Water Efficiency Conference 2016

Waste heat recovery from showers: Case study of a university sport facility in the UK

Kenneth Ip[1*], Kaiming She[1]

[1]Universtiy of Brighton, School of Environment and Technology
Cockcroft Building, Lewes Road,
Brighton, BN2 4GJ

ABSTRACT

Recovery of waste water heat in the discharge from showers to preheat the incoming cold water has been promoted as a cost effective, energy efficient and low carbon design option. Its ability to reduce carbon emissions is recognised in the domestic Standard Assessment Procedure (SAP) - the energy assessment tool in the UK for demonstrating compliance with the Building Regulation Part L for dwellings. Incentivised by its carbon-cost effectiveness, waste water heat recovery units have been incorporated in the newly constructed Falmer Sports Pavilion at the University of Brighton in the UK. This £2m sports development serving several football fields was completed in August 2015 providing eight first-rate changing and shower rooms for students, staff and external organisations. There are six shower rooms on the ground floor and two shower rooms on the first floor, each fitted with 5 or 6 thermostatically controlled shower units. Inline type of waste water heat recovery units are installed, each consisted of a copper pipe section wound by an external coil of smaller copper pipe through which the cold water is warmed and subsequently supplied to the shower mixers.

This paper reports on the performance evaluation of this waste heat recovery system with the aims to establish the in-situ energy performance and the annual energy and savings. Extracting details from the specification and the schematic diagrams, a heat transfer mathematical model representing the system has been established, which informed the development of the methodology for measuring the in-situ performance of individual and multiple use the showers in each changing room. Using a system thinking modelling technique, a quasi-dynamic simulation computer model was developed. The model incorporated the heat transfer components utilising performance parameters monitored in situ. It also featured the use of probabilistic profiles of daily usage over the whole year. The results indicated that the thermal effectiveness was over 60% with significant potential for energy saving but the overall reduction was largely influenced by the volume of water used. Although the payback periods were long, they could be much reduced through more effective design, correct installation and market competitions.

Keywords: domestic hot water, showers, heat recovery, modelling, energy and cost savings, sport facilities

1. INTRODUCTION

With significant thermal improvements and adoption of low energy lights and appliances, domestic hot water energy consumption is fast becoming the major component of energy expenditure in modern buildings. The main use of hot water in domestic buildings is for the shower/bath which accounts for nearly 21% of the total consumption [1]. Hot water is normally heated by gas or electric boilers which raise the temperature to over 60° and mixed with cold water to a temperature of around 40°C, in the case of use for showers, before the water is used. This low grade heat in the warm water, which normally discharged to the drain, still has a much higher temperature than the incoming cold water, hence, offers a good potential for heat recovery. Among a number of heat recovery options available for

* Tel.: +44 1273 642381; fax: +44 1273 642285
E-mail: k.ip@brighton.ac.uk

designers, in-line pipe heat exchanger (see Figure 1) presents some distinct advantages as they have no moving parts, compact and proclaimed to have higher heat recovery efficiencies.

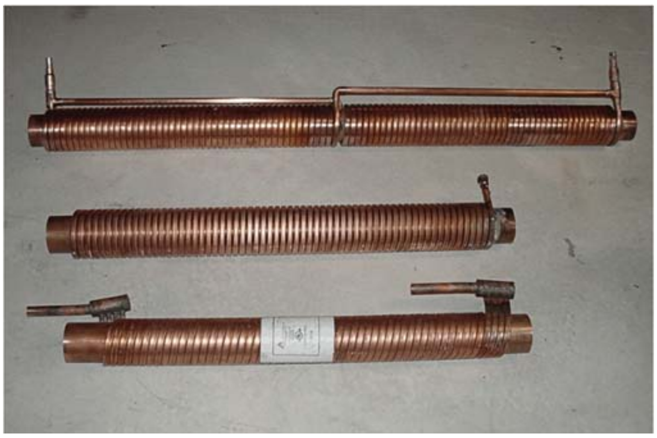


Figure 1 Example tubular design WWHR pipe products [2]

Incentivized by its carbon-cost effectiveness and the recognition in the UK's Standard Assessment Procedure – an energy assessment tool for demonstrating compliance with Part L of the Building Regulations for dwellings [3] - waste water heat recovery units have been incorporated in the newly constructed Falmer Sports Pavilion at the University of Brighton in the UK. This £2m sports development serving several football fields was completed in August 2015 providing eight first-rate changing and shower rooms for students, staff and external organisations. There are six shower rooms on the ground floor and two shower rooms on the first floor, each fitted with 5 and 6 thermostatically controlled shower units. Inline type of waste water heat recovery units were installed, each consisted of a copper pipe section wound by an external coil of smaller copper pipe through which the cold water would be warmed and subsequently supplied to the shower mixers.

This installation provided an opportunity for evaluating the in-situ performance of WWHR, in collaboration of the Estate Department of the university, enabling the collection of data for informed decision making of future adoption of such technology in new or refurbishment projects. The research aims are twofold: firstly to establish the effectiveness of this device in operation; secondly to identify the potential cost and energy savings under different operating conditions. The tasks thus involved developing a methodology for performance measurements on the installations on site; developing a modelling tool for performance evaluation; measuring the in-situ performance and establishing the annual energy and cost savings.

2. METHODOLOGY

Opened in 2015, the Sport Pavilion is a two-storey multi-use facility at the University of Brighton's Falmer campus, see Figure 2. The ground floor features a plant room and changing rooms for the surrounding sports complex. The upper floor features two further changing rooms, four seminar rooms, toilets and first-aid room.

Domestic hot water is produced by a series of grid supplied natural gas boilers. The eight main changing rooms each has a block of five or six showers. Each shower block on the upper floor utilizes a single heat recovery pipe mounted into the vertical PVC-u drainage stack below; the six rooms on the ground floor could not use this configuration so employed two horizontal heat recovery pipes. The configuration of the shower units and the heat recovery pipe for one shower room on the first floor is illustrated in Figure 3.

Fig. 2. Changing room layout

Based on the system schematic configuration, mathematical equations describing the thermal model were established which enabled the identification of key parameters for experimental measurements. Data were collected under different operating profiles to establish the effectiveness of the heat recovery pipe, which were subsequently applied to the simulation model to evaluate the weekly and annual system performance and potential savings.

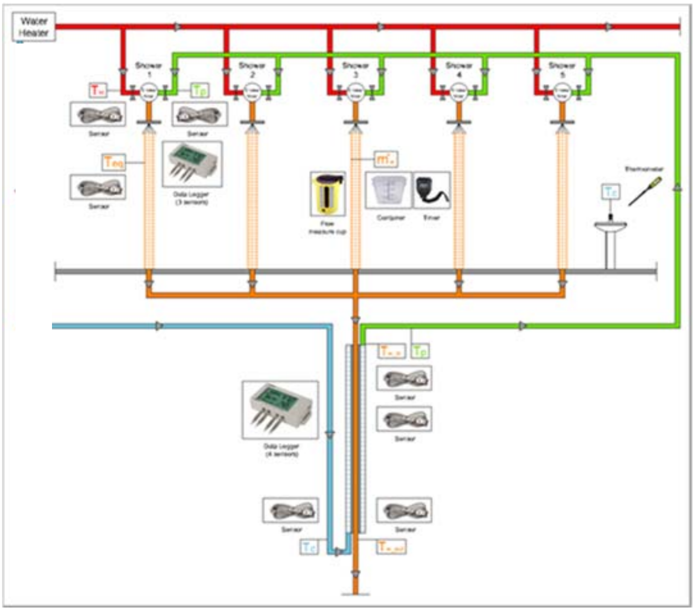


Fig. 3 System configuration and experimental measurements

2.1 Thermal and simulation models

The heat recovery unit is a counter flow heat exchanger, its efficiency can be represented by the term effectiveness ε [4] as:

$$\varepsilon = \frac{\dot{Q}}{\dot{Q}_{max}}$$

Where $\dot{Q}_{max}$ is the theoretical maximum heat transfer rate, for counter flow is:

$$\dot{Q}_{max} = C_{min} * \left(T_{h,in} - T_{c,in}\right)$$

If the effectiveness is known then the thermal power exchanged will be:

$$\dot{Q} = \varepsilon * C_{min} * \left(T_{h,in} - T_{c,in}\right)$$

$$C_{min} = \min\begin{cases} \dot{m}_c * c_{p,c} \\ \dot{m}_h * c_{p,h} \end{cases}$$

The heat transfer between the hot fluid $\dot{Q}_c$ and the cold fluid $\dot{Q}_h$ are:

$$\dot{Q}_c = \dot{m}_c * c_{p,c} * \left(T_{c,in} - T_{c,out}\right)$$

$$\dot{Q}_h = \dot{m}_h * c_{p,h} * \left(T_{h,in} - T_{h,out}\right)$$

At each shower mixer the following mass and energy balance equations are applied:

$$\dot{m}_w = \dot{m}_h + \dot{m}_c$$

$$(\dot{m}_h * T_h) + (\dot{m}_c * T_{p,in}) = (\dot{m}_w * T_{eq})$$

Where:

C_{min} represents the smaller thermal capacity

$\dot{Q}\ and\ \dot{Q}_{max}$ are the actual and maximum heat transfer rate [W]

$\dot{m}_c, c_{p,c}\ and\ \dot{m}_h, c_{p,h}$ are mass flow rates [kg/s] and specific heat capacities [J/kg K] of the cold and hot fluids.

T_{eq}, T_h, and $T_{p,in}$ are the temperatures of the water coming out from the shower, hot water and cold water supplies

2.2 Experimental measurements

Parameters identified for the measurement and the corresponding equipment used are shown in Table 1 and illustrated in Figure 3. Experiments are carried out to establish the heat transfer effectiveness of the heat recovery pipe and the results are later applied in the simulation models. As the experiment commenced after the project handover, only parameters accessible for measurements were considered.

Table 1. Parameters in experimental measurements

Parameter	***Unit***
Mixer	
Shower mass water flow rate	kg/s
Shower water temperature	°C
Hot water temperature	°C
Inlet preheated water temperature	°C
Heat recovery pipe	
Pipe heat exchanger	
Inlet drain water temperature	°C
Outlet drain water temperature	°C
Inlet preheated water temperature	°C
Outlet preheated water temperature	°C

2.3 System simulation

To enable annual evaluation and be able to apply the results to other types of buildings and system configurations, a dynamics system simulation software was adopted which allowed quasi-dynamic simulation of operation of shower units. The selected system thinking simulation software STELLA [5], allows dynamic visualization and communicate of complex systems. It has been adopted to evaluate the thermal performance and potential energy savings under different usage profiles. The model building process is realized through the use of "Stocks and Flows and Causal Loop" diagrams [6], as shown in Figure 3, to represent the overall causal relationships existing between parts composing the system. An interactive user friendly interface has been developed in the software which allows effective input-output for case study evaluations as shown on the right hand side of Figure 4.

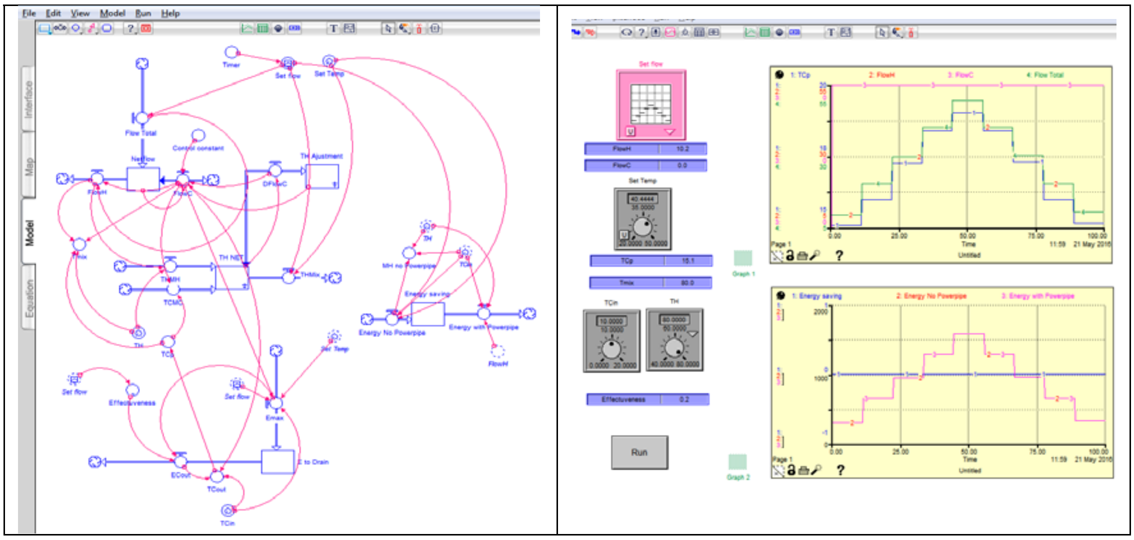


Fig. 4. System model (left) and user interface (right)

Projected user profiles based on estimates from the sport centre were established for evaluating impacts to the annual energy consumptions and financial costs. Firstly the profiles of simultaneous demand of hot water due to number of showers in operation with respect to three group sizes of 10, 15 and 20 users were established, see Figure 4. Secondly four weekly room usage scenarios (see table 2), from light to intense intensities, were devised enabling evaluation of periodic water demand and energy consumptions.

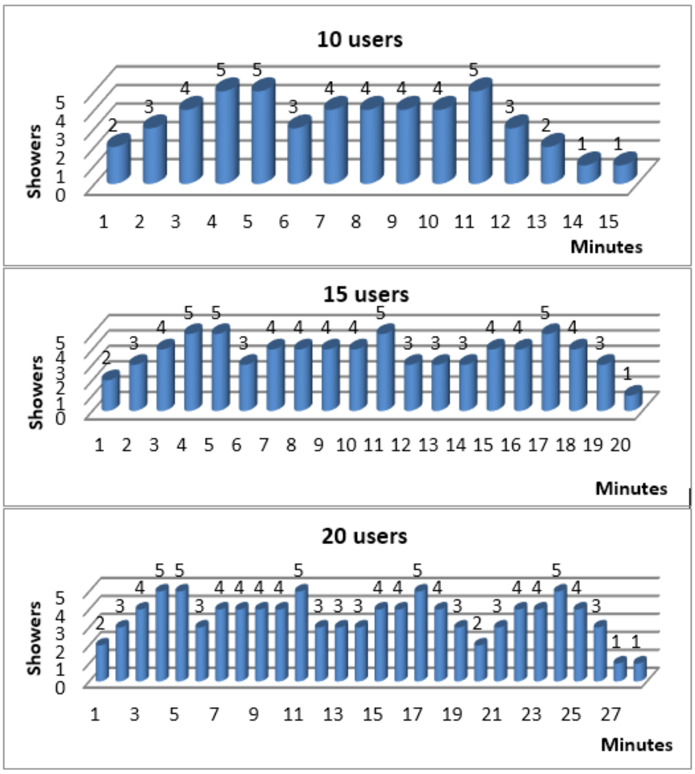
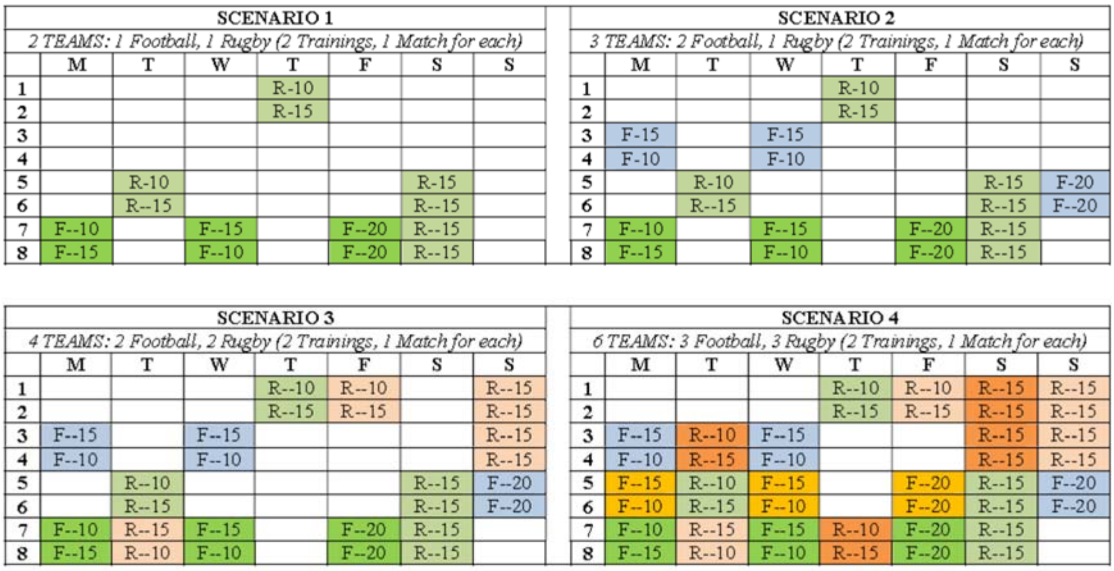


Fig. 4. Showers in use and duration for three groups types

Table 2. Scenarios of usage of different intensities



SCENARIO 1

2 TEAMS: 1 Football, 1 Rugby (2 Trainings, 1 Match for each)

	M	T	W	T	F	S	S
1				R-10			
2				R-15			
3							
4							
5		R-10				R-15	
6		R--15				R--15	
7	F--10		F--15		F--20	R--15	
8	F--15		F--10		F--20	R--15	

SCENARIO 2

3 TEAMS: 2 Football, 1 Rugby (2 Trainings, 1 Match for each)

	M	T	W	T	F	S	S
1				R-10			
2				R-15			
3	F-15		F-15				
4	F-10		F-10				
5		R-10				R-15	F-20
6		R--15				R--15	F--20
7	F--10		F--15		F--20	R--15	
8	F--15		F--10		F--20	R--15	

SCENARIO 3

4 TEAMS: 2 Football, 2 Rugby (2 Trainings, 1 Match for each)

	M	T	W	T	F	S	S
1				R--10	R--10		R--15
2				R--15	R--15		R--15
3	F--15		F--15				R--15
4	F--10		F--10				R--15
5		R--10				R--15	F--20
6		R--15				R--15	F--20
7	F--10	R--15	F--15		F--20	R--15	
8	F--15	R--10	F--10		F--20	R--15	

SCENARIO 4

6 TEAMS: 3 Football, 3 Rugby (2 Trainings, 1 Match for each)

	M	T	W	T	F	S	S
1				R--10	R--10	R--15	R--15
2				R--15	R--15	R--15	R--15
3	F--15	R--10	F--15			R--15	R--15
4	F--10	R--15	F--10			R--15	R--15
5	F--15	R--10	F--15		F--20	R--15	F--20
6	F--10	R--15	F--10		F--20	R--15	F--20
7	F--10	R--15	F--15	R--10	F--20	R--15	
8	F--15	R--10	F--10	R--15	F--20	R--15	

Where F represents Football and R for Ruby, the associated number indicates the number of users.

3. RESULTS AND DISCUSSION

Summary results for changing room 8 which represents a typical installation correctly installed with the vertical configuration and counter-flow arrangement are reported. Table 3 shows the flow and temperature values when three shower heads were operating simultaneously. The calculated effectiveness of 0.647 indicates that nearly 65% of the maximum possible recoverable heat can be retrieved to preheat the incoming cold water resulting in temperature rise of nearly 10°C.

Table 3. Indicative parameters and effectiveness

Parameter	***Symbol***	***Value***	***Unit***
No of showers running	--	3	--
Shower water flow rate	$\dot{m}_w$	0.2	kg/s
Hot water flow rate	$\dot{m}_h$	0.11	kg/s
Preheated water flow rate	$\dot{m}_p$	0.085	kg/s
Shower water temperature	T_{eq}	31.6	°C
Hot water temperature	T_h	50.6	°C
Inlet preheated water temperature	T_{p_in}	17.4	°C
Inlet Drain water temperature	T_{w_in}	25.6	°C
Outlet Drain water temperature	T_{w_out}	16.9	°C
Inlet cold water temperature	T_{c_in}	10.4	°C
Outlet preheated water temperature	T_{p_out}	20.3	kW
Effectiveness	ε	0.65	/

Table 4 is the weekly saving based on the assumed scenarios. The weekly savings vary between £40 and £119 are highly dependent on the water usage correspond to the water consumptions in the four scenarios.

Table 4. Weekly savings

	User profile	***No. of sessions***	***Energy Recovered***		
			Per session	***Weekly***	***Weekly total***
			kWh	***kWh***	***kWh***
Scenario 1	1	4	1.99	7.96	39.80
	2	8	2.99	23.88	
	3	2	3.98	7.96	
Scenario 2	1	6	1.99	11.94	57.71
	2	10	2.99	29.85	
	3	4	3.98	15.92	
Scenario 3	1	8	1.99	15.92	79.60
	2	16	2.99	47.76	
	3	4	3.98	15.92	
Scenario 4	1	12	1.99	23.88	119.40
	2	24	2.99	71.64	
	3	6	3.98	23.88	

Table 5 is a simple financial analysis on the potential periods of payback of the scenarios studied. The payback periods of over ten years may be considered as long, but the heat recovery units are maintenance free and replacement is deemed unnecessary over the life of the building. Judging by the actual water flow volumes, there is significant saving if only one recovery pipe was used to serve two change rooms and the pipes were better insulated to minimise the heat loss as indicated by the reduction in temperature of the cold water entering the shower heads.

Table 5 Payback analysis

	Unit	***Scenario***			
		1	***2***	***3***	***4***
Annual savings @40 weeks/yr	kWh	1592.00	2308.40	3184.00	4776.00
Fuel cost (gas @£0.0166/kWh)	£	26.43	38.32	52.85	79.28
Pay back @£960/unit	Year	36.33	25.05	18.16	12.11
Pay back for 1 unit serving 2 shower rooms	Year	18.16	12.53	9.08	6.05
Cost for return in investment 5 years	£	827.86	768.40	695.73	563.59

4. CONCLUSION

This study has demonstrated the utilization of waste heat recovery technology in a sport facility where a high simultaneous usage of hot water for showers was expected. The results showed that correctly installed pipe heat exchangers exhibited good effectiveness to recovering heat from the waste water. Such devices are certainly cost effective in cases where there is sufficiently high water volume flows. However, with water efficient low flow shower heads the amount of heat can be recovered from the waste water is reduced resulting in the payback periods in excess of 10 years. Nonetheless, this can be significantly reduced if the full capacity of the heat recovery pipe is utilized through combining two discharges from two change rooms and the pipework are better insulated. Long durability and maintenance free are clear benefits to this kind of system. This on-going research will continue to explore the life cycle environmental impact and to develop the simulation model to extend the evaluation of the wider impact on the capacities of heating plants and associated equipment.

ACKNOWLEDGEMENTS

The authors would like to thank Ms. Abagail Dombey (Environmental Manager) and Mr. Robert Baker (Energy Management Manager) of the Estate Department of the University of Brighton who supported this project. Also to Miss Annalisa Chiodi, Mr. Roland Martin and Mr. Ryan Mills who contributed to the data collection.

REFERENCES

1. Waterwise. 2011. *Water – the facts why do we need to think about water?* [Online]. Available: http://www.waterwise.org.uk/data/resources/25/Water_factsheet_2012.pdf [Accessed].
2. Zaloum, C., J. Gusdorf, and A. Parekh, *Drain Water Heat Recovery Characterization and Modeling*. 2007, Natural Resources Canada, Ottawa.
3. DECC, *The Government's Standard Assessment Procedure for Energy Rating of Dwellings* Revision 1 ed. 2014, Watford: BRE.
4. Holman, J.P., *Heat Transfer*. 2002, New York: McGraw-Hill, Inc.
5. *STELLA modeling & simulation software* [Online]. Available: http://www.iseesystems.com/softwares/Education/StellaSoftware.aspx [Accessed 31 May 2016].
6. Richmond, B., *Introduction to system thinking - Stella Software*. 2013: ISEE Systems.