WASTE TO WORTH: EVALUATION OF POTENTIAL WASTE HEAT RECOVERY SYSTEM WITHIN COMMERCIAL KITCHENS IN NORTHERN IRELAND

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INTRODUCTION

This paper presents results from a study that evaluated the potential of waste heat recovery technology within the context of commercial kitchens in Northern Ireland. The study, which involved both numerical simulation and measured data from five restaurant kitchens in Belfast, revealed that heat recovery technology provided substantial economic and environmental savings. Compact devices such as the spiral tube heat exchanger can be utilized as a sustainable solution to retrofit existing hot water systems. We recommend, however, that subsequent research be conducted to broaden the scope of this study by using complementary technologies such as solar panels, wind turbines, or modified cookers that would provide a holistic and sustainable solution for the catering industry.

KEYWORDS

CO_2 emissions, heat exchanger, energy recovery, sustainability, UK

BACKGROUND

Interest in the use of heat recovery technology has been around since the oil energy crisis of the 1970s drove oil-reliant industries such as the Central Electricity Board to find solutions to waste heat (Murgatroyd, 1977). However, after the crisis, all was quickly forgotten, and more recently, the price of petroleum products has skyrocketed. Other factors that continue to encourage the investigation of heat recovery systems are the potential for maximizing the cost utility of energy, in addition to reducing their impact on the environment. In the United Kingdom in particular, the main driver has been the tough, self-imposed government legislation coming out of the Climate Change Act 2008, which set targets of reduction of CO_2 emissions to 80% below the 1990 baseline data (Law, Harvey and Reay, 2012).

Catering facilities in urban areas are major contributors to carbon emissions. Moreover, inefficiencies in restaurant food production contribute to the consumption of about 2.5 times more energy than any other type of commercial building (Energy Star, 2010). The UK has

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over 273,000 catering facilities (Caterbase, 2010)[4] emitting over 48 million tonnes of CO_2 annually. Sadly, the food sector continues to ignore this fact. It is estimated that over the last ten years, the energy required to produce food in restaurants has risen by 25% (FCSI, 2008).

A study by the Carbon Trust suggests that, ". . . as little as 40% of the energy consumed in the catering facilities is used for the preparation and storage of food; much is wasted energy and dispersed as heat . . ." (2008, p. 2). This excess heat contains both smoke and other toxins, which must be removed via mechanical ventilation, consuming an average of 15% of the overall electricity use. A study of the energy consumption patterns for different activities in non-domestic buildings in 2004 revealed that the hotel and catering sectors consumed approximately 9,300 GWh. Further analysis showed that restaurants with commercial kitchens contributed over 25% of that total (Mortimer, Elsayed and Grant, 2000, p. 717).

The loss of 60% of energy during the cooking process is an inefficiency within the system that is difficult to reduce without the redesign of the equipment used, or changing how we cook. McKeena (2009) points out that there are three ways to increase energy efficiency: through behavioral changes; through technological changes, and finally through policy-related changes. Within the UK, the focus has mainly been on the latter two, which has been criticized by scholars Stevenson & Leaman (2010), who argued that without user feedback it would be difficult to see the connections between the behavior of the users and energy savings. The wasted heat could be harvested through a technological change by retrofitting existing euipment or through outright purchase of newer energy-efficient units.

The catering industry does not have a good history in trying to recover this heat loss, yet it is known that "over 50% of waste heat can be recovered using heat recovery devices, thus significantly reducing energy costs" (Gerstler, 2002). This industry produces half as much as the 91 million tonnes of emissions put out by the private car sector in the UK each year (Adam and Evans, 2006). A similar study by the Chartered Institute of Building Service Engineers (CIBSE, 2009) estimated that over £400 million is spent on energy each year within both the private and commercial kitchen sector alone. However, despite substantial increases in the cost of energy use, the catering sector has seemingly snubbed its responsibility to a sustainable future.

Caterbase (2010) estimated that within the UK, there are 273,000 catering facilities and within the central business district of Belfast, over 2,300 catering facilities that have commercial kitchens, locations indicated in Figure 1 (NISRA, 2010). An interpolation of the overall energy consumption previously mentioned above would attribute the consumption in Belfast CBD to approximately 21.1 GWh, costing approximately £3.17 million at current electricity rates (November 2012).

The issue of waste within commercial kitchens has been extensively documented, with many studies focusing on the efficiency of the equipment itself (Efficiency Partnership, 2006; Clarke, 2006 & Carbon Trust, 2008). More recently, research has recognized that the significance of cooking time has an impact on the finances of the establishments and a burden on the environment. Others have taken a different approach by considering the impact this wasteful process could have on the working environment suggesting that working within an overheated environment contributed about 30% loss in productivity by the kitchen staff (Livchak and Fisher, 2007).

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[4]Caterbase was a broad-based UK programme offered by Hotels and Catering Board to help professionals develop skills to acceptable standards.

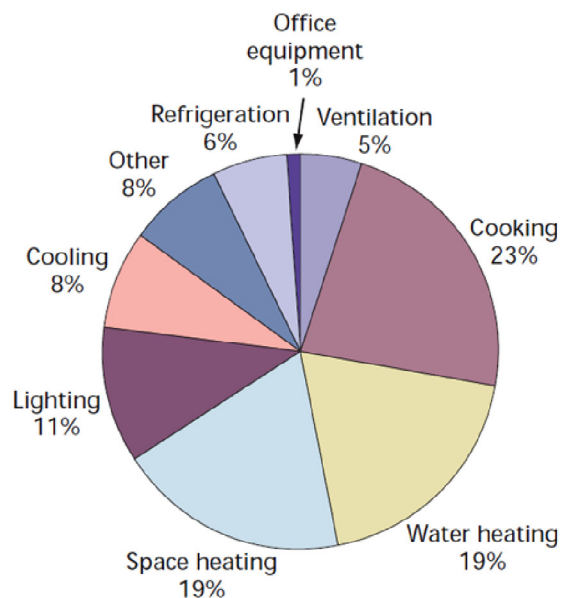**FIGURE 1.** Map indicating density of foodservice industry in Belfast City Centre, NI (Google 2012).
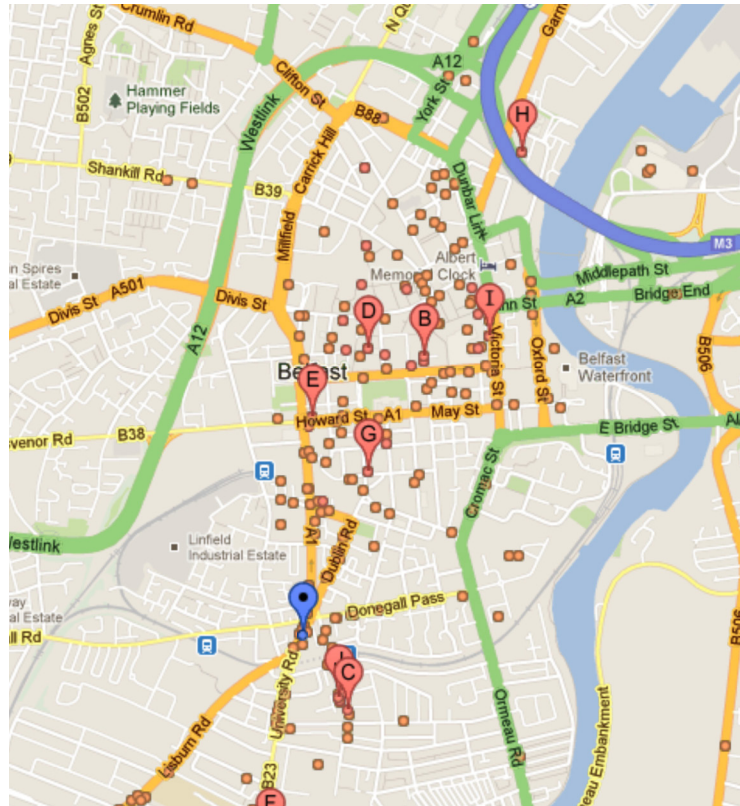
The study, however critically ignored the environmental impact incurred despite the replacement of one form of mechanical ventilation for another that translates to the restaurant owners simply replacing the savings made with the expense of additional ventilation. A recent American study by the Catering for a Sustainable Future Group, CSFG (2009), an environmentally-conscious group of caterers, produced the following chart that indicates where energy was used within the food services sector (Figure 2). The heating of water for the catering facilities consumed 19% of the total energy consumption used in the catering sector, which could potentially be recovered from the kitchen extract ventilation system (Kuck, 2002).

Research Context and Methodology

The study focused on evaluating the heat recovery potential from five catering establishments in Belfast that were selected on the

FIGURE 2. Break down of energy consumption from the food service industry (Catering for a Sustainable Future, Group, 2009).
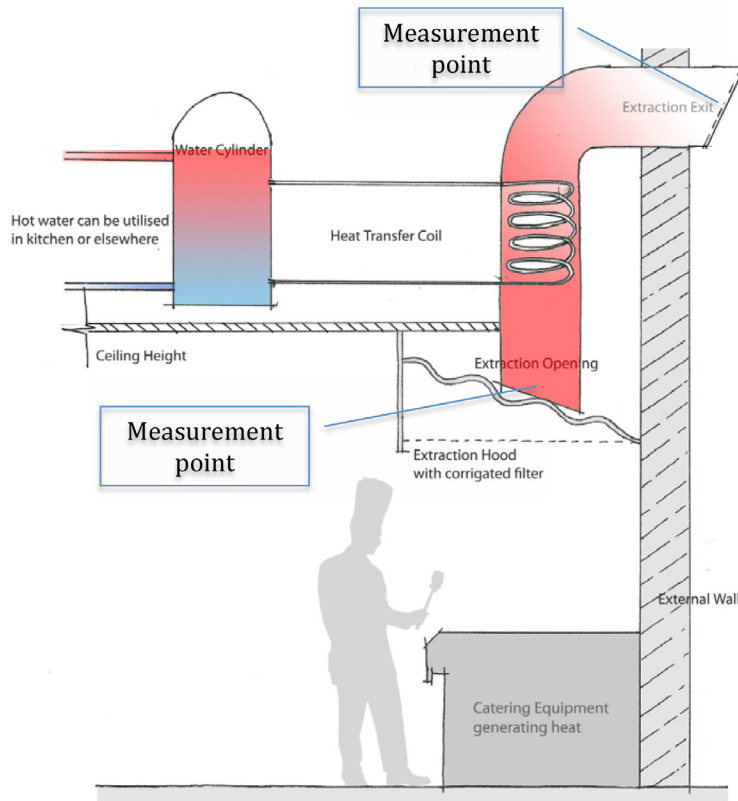
FIGURE 3. Experimental Arrangement.

Measurement point

Water Cylinder

Hot water can be utilised in kitchen or elsewhere

Heat Transfer Coil

Ceiling Height

Measurement point

Extraction Exit

Extraction Opening

Extraction Hood with corrigated filter

External Wall

Catering Equipment generating heat

basis of ease of access, location, and size. A survey of existing restaurants in Belfast was carried out. For consistency, only those that offered 2 meals per day and served at least 150 people during peak hours were selected. Multiple temperature measurements of the hood inlets and extract outlets were taken using a Fluke FLIR E50bx thermal imaging camera over five days from Monday, August 1, to Friday, August 5, 2011, between 9:00 am and 6:00 pm with extra readings taken every 15 minutes during the peak lunch period of 12:00 noon to 2:00 pm. The camera, which has an operating temperature range of –20° to 120°C and an accuracy of 2°C, was held perpendicular to the surface being measured and was focused at the center of the extract vent in the interior and exterior (Figure 3).

The study relies on the hypothetical application of a constant heat exchanger to the five caterers, offering a potential value and not a categorical indication of an individual establishment's heat recovery potential. In addition, practical issues such as fouling or the impact of trapped air in the system were not considered during the simulations. Water was assumed to flow from a cylinder into the spiral coil heat exchanger flowing back to the hot water cylinder with little mixing taking place. The kitchens had the following similar equipment supplied by Sentry Kitchen Equipment (Table 1).

TABLE 1. Dimensions of Experimental Unit.

Extract duct diameter	400 mm (0.4 m)
Spiral heat exchanger copper tube diameter	10 mm (0.01m)
Diameter of spiral in duct	200 mm (0.2 m)
Minimum length of extract duct before exit	600 mm (0.6 m)
Length of copper tube	37680 mm (37.68 m)

Heat Recovery System

Waste heat generated from catering systems is considered low-grade because the temperature range is below 260°C (Watts Committee, 1994), hence it is most efficient to recover the heat at the source or as close as possible to the source. The applications for this type of heat are for space heating and preheating of water for use within the premises. There are several ways to recover the heat through the use of a heat sink such as heat exchanger, heat pumps, or remote transportation as pointed out by Al-Rabghi *et. al.* (1993). Most recovery systems rely on the heat exchanger, of which there are three predominant types based on the transfer fluids: gas–gas systems, gas–liquid systems, and liquid–liquid systems. Kukac & Liu (2002) provide an extensive review of the advantages and disadvantages of the various geometrical arrangements as well as transfer fluids. This study utilizes the gas-liquid exchange spiral system that is the most efficient, yet cost effective, as evidenced by the literature reviews.

The major barrier to the installation of the heat recovery technology systems within the catering industry has been of an economic nature, as pointed out by Al-Rabghi *et. al.* (1993). The view is supported by Jeffe & Stavins (1994), who argued that a gap between the cost-effective potential for energy savings and its implementation always exists. The economic gap is included because of the heterogeneity within that particular sector, the hidden costs of uptake of the technology, the lack of access to capital to make the improvements, and finally the risks that maybe associated with the endeavor (Sorrell *et. al.,* 2004). However, there are benefits that include the reduction in the sizing of the hot-water system, total space heating energy costs, increased productivity of kitchen staff by 10–25%, all within a relatively modest payback period of less than two years (Newborough & Probat, 1988).

RESULTS AND DISCUSSIONS

In the commercial kitchen cooking environment, food safety is of utmost importance, hence hot water temperatures for washing are required to be above 41°C according to Part G of the UK Building Regulations. Earlier, we pointed out that wasted energy could be captured and reused. The calculations from the Belfast study revealed that an average of 540 watts of heat lost hourly could be recovered through the installation of such a system (Figure 4). The amount is spread fairly uniformly throughout the day, though it spikes between 12:00 noon and 2:00 pm.

The study revealed that in most of the cases studied (3/5) the average temperature exceeded 41°C. That not only meets the UK Building Regulations, but also coincides with the period when peak demand for use of hot water in the kitchen exists (Figure 5). In the two cases where the temperatures were below 41°C, it we determined that it was still close enough to make a significant contribution to the preheating of a water system supplemented with an electrical heater. Therefore, to get a clearer picture, further studies should be taken to examine what the impact would be.

The study revealed that it is possible to achieve an average hourly temperature of 48.9°C (Table 2) and that there is great potential for such a system contributing to savings in annual cost of water heating to an equivalent of £290 (November 2012 values).

This may appear small, however, considering that the work was carried out only on small kitchen extract units, this is likely to increase with scaling up, as well as improvements to the installed heat recovery system. The cost of retrofitting such a unit according to Sentry
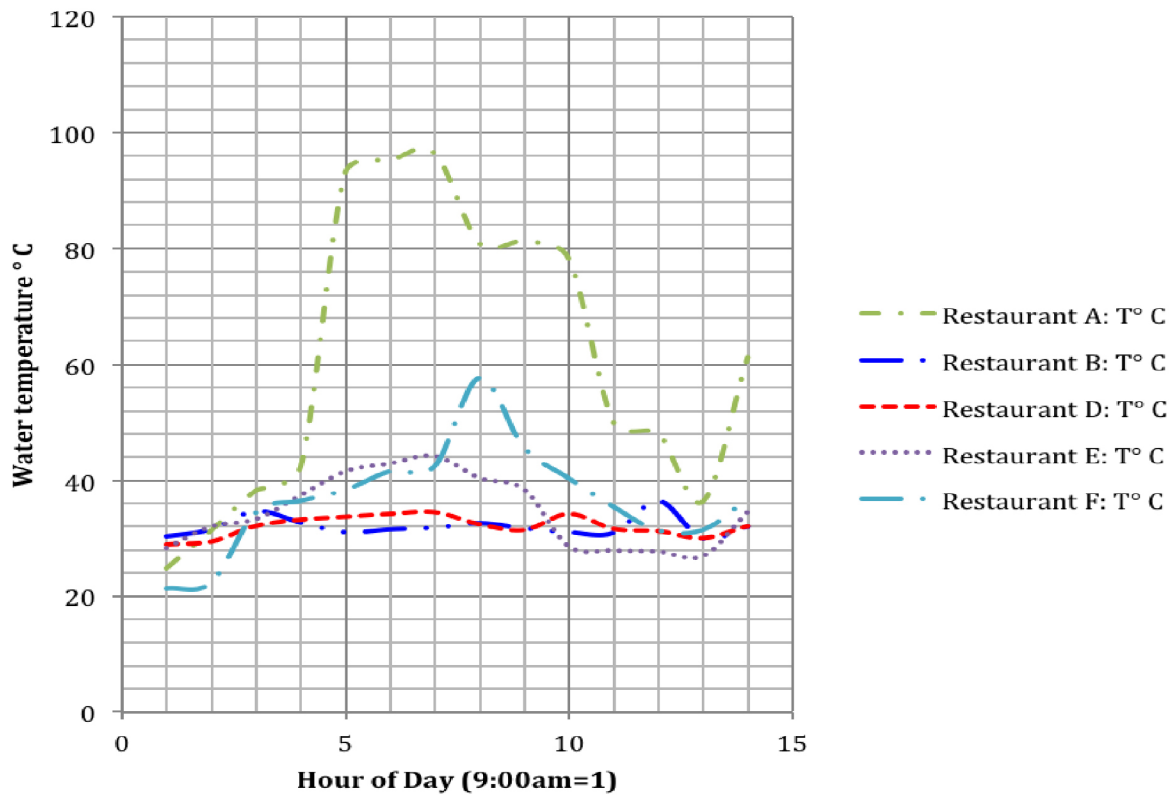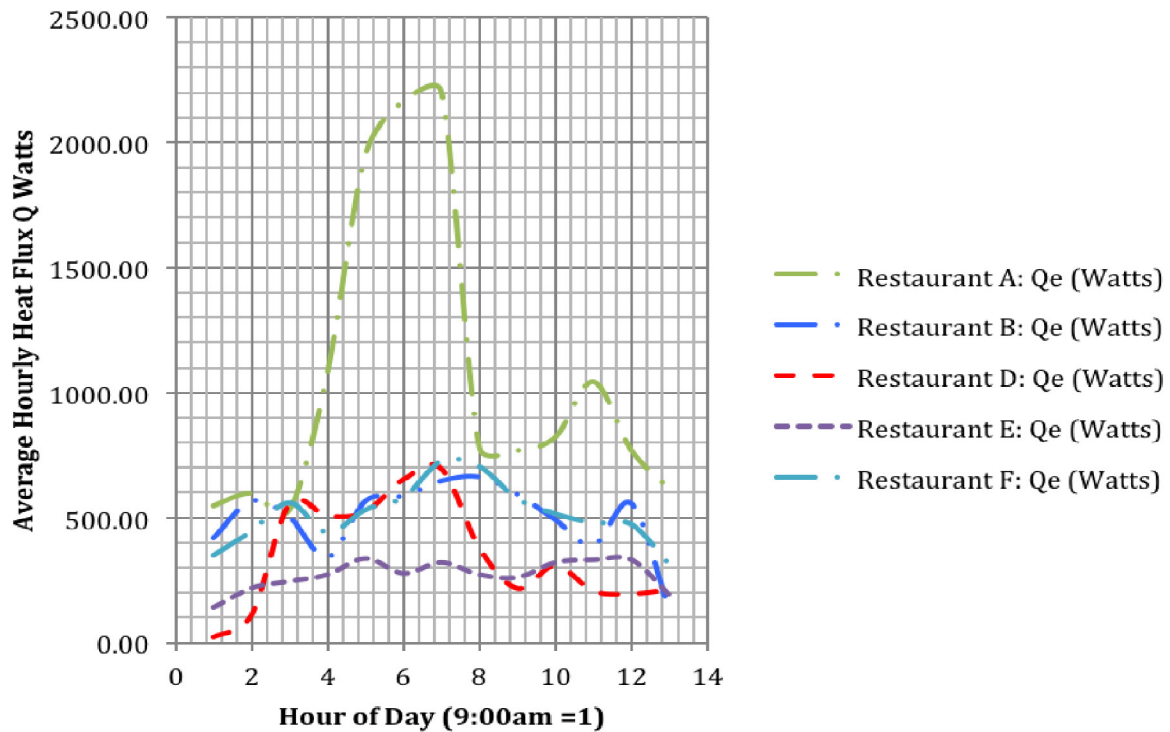
FIGURE 4. Comparative Profiles of Water Temperature During the Day.

FIGURE 5. Comparative Profiles of Heat Flux During the Day.

TABLE 2. Average Hourly Water Temperature, CO_2 Emissions and Annual Energy Savings.

Description	Tw °C	Tw °C	Average Hourly Heat Flax Watts	Average Daily Heat Recovered x7 KWh	Total Weekly Heat Recovered x7 x 6.5 KWh	Total Annual Heat Recovered KWh	Total Savings @ £ 0.0791/ KWh + 91.25 Standing Charge	Total CO_2 Emissions Saved kgCO_2 per kWh
Catering Facility A	70.92	79.22	1066.19	7.46	48.51	2522.61	290.79	913.69
Catering Facility B	44.10	47.94	494.06	3.46	22.48	1168.95	183.71	423.40
Catering Facility D	37.38	40.15	355.26	2.49	16.16	840.55	157.74	304.45
Catering Facility E	44.02	48.03	272.23	1.91	12.39	644.10	142.20	233.29
Catering Facility F	31.99	34.11	514.30	3.60	23.40	1216.83	187.50	440.74
Average	45.68	49.89	540.41	3.78	24.59	1278.61	192.39	463.11

Equipment (Ireland) was estimated at £400, suggesting an average payback period of two years. In addition, the average annual electricity costs for restaurants in 2011 was £2000 (DECC 2012), suggesting that the application could result in annual savings of almost 10%. The system would also allow a potential reduction in annual CO_2 emissions of at least 463 kg per kWh of electricity saved, which is significant when weighed against the fact that hot water heating accounts for 19% of the energy used in catering facilities (Mortimer, Elsayed & Grant, 2000; and Catering for a Sustainable Future Group, 2009). If the recovered heat were used solely for heating the water system, the annual reduction to the cost of energy used in 273,000 restaurants in the UK would be close to £52.5 million.

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