any kind of heat recovery is the standard construction.

On the following pages, construction A) and then B) is demonstrated (Figs. 1-2). Signs of rooms are on the right side of figures:

1. Scalding room
2. Zone 12 °C
3. Zone 16 °C
4. Zone 20 °C

In case of construction A) there are three branches tied up paralelly substituting the conventional condenser. All three branches can be disconnected with ball valves on the two sides. At the end of branches, they unite with automated diverter valves. There is an option to disconnect the air heaters also, with diverter valves. There are also conventional air heaters installed after the heat recovery ones, for the case of heat recovery malfunction or for tempering heating and post-heating. They are supplied by a condensing boiler. These air heaters are illustrated with

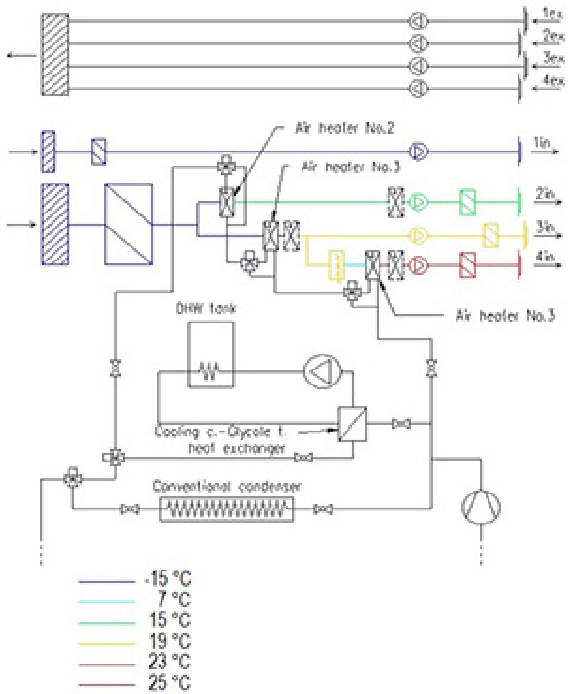

Fig. 1. The schematic technical diagram of Construction A)

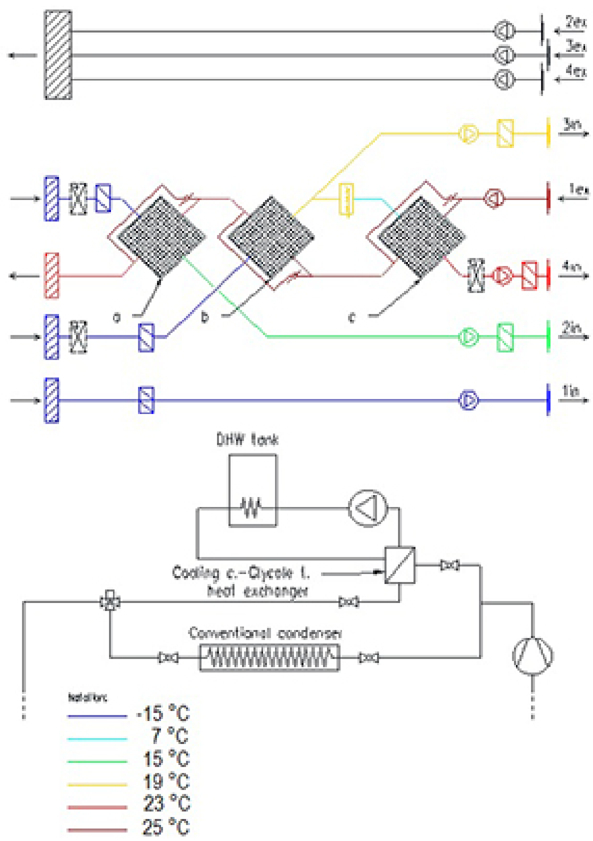

Fig. 2 The schematic technical diagram of Construction B)

dashed lines. The DHW preheater is connected with an NTH heat exchanger.

In case of construction B) the heating of rooms is solved with cross flow plate-type air-to-air heat recovery units. The arrangement of heat exchangers is the same as in case A) from the ventilated air side. From the exhaust air side, they are connected in series with bypass branches for each. In addition, an NTH heat exchanger is also installed on the cooling circle of shocker. On secondary side glycole tincture flows, this lets through a spiral heat exchanger in the hot water tank. Here, in B) te only circle separated from the cooling circe is this latter. The conventional condenser is attached directly, because heat ejection is more effective on the temperature level 35 °C. If it was on an indirect circle, the temperature would be lower and in summer conditions heat ejection would be worse.

On Figs. 1-2 the meaning of "in" is the injected fresh air into the conditioned spaces, while "ex" represents the exhaust air delivered form the given spaces.

3.1 Investigation of Construction A)

In case A) we can't use the same air heaters as in standard case. Thanks to lower flow temperature and the caused smaller temperature differential, higher heat exchange surface is necessary. On the margin, the same heat exchanger can't be used with refrigerant R134A and water coincidentally. It is also important to actuate a post-heater, because of insufficient heat recovery performance. Incremental costs are compounded by the expenses of DHW preheater parts and construction, and costs of the three large-surfaced air heaters and their installation costs. Examining the DHW preheater's installation, it consists of a 104.7 kW NTH heat exchanger's a pump and a spiral heat exchanger capable to eject 104.7 kW heat flow to the inlet water in the water tank. Additionally, five automated diverter valves steepen the investment. Datas of air heaters were inserted in a heat exchanger designer program from Zeller Consulting Souisse, and then results given by program were used in the following. Installing the spyral coil heat exchanger in the preheater DHW tank can not be implemented, so we overestimated the costs with a new two heater coil-equipped DHW tank. The Hungarian distributor of Alfa Laval supported our research with price offer for the 104.7 kW NTH heat exchanger. Unfortunately, they could not provide this kind of heat exchanger, but a low flow resistance plate-type one was recommended instead of it. Its pressure drop is only 756 Pa, which is an acceptable value.

The investment costs:

- 1 Zeller 32.0/27.7/12.4- 1R- 46T- 1381A- 2.9PA- 11C-17- 16 air heater, 548 €

- 1 Zeller 32.0/27.7/12.4- 1R- 46T- 1310A- 8.0PA- 22C-88- 54 air heater, 752 €
- 1 Zeller 32.0/27.7/12.4- 1R- 46T- 1357A- 8.0PA- 11C-41- 35 air heater, 545 €
- 1 Alfa-Laval AC-230EQ-210H plate-type heat exchanger, 3500 €
- 1 Grundfos CR45-1-1 pump, 988 €
- 1 Remeha HT 500 ERR water tank with two heat exchanger coils, 1159 €
- 5 diverter valves with valve engine and control system, 1587 €
- The installation works, which is 317 €.

Summarizing, the total investment cost is **9.396 €.**

When installing a new energy system, it is essential to calculate the annual savings of primary energy sources. In case of condenser heat utilization DHW preheating has the higher priority, while heating is secondary. Warming up the DHW from 11 °C to 33 °C would be performed by gas-fired boilers, when heat recovery is not available. First it doesn't seem to be a great amount of energy, but considering water's high heat capacity and high mass flow rate, it must be significant. In the last column of Tables 4-5 total daily heat demands must be distributed by 8 h, assuming that, shift in the slaughterhouse and working period of preheater is 8 h every day.

In terms of payback calculations, this average performance can be applied also for morning heating up, for 1.5 hours. Preheater starts coincidentally with the shocker's cooling cycle. It warms up water to the desired temperature, because heat loss occurs on the walls of the DHW tank, and water temperature sinks significantly at night.

Heating of the building works 9.5 hours a day, between stationary conditions. In the calculation of saving, we assumed the performance of morning heating up equal to normal stationary heating. In the half of annual heating period the condenser's heat flow wouldn't be able to cover this incremental performance, necessary for heating up. In the other half of heating period, this increment is negligible. These steps in the calculation set back the return period. On the following figures (Figs. 3-6) we illustrate the heat demand in the function of external temperature.

Let heat demand of DHW preheater be constantly 81.13 kW, independently of external temperature. But performance of air heaters depends strongly on external temperature. All three air heaters reach their maximal performance in case of -15 °C, the design ambient temperature (Table 2.2), while No. 1 heats up to 15 °C, No. 2 up to 19 °C, No. 3 up to 20 °C. Curves of air heaters No. 1 and 2 are linear, but in case of No. 3 it becomes a polinomial function, since humidity of external air rises significantly with temperature. This behaviour influences air moisturizing

Table 4 Water demand of DHW preheating

Spaces	Mass flow ratio (kg/s)	Working period (h)	Daily water demand (kg)
Scalding	0.8333	8	2.400E+04
Knife washing	0.002778	8	8.001E+01
Hand washing	0.009722	8	2.800E+02
Shower	0.2917	1	1.050E+03
Sum	1.1375		2.541E+04

Table 5 Heat demand of DHW preheating

Spaces	Daily heat demand (MJ)	Average performance (kW)
Scalding	206.95	76.63
Knife washing	7.36	0.26
Hand washing	25.75	0.89
Shower	96.57	3.35
Sum	336.63	81.13

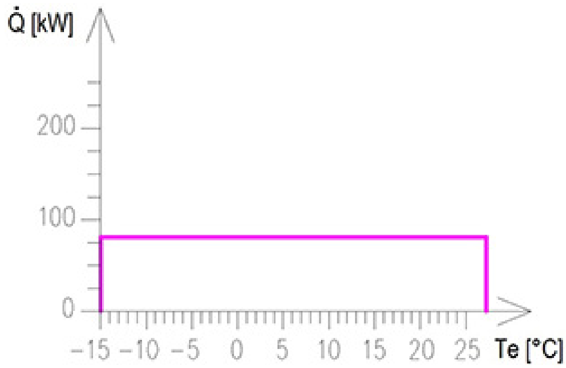

Fig. 3 Performance of DHW preheater in the function of external temperature

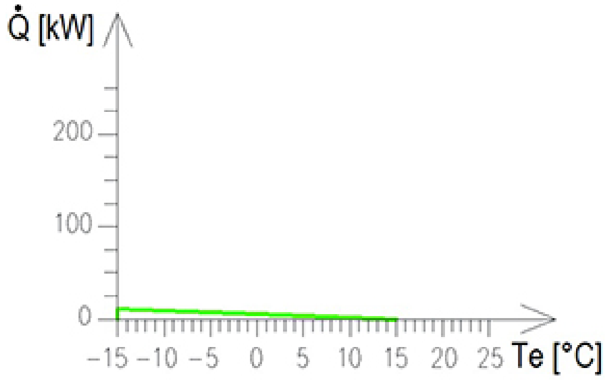

Fig. 4 Performance of air heater No. 1 in the function of external temperature

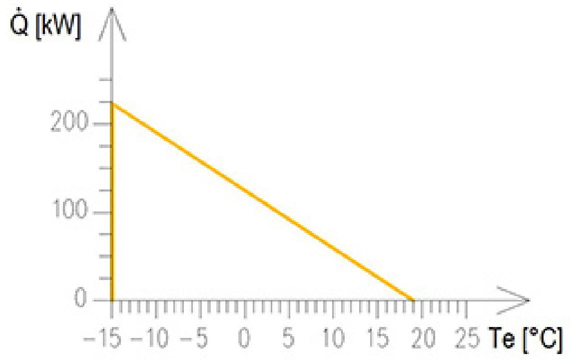

Fig. 5 Performance of air heater No. 2 in the function of external temperature

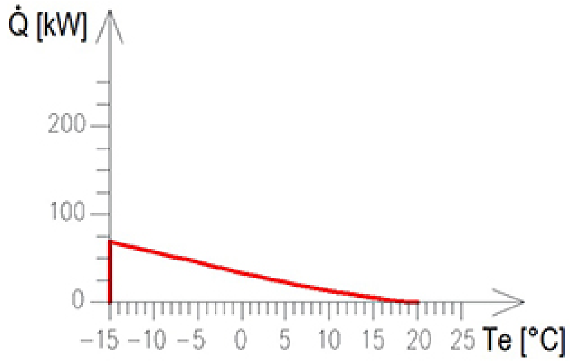

Fig. 6 Performance of air heater No. 3 in the function of external temperature

intensity and post-heating indirectly. It is quite easy to assign the inlet temperature in air heater No. 3 with framing on h-x diagram (Fig. 7). This framing is illustrated in Fig. 2.6. on an example: we start from point -4 °C and 80 % relative humidity, and warm up the air in air heater No. 2 until 19 °C. After this, comes moisturizing via the adiabatic moisturizer to 95 % relative humidity. Temperature is easily readable in this point, it becomes 8.3 °C. From this point, the post-heater's duty is to warm up the air again.

I performed this framing for all integer value temperatures from -15 °C to 19 °C. Since external temperature gets higher, humidity also rises and the sprayed water mass flow rate diminishes. As a consequence, inlet temperature in air heater No. 3 increases.

Post-heating initial temperatures (T_{ph}) belonging to the appropriate external temperatures are listed in a table, and illustrated on a diagram (Fig. 8).

According to these datas we could frame the characteristic curve of air heater No. 3, thus aware of all three air heater's and DHW preheater's performance curve it is preferable to handle them together.

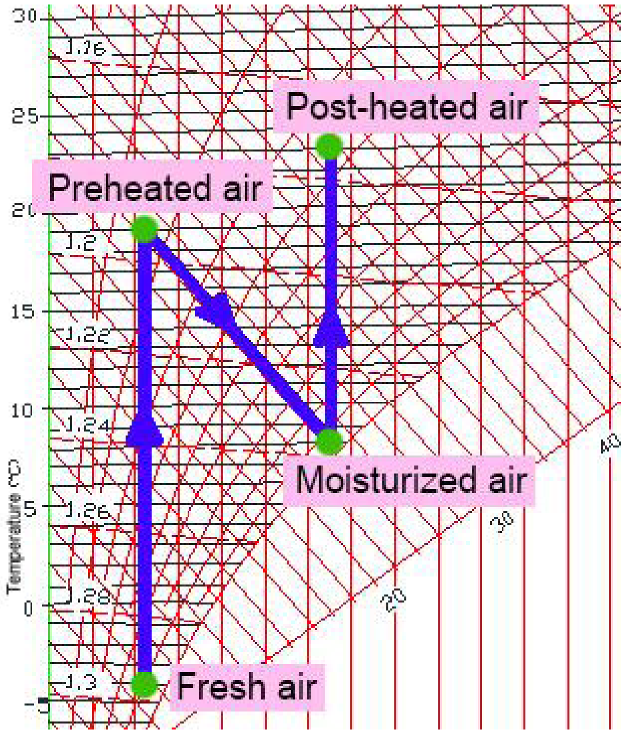

Fig. 7 Air handling process in h-x chart

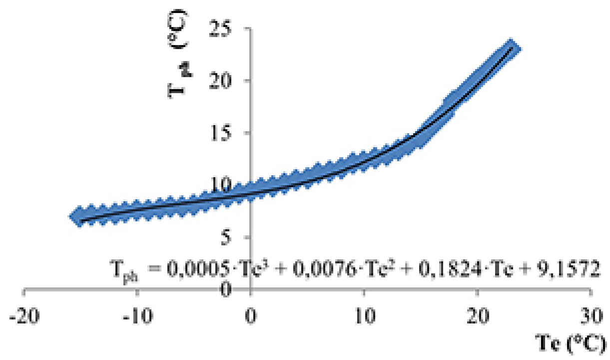

Fig. 8 Initial post-heating temperature in function of ambient air temperature

Each characteristic curve is fitted onto each other, thus summing up the performance values, we obtained the summarized heat demand diagram (Fig. 9).

Annual saving is computable only if we find relation between run period and performance. There is a curve, called frequency distribution of temperature, which helps finding the relation. This is a duration chart, which shows how often does external temperature stay under assigned temperature limits, according to long-term averages (Fig. 10).

We blocked in the condenser's heat performance in the obtained performance-period curve, too. It is the available, consumable heat performance, a dim pink line illustrates it. As it is visible, in a short part of the heating period, the

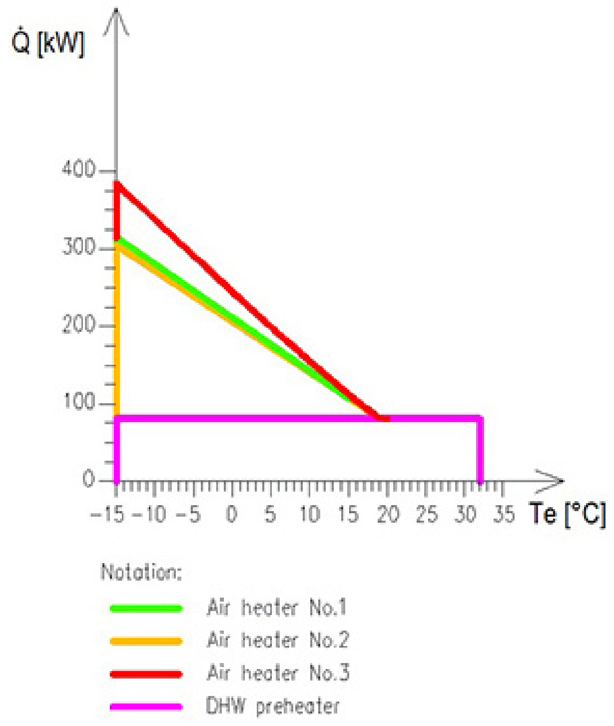

Fig. 9 Summarized heating energy demand diagram

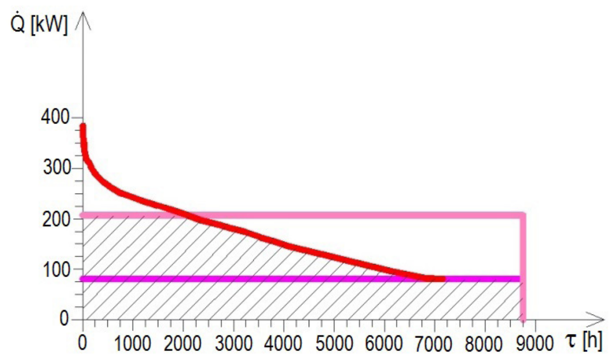

Fig. 10 The performance-time duration curve

condenser can't cover all the needs. There are also periods, when a part of the heat is not utilized, the rest must be rejected to environment. The saved amount of heat is illustrated with cross-hatch. The area covered by this, could be measured by AutoCAD's surface measuring module. The total saved heat becomes 4.502TJ, but the shocker's cooling cycle doesn't work all day, only 9.5 and does it only on weekdays. Portion of working period (Eq. (14)):

$$\frac{9.5\frac{\text{h}}{\text{day}}\cdot 5\frac{\text{days}}{\text{week}}\cdot 52\frac{\text{weeks}}{\text{annum}}}{8760\ \text{h}} = 0.282\ . \tag{14}$$

Multiplied with this coefficient, the real saving is by Eq. (15):

$$Q_{savings,\,a} = 0.282\cdot 4.502 = 1.27\ \text{TJ}\ . \tag{15}$$

Divided with annual boiler efficiency, we get the heating value of saved fuel by Eq. (16):

$$Q_{saving,\,fuel,\,a} = \frac{Q_{saving,\,a}}{\eta} = \frac{1.27\ \text{TJ}}{0.75} = 1.693\ \text{TJ}\ . \tag{16}$$

Finally, the saved expenses aware of natural gas price by Eq. (17):

$$C = p\cdot Q_{fuel} = 0.00618\frac{€}{MJ}\cdot 1693000\frac{MJ}{a} = 10463\ €/a. \tag{17}$$

Electricity consumed by the pump of DHW preheater circle, which is an incremental operational cost by Eq. (18):

$$W_{pump,\,e} = \tau\cdot\frac{\Delta p\dot{V}}{\eta_{pump}} = 2470\cdot\frac{45600\cdot 0.01}{0.79} = 1426\ \text{kWh}\ . \tag{18}$$

According to the total electricity consumption of the slaughterhouse, it belongs to A1 pricing category, which distinguishes peak load and its opposite. The factory works in the supplyer assigned peak period, when price of electricity is 0.1379 €/kWh. Thus, pump operational cost is were calculated by Eq. (19).

$$C = p\cdot W_e = 43.44\frac{€}{\text{kWh}} * 1426\ \text{kWh} = 196.6\ €/a \tag{19}$$

Thus altogether incremental energy costs of construction A) is 196.6/a. Incremental investment costs were paid in one sum, without taking a loan. The easiest way to exemplify the return, might be a diagram. The costs of standard construction and A) construction were illustrated in function of time. Let us assume, that zero point is standard construction's investment cost. Consequently, incremental costs occur as absolute expenses. Standard construction's operating costs are equal to the occurring expenditures without any heat recovery technology.

An idea presents itself, that heat recovery unit is installed during the building of the slaughterhouse, coincidentally with the installation of conventional air handlers. In this case, the air heaters supplied from the conventional gas boiler have got only supplementary role. Considering it, the conventional air heaters would be designed to provide total design heat flow only if redundancy was the concept at engineering. From now on, this construction is called A1). If heat recovery failure occurs and can't supply heat, the other conventional air heaters can cover all the demand. However, much more economical construction is, when they are designed only to the rest heat performance, which is not covered by the heat recovery air heaters. In details, it means that smaller surfaced heat exchangers, smaller gas boiler and smaller diameter pipes are necessary. From now on, this compound is called A2). This causes a difference in thrift, compared with A1) its payback period is expected to be shorter. Zero point is the investment cost of standard case, additional cost is the heat recovery unit's investment cost, and the difference between the two gas-supplied air heater system's price must be educed (Fig. 11).

We obtained price offers for each air heater in case A1) and A2) from the Hungarian distributor of Rosenberg air handling unit producer. The data of conventional air heaters can be found in Table 6.

Rosenberg gave absolutely the same prices for air heaters independently from performance. Thus air heaters don't play role in the differential costs between the two constructions. However, gas boilers make a very significant difference.

As heat source, we selected high performance gas boilers from Viessmann. In case of A1) the gas boiler is designed to the total heat demand, which means 384kW heat flow rate, desired from the gas boiler. According to it, we selected the 408kW nominal performance model from the high performance Vitodens boiler family. Gross price, which we obtained from the manufacturer, is **26 130.** In case of A2) we selected the same kind of boiler, but a lower performance one with 187kW. Its gross price is **16 286**.

During operation, nominal performance of both construction is equal to the A2) design performance, because conventional gas supplied heating of A1) operates on its design performance only if heat recovery unit breaks down and the external temperature is also at design temperature. Accordingly, boiler of A1) is going to work on

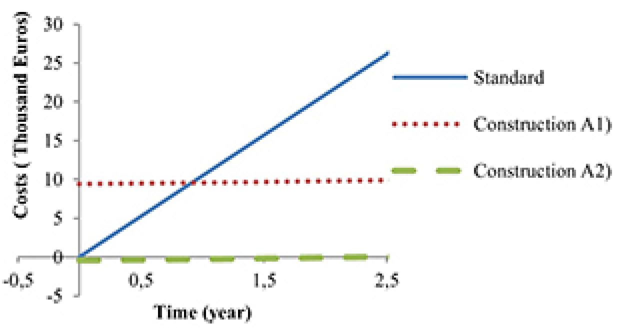

Fig. 11 The payback period of Construction A)

Table 6 Investment costs of air heating coils

Air heater #	A1)	A2)
1.	122	122
2.	338	338
3.	235	235

part-load. Fortunately, while it is a condensing furnace, the efficiency doesn't change drastically with load reduction. The pump is also at the same operating point. So there is no significant difference in operating between the two analysed constructions.

Finally the total difference is the bias between the two furnace's price: 16 286. This price compared with the pipe price differences, this latter can be neglected. This means, that payback curve of A2) starts from that much below compared with curve of A1).

3.2 Investigation of Construction B)

Summing up, the investment costs:

- 1 Zeller 10,7kW cross-flow plate type heat exchanger, 1627 €
- 1 Zeller 223kW cross-flow plate type heat exchanger, 1775 €
- 1 Zeller 68,6kW cross-flow plate type heat exchanger, 1627 €
- 1 Alfa-Laval AC-230EQ-210H plate type heat exchanger, 3500 €
- 1 Grundfos CR45-1-1 pump, 988 €
- 1 Remeha HT 500 ERR water tank with two heat exchanger coils, 1159 €
- The installation works, which is 317 €.

By this way the total investment cost is 11.454 €.

The scalding room operates all the time, when meat process is running. Thanks to the high heat load inside it, the exhaust 25 °C and 25 kg/s air ensures the heating of building between every condition. However, there is no heating before the operational hours of the slaughterhouse, which means preheating is not solved with this heat recovery construction. As a consequence, conventional air heaters must ensure it.

Thus, heat exchangers operate 8 hours daily, their performance in function of external temperature is the same as in case of A). Since the same frequency distribution curve is used, the framing applied in Fig. 12 results almost the same, with one difference: it doesn't contain DHW preheating – this role is played by the condenser heat utilizer. The air-to-air heat recovery units cover the entire heating demand. In case of normal operation, the conventional gas-supplied heaters are not used.

The heating energy saved is the area under the curve, which must be multiplied with the appropriate utilization ratio. As described above, the air heaters operate 8 hours daily. Based on it, the ratio was calculated by Eq. (20):

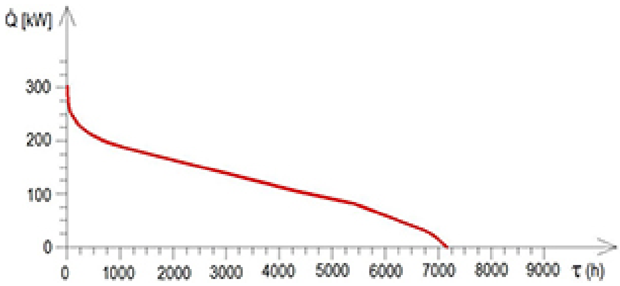

Fig. 12 The energy savings in heating

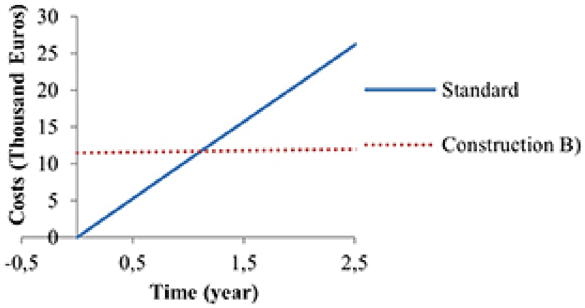

Fig. 13 The payback period of Construction B)

$$\frac{8\frac{\mathrm{h}}{\mathrm{day}}\cdot 5\frac{\mathrm{days}}{\mathrm{week}}\cdot 52\frac{\mathrm{weeks}}{\mathrm{annum}}}{8760\ \mathrm{h}} = 0.2374. \tag{20}$$

Heat amount measured with AutoCAD area measuring tool is 2.254TJ, while the real saving was calculated by Eq. (21).

$$Q_{saving,\,annual,\,heating} = 0.2374 \cdot 2.254 = 535\ GJ \tag{21}$$

The performance of the condenser heat utilizer DHW preheater is also covered entirely during the daily 9.5 hours operating period. Thus annual saved heat was calculated by Eqs. (22)-(23):

$$Q_{saving,\,annual,\,DHW} = \dot{Q}_{daily\ average} \cdot \tau \tag{22}$$

$$\begin{aligned} Q_{saving,\,annual,\,DHW} &= 81130W \cdot 3600\frac{\mathrm{s}}{\mathrm{h}} \cdot 9.5\frac{\mathrm{h}}{\mathrm{day}} \cdot 5\frac{\mathrm{days}}{\mathrm{week}} \cdot 52\frac{\mathrm{weeks}}{a} \\ &= 721\ GJ. \end{aligned} \tag{23}$$

Total annual saved heat amount is their sum was calculated by Eqs. (24)-(25).

$$Q_{saving,\,annual} = Q_{saving,\,annual,\,heating} + Q_{saving,\,annual,\,DHW} \tag{24}$$

$$Q_{saving,\,annual} = 535\ GJ + 721\ GJ = 1256\ GJ = 1.256\ TJ \tag{25}$$

Divided by the annual boiler efficiency, we obtain the saved fuel's energy content (Eq. (26)).

$$Q_{saving,\,fuel,\,annual} = \frac{Q_{saving,\,annual}}{\eta} = 1.675\ TJ \tag{26}$$

Finally, the saved costs aware of natural gas price (Eq. (27)).

$$C = p \cdot Q_{fuel} = 6.181\frac{€}{GJ} \cdot 1972\frac{GJ}{a} = 10352\ \ €/a \tag{27}$$

Pump operation cost of the DHW preheating circle is 196.6/a, the same value as in case A). Incremental investment costs were paid in one sum, without taking a loan. The easiest way to exemplify the return, might be a diagram. On Fig. 13 the costs of standard construction and B) construction were illustrated in function of time. Let us assume, that zero point is standard construction's investment cost. Consequently, incremental costs occur as absolute expenses. Standard construction's operating costs are equal to the occurring expenditures without any heat recovery technology.

4 Results and conclusions

The utilizing heat of a cooling circle's condenser is a quite quickly returnable investment. The time of payback is around 330 days in case of A) construction (condenser heat utilizing for hot water preheating and air heating), according to the corresponding diagram. This value is exceptionally good for a return period. Payback period of A2) became even better. It returns immediately, because setup of lower nominal performance gas-supplied air heaters means a greater saving, then incremental costs of the heat recovery unit. In fact, price of construction A2) is lower than the price of standard case. If similar heat utilizers on other cooling circles of the slaughterhouse were installed, all the heating and hot water preheating demands would be covered throughout the year. This kind of waste heat utilizer can be used in any type of facility, where heating and cooling demands occur coincidentally. Competitor might be the plate type air-to-air heat recovery unit. Here, in case B) (condenser heat utilizing for hot water preheating and applying heat recovery unit for air heating) the operational costs are the same as in case A1) and A2), however, the investment expenses are higher. As a conclusion, the return time is also longer, it is around 350 days, according to the corresponding diagram. All three constructions have their disadvantages: A1) and A2) is unable to cover all the heating and hot water preheating needs in a certain part of the year, while B) cannot cover it during the heating up period. Comparing the constructions, A2) might be the best choice, but it is feasible only if its installation is in coincidence with the building of the facility. If it is not possible, A1) might be the favourable because of shorter payback period. At each investment or construction work, we must plan the operation of heat pumps very substantially, and beyond the cooling demands, we should always investigate the coincidental heating demands. It's also true for the opposite direction: if we apply the heat pump basically for heating or hot water preheating purpose, we should utilize the cooling performance of the evaporator, if there is such demand. Considering this approach, significant savings without any negative change on the cooling circle's operation can be achieved. The investment to recover heat from the investigated condenser unit has not been realized, but it is under consideration by the investors.

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