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SOLUTIONS OF ENERGY OPTIMISATION IN INDUSTRIAL PLANTS

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Abstract: *This paper is a short study on the potential of Heat Recovery (HR) systems advantages in industrial applications. By using the recovered heat from different waste streams, global efficiency can be improved. In mean time the running costs are set back together with a significant CO_2 reduction. The Heating-Ventilation-Air Conditioning system will keep the same comfort level by combining in innovative way the existing "traditional" systems with the HR opportunities. All these will be coordinated by a master control system which needs to think global about building & production demands.*

Key words: *heat recovery, energy, cost estimation.*

1. Introduction

We live in a modern world and we spend most of the time inside a building and use energy to ensure productivity and wellbeing. Optimized energy use is widely discussed since many years, but the increasing primary energy costs and the continuous industrial expansion is putting more and more pressure on these topics.

There are many new technologies available meant to reduce the consumption of energy. There are also a lot of political decisions, directives and laws which push us to be more and more economic. Probably the biggest pressure on people was and will always be the costs and the profit margins by means of capital key figures.

According to BP issued Energy Outlook 2030 report, in the last 20 years world faced an energy consumption grew of 45% and an approximately 39% additional grow is forecasted for the next 20 years. These figures shows that by 2030 we will use the double of the energy we used in 1990.

EU norms by means of Energy Labeling, EuP directives and other design guidelines try to put in practice the 2020 project of 3x20. These means 20% less greenhouse gas emission, 20% higher energy efficiency and 20% renewable energies.

Beside of the new technologies available we should not forget that these technological features must work in a perfect harmony and never the less the continuous improvement analyses must have basis on optimal and rational use of the resources.

The study spots on how to use residual energy resources by combination of existing basic technologies with optimum control management of automation systems.

2. Theory & Facts

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Industrial facilities often use different technologies, where by means of technology there are lot of wastes that could be reused.

Typical applications might come from moulding processes, compressed air, food industry, etc.

Any industrial application that involves thermal processes like heating and cooling could be potentially generator of waste energy. However, not always the waste energy can be usefully recovered. For this reason we should say that any waste heat stream shall be considered by means of its quantity (approximate energy content), quality (typical temperatures) and recovery systems availability for certain application.

The three main items of the heat recovery of waste energy shall be considered as follows:

Quantity: It is important to consider this is a function of mass flow rate, temperature and composition, which is defined on the energy consumption of the process. Nevertheless, in case of quantity we should consider the timeline availability (all the time or maybe couple of hours a day).

Quality*:* it refers to the typical temperature. Some of the waste heat streams might have low temperatures, which make them available for limited applications, others could have higher temperatures which shall be used for wider application range of reuse or conversion. This component is an important one in the feasibility of the heat recovery calculation.

Recovery system availability: This chapter is the component which makes the recovery process itself to happen. For various streams we have different recovery processes available with different efficiencies.

An important remark upon heat recovery processes of waste energy is that most of the recovery systems frequently used is for recovering high temperatures heat streams, just like from electric plants or metal molding processes. Commonly these are used for district heating (Heat & Power Plant) or maybe also for cooling.

But, what happens with low temperature heat streams – typically below 100˚C? The low temperature streams were mainly avoided because of high investment costs. In the following pages some of these applications will be discussed. There are many waste energy streams we could use with low temperatures. Within these we can put the ventilation air inside buildings, compressed air-, cooling systems-, exhausted hot gas heat recovery.

A basic theory which could apply to these low temperatures heat energy recovery is the heat pump theory, explained in equation (1).

$$HeatPumpEnergy + primaryPumpedEnergy + ThermalEnergyofthe\,umpSystem \quad (1)$$

Lookup for the processes that needs residual heat to be exhausted. Some typical applications are widely spread just like:

Industrial cooling processes – with chilled water loop or Direct Expansion solutions.

Hot Gas exhaust – like drying ovens, compressed air stations.

These two typical applications are general available (at least one of them) in mainly all production facilities. Moreover, these applications are low temperature waste streams, which could be, depending on case, used on the heating system as addition.

To define the feasibility of the reuse of these energies we need to know the following:

- Temperatures - t_{exh} [°C],
- Mass Flow rate – m [m^3/h],
- Timeline – nr. of hours used – T [h].

As soon as is indicated the total waste

heat stream capacity and its timeframe we must calculate against the energy demand of the building it will feed. Seasonal energy demand vs. heat recovery energy gain will define the efficiency ratio, and it will give an overall picture of the add value. The energy gain of HR system could be considered for given periods of time, just like on a daily/monthly or seasonal use.

Heat recovery systems must have a backup solution of the base system, so we have 100% coverage for any circumstances. On other hand, HR system shall never be the single solution to dissipate the waste heat.

The reason of the statement above is that not always the entire waste heat stream can be used inside the heating system as well as sometimes it can't cover the losses of the building. A certain example will be shown later.

Studying the saving potential of the waste energy certain analyze of the building heat loss profile is a must. On the heat loss profile we need to consider the following:

- Heating season – as average period for calculations;
- Minimum/Maximum/Average Outdoor temperature – frequency of this. (number of days/heating season);
- Load profile of above mentioned days – to compare with the heat recovery capacity;
- Monthly loading profile based on multi annual average temperatures.

With all these data we can simulate the saving potential of the system and spot where heat recovery gives more energy than the demand.

Basic calculation of full season load divided by sum of full period waste energy stream might result in errors in calculation. Shorter periods need to be considered to get more accurate data.

As mentioned, the calculations give only empiric calculation on saving potential. For this reason on implementation period a proper management must be done to follow the system and improve if needed.

This type of application must be done during a multi-annual contract together with customer. After implementing waste heat energy recovery system, it is easy to do the calculations based on degree days method, which might give a reference base to see if there were improvements on the system.

Degree days method will help the customer to compare more or less on same base the different periods. For example one of the winters might be harder, where more heat is required. The next year could be easier, but the less energy cost doesn't necessarily mean, the system was better in efficiency. This follow-up procedure might be used on bases of standard 15˚C or 18.5˚C base temperature calculation of degree days.

As long as the HVAC system will have multiple heat source feeders after-optimization is the most important to avoid wrong functionality.

The reason, why low temperature waste heat sources (the biggest amount of this waste energy sources) are not often reused or implemented is because of the costs against benefits. Even if from engineering point of view the system works well, by the end of the day the decision is taken on financing point of view.

In any cases, the most important ratio of reusing the waste heat energy will be defined by Return Of Investment (ROI) point. Any system like this will be feasible only if this ROI will point to a period less than 4-5 years.

Usually the target is around 3 years of ROI, which can be easily calculated and handled. This sort of investments with ROI > 7 years could be named Never Return Investments.

In these perspectives the calculations of the system shall be carefully considered and maybe additional benefits must be also pointed. (e.g. safety issues, new investments plan, old systems functionality, etc)

The following basic steps must be considered:

Heat Recovery systems of waste heat energy are potential energy savers, which shall be defined inside the facility.

Heat Recovery Capacity = Efficiency x Waste Energy - expressed at base exhaust temperature.

Existing System must be able to receive the waste energy partly or fully

Building Dynamics must be considered to define whether the waste energy could be used or not.

Define schematic of system.

Implement with the proper control system. The control system is the heart of the designed optimized system. If the automation and control system is not properly done we could rather waste energy than saving it!

3. Example of Energy Optimisation by means of Heat Recovery:

The following example shows the heat recovery potential calculation of an existing production facility.

The facility is located in Arad County and its activity is juice bag (package) production.

Basic input data:

Year of construction: 2007 - 2012.

Type of building: Industrial production hall made of concrete structure with insulated concrete panel walls, sandwich panel roof structure.

Climate zone: II ($t_{min\ winter}$ = -15˚C D.B, $t_{max\ summer}$ = +35˚C D.B.)

Internal Temperature: Offices: 22˚C ±2K in winter, 26˚C±2K in summer

Production hall & storage: 24˚C ±1K all round year.

Temperature setback is done by BMS system during night time – 3K from setpoint.

Heat losses (including Fresh Air heat losses) = 800 kW – 285 kW internal gain = 515 kW

Cooling load = 850 kW (including internal gains). No technological cooling considered.

Technological equipments cooling need

1 x Extruder machine	1x12 kW=	12 kW
9 x Bag machines	9x18 kW=	162 kW
1x Bag machine(2015)	1x18 kW=	18 kW
Total gain on techn. cooling		192 kW

Production working time: 2 shifts/day – 8 hours/shift.

Recorded working hours of equipments (supplied by client): 12h/day (4 hours for maintenance, row material load, etc)

Number of working days/year: 285 Days (6 days/week, 2 breaks of 2 weeks for Holiday)

Technological cooling is short in capacity in winter time, due to fact that air cooled chillers has got no glycol loop at this stage, therefore, they are drained before freezing temperature occurs.

The sum of existing Water cooled chiller capacity = 96kW. This will be supplied by one additional unit with 90kW nominal capacity and one master controller. Total cooling capacity will be 186kW at 7/12˚C

Total condensing energy of the water cooled chillers: 220kW at 42/37˚C

Compressed Air system:

Three Units are working at 70% load each. Group control is supplied by manufacturer of compressors. The 2 shifts sum 16hrs of working/day.

Capacity = 260kW.

Plate heat exchanger recovering capacity at real working conditions: HR eff. x El.Load x Thermal energy percent = 90% x 208 x 80% = 149,76kW. – at 50/45°C

Compressors has got double heat exchanger solution – inverter driven fan for air cooled mode and Plate heat exchanger for water cooling. Working criteria is given by outside control. If no need for LPHW production – fan is switched to higher speed.

According to the listed sources above we have got available capacities of waste energy stream as follows:

Technological cooling: Q=220kWh; t_{exh}=42˚C; T=12 hrs/day – from recorded data.

Total heat stream: 2640kWh/day at 42˚C

Compressed air LPHW recovery = 150kW t_{exh}=45˚C; T=16 hrs/day

Total heat stream: 2400kWh/day at 45˚C

These resources could lead to savings on the Heating system of the building.

User of Waste Energy:

Total Heat Losses: 515kW at -15˚C

Heating Season : 166 days, from 22.10 to 06.04.(according to Table 2.2.3 Appendix III – "Manualul de Instalatii - Incălzire")

Calculation Base: For easier calculations period will be considered 15.10-15.04 – 182 days

Temperature statistic data for 5 year timeline 2009-2013:

Average winter temperatures (2013-2009 – Oct.-Apr.): 4.34˚C

Average number of lowest temperature days/season (-15˚C or less): 3 days (0.02% of winter season)

Average number of highest temperature days/season(+15˚C): 10 days (0.06% of winter season)

Average number of days with temp around reference temp: (4.34˚C±0.5K): 14 days (0.85% of winter season)

The monthly energy demand on the calculation base. Table 1

	OCT	NOV	DEC	JAN	FEB	MAR	APR
External Average Temp [˚C]	11,7	7,6	1,2	-0,5	0,0	6,	12,6
Total En. Demand [kWh]	58526	156309	224168	240768	213023	175190	54078
Nr. Of days	16	30	31	31	28	31	15

Energy recovery from the waste energy stream Table 2

	OCT	NOV	DEC	JAN	FEB	MAR	APR
Recov. En. from Cooling [kWh]	34320	68640	55440	66000	63360	71280	34320
Recov. En. from Compres.[kWh]	31200	62400	50400	60000	57600	64800	31200
Total Recov. Energy [kWh]	65520	131040	105840	126000	120960	136080	65520

On table 2 it is quantified the energy recovered from the waste energy stream – during work time. Calculation refers to working days only.

We can see clearly on based on table 1 and table 2, that we have got an extra energy on recovery system which cannot be fully used on October and April, but all the other months does need additional heat energy from the Boiler Plant room.

The graphical presentation of the data is presented on figure 1 According to the calculations the total estimated energy need is 1.122.062 kWh, from which the Waste Energy by means of recovery system can cover 65%, 732.524 kWh . This means a big potential of savings.

For Safety measurement 3 points simulation is made as verification.

Loads are simulated at random dates where outside temperature is at lowest point (-15˚C), than at highest maximum temperature for heating season (+15˚C) and on average yearly temperature as daily maximum (+4˚C). These results can be seen on figure 2 , 3 and 4.

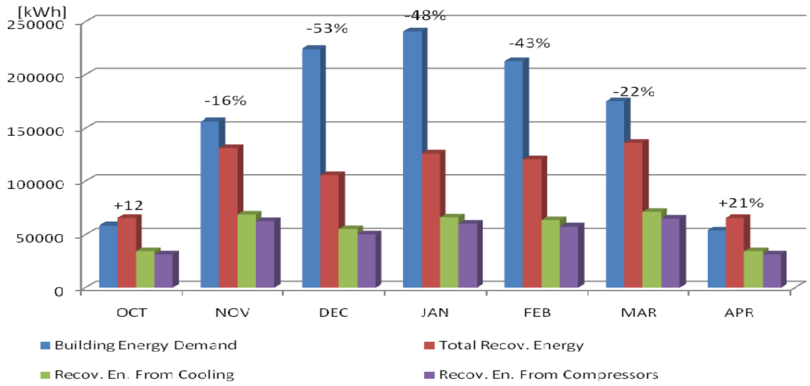

Fig. 1. *Monthly energy demand estimation of building vs. recovered waste energy amount*

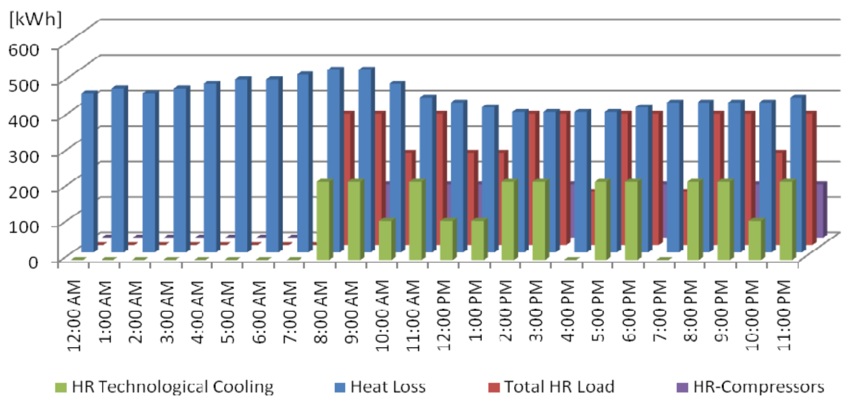

Fig. 2. *Daily load profile waste heat recovery - hourly load (ref. date 02.02.12, Text min=-15℃, Heat losses 10666kWh, Heat Gain 5040 kWh, Coverage 47,25 %)*

The HVAC system consist about fancoils, AHU's and floor heating system. According to Manufacturers data sheet, the AHU units coils have been designed to 50/45°C heating water temperature, while the fan-coil units can work on the same low temperature, since the capacity can cover the losses.

Furthermore, extra capacity might be stored in a buffer tank.

Since the waste energy from compressed air system is many time excessive heat, we might consider a buffer tank and a modulating changeover valve to load tank with hot energy in case of available extra energy from compressed air.

Nevertheless, considering the temperature differences and enthalpies when load is pumped to buffer, we could increase the capacity of the recovered system. In these conditions, we can have an extra percent on efficiency, but this needs further investigations on the implementation field.

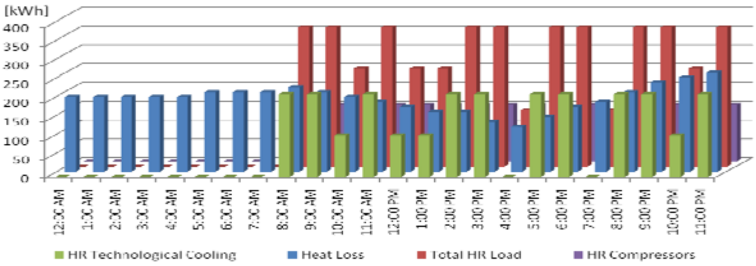

Fig. 3. *Daily load profile waste heat recovery - hourly load (ref. date 01.03.10, Text min=+15°C, Heat losses 4646 kWh, Heat Gain 5040 kWh, Coverage 108,47 % - Excesive energy on cooling recovery - critical time 14:00 - 16:00 and 17:00 - 19:00)*

As figure 3 shows, there are situations, when the heat loss is less than the recovered heat from technological cooling. In these conditions if it is necessary an external cooler shall switch on by the control board. In case of isolated situations, the external cooler might not be needed, since there are time gaps with almost 0 heat recovery from cooling (switch changes and row material preparations or even coffee & snack brake). These issues must be checked on real conditions and the control system to be properly modified/set.

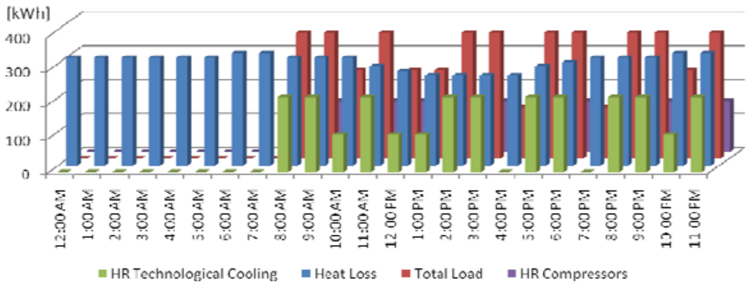

Fig. 4. *Daily load profile waste heat recovery - hourly load (ref. date 07.12.13, Text min=+4°C, Heat losses 7339 kWh, Heat Gain 5040 kWh, Coverage 68,67 %)*

The control system must follow with priority the cooling processes. For safety measure, one air cooled chiller, next to Old Plant room shall be converted to glycol solutions. This needs a buffer tank, a plate heat exchanger one extra pump and fixing materials, piping, approx. 750l of ethylene-glycol. In this case, we can have double safety factor by means of 100% redundancy on technological cooling 365 days and possibility to switch anytime to outdoor system, if there is no possibility to dissipate the heat from condensing into the heating loop.

A little cheaper alternative could be the usage of a dry cooler, but the cost difference would be about 10%, since air cooled chiller is already available on customer's site.

Cost of the new investment**.**

Total cost of the new investment is 69.000 EUR, including all the hydraulic changes, the new chiller, controllers and

Return of investment calculation:

Natural Gas rate: 155,99 RON/MWh – type B.3 according to DistriGaz Vest public price list, ANRE 58/27.06.2014 – annex. Nr.9 .

Natural Gas price = 34,66 EUR/MWh

Gas fired boiler efficiency: 95%

Annual savings on Heating Energy: 732.524 kWh

Total Energy Demand= 732.524kWh/ 95% = 771.077kWh = 771 MWh

Annual savings of Gas = 26.722,86 EUR

Interest rate: 5%/year

Gas Cost savings at 5 year = 147.661EUR

Return of investment = 2.5 years – 3 years

Benefits & Environmental Protection:

The above presented solution proposal gives benefits in many ways as follows:

After the return of new investment around 30.000 EUR annual savings can be expected.

The environment protection is improved. While EU-27 average CO_2 emission for 2013 is specified to be 352g/kWh in case of electricity production, some countries from Europe have got less than 30 g/kWh.

In the case of our example the amount of CO_2 saved equals to 257 tons of CO_2 emission reduction yearly.

An amount of 73.715 m^3 of gas can be saved based on average calorie rate of Natural Gas = 10.46kWh/m^3.

People satisfaction factor is increased. According to Human Resource statistics, employees working for environment friend companies are more optimistic and happier than others. This could results in better approach and higher productivity.

3. Conclusions:

The recovery of low temperature waste heat streams, especially from industrial cooling processes and compressed air could be useful. It can be used generally in one existing chiller glycol conversion new or existing buildings as well, but this needs a lot of attention pay on system inside the building. It won't be used as long as it is designed on high ongoing temperatures.When a new building is considered this solution could be included to keep costs at minimum. Non return financing can be obtained for these apps (EU financing on renewable energies, 2020 directives, LEED certificates, etc)

The heat recovery systems could be applied in best way in case of new buildings, but retrofitting is also possible depending on the available system.

In ultimate case of 70˚C+ temperatures on waste energy, depending on application, beside of heating, absorption cooling system could be also considered. This would keep electricity use at bottom as well.However, not every system is suitable for this sort of implementation, therefore overall view must be considered and none of the projects shall stop at turnkey execution, but further optimization shall be considered.

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