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ÚSTAV PROCESNÍHO INŽENÝRSTVÍ
INSTITUTE OF PROCESS ENGINEERING

VYUŽITÍ ODPADNÍHO TEPLA Z PRŮMYSLOVÉHO SUŠIČE PRÁDLA

WASTE HEAT RECOVERY FROM AN INDUSTRIAL LAUNDRY DRYER

BAKALÁŘSKÁ PRÁCE
BACHELOR'S THESIS

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Assignment Bachelor's Thesis

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Student:	**Gabriela Kyzlinková**
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As provided for by the Act No. 111/98 Coll. on higher education institutions and the BUT Study and Examination Regulations, the director of the Institute hereby assigns the following topic of Bachelor's Thesis:

Waste heat recovery from an industrial laundry dryer

Brief Description:

Large–capacity laundry drying is a highly energy–intensive process. Industrial dryers are usually gas–heated. They have a capacity of up to 90 kg of dry linen. After extraction, the linen still contains about 50% water. The price of natural gas is therefore decisive for their operating costs. The waste stream of wet flue gases has a temperature of 60 – 80 °C. It is usually released without use. The work will focus on the possibilities of using this waste heat and its integration into the laundry process.

Bachelor's Thesis goals:

- Introduction to the waste heat recovery in industry
- Overview of technologies for the waste heat recovery from dryers
- Assessment of the available heat in the flue gas from a selected industrial dryer
- Proposal of a suitable way of waste heat recovery from the flue gas

Recommended bibliography:

JOUHARA, H. Waste heat recovery in Process Industries. Wiley-VCH, 2022. ISBN: 978-3527348565.

MÁŠA, V.; BOBÁK, P.; STEHLÍK, P.; KUBA, P. Analysis of energy efficient and environmentally friendly technologies in professional laundry service. Clean Technologies and Environmental Policy, 2013, roč. 15, č. 3, s. 445-457. ISSN: 1618- 954X.

BOBÁK, P.; PAVLAS, M.; MÁŠA, V.; JEGLA, Z.; KŠENZULIAK, V. Heat Recovery in ProfessionalLaundry Care Process. Chemical Engineering Transactions, 2012, roč. 29, č. 1, s. 391-396. ISSN: 1974- 9791.

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In Brno,

L. S.

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FME dean

Abstract

On daily basis we listen to issues associated with energy prices constantly increasing, non-renewable resources running out and challenges to utilize every joule of energy possible. These issues can be addressed by waste heat recovery which has become the main topic of this thesis. The ideal situation would be to recover all the heat that industrial processes release without use. The thesis focuses on laundry industry and especially waste heat recovery from industrial laundry dryers. The heat in the flue gas from dryers is not used in laundries mainly because it contains small textile particles from laundry and there is a risk of fouling of the waste heat recovery system. The thesis assesses the potential benefit of using this waste heat. Main focus was on calculation of waste heat from multiple laundry dryers located in an industrial laundry facility as well as its economic evaluation. It was found that the recovery of this waste heat can bring up to 89 kW of heat output in this case study. Recuperated heat can be utilized for water heating, and thereby reduce the operating costs of the process. Shell and tube heat exchanger was proposed as the best solution if cleaned daily to minimize presence of the textile residues. The result of the thesis can find application in a number of laundry facilities.

Keywords

laundry process, waste heat recovery, heat exchanger, laundry dryer

Abstrakt

Každým dnem slýcháme o problémech spojených s cenami energií, které neustále rostou a o neudržitelnosti neobnovitelných zdrojů se snahou využít každý joule energie, který máme k dispozici. Tyto problémy se pojí s využitím odpadního tepla, což je hlavním motivem této bakalářské práce. V ideální situaci by bylo možné využití veškerého tepla, které z procesů volně uniká bez dalšího zužitkování. Tato bakalářská práce se zabývá prádelenským procesem, a to zejména využitím odpadního tepla z průmyslových sušičů prádla. Teplo ve spalinách v sušičích se nevyužívá a hlavním důvodem je výskyt textilního otěru z prádla, což způsobuje riziko zanešení systému pro využití odpadního tepla. Práce posuzuje možný přínos využití tohoto odpadního tepla. Pozornost bude věnována výpočtu odpadního tepla z několika sušičů z prádelenského průmyslu a stejně tak porovnání ekonomického zhodnocení. V této studii bylo zjištěno, že při využití tohoto odpadního tepla můžeme dosáhnout až 89 kW tepelného výkonu. Rekuperované teplo může být využito k ohřevu vodu, což by vedlo ke snížení provozních nákladů. Zvolen byl plášťový a trubkový výměník, kde by v případě denního čištění došlo ke snížení textilního otěru. Výsledky této práce mohou být aplikovány do nejrůznějších průmyslových prádelen.

Klíčová slova

prádelenský proces, využití odpadního tepla, tepelný výměník, průmyslový sušič prádla

Rozšířený abstrakt

Každým dnem slýcháme o problémem spojených s tématy cen energií, které neustále rostou. Vedou se diskuze o ekologických aspektech neobnovitelných zdrojů a jak málo času nám zbývá, než nám opravdu dojdou. Jedním z hlavních cílů domácností, společností i firem je zužitkovat každý joule energie co nejefektivněji a tím udržovat výdaje za energii na minimu. Jedním z efektů je skutečnost, že se zejména ve větších provozech začalo využívat odpadní teplo. Provozovatelé se intenzivně zajímají o možné zdroje tohoto tepla, snaží se zjistit jeho množství a odhadnout dosažitelnou úsporu.

Právě systémy pro zpětné využití odpadního tepla jsou předmětem této bakalářské práce. Oblastí, kde bychom se na využití odpadního tepla mohli zaměřit je několik. Tato práce se zaměřuje na prádelenský průmysl. Na základě studia literatury a také osobní zkušenosti s konkrétním provozem mohu konstatovat, že ve větších průmyslových prádelnách se zpracovatelskou kapacitou nad 5t prádla za směnu odchází bez využití v odpadních proudech vyšší desítky i stovky kW tepelného výkonu. Ve většině prádelen se proto už téma odpadního tepla řeší a na trhu je i několik typů výměníků, které jsou napojeny například na odpadní vodu z praček nebo také na žehlící kalandr. V prádelenském provozu je ale další zařízení, které produkuje velké množství odpadního tepla, a to jsou průmyslové sušiče prádla. Průmyslové sušiče pojmou okolo 30-90 kg prádla, ve kterém po odstředění zůstalo 30 - 50% vody a tuto vodu musí odpařit za 20-30 minut. K tomu potřebují velké množství energie, kterou je stroji dodán zemním plynem nebo párou. Hlavním problémem, proč se zatím nepraktikuje použití výměníku spojených s odpadním teplem ze sušičů je přítomnost textilního otěru v odpadním proudu.

Praktická část práce předpokládá výpočet odpadního tepla z několika sušičů v konkrétní velkokapacitní prádelně. Představí také ekonomické zhodnocení a výběr vhodného výměníku. Součástí výpočtů je také stanovení rosného bodu v odpadním proudu, abychom zjistili, v jakých případech dojde ke kondenzaci ve výměníku a jaká pozitiva a negativa to s sebou ponese.

Bylo zjištěno že z této prádelny uniká až 89 kW tepelného výkonu v případě, že jedou dva větší sušiče o kapacitě 77 kg a současně tři menší o kapacitě 34 kg, což je běžný provozní stav. Pokud by se toto teplo zužitkovalo pomocí vhodného výměníku, úspora na provozních nákladech prádelny by odpovídala 730 000 Kč. Výměník ovšem musí být navržen tak, aby mohla probíhat efektivně jeho údržba i každodenní čištění. Zvolen byl trubkový výměník, který by byl opatřen víkem pro snadné zpřístupnění teplosměnných ploch a jejich údržbu. Před výměníkem by byl umístěn filtr pro omezení množství otěru vstupujícího do výměníku. Při finálním návrhu je třeba zohlednit možné tlakové ztráty tohoto filtru i výměníku.

Ideálním pokračováním výzkumu by byl konstrukční návrh takového výměníku a jeho integrace do prádelenského provozu. Tento výměník by musel být korektně vypočítán, navrhnut a také přímo umístěn do provozu. Tím by došlo k ověření teoretických předpokladů a mohly se stanovit investiční a provozní náklady celého rekuperačního systému.

Bibliographic citation

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Affirmation

I declare that this bachelor thesis is my work, led by my supervisor and all used references are listed in the bibliography.

Date

Gabriela Kyzlinková

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Firstly, I would like to kindly express my gratitude to my supervisor doc. Ing. Vítězslav Máša, Ph.D. for his guidance, assistance, support and patience he provided me when writing my bachelor thesis. I would also like to acknowledge Ing. Bohuslav Kilkovský, Ph.D. and Ing. David Horňák for their time, assistance and a helping hand with the practical part of my thesis. My thanks go to anyone else from the Institute of Process Engineering who help me in any other way in the last couple of months. Finally, I would like to thank my partner, family and close friends for their moral support and kind words that kept me going through all the hardships.

Contents

1. Introduction

Nowadays we often face issues with energy prices constantly increasing. Majority of businesses have been forced to increase prices to be feasible. Some businesses even bankrupted because they lost their customers as a result of unaffordable services. This has pushed owners and operators to consider energy efficiency of processes and to implement energy saving measures. One option is the purchase of new, more efficient technologies, which are usually very demanding in terms of investment. An efficient alternative is the installation of waste heat recovery systems that can reduce the heat loss of the technology. Even small and medium industries (SME) started to implement various waste heat recovery technologies to reuse the energy and keep their expenses as low as possible.

There are multiple industries we can focus on and propose waste heat recovery solutions. For this thesis a laundry industry was chosen. In a regular laundry facility, waste heat recovery technologies are usually implemented on washing machines and ironers, but not on laundry dryers. The main problem we are dealing with is the presence of textile residues which makes the design of the system more complicated.

The main goal of this thesis is to calculate the amount of energy that is being wasted from multiple laundry dryers from a particular laundry facility. All the calculations in this thesis have been based on data collection from Homola laundry facility (Czech Republic). Other result is the value of the dew point that indicates whether condensation will occur during a process and what positive and negative effects it has. Finally, the economic evaluation of the waste heat recovery benefits is provided.

The motivation behind this thesis is the assumption that there is a huge amount of waste heat in the laundry dryer waste stream and it is worth to use it. I assume that with the appropriate waste heat recovery technology we could reuse a lot of energy that would be otherwise wasted. There will be initial investments into this waste heat recovery technology, but I suppose it will have a very good payback period.

2. Waste heat recovery

As we are dealing with increasing energy prices, one of our biggest tools to decrease energy usage is to implement waste heat recovery into industries. This chapter will cover the definition of waste heat, how it gets affected, what are its sources and some examples of waste heat from industries.

2.1.Definition of waste heat

Energy generated during industrial processes as a byproduct, further proceeded to atmosphere or into the sewer without any use is considered industrial waste heat. Main sources of waste heat are hot combustion gases, heat transfer from heated equipment or heated water all released into the environment. We can estimate that 20-50% of total energy consumption ends up being waste heat depending on different processes. With modern waste heat recovery technologies as well as better equipment efficiency, we can re-use some of this waste heat. Some examples of waste heat usage are generating electricity or preheating combustion engines. When recovering waste heat, we can either reuse it within the same system for example by using combustion exhaust gases to preheat combustion air. Alternatively, we can transfer waste heat to another one system for example by using heat exchanger. [1]

2.2.Factors affecting waste heat recovery utility

There are several limitations and concerns when considering waste heat recovery such as heat quantity, quality, temperature and waste stream composition. All of parameters mentioned can guide us to proper design as well as correct choice of material. Heat quantity is defined by the amount of energy stored in a waste heat stream that depends on its temperature and mass flow rate. Although heat quantity explains how much energy is contained, another important factor is heat quality that determines waste heat recovery utility. Waste heat temperatures range between lower temperatures around 38-93°C to higher temperatures up to 1316°C and the temperature difference between heat source and heat sink is what defines the waste heat quality. This temperature difference determines the maximal theoretical efficiency when converting thermal waste energy to another energy form while neglecting any energy loses. This theoretical value is given by Carnot efficiency. Carnot efficiency increases significantly with higher temperature difference. [1, 2]

2.3.Sources of waste heat

Waste heat is released as a byproduct in numerous processes, for example in boilers, furnaces or gas turbines. It is considered that around 30-90% of this waste heat can be further used for other purposes such as preheating fresh air or any other heating processes. Another example would be air compressing facilities where around 90% of the electrical capacity can be restored and used for heating water. [3] Waste heat is than used mainly for preheating of water for households, processes or boiler feedwater preheating; for combustion air preheating or space heating. Waste heat recovery has huge economic benefits as there is no additional energy needed as it is replaced by waste heat energy. [1]

2.4.Categorization of waste heat based on temperature

Waste heat temperature is a very relevant factor that determines overall waste heat quality. Temperatures can vary significantly and range from low temperatures around 38-93°C to higher temperatures up to 1316°C. We can divide temperature ranges to ultra-low, low, medium, high and ultra-high quality.

- Ultra-low temperature: below 121°C. Main sources are various cooling mediums such as cooing tower water. Its recovery is influenced by condensation temperature of combustion products and flue gases. Waste heat below 121°C can be for example used in heat pumps. [4]
- Low temperature: 121°C-232°C. Some of the sources are: Hot processed liquids, cooling water from air compressors/internal combustion engines/ air-conditioning, exhaust gases exiting recovery devices. They are typically used for space heating and domestic water heating. The power is generated with lower efficiency. [1]
- Medium temperature: 232°C-649°C. Main sources are: gas turbine exhaust, heat treating furnace, drying and baking ovens. They can be used for combustion air preheat, furnace load/feedwater preheating or they can be transferred to low-temperature processes. [1]
- High temperature: 649°C-871°C. Some common sources are basic oxygen furnace, steel heating furnace, glass melting furnace, etc. They are further used for combustion air preheating, furnace load preheating. Main advantage is high quality energy that can be used in broad range of processes with different temperature requirements. [1]
- Ultra-high temperature: above 871°C. Processing of waste heat at this temperature requires use of special high-temperature materials, selection material as well as equipment impacts the amount of contaminants content in the stream. Waste heat at this temperature can be sourced from glass furnaces or reverberatory furnaces. [4]

2.5.Waste heat in industry

Industrial waste heat can be understood as heat rejected from industrial processes. The most common processes are gaseous streams such as exhaust gas or cooling air, liquid streams and some solids [5]. There are numerous industries that benefit from waste heat recovery system such as:

- **Iron and steel manufacturing**
  Iron and steel industry consists of numerous high temperature furnaces that account for up to 60% of their energy consumption. Recovery from clean gaseous streams is very common, but to process heavily contaminated exhaust gases from furnaces is quite challenging. Heat recovery techniques are available, but their use is limited and complicated with high investment costs. [6]

- **Glass manufacturing**
  In glass industry energy consumption is significant cost of the sector and approximately half of the energy is consumed in the melting furnace. Waste heat energy is mainly in form of furnace flues, while recovering this waste heat can be significant change for the industry. We can achieve greater energy optimization as well as emission reduction. Main waste heat recovery technologies used in glass industry are Organic Rankine cycle as well as Kaline cycle with the assumption of allowing up to 60% of electricity being produced by their own waste heat flow. [7]

- **Cement manufacturing**
  Waste heat recovery systems used in cement industry operate on Rankine cycle. Waste heat recovery systems consist of heat exchangers or heat recovery steam generators that transfer heat from exhaust gases to working fluid. Different types of Rankine cycles used in cement manufacturing are Steam Rankine cycle that uses water as working fluid and generates steam in a waste heat boiler, Organic Rankine cycle that uses high molecular mass as organic working fluid that has a lower boiling point therefore it can use waste heat at lower temperatures and offers greater efficiency or Kalina Cycle that uses mixture of water and ammonia as working fluid that also operates at lower temperatures and is supposed to be up to 15-20% more efficient than ORCs at the same temperature. The assumption is that waste heat recovery can provide up to 30% of overall electricity needs for the industry. Main advantages are reduction of purchased power consumption, reduction of green gas emissions and increasing of plant power reliability. [8]

- **Aluminum production**
  Aluminum ranks as second most highly produced metal in the world. Production of aluminum still leaves some environmental impact while some new technologies aim to recover up to 40% of available waste heat. Aluminum industry is currently responsible for at least 1% of greenhouse emissions and 2,5% of CO_2. The industry is taking steps to improve their impact on the planet by using hydroelectric energy, modernization of equipment, etc.
  Waste heat could be recovered by use of recuperators, air preheaters or heat pumps. Heat recovery in this industry is not easy due to streams that carry exhaust gases that can lead to corrosion, that is why frequent maintenance or replacement of components is essential.
  Current applications of waste heat technologies would include: space heating, generation of electricity by different methods depending on heat quality and overall optimization of aluminum industry when waste heat is used to shorten some stages of production. [9]

- **Metal casting**
  Metal casting requires high temperature for heating and melting of metals and around 55% of industry energy consumption are from melting processes. Large amount of heat from melting processes is lost to the atmosphere while it could be recovered and save up to 20% of manufacture's energy costs.
  Waste heat is mainly used for preheating of material and combustion air or for space heating.
  For example, aluminum casting industry deals with high temperature exhaust that uses recuperators for preheating of combustion air that can save up to 30% of energy consumption. This industry also uses steam od organic Rankine cycle to generate electricity. [10]

This overview of different waste heat recovery technologies and ideas used in various industries gives us an idea of how to create more energy efficient and more environmentally smart industries. Majority of processes mentioned above are high temperature sources of waste heat where its recovery has been already managed well. I would like to use this knowledge and implement it to the case of laundry industry that would classify as low heat source where there is room for improvement of waste heat recovery procedure. In the following chapter different waste heat recovery technologies will be presented.

3. Overview of waste heat recovery technologies

There are multiple waste heat recovery technologies these days and they can be categorized in different ways. Technologies can be classified as active or passive depending whether it requires external energy input or not. [11]

3.1.Heat exchange (passive)

Technologies where the recovered waste heat is used directly at the same or lower temperature. Heat exchanger are mainly used to transfer heat from combustion exhaust gases to combustion air entering the furnace. As we use preheated air at higher temperature in the furnace, we supply less energy by the fuel. [1]

3.1.1. Shell and tube heat exchanger

Sheel and tube heat exchanger have large range of pressures and temperatures and due to their flexibility are currently the most popular on the market. They have simple design, low purchase cost, easy maintenance and relatively very high heat transfer rate. They consist of number of tubes placed in cylindrical container called shell. Each tube passes through number of baffles and tube sheets, where one is fixed and the other one is free to move to allow thermal expansion. The heat is transferred within two fluids while there is no possible contamination. [12]

There is a lot of different designs of shell and tube heat exchangers and they can be classified upon different criterion. We can categorize them based on flow direction into: parallel flow, counter flow (most efficient) and cross flow. We can also classify them based on flowing cycles as:

- Single pass heat exchanger: flowing medium passes over the other one only once
- Multi pass in the tubes: this type of heat exchanger is known as U-tube shell and tube exchanger, where "U" shaped bends in the tubes allow the fluid to flow back and forth across the length of the exchanger.
- Multi pass in the shell: by inserting baffles on the shell side of the exchanger we can direct the shell side fluid back and forth across the tube and achieve multiple passing which increases efficiency. [12]

3.1.2. Plate heat exchanger

They are used when we need to transfer heat from one fluid to another one and avoid any contamination. The exchanger is made of multiple thin plates that are parallelly stacked to form hollow shell. Each plate has slightly different design to allow only one type of fluid to pass through one gap, while the other fluid gets directed to flow through opposite gap. This way both hot and cold fluid pass through each section of the heat exchanger alternating front and back plates without any contamination. Throughout the exchange both hot and cold fluids are exposed to large surface area causing larger heat transfer coefficient. [11]

Plates in the exchanger can be gasketed, brazed or welded together each providing different advantages and disadvantages. Gasketed plates can contribute to very efficient heat transfer with recovery rate to up to 90%. Brazed plates have different design and are more resistant to higher pressure as well as temperature. Welded plates offer better flexibility and resistance when undergoing thermal cycling and pressure variation. [11]

3.1.3. Double pipe heat exchanger

Double pipe heat exchanger is made of two concentric pipes parted by a mechanical closure. There is a smaller pipe that carries cold fluid and another large pipe surrounding the small pipe that has the hot fluid, this allows them to transfer heat without mixing. Cold fluid enters the system and it takes in the heat from the working fluid. The internal wall of the small pipe works as a heat switch and as a conductive barrier. It has simple design, easy operation, low production price, easy maintenance and is suitable for smaller areas. We can recognize two types of double pipe heat exchangers: Counter flow and Parallel flow. In counter flow heat exchanger fluid flow in opposite direction. It is one of the most effective designs which allows the highest temperature difference between hydraulic fluids and it has the highest heat transfer coefficient. In a parallel flow heat exchanger both fluids flow in the same direction. It is less efficient than counter flow heat exchangers but some applications require parallel flow. [13]

3.2.Waste heat to heat (active)

Waste heat is used to produce thermal energy at a higher temperature. The most common waste heat to heat technology are heat pumps. Main purpose of a heat pump is to transfer low temperature heat to high temperature heat while using some external energy input in form of driving force. Some of low temperature energy sources of heat pumps are: air, surface, underground water and other renewable energy sources. [14]

Heat pumps have four main components: condenser, evaporator, compressor and expansion device such as expansion valve. Working fluid that passes through all of the components is called refrigerant [15]. The working cycle starts when refrigerant is pumped through the expansion valve to evaporator at the indoor coils. While liquid refrigerant flows through the inside coils, heat from the outside causes the refrigerant to heat up and it transfer to gas form. After this phase change refrigerant passes through the compressor, where it gets pressurized and flows to the outside coils functioning as condenser. The outside air is cooler than the refrigerant which leads to condensation and cooling of the working fluid. Warm and liquid refrigerant is pumped through the expansion valve which reduces the pressure and cools down the liquid. We reached the end of cycle when refrigerant is ready to pumped back to the inside coils and the cycle starts again. [16]

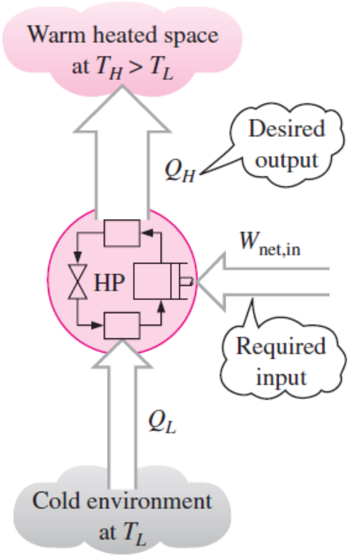

Fig. 3.1 Scheme of a heat pump [2]

The efficiency of a heat pump is expresses by the Coefficient of Performance (COP). It is calculated as a ratio of energy needed in the compressor and the amount of useful output energy. The higher COP is the more efficient the heat pump is. Efficiency of a heat pump depends on temperature difference between condensation and evaporation temperature as well as temperature difference between high temperature source and low temperature sink. [15]

COP is defined as: $\text{COP}=\frac{desired\ output}{\text{required input}}=\frac{Qh}{\text{Wnet,in}}$

There are multiple ways to categorize heat pumps. We can classify multiple types of heat pumps based on source of the heat such as: air to air, air to water, water to water, ground source, etc. We can also categorize heat pumps based on the principle of working as:

- *Mechanical heat pumps*: The principle of working is based on compressor, often driven by electrical power, that increases pressure of refrigerant. We can recognize 2 different systems: pump system and direct expansion system. Mechanical pumps are currently the most popular, but both absorption and adsorption heat pumps are gaining more and more interest on the market. [15]
- *Absorption heat pumps*: The heat pumps are driven by thermal energy instead of mechanical one, where the thermal heat is delivered by combustion of natural gases or by a stream. Their main use is in systems that require both cooling and heating. [15]
- *Adsorption heat pumps*: The principle of working is the same as absorption heat pumps. The only difference is the use of solid-sorption instead of liquid-sorption. This system is used mainly in smaller heat pump systems focused on cooling. [15]

3.3.Waste heat to cold (active)

Waste heat that is used for cooling purposes. Main technology used for cooling purposes are absorption and adsorption chillers. They are used in commercial buildings and industrial plants to provide air-conditioning, refrigeration and cooling of fluids. We recognize two types of chillers: vapor compression and sorption. Vapor compression use compressors mostly powered by electrical motor, but sorption chillers are driven by thermal energy. We also recognize two different designs of sorption chillers: absorption and adsorption. Main difference is that absorption chillers use fluid refrigerants and absorbents, but adsorption chillers use fluid refrigerants and solid sorbents. Chillers are most cost effective at sites that require significant space air conditioning or load cooling. Some examples of the sites would be hospitals, college campuses or hotels. [17]

During the absorption cycle thermal compressor takes low pressure refrigerant vapor form the evaporator delivers high pressure refrigerant vapor to the condenser. Thermal compressor uses an absorbent fluid to chemically bond with the refrigerant vapor and the mixture is pumped to the generator using relatively small electric pump. Using thermal energy refrigerant is boiled in the generator and refrigerant vapor flows to the condenser where it changes its phase and becomes liquid and the cycle can repeat. [17]

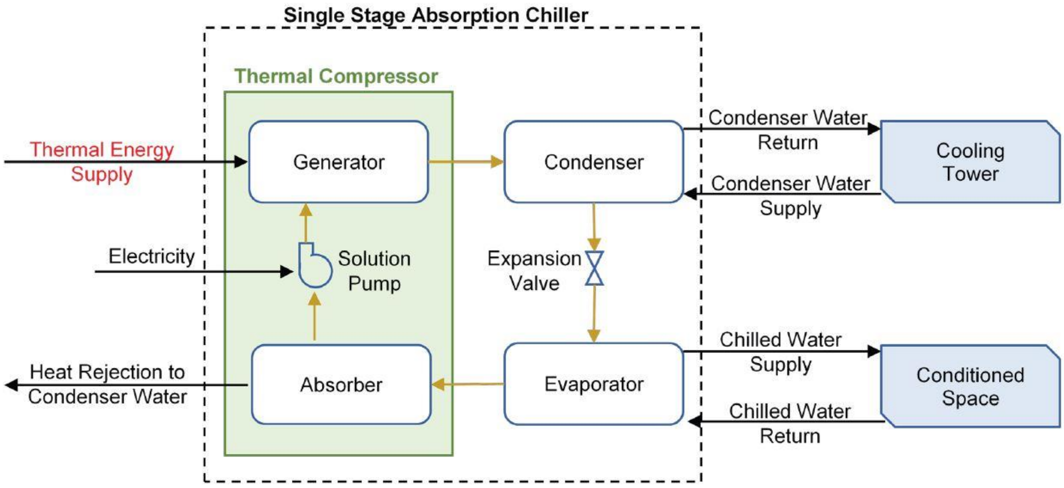

Fig. 3.2 Scheme of a single stage absorption chiller [17]

3.4.Waste heat to power (active)

Waste heat that is converted into electricity.

3.4.1. Organic Rankine cycle

Organic Rankine cycle works on the principle of the Clausius-Rankine cycle, but it uses organic substances as the working fluid to generate power, instead of water or steam. It makes the system suitable for utilization of low-grade waste heat and also to use power sources such as biomass or geothermal energy. [18]

Clausius-Rankine cycle is ideal cycle for vapor power plants, it doesn't involve any internal irreversibilities and consists of four processes:

- Isentropic compression in a pump
- Constant pressure heat addition in a boiler
- Isentropic expansion in a turbine
- Constant pressure heat rejection in a condenser

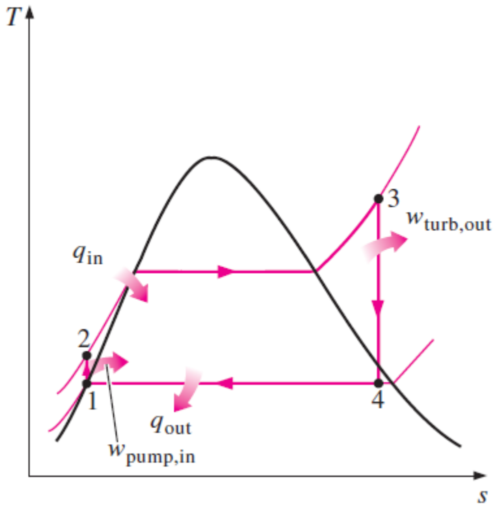

Fig. 3.3 Ideal Rankine cycle in a T-s diagram [2]

3.4.2. Kalina cycle

Kalina cycle also works on the principle of Rankine cycle and it uses the working fluid in a closed cycle to generate electricity. Most commonly used working fluid is a mixture of water and ammonia. Unlike the other cycles, temperature of working fluid is not constant during boiling. The average heat rejection temperature is lower and the average heat addition temperature is higher compared to Rankine cycle which leads to higher efficiency. [18] Kalina cycles are suitable for low-temperature energy sources such as waste heat from gas turbines or waste heat from iron and steel industry.

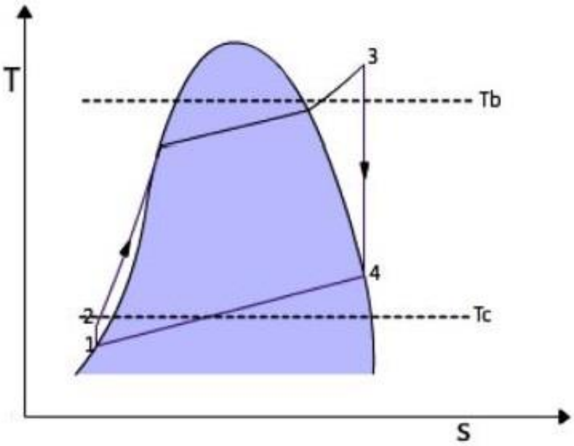

Fig. 3.4 Ideal Kalina cycle in a T-s diagram [18]

3.4.3. Supercritical CO_2 cycle

Supercritical CO_2 power cycles operate in similar manner to turbine cycles, but they are using supercritical CO_2 as a working fluid. The cycle runs above the critical point of CO_2 (exactly above temperature of 304 K and pressure of 7380 kPa) where it does not undergo phase change but its density changes drastically. If we set carbon dioxide above its critical temperature and pressure it behaves as a gas although it still has density of a liquid. Supercritical CO_2 power cycles can lead to increased thermal efficiencies as well as higher power density. Main advantages of using supercritical CO_2 conserves water usage, lowers electricity costs and enables affordable power generation from local heat sources. [19, 20]

3.5.Summary

From different technologies mentioned above, the most commonly used are heat exchangers. Heat pumps are currently becoming more popular and are experiencing growth in popularity. Heat exchangers are well tried and remain the most accessible waste heat recovery technology, which is why this technology will be considered in my practical part.

4. Laundry process

This chapter will cover basic operation functions in laundry industry as well as waste heat technologies used in the industry. As the main aim of this research is to calculate waste heat from laundry dryers, focus will be given to these appliances.

4.1.Characteristics of laundry process

Laundry process is a very complex process that starts with pick-up of laundry from a client and ends with return of laundry that has been sorted, washed, dried, ironed and folded. Typical clients are hotels, restaurants, hospitals or factories and we need to provide them with quality service, what clients are looking for is to get their laundry washed quickly, properly and at relatively low costs.

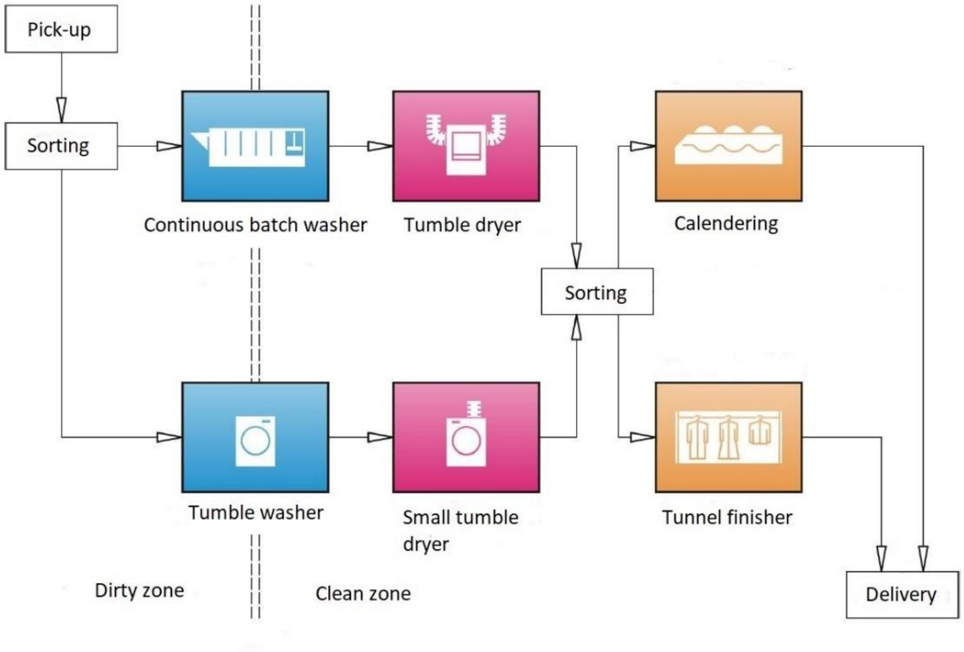

Fig. 4.1 Simplified scheme of a laundry process [21]

As mentioned above, laundry process starts with a pick-up from a client. Laundry is then sorted into loads based on color and level of contamination. Laundry is than washed in a washing machine. Tumble washers are practical for smaller loads that are highly contaminated, while continuous batch washers are suitable for normal level of impurity and even for bigger loads. Laundry from continuous batch washers is drained in press and automatically transferred to a tumble dryer, but laundry from a tumble washer needs to be put in a smaller tumble dryer manually. Laundry is then sorted and can be either ironed using calendaring for flat textile or tunnel finisher for shaped textile. Laundry is than ready to be delivered back to a customer. [21]

There is a partition dividing the space into two sections: dirty zone- where we keep dirty laundry that can be contaminated and clean zone- where we process clean laundry. The only way to cross the partition is through disinfection chamber.

4.2.Current waste heat recovery systems in laundries

With current economic situation and high energy consumption laundry facilities experience difficulties. It is more important than before to be as energy efficient as possible and try to reuse energy whenever we can. Majority of devices in a laundry facility are already connected to some waste heat recovery technology.

Before designing appropriate heat recovery systems in laundry processes, we need to acknowledge number of difficulties such as different heat media sources, contaminated media, dynamics of a process and lack of operation data. All main streams in laundry process contain certain number of pollutants. If we do want to implement heat recovery system, we firstly need to eliminate these pollutants by filtration or separation. We also need to adjust heat exchangers appropriately which can lead to lower performance. From dryers, ironers and tunnel finisher outlet stream is in form of humid air and we mostly deal with textile dust and moisture. From washers the outlet stream is in form of hot waste water and we work with solid and organic pollutants and dissolved detergents. [22]

In the figure below, you can see optimized laundry process. Different waste heat recovery technologies have been designed to reuse waste heat from a washing machine and wet air from ironing and tunnel finishers. In the washing machines waste water is used to heat up the incoming cold water for the next load. This waste heat recovery system does not only help to reduce energy consumption, but also emissions of CO_2. In current laundry facilities, tumble dryers remain the only devices from which warm humid air is freely released into the atmosphere and is not reused. [23, 24]

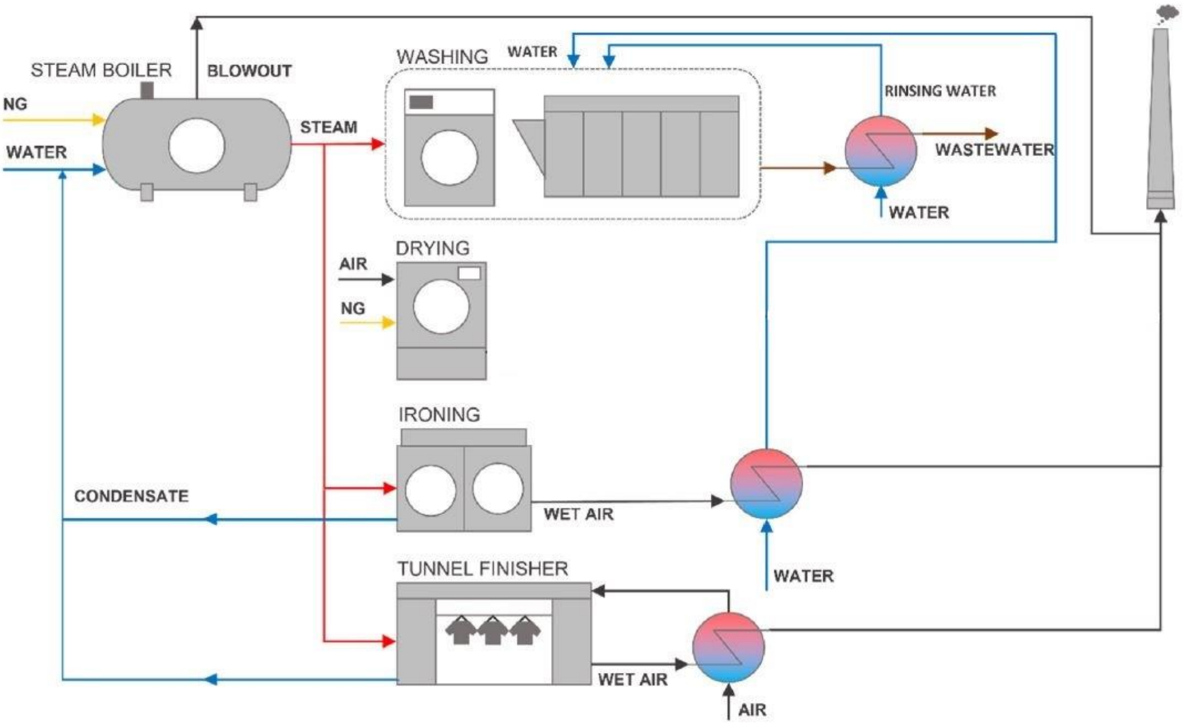

Fig. 4.2 Layout of optimized laundry process [24]

4.3.Laundry dryers and WHR

Laundry dryer is a device that follows after washer and its main purpose is to eliminate humidity contained in washed laundry and prepare it for ironing. Based on a design we can categorize dryers into axial and radial. In axial dryer hot air that dries up the laundry flows in the direction of rotation axis of the drum, while in radial dryer hot air flows in direction perpendicular to the rotation axis. We can experience some energy losses when using radial dryers due to outer stream of hot air not being properly utilized. [21]

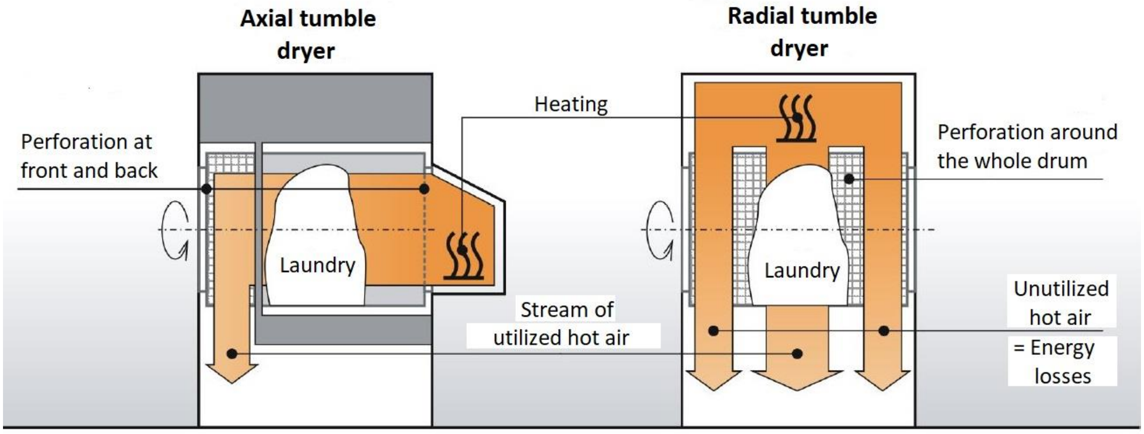

Fig. 4.3 Axial and Radial Laundry Dryers [21]

To dry the laundry, we start with heating that leads to evaporation of humidity contained in laundry. For heating process, there are two options. We can use hot air that is heated in steam heat exchanger or flue gases directly heated in natural gas combustion chamber before entering the dryer to desired temperature which is around 150°C to 180°C.

Important parameters for laundry drying are:

- Laundry humidity - is the amount of water in kilograms contained in 1kg of dry laundry.
- Average water evaporation - amount of water the dryer can remove from laundry in certain time period. It depends on size of the drum as well as quality of hot air.
- Dryer cycle - time for drying of 1 laundry load and for loading and unloading it. Dryer cycle depends mainly on temperature of drying medium (hot air/flue gas) and should not be longer than washing cycle, so there would not be delay when laundry is washed and ready to be dried.

Energy is brought to the dryer in form of steam of natural gas that is used to heat the drying medium (hot air), evaporate the humidity from laundry and to cover losses from environment. Energy used to evaporate humidity is around 2500 kJ per 1 l of evaporated water. Only small amount of energy is used for heating of laundry (around 78 kJ per 1 kg of laundry to increase temperature by 60°C). [21]

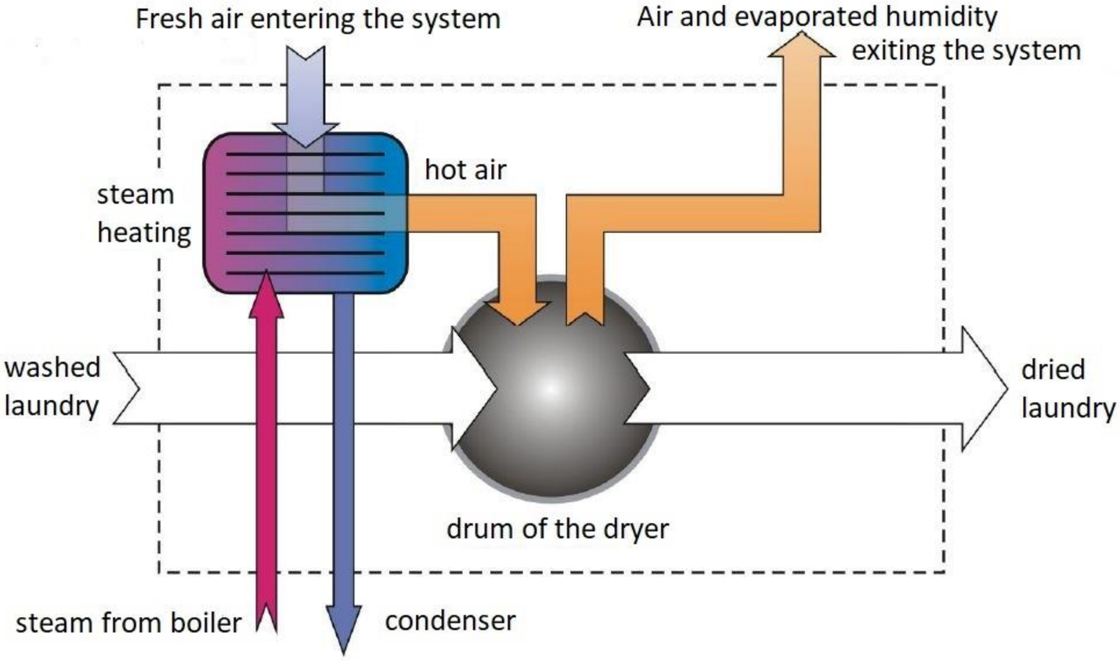

Fig. 4.4 Scheme of a steam tumble dryer [21]

In the scheme of a tumble dryer above we can see that warm and humid air is released into the atmosphere without any further use. Tumble dryers are the only devices within laundry process that does not use any waste heat recovery technologies to reuse warm air exiting the device. Before connecting any type of waste heat recovery technology, we would need the warm air to go through a lint filter chamber to remove lint from the air so we can further use it. In lint filter chamber it would also lose some energy to the surroundings as well as it would undergo pressure drop. Then the air enters a fan and can be reused in two different scenarios. It can either circulate back and mix directly with the incoming stream while preheating the air before it enters the drum, or it can flow directly into a heat exchanger. [22]

With this knowledge of laundry process, drying process and waste heat recovery in a laundry dryer we will move to the next chapter where the calculation will take place. Calculation of waste heat from multiple laundry dryer will be provided as well as evaluation of placement of heat exchanger onto different temperature and flow rate water streams.

5. Proposal of the waste heat recovery system – a case study

Practical part of the research is focused on utilization of waste heat. Solution will be conservative and waste heat recovery technology used will be heat exchanger as it is well-tried, convenient and is commonly used within laundry industry.

5.1.Homola laundry facility

In previous chapters we talked about waste heat recovery, its sources as well as different WHR technologies. Then laundry process was introduced and explained. Now I would like to focus on calculation of waste heat from a particular laundry dryer. Calculation would be based on laundry facility Homola. As you can see in the figure attached below, there is a partial waste heat recovery in the facility. The hot humid air leaving ironers is used to preheat some amount of fresh water. There is also some amount of fresh water that is pre-heated with wastewater from washing machines.

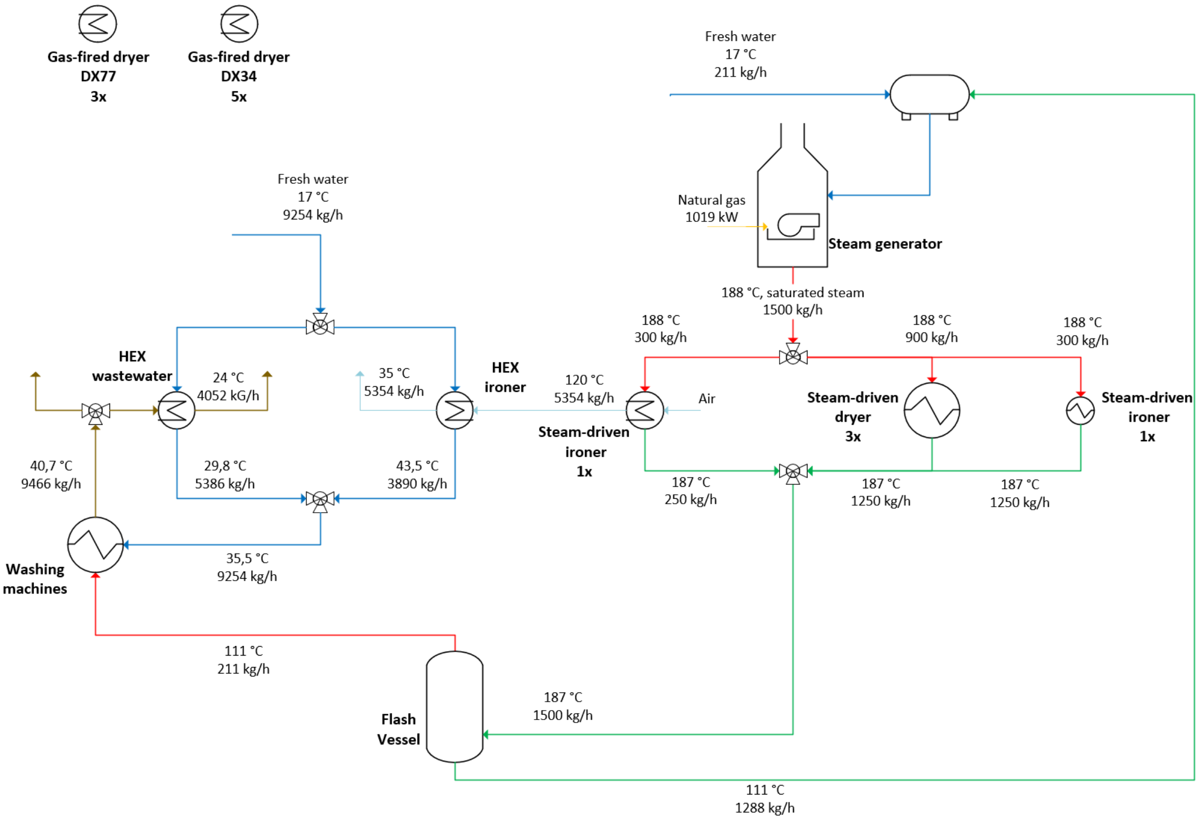

Fig. 5.1 Scheme of a laundry facility Homola

The main goal is to find technology suitable for waste heat recovery from gas-fired dryers that would not be negatively affected by fouling. In my calculations I will compare different locations suitable for heat exchanger placement. In Homola laundry facility there are 3 larger dryers Dx77 and 5 smaller dryers Dx34, when calculating waste heat I will consider operation of 2 larger and 3 smaller dryers as average operational state.

Before calculation I will introduce appropriate data. At the beginning of academic year 2022 there has been data collection carried out in laundry facility Homola. Data has been compiled using software Torreo. Average values have been determined for one drying cycle using both Dx77 and Dx34. In the table below you can see all data used for calculation of waste heat.

Tab. 5.1 Data for Dx77 and Dx34

Symbol	**Quantity**	**Dx77**	**Dx34**
T [°C]	Average temperature of air flow	67,7	72,4
$\dot{m}_{dry\ air}$ [kgsv/s]	Mass flow rate of dry air	0,703	0,241
$\dot{m}_{vapor}$ [kgH_2O/s]	Mass flow rate of vapor	0,0277	0,00617
x [kgH_2O/kgsv]	Specific humidity of humid air	0,0394	0,0256
RH [%]	Relative humidity of humid air	21,9	11,6
$cp_{humid\ air}$ [J/kgK]	Specific heat of humid air	1010	1010
cp_{vapor} [J/kgK]	Specific heat of vapor	1840	1840
cp_{water} [J/kgK]	Specific heat of water	4180	4180
l [J]	Latent heat of vaporization	2500000	2500000

When designing heat exchanger ensure there is at least couple degrees difference between higher temperature medium leaving the exchanger and lower temperature medium entering the exchanger. In our case it means that we will cool down the air from dryers to a minimum temperature that is couple degrees higher than entering fresh water.

5.2.Calculation of dew point

Dew point temperature is defined as the temperature at which condensation begins when the air is cooled at constant pressure [2]. It is essential to calculate dew point to determine under what temperatures condensation will occur and to take this information into consideration when choosing appropriate heat exchanger. For the calculation of dew point we will use Magnus- Tetens formula.

$$T_s = \frac{b \cdot \alpha(T;RH)}{a - \alpha(T;RH)}$$

$$\alpha(T;RH) = \ln\left(\frac{RH}{100}\right) + \frac{a \cdot T}{b + T}$$

T_s represents dew point temperature

b= 243,12 (coefficient)

a= 17,62 (coefficient)

RH represents relative humidity

α is a function of temperature of air and its relative humidity

a) Calculation of dew point temperature for laundry dryer Dx77

Input parameters are:
T= 67,7°C
RH= 21,9%
a= 17,27 ; b= 237,3

$$\boldsymbol{\alpha(T;RH)} = \ln\left(\frac{RH}{100}\right) + \frac{a \cdot T}{b + T} = \ln\left(\frac{21{,}9}{100}\right) + \frac{17{,}27 \cdot 67{,}7}{237{,}3 + 67{,}7} = 2{,}31$$

$$\boldsymbol{T_s = \frac{b \cdot \alpha(T;RH)}{a - \alpha(T;RH)} = \frac{237,3 \cdot 2,31}{17,27 - 2,31} = 36,2°C}$$

b) Calculation of dew point temperature for laundry dryer Dx34

Input parameters are:
T= 72,4°C
RH= 11,6%
a= 17,27 ; b= 237,3

$$\boldsymbol{\alpha(T;RH)} = \ln\left(\frac{RH}{100}\right) + \frac{a \cdot T}{b + T} = \ln\left(\frac{11{,}6}{100}\right) + \frac{17{,}27 \cdot 72{,}4}{237{,}3 + 72{,}4} = 1{,}88$$

$$\boldsymbol{T_s = \frac{b \cdot \alpha(T;RH)}{a - \alpha(T;RH)} = \frac{237,3 \cdot 1,88}{17,27 - 1,88} = 28,9°C}$$

Dew point temperatures calculated are 36,2°C for Dx77 and 28,9°C for Dx34. It means that if we cool these mediums down to lower temperature than dew point temperature, we will have to deal with condensation in a heat exchanger. That can provide us with more energy but heat exchanger would need more maintenance.

We calculated with average relative humidity as it changes through the drying cycle. Relative humidity fluctuates between 10-50% in both Dx77 and Dx34 laundry dryers. You can see in the graph beside how humidity changes during one drying cycle.

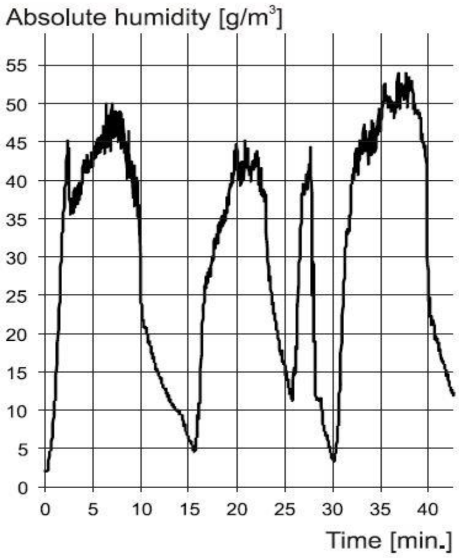

Fig. 5.2 Humidity throughout drying cycle [22]

5.3.Calculation of heat from a particular dryer

Different placements for heat exchanger will be presented. Each case will calculate with different input parameters such as temperature and flow rate of the water.

Placement A

The inlet temperature of water is 29,8°C with flow rate of 5386 kg/h.

Heat exchanger would be placed after the wastewater heat exchanger. After exiting the exchanger, it would then mix with water coming out of the ironer heat exchanger. Using this placement of heat exchanger, we would cool our humid air down to 35°C which is lower than dew point temperature of laundry dryer Dx77. That would cause condensation in the heat exchanger, which can provide us with more energy but also more difficult maintenance of the exchanger. Dew point temperature of Dx34 is lower than 35°C so condensation will not occur.

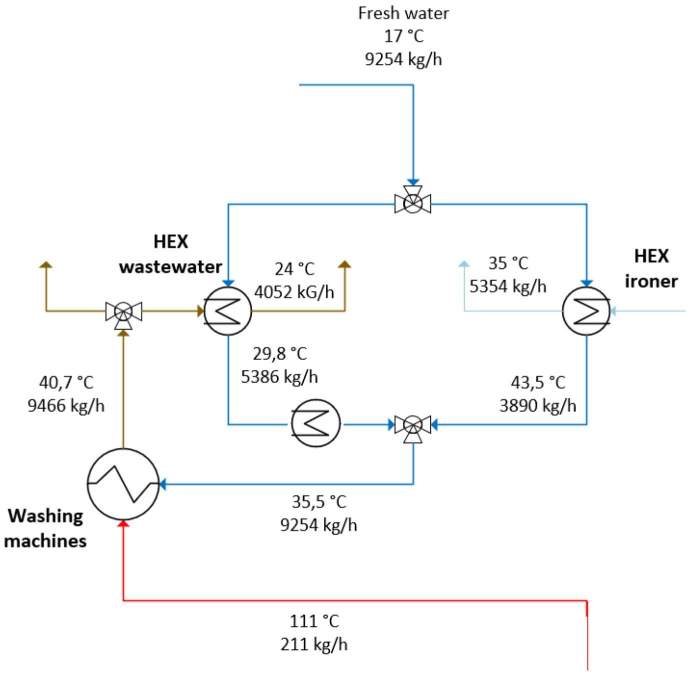

Fig. 5.3 Scheme of a laundry facility Homola- Placement A

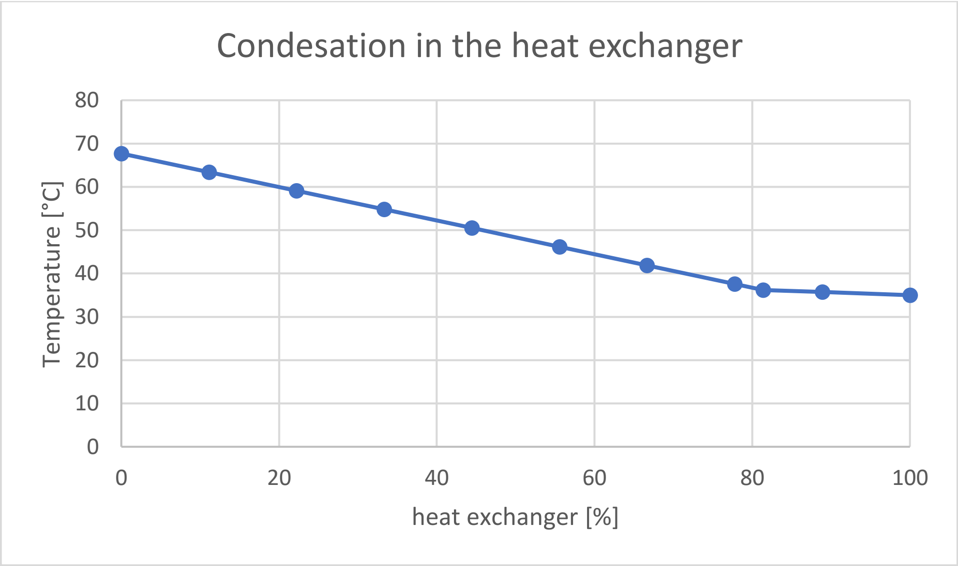

Fig. 5.4 Condensation in Dx77 - Placement A

Placement B

The inlet temperature of water is 43,5°C with flow rate of 3890 kg/h.

Heat exchanger would be placed after the ironer heat exchanger. After exiting the exchanger, it would then mix with water coming out of the wastewater heat exchanger.

Using this placement of heat exchanger, we would cool our humid air down to 48°C which is higher than dew point temperature of both laundry dryers. We do not have to consider condensation.

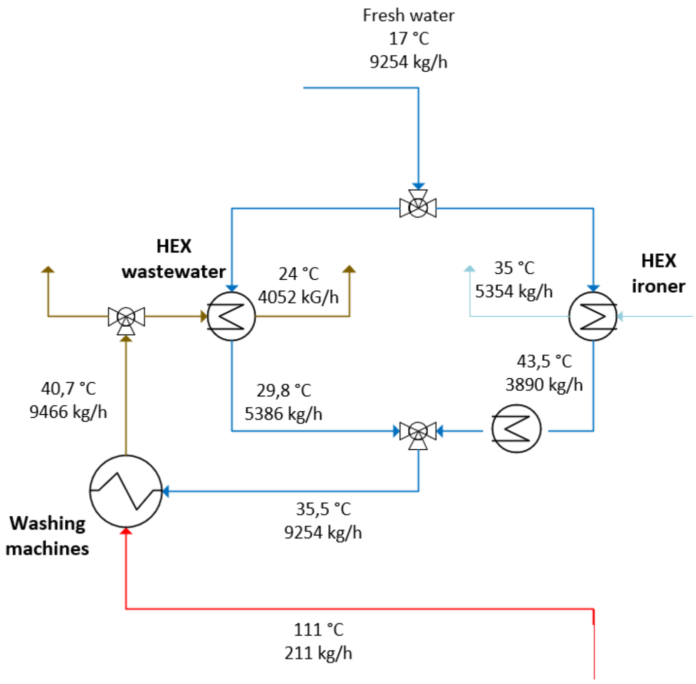

Fig. 5.5 Scheme of a laundry facility Homola- Placement B

Placement C

The inlet temperature of water is 35,5°C with flow rate of 9254 kg/h.

Heat exchanger would be placed after the mixing chamber of water from wastewater heat exchanger and ironer heat exchanger. After exiting the exchanger, there will be no mixing needed.

Using this placement of heat exchanger, we would cool our humid air down to 40°C which is higher than dew point temperature of both laundry dryers. We do not have to consider condensation.

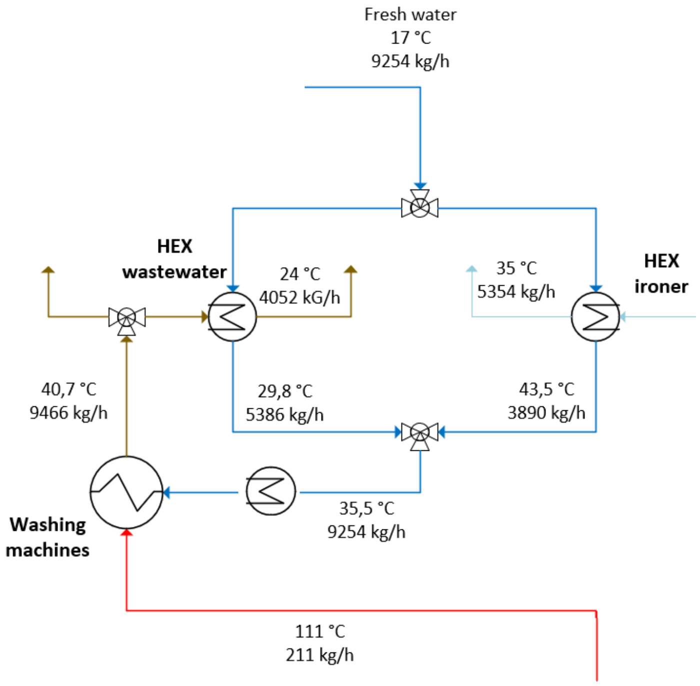

Fig. 5.6 Scheme of a laundry facility Homola- Placement C

Placement D

The inlet temperature of water is 17°C with flow rate of 9254 kg/h.

Heat exchanger would be placed directly on the fresh water stream. After exiting the exchanger, it would continue to wastewater heat exchanger or ironer heat exchanger.

Using this placement of heat exchanger, we would cool our humid air down to 23°C which is lower than dew point temperature of both laundry dryers. That would cause condensation in the heat exchanger, which can provide us with more energy but also more difficult maintenance of the exchanger.

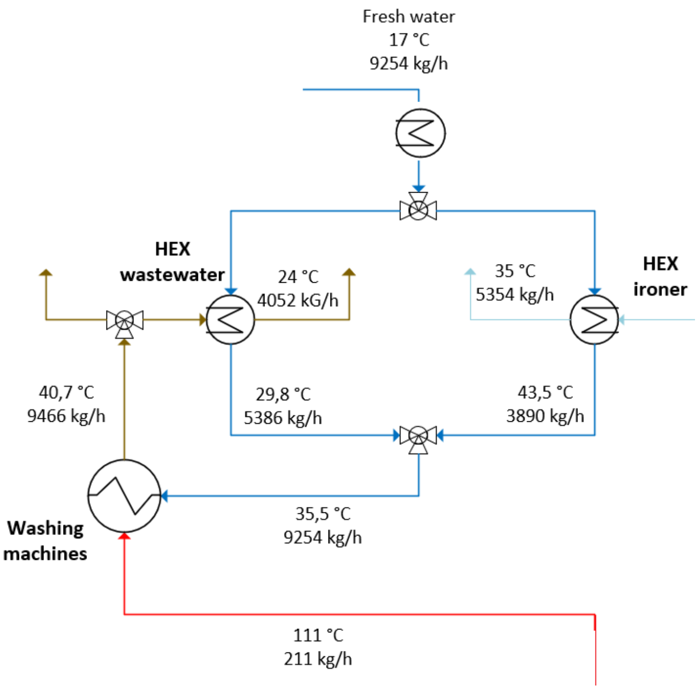

Fig. 5.7 Scheme of a laundry facility Homola- Placement D

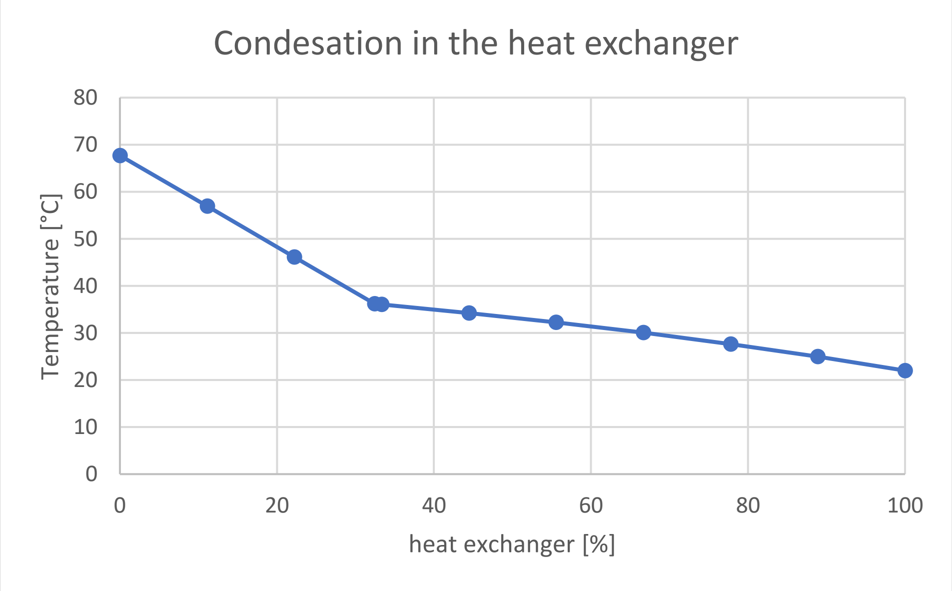

Fig. 5.8 Condensation in Dx77 - Placement D

Placement E

The inlet temperature of water is 17°C but the flow rate is unknown.

Heat exchanger would be placed directly on the fresh water stream. After exiting the chamber where water would divide into 3 stream all headed into different heat exchanger.

Using this placement of heat exchanger, we would cool our humid air down to 23°C which is lower than dew point temperature of both laundry dryers. That would cause condensation in the heat exchanger, which can provide us with more energy but also more difficult maintenance of the exchanger.

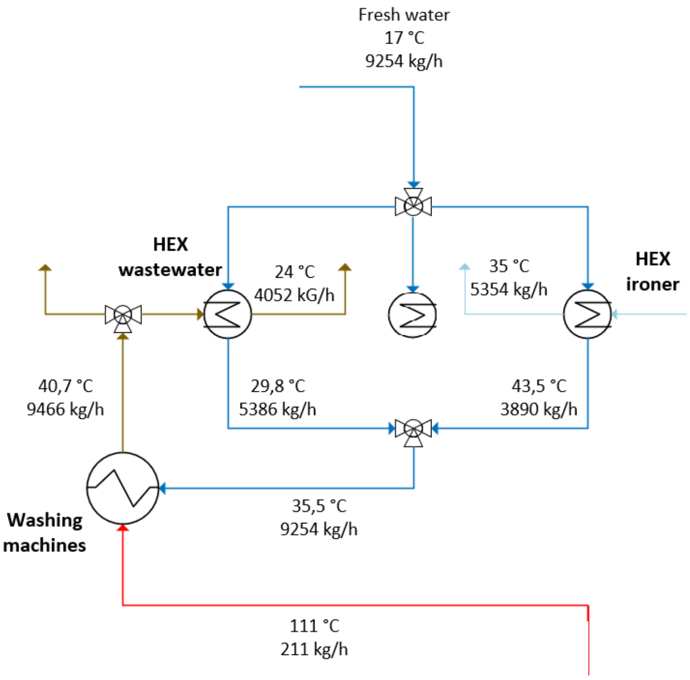

Fig. 5.9 Scheme of a laundry facility Homola- Placement E

Calculation

Before calculation can start, condensation needs to be taken into consideration. If there will be condensation in the heat exchanger, specific humidity will decrease. If the final temperature is higher than dew point and condensation will not occur, then the specific humidity remains constant.

After this step the calculation process would be the same for any given placement. On the following page there will be a demonstration of calculation provided for placement A.

Placement A – calculation

Condensation needs to be taken into consideration when calculating the heat because both specific humidity as well as temperature will differ at the inlet and outlet.

Partial pressure and specific humidity would be calculated using formulas:

$$\ln p_v = 23{,}58 - \left(\frac{4044{,}2}{235{,}6+T}\right)$$

$$x = 0{,}622 \cdot \left(\frac{pv}{p-pv}\right)$$

Partial pressure: $\ln p_v = 23{,}58 - \left(\frac{4044{,}2}{235{,}6+35}\right) = 8{,}635$ $p_v = 5623$ Pa

Specific humidity: $x = 0{,}622 \cdot \left(\frac{5623}{101325-5623}\right)$ $x = 0{,}0365$ $kgH_2O/kgsv$

This outlet specific humidity calculation would be used for Dx77 as we deal with condensation. For Dx34 specific humidity remains constant.

Specific enthalpy

$h = h_{sv} + h_{vp} = c_{sv} \cdot t + x \cdot (c_{vp} \cdot t + l)$

Dx77:

$h_1 = 1010 \cdot 67{,}7 + 0{,}0394 \cdot (1840 \cdot 67{,}7 + 2500000) =$ **171785** J/kg

$h_2 = 1010 \cdot 35 + 0{,}0365 \cdot (1840 \cdot 35 + 2500000) =$ **128951** J/kg

Dx34:

$h_1 = 1010 \cdot 72{,}4 + 0{,}0256 \cdot (1840 \cdot 72{,}4 + 2500000) =$ **140534** J/kg

$h_2 = 1010 \cdot 35 + 0{,}0256 \cdot (1840 \cdot 35 + 2500000) =$ **100999** J/kg

Formulas:

$dh = cp(T) \cdot dT$

$Q = m \cdot (h_1 - h_2) = m \cdot cp \cdot (\Delta T)$

Heat from the dryers

DX77

With the assumption that 1 cycle takes 35 minutes we can calculate

m= 0,703·60·35 = 1476,30 kg/cycle

Heat released from 1 dryer per 1 cycle

$Q = m\cdot(h_1 - h_2) = 1476{,}3\cdot(171785 - 128951) =$ **63 235 834** J

Having 2 dryers we get

Q = 2·63 235 834 = **126 471 668 J**

DX34

With the assumption that 1 cycle takes 35 minutes we can calculate

m= 0,241·60·35 = 506,1 kg/cycle

Heat released from 1 dryer per 1 cycle

$Q = m\cdot(h_1 - h_2) = 506{,}1\cdot(140534 - 100999) =$ **20 008 664** J

Having 3 dryers we get

Q = 3·20 008 664 = **60 025 991 J**

In total from all 5 dryers per 1 cycle we obtain

Q = 126 471 668 + 60 025 991 **= 186 497 659 J**

From the law of energy conservation, we know that energy supplied to thy system has to be equal to energy obtained from the system. Knowing energy supplied to the system we can calculate by how much we can heat up the water.

$Q_{in}=Q_{out}$

Mass flow rate of water m = **5386** kg/h = **3142** kg/cycle

$$Q = m\cdot cp\cdot(\Delta T) \rightarrow \Delta T = \frac{Q}{m\cdot cp} = \frac{186\ 497\ 659}{3142\cdot 4180} = \mathbf{14{,}2°C}$$

It means we can heat the water to **42,33°C**

Mixing chamber

After mixing these mediums in a mixing chamber we get

1. Medium - 42,33°C, 5386 kg/h
2. Medium – 43,5°C, 3890 kg/h

Final temperature would be calculated using ratios of mediums as:

$$T = \left(\frac{5386}{(5386+3890)}\cdot 42{,}33\right) + \left(\frac{3890}{(5386+3890)}\cdot 43{,}5\right) = \mathbf{44°C}$$

This calculation could be implemented for any placement. In the table below I provided the results for other placements. Calculation at placement E would be challenging as the input parameters are unknown, but it could potentially be the most convenient location.

Tab. 5.2 Results for cases A, B, C and D

Parameters		**Case A**	**Case B**	**Case C**	**Case D**
T [°C] - Inlet temperature		29,8	43,5	35,5	17
ṁ [kg/h] - Mass flow rate		5386	3890	9254	9254
p_v [Pa] - Partial pressure		5623	-	-	2811
x [kgH$_2$O/kgsv] - Specific humidity		0,0365	-	-	0,0178
h_2 [J/kg] - Outlet enthalpy for Dx77		128951	150460	141800	68483
h_2 [J/kg] - Outlet enthalpy for Dx34		100999	114741	106284	68483
Q [J] - Heat released from Dx77		63 235 834	31 482 098	44 266 856	152 504 743
Q [J] - Heat released from Dx34		20 008 664	13 053 837	17 333 925	36 465 011
Q [J] - Heat released from all dryers combined		**186 497 659**	**102 125 707**	**140 535 487**	**414 404 519**
ṁ [kg/cycle] - Mass flow rate		3142	2269	5398	5398
T [°C] - Water temperature change		**14,2**	**10,77**	**6,23**	**18,37**
T [°C] - Outlet water temperature		42,33	54,27	41,73	35,37
T [°C] - Temperature after mixing		44	40,06	41,73	-

From the table below we can see that placement D would provide us with by far the largest amount of energy due to condensation. This placement would also change input parameters for waste water heat exchanger as well as ironer heat exchanger. Without the knowledge of energy of the waste heat from these two heat exchangers, it would be hard to evaluate if this position is more convenient than previous suggested positions. Economic analysis will be provided for placement A as it provides the highest amount of energy without interfering into current laundry facility setting.

Other parameters affecting the final temperature

There are multiple parameters not included in calculations that would slightly affect its result. There have been no thermal loses included in calculations above. We also need to take in consideration calculation with average values of temperature and humidity due to unstability of the cycle. Graphs displaying temperature change throughout the cycle from data collection in 2022 are attached below. Due to discontinuous operation of dryer, we calculated with ideal case of all dryers undergoing the cycle at the same time. In real operation we would obtain lower released heat and would not be able to heat up the water to the same temperature. We need to consider this only a theoretical value.

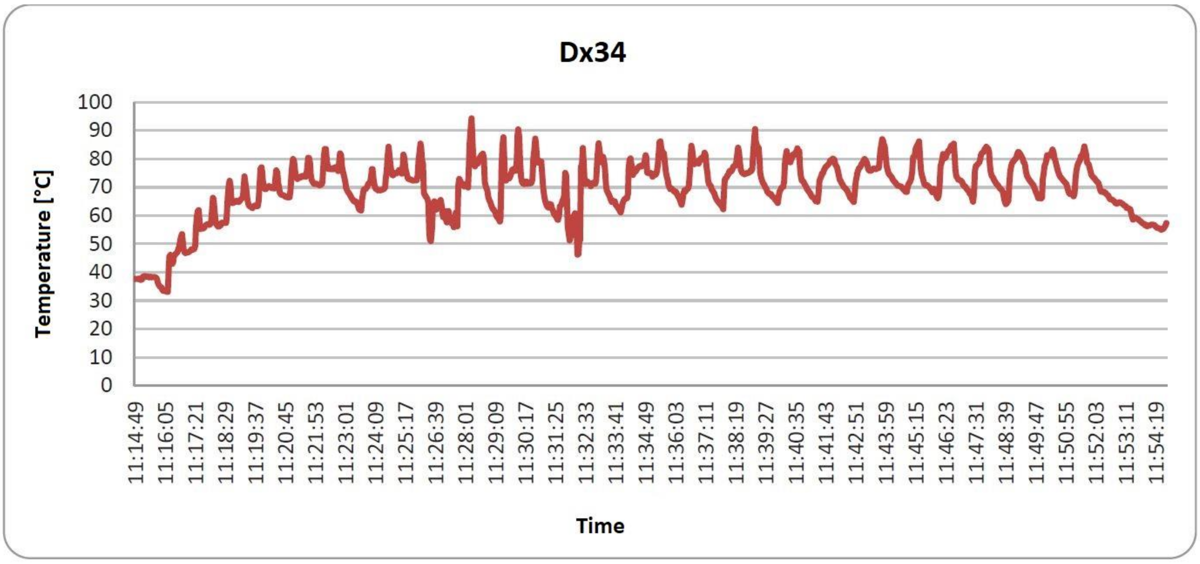

Fig. 5.10 Temperature change throughout the cycle Dx34

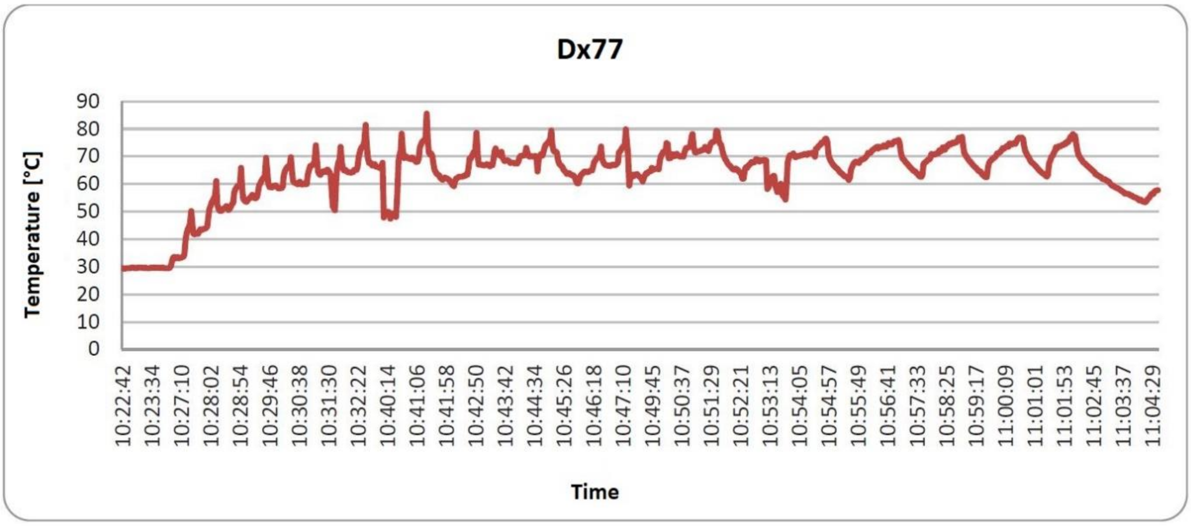

Fig. 5.11 Temperature change throughout the cycle Dx77

5.4.Economic analysis

In the previous chapter we calculated how much energy we could get if we place heat exchanger on different temperature streams. The highest amount of energy would be obtained from the lowest temperature stream at placement d). This placement is not suitable as it would completely change input parameters for waste water heat exchanger as well as ironer heat exchanger. The second highest amount of energy would be obtained at placement a) as condensation would occur. Economic evaluation will be calculated from the assumption that we would obtain 186 497 659 J/cycle as calculated in chapter 5.3. placement a).

To calculate the amount of energy in J/s under the assumption that 1 cycle takes 35 mins:

$186\,497\,659 / (35 \cdot 60) = 88\,808$ J/s ≐ **88,8 kW**

Calculation of kWh wasted every year under the assumption that:

- Homola laundry facility runs every day for a 12-hour long shifts
- 15% of total time is used for laundry transfer

$12 \cdot 365 \cdot 0{,}85 =$ **3723 hr/year**

$3723 \cdot 88{,}8 =$ **330 602 kWh**

In the Homola laundry facility there is a natural has boiler with 90% efficiency. If ideal gas boiler can convert 1m^3 of natural gas to 10,55 kWh [26] than boiler with 90% efficiency can convert 1m^3 of gas to 9,5 kWh.

To get 330 602 kWh we would need (330 602 / 9,5) **34 800 m^3** of natural gas.

Price of natural gas variates, but if we would choose E. ON as our supplier the price would average to **21 CZK/m^3** [27].

As we need 34800 m^3 of natural gas at price of 21 CZK/m^3, that would cost us **730 830 CZK**.

After installation of a suitable heat exchanger placed on placement a) which is on the water stream at 29,8°C we could save around 730 000 CZK. We need to take into consideration initial investment of buying a heat exchanger as well as its regular maintenance. Then we could calculate after what time period this investment would actually become profitable.

5.5.Heat exchanger design

In chapter 3.1. different types of heat exchangers were discussed. The most common types of heat exchanger used are shell and tube, plate and double pipe. Due to the amount of textile abrasion, we need a heat exchanger, that would undergo daily cleaning as well as frequent maintenance. Both plate heat exchanger and double pipe heat exchanger can be easily blocked and are not convenient for unclean mediums. The best option would be to use shell and tube heat exchanger with a lid cover. That would allow the exchanger to be cleaned daily and maintained when needed.

As important as it is to select appropriate heat exchanger it is also essential to choose suitable filter. If we implement filter into the system before the heat exchanger, we would minimize the amount of textile abrasion. Fitting filter would decrease the amount of textile abrasion while not generating large pressure loses. I would suggest pressure gauge to be involved to indicate if the pressure is getting dangerously low as it could block the pipe.

Condensation in a heat exchanger is something we definitely need to take into consideration. Condensation provides us with higher energy because of latent heat and humidity change, but it also causes some difficulties in the exchanger such as corrosion, that is why we need to acknowledge this when choosing heat exchanger material. Stainless steel could be considered as it is somehow resistant to corrosion.

6. Conclusion

The main purpose of this research was to calculate waste heat from a particular laundry dryer. It focused on calculation of dew point, comparison of different placements of the heat exchanger and its suitable type as well as economic evaluation if it is worth investing into installing new heat exchanger into the laundry facility.

The procedure of this thesis was as followed.

- Theoretical study and literature review to set grounds
- Information about waste heat recovery and its sources, waste heat recovery technologies such as different types of heat exchangers, cycles and laundry process, its definition as well as current waste heat recovery technologies was collected
- Practical calculations of waste heat, dew point and economic profit

Required targets have been achieved. Maximum waste heat calculated was up to 89 kW, that is in the case that two larger dryers with a capacity of 77kg and tree smaller dryers with capacity of 34kg are in operation and heat exchanger would be placed on water stream at 29,8°C with flow rate 5386 kg/h, temperature change of 14,2°C could be reached and the final temperature of water stream after mixing would be 44°C. If suitable heat exchanger would be installed, we could save up to 730 000 CZK every year. That would be under the assumption that laundry facility would be running daily for 12-hour long shifts. Appropriate heat exchanger, preferably shell and tube, would be used as well as proper filtration to minimize its fouling with textile residues.

Future work should be focused on actual design and calculation of the shell and tube heat exchanger. This heat exchanger would need to be manufactured with a service lid that would allow daily cleaning as well as maintenance. To decrease the amount of textile residues and fouling of the heat exchanger, proper filtration should be provided. There would certainly be a lot of interest in this system among laundry operators.

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