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A Two Year Comparison of Energy and CO_2 Emissions of an Industrial Refrigeration Plant after the Installation of a Waste Heat Recovery System

Rob Turnbull[a,*], Tariq Muneer[a]

[a] *Edinburgh Napier University, Merchiston Campus, 10 Colinton Road, Edinburgh, EH10 5DT5 United Kingdom*

Abstract

The Paris Agreement aims to combat climate change by keeping a global temperature rise this century well below 2°C by the reduction of CO_2 production. Scotland aims to be a world leader in the change and has set ambitious targets to meet this commitment. With nearly 70% of the energy cost in the production of ice cream spent on refrigeration, any improvement in their efficiency will reduce energy costs and CO_2 production. A waste heat recovery system presents a great opportunity to reclaim energy from the onsite refrigeration systems and convert it into useful hot water. A £216,275 project funded by The Engineering and Physical Sciences Research Council and Innovate UK was setup to investigate the use of a waste recovery system within an onsite refrigeration system. The results showed a savings of 5% by the refrigeration plant in total along with an individual saving of 27% by the compressor within the refrigeration system. The WHRS also produced a supply of hot water which could be used onsite within the manufacturing or cleaning processes required onsite.

Keywords: Energy Reduction; Two Year Analysis; Waste heat Recovery System; CO_2 Reduction

* Corresponding author. Tel.: +44 0131 455 2369
E-mail address: R.Turnbull@napier.ac.uk

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Nomenclature

CiP	Clean in Process
CTA	Control Temperature Area
HWR	Hot Water Reservoir
WHRS	Waste Heat Recovery System

1. Introduction

The Paris Agreement, which was signed in 2015 by 195 countries aims to mitigate the impact of the global warming by reducing the global mean temperature rise well below 2ºC [1], [2]. Scotland has placed even stricter targets on itself with the aim of becoming a world leader by reducing its CO_2 emissions by 42% by 2020 [3]. The food and drinks industry is the 4th highest industrial energy user in the UK, consuming 24.6TWh of energy and emitted approximately 9.1MteCO_2 in 2014, this was just over 1% of the total UK CO_2 emissions[1]. With nearly 70% of the energy cost in the production of ice cream spent on refrigeration, any improvement in their efficiency will reduce energy costs and CO_2 production[4]. There is an estimated potential for waste heat recovery of 2.8 TWh/year in the UK food and beverage industry which can be classed as green and carbon neutral. If this waste energy could be used to replace conventional gas heating processes than it would be possible to save £70 million/year as well as 500,000 tonnes of CO_2/year [5].

Mackie's of Scotland, the biggest ice cream producer in Scotland and 5th in the UK [6] is also committed to reducing its CO_2 and waste production as well as energy demand on the grid. Having already installed 4 turbines with a combined capacity of 3 MW and a 1.8 MW array of solar panels to help offset their energy demand, their site also has a 400 kW biomass plant to provide heating to the offices and houses onsite [7]. However, being a large ice cream producer also requires large amounts of refrigeration onsite with several cold stores used for the storage of the produced ice cream. Although the need for refrigeration cannot be replaced in the industry, the waste from this process could be recovered and recycled in a more useful way, instead of being vented to the atmosphere where it can contribute to global warming. Retrofitting a desuperheater to the already existing refrigeration system could be used to extract the waste heat and use it to heat water, which can be used onsite in either the manufacturing process or many of the cleaning processes required onsite. One such example of the hot water demand of the site which the WHRS could supply is the clean-in-process (CiP) system. This system requires 500 litres of water at 70ºC per week to clean the tanks and pipes of the ice cream plant. This is currently achieved by producing steam with an onsite diesel boiler and then exchanging heat between the steam and mains supply water at around 10ºC. If the WHRS could replace the mains supply water with water at 60ºC, the energy demand of boiler could be reduced.

Therefore a £216,275 project funded by The Engineering and Physical Sciences Research Council and Innovate UK was setup to investigate the benefits of using of a waste heat recovery system on an industrial site of this scale. A desuperheater provide by Waste Heat Recovery Limited (WHRL) was installed at Mackie's site in Inverurie. The refrigeration system was monitored for a year before and after the installation. This energy demand data was analysed to determine the impact of the WHRS on the refrigeration system and if any changes in energy demand and CO_2 emissions could be determined.

1.1. Refrigeration System

A standard refrigeration system consists of a compressor, condenser, expansion valve, evaporator and a defrost circuit. The temperature within the controlled temperature area (CTA) is maintained by controlling the pressure, temperature and mass flow rate of the refrigerant through these components. The addition of defrost circuit also prevents any ice build-up on the evaporator, which reduces the efficiency of the refrigeration system. Fig 1 shows a simple illustration of a refrigeration system.

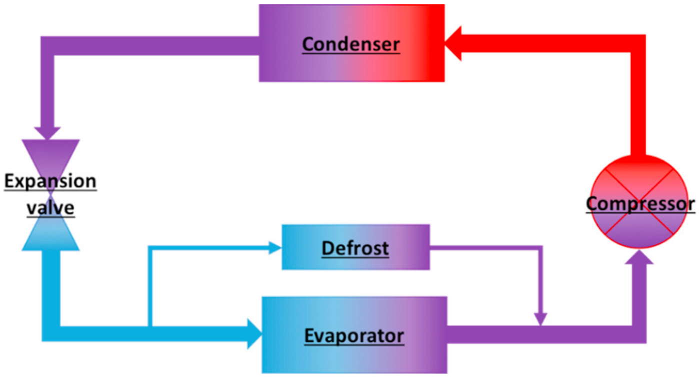

Fig. 1. Simple Illustration of the Refrigeration Cycle

The cooling of the CTA is achieved by the removal of heat at the evaporator by boiling and superheating the liquid refrigerant at low pressure. At low pressure, the boiling temperature of the refrigerant is lower than the required CTA temperature which allows the transfer of heat to the refrigerant. As the temperature exiting the evaporator is lower than that of the ambient environment, the compressor is used to increase the pressure and therefore temperature of the exiting gas. As the temperature of the gas is now higher than the ambient environment, the condenser is able to reject heat from the refrigerant to the ambient environment causing the refrigerant to condense. The liquid refrigerant than passes through the expansion valve which controls the mass flow rate entering the evaporator to maintain the temperature in the CTA.

1.2. Mackie's Refrigeration System

The refrigeration system at Mackie's consists of two refrigeration systems, System 1 and System 2 and is collectively known as the York Plant. It is an R404a based refrigeration system and is used to maintain the CTA in the cold stores onsite. Each refrigeration system consists of two sets of compressors, an air-cooled condenser, an evaporator and a defrost system. The two sets of compressors operate in parallel with each other with the flow of the refrigerant exiting the evaporator split into each of compressors, before the flow is recombined to enter the condenser. The defrost system operates by shutting down the compressors for a short period, allowing the flow of hot gas to melt any ice build on the evaporators within the CTA. The control system is setup such that System 1 takes the majority of the cooling load with System 2 only being required when the cooling load increases beyond System 1's capabilities. Therefore System compressor 2 are rarely operational as the cooling load is never high enough to demand all 4 compressors to be online simultaneously.

1.3. Baseline Data

To determine the baseline energy usage before the installation of the WHRS, Enistic power meters were installed within these two systems at Mackie's, they were used to measure data from the following systems:

- FM York (Main power supply to the refrigeration system)
- FM York System 1 Compressor 1
- FM York System 1 Compressor 2
- FM York System 1 Defrost
- FM York System 2 Compressor 1
- FM York System 2 Compressor 2

- FM York System 2 Defrost

From the analysis of this data, the baseline energy usage of the York Plant could be determined before the installation of the WHRS.

1.4. Desuperheater

A desuperheater is essentially a bank of heat exchangers which are installed between the compressor and the condenser and removes heat from the refrigerant before entering the condenser. The heat exchangers are used to heat water which is then stored onsite and can be repurposed for other uses. The location of the Desuperheater in the refrigeration cycle is shown in Fig 2.

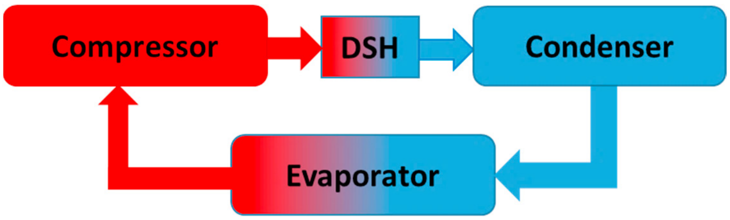

Fig. 2. Simple Illustration of Desuperheater Installation

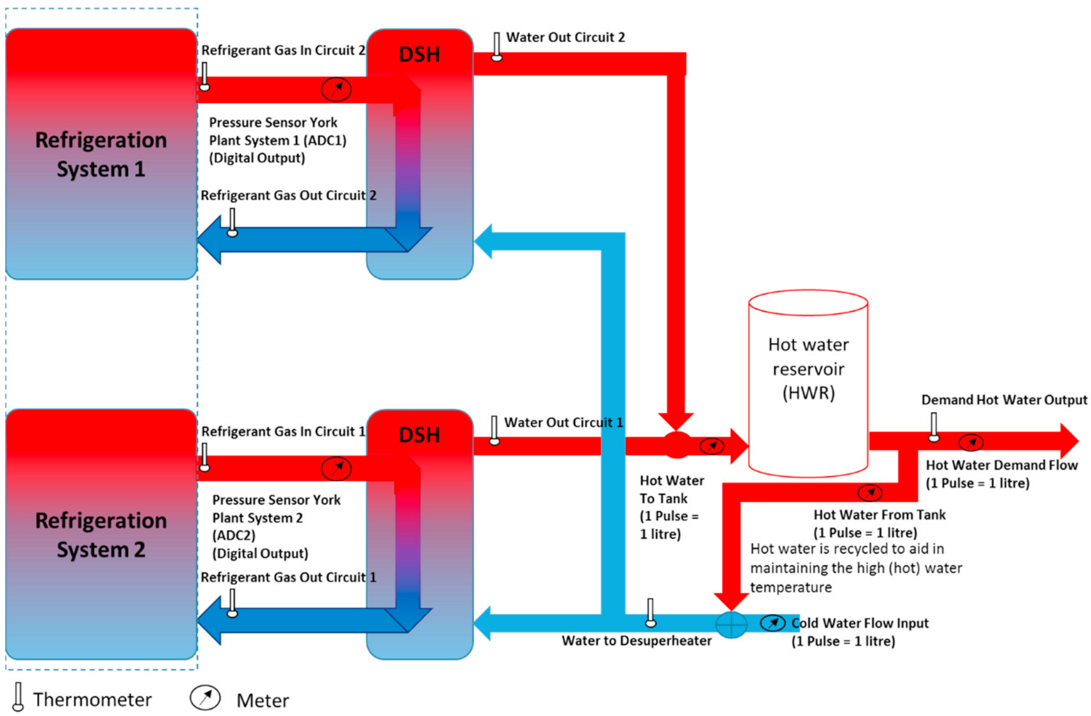

Fig. 3. Complete York Plant and WHRL System

The desuperheater supplied by WHRL, consists of 4 heat exchangers which are supplied with hot refrigerant by the York Plant. System 1 supplies two of the WHRL heat exchangers and System 2 the other two. The hot water that is produced by the system is stored onsite in a hot water reservoir (HWR), which can be used to supply hot water to various activities onsite. The WHRL system has two modes of operation, recirculation and cold fill mode. During recirculation mode, hot water is taken from the HWR and passed through the desuperheaters again, this helps to maintain a high water temperature in the HWR. Cold fill mode is required when enough water has been used from the HWR that falls below a set level point. Cold water is then added to the system via the desuperheater's intake so as not to impact the temperature of the HWR. The complete system along with all other sensors which was installed for alternative analysis are shown in Fig. 3.

2. Methodology

Enistic Sub4 power meters were installed on all major components of the Mackie's refrigeration including the main supply, compressors and defrost circuits. However, the condenser could not be metered due the inaccessibility of the equipment. Energy data was then collected for a year prior to the installation of the WHRS to determine the baseline energy reading for the refrigeration over the course of a standard year. The WHRS was then installed within the refrigeration system in October 2016 and readings were then taken every 15 minutes from all sensors. Energy data were then summed to give the total energy usage per month. The condenser energy data was calculated by summing the individual systems and subtracting from the overall energy usage by the refrigeration plant. This data was then used to compare and determine the effect of the installation of WHRS on the refrigeration system and its energy usage.

3. Results

Initially the overall monthly energy usage for York Plant system was compared with the baseline and the savings calculated for the year after pre and post installation, this is shown in Fig. 4.

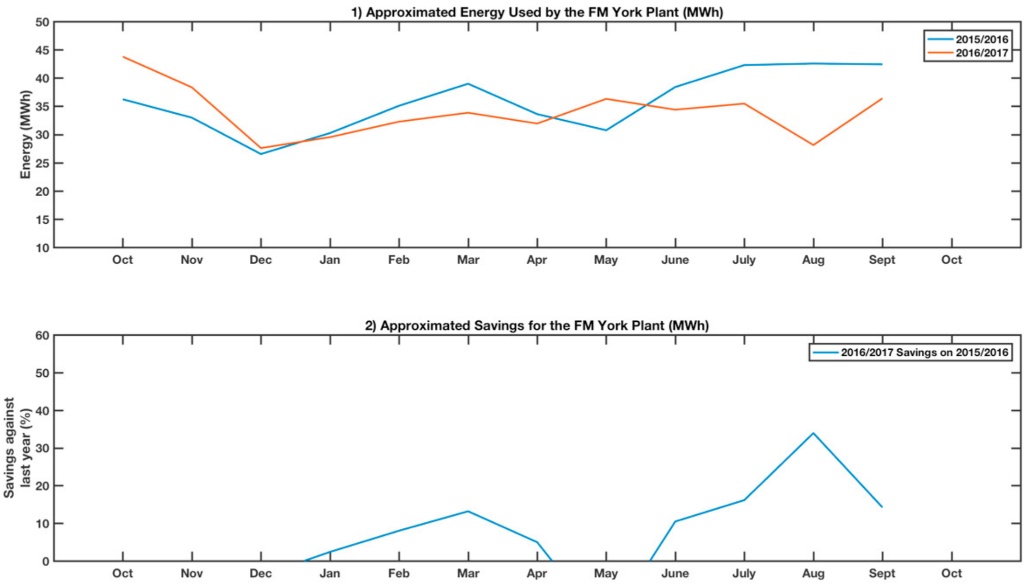

Fig. 4. Approximated Savings of the York Plant

The results showed that after an initial rise in energy usage by the Work Plant, it then showed a reduction in the majority of the remaining months. The absence of savings in May was due to an abnormal reduction in energy demand in the baseline data which caused the post installation value to be higher. Therefore, the installation of the WHRS led to a 5% reduction over the year in energy usage for the York Plant, reducing from 430 MWh to 407 MWh. This savings of 23 MWh of the course of the year will lead to 6.5 tonnes reduction in CO_2e being produced by the UK electricity grid [8].

To determine the source of the savings within the refrigeration plant, the individual system which had been metered were then compared with their baseline and their savings calculated, these are shown in Fig. 5.

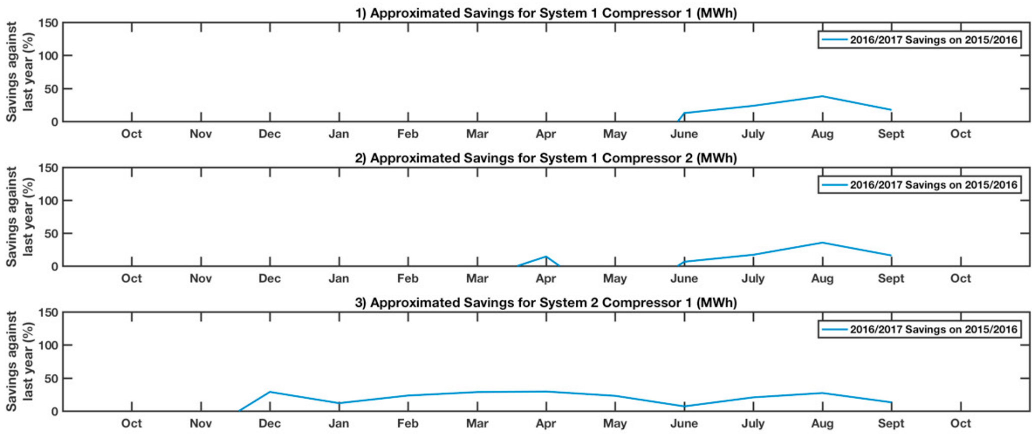

Fig. 5. Approximated Savings of the York Plant

The only consistent savings shown by the individual systems was by System 2 Compressor 1. This shows that due the control setup of the refrigeration system, as explained in Section 1.2, System 2 is no longer being called upon as often to maintain the CTA. This shows that there has been and increase efficiency of the refrigeration plant as it is able to maintain the CTA using less energy. The remaining systems savings that were monitored these are shown in Fig.6.

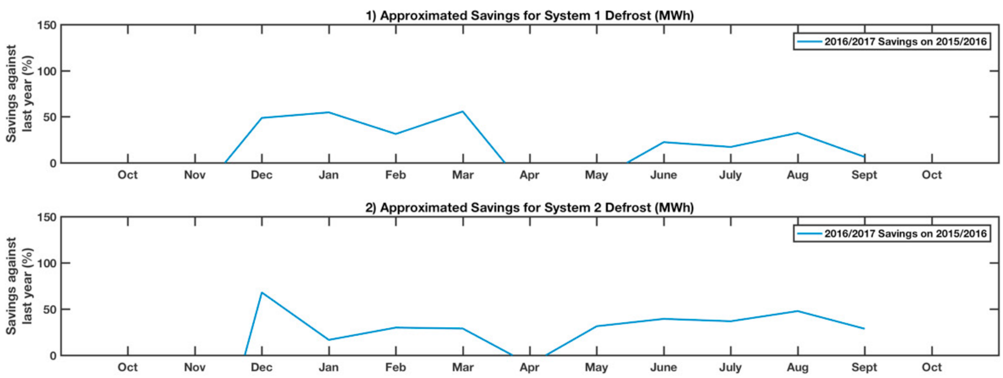

Fig. 6. Energy Savings of the Individual Systems of the York Plant

Both the defrost systems are showing savings over the year, with a 20% and 17% saving in System 1 and System 2 respectively. However, the defrost systems only use a relatively small amount of energy when compared to the other components. The condenser unfortunately could not be metered due to its low current draw, however it could be calculated by subtracting the metered systems from the total York Plant usage. This gave an approximation of the condenser is shown in Fig. 7.

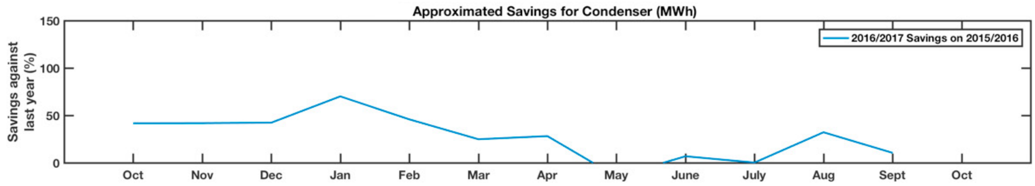

Fig. 7. Energy Savings by the Condenser

The condenser showed a consistent saving on the year with a total saving of 27%, dropping from 124 MWh's to 90 MWh's since the installation of the WHRS.

4. Conclusion

The installation of the WHRS has shown to reduce the overall energy consumption of the York Plant refrigeration system located at Mackie's of Scotland in Inverurie. These savings will have produced a 6.5 tonne saving in CO_2e emissions produced by the grid over the course of the year. The main saving have come from the reduction of the energy use of the condenser as well the decreasing the use of slave system to maintain the CTA. These reductions are due to the WHRS removing heat from the refrigerant before it reaches the condenser, therefore the reducing the energy required to condense the refrigerant. As such, the refrigeration system is able to cool the CTA more effectively and efficiently and does not require the use of its backup system as frequently over the course of the year.

The system shows great promise as it is able to be retrofitted to any refrigeration cycle and produce savings by the reduction of energy usage by the condenser and extra compressors. As a byproduct, hot water is also produced by WHRS which can then be used elsewhere onsite in many other processes, as the food and drink industry are in constant need of a readily supply of hot water. These include such systems as the CiP along with preheating water for wash down services and general cleaning of the facility. This current system has also been used to provide heating for an onsite hostel, however this was initiated after the conclusion of the first year and therefore not included in the paper. Typically, these processes are supplied with hot water which is heated using conventional means, such diesel boilers. By the removal of these conventional heating techniques, more CO_2 savings will also be produced by these systems on site.

With just the savings from the grid electricity alone the payback period on this system is around 20 years, however this is likely to be greatly reduced due to the replacement of other systems onsite along with many uses for the hot water which have yet to be found.

5. Acknowledgement

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