Water Efficiency Conference 2016

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

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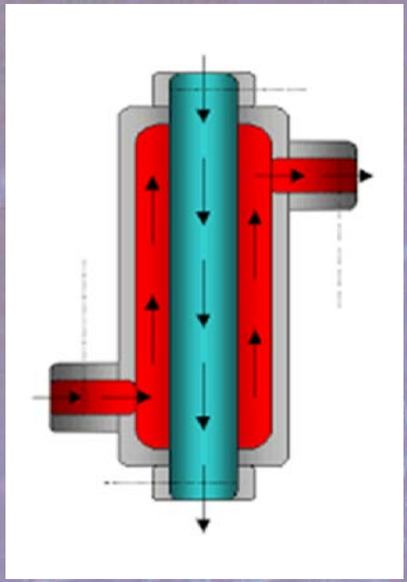
Outline

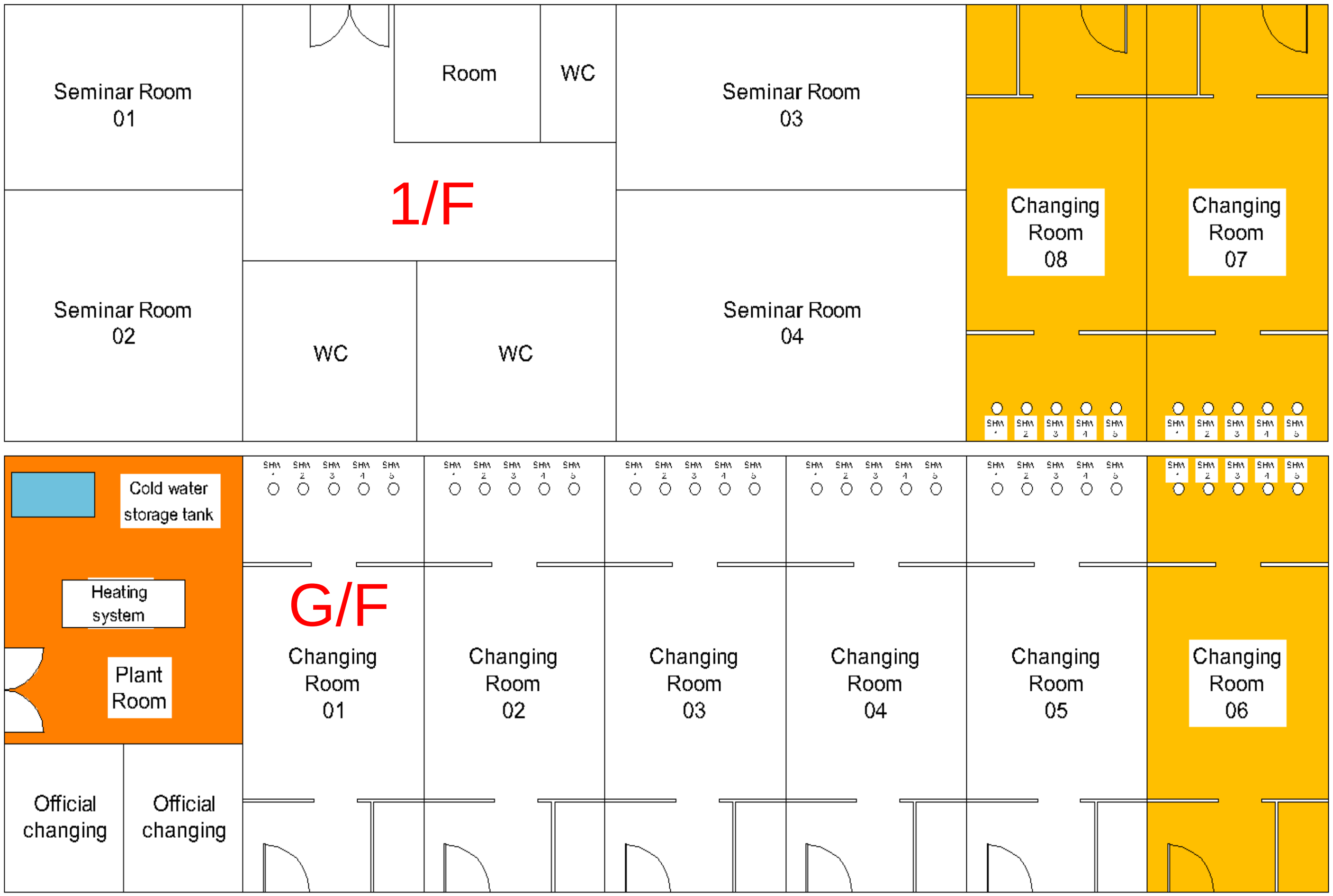
- Background
- Methodology
- Experimental measurements
- System modelling and evaluation
- Analysis and results
- Conclusions

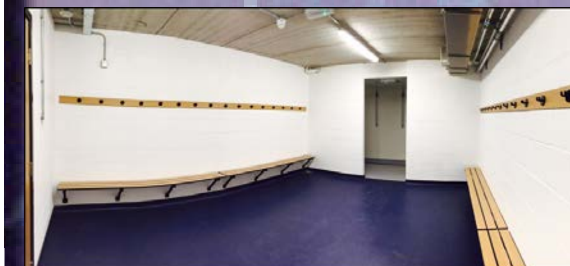
Background – waste heat recovery

- Operating principle is simple
- Claims to be highly effective
- Carbon reduction potential
- SAP accepted



Falmer Sports Pavilion





Methodology

- Establish heat transfer model
- Identify parameters to measure
- Experimental measurements
- Computer modelling
- Performance evaluation

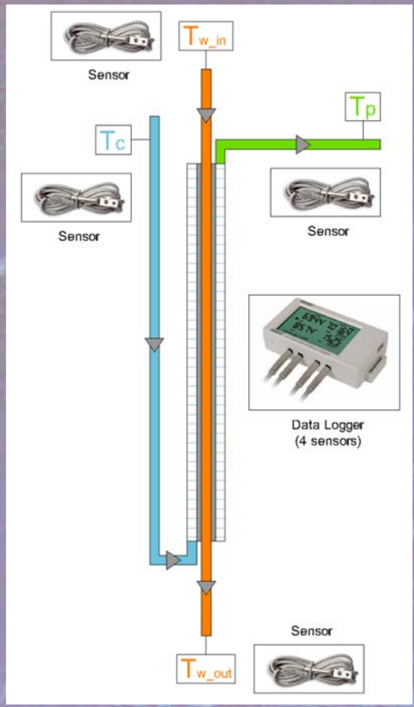
Methodology – heat transfer model (1)

- Effectiveness ε :

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

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

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



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Methodology – heat transfer model (2)

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

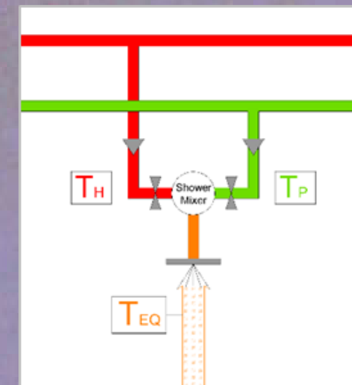
$$\dot{Q}_c = \dot{m}_c * c_{p,c} * \left(T_{c,in} - T_{c,out}\right)$$

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

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

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

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



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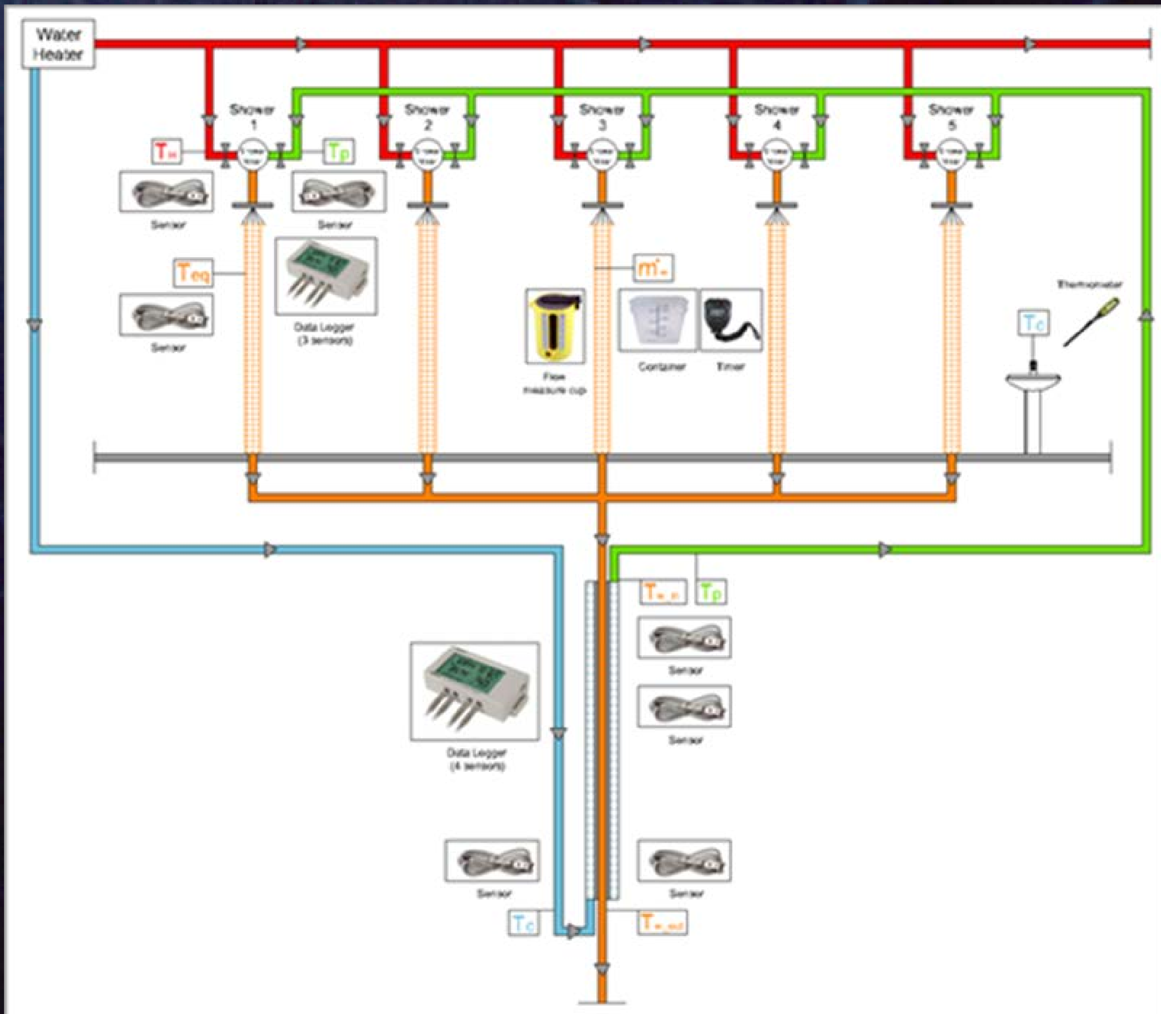
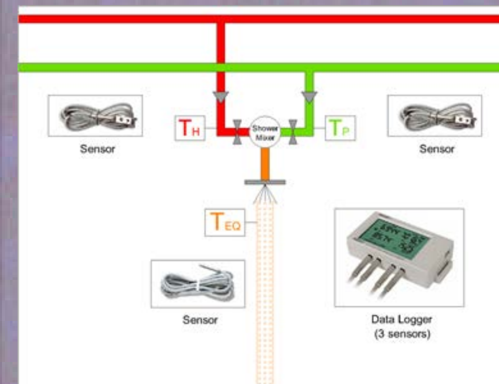
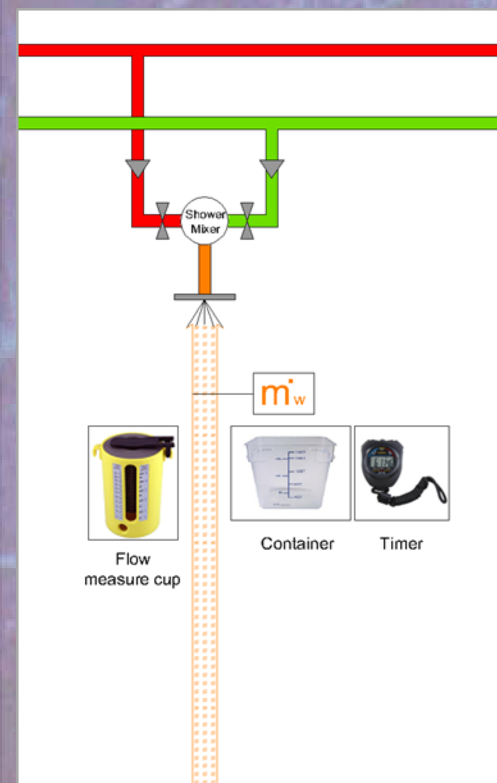
Methodology – parameters to measure

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	
Inlet drain water temperature	°C
Outlet drain water temperature	°C
Inlet preheated water temperature	°C
Outlet preheated water temperature	°C

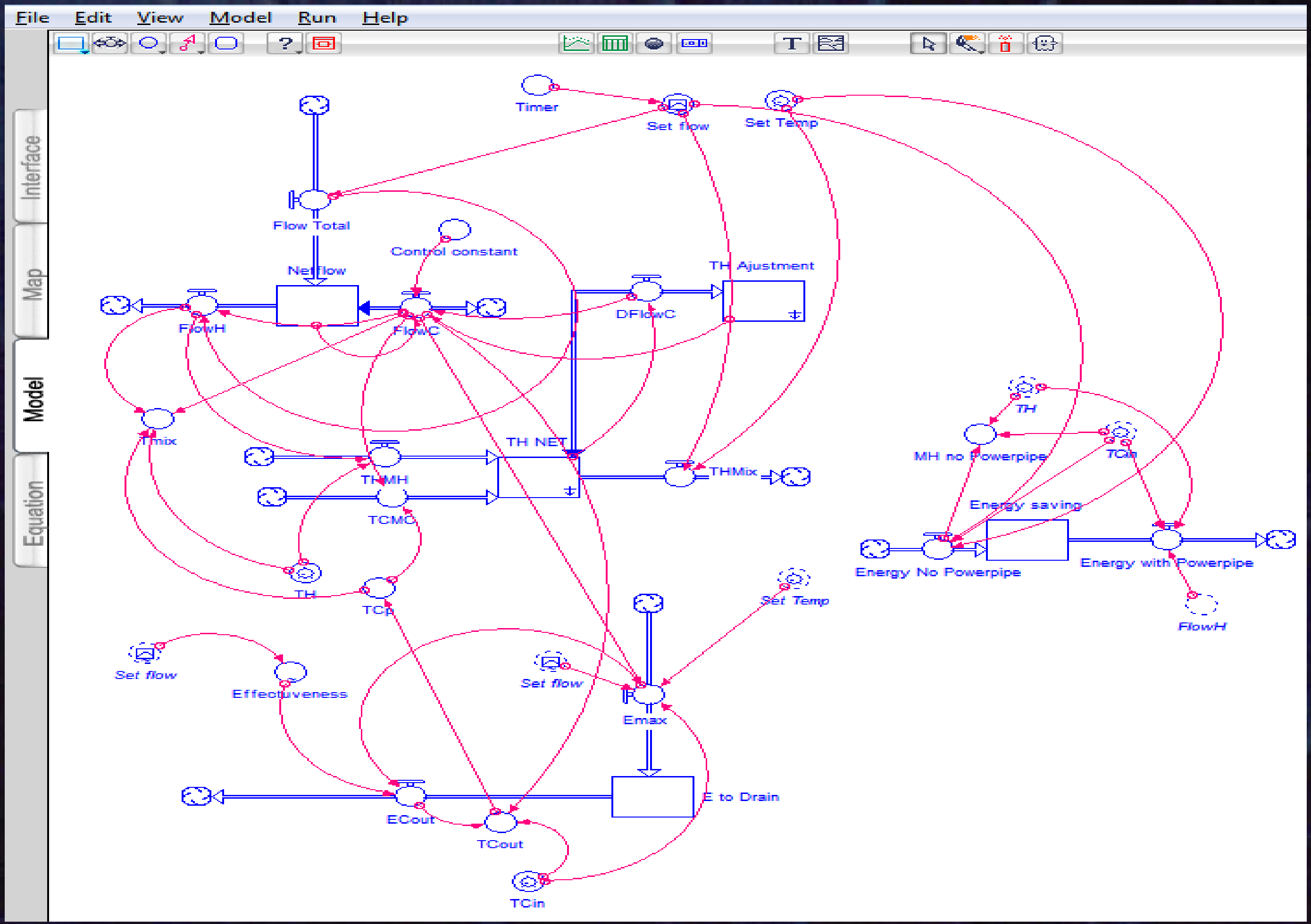
Experimental measurements







System simulation - model



- Dynamic system simulation model
- Graphically link the causal relationship between stocks and flow of the set variables

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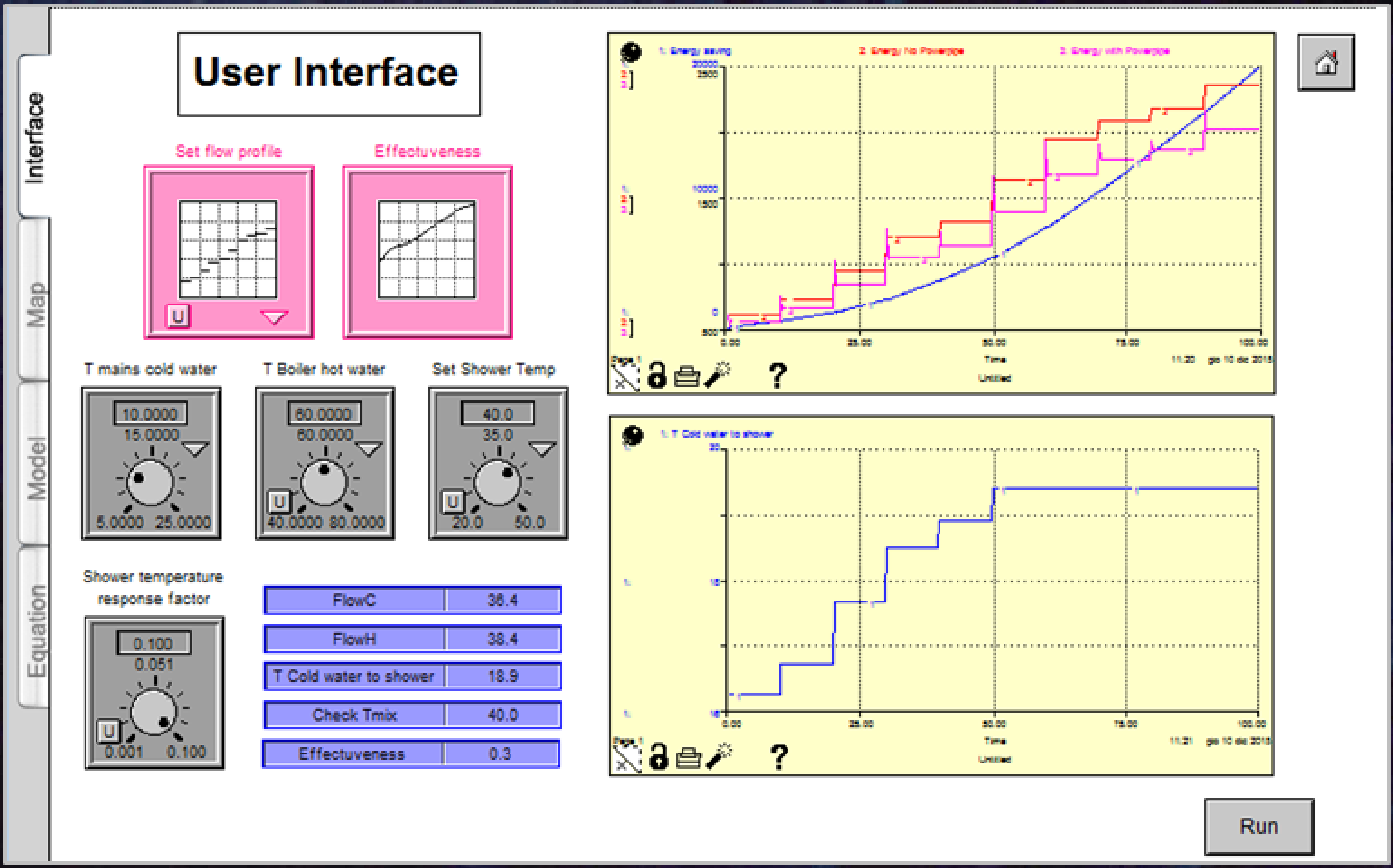
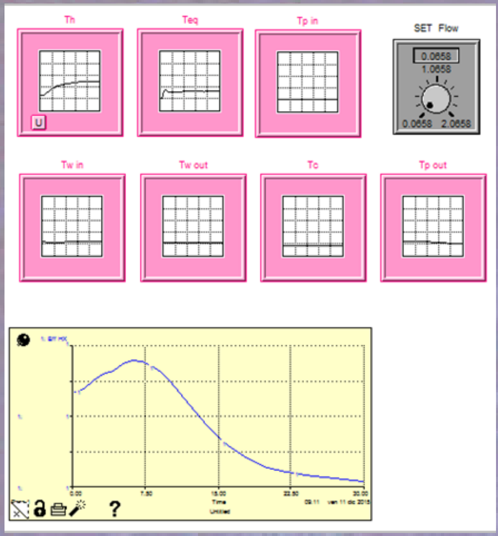
System simulation - outputs





System simulation – Scenarios and user profiles

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

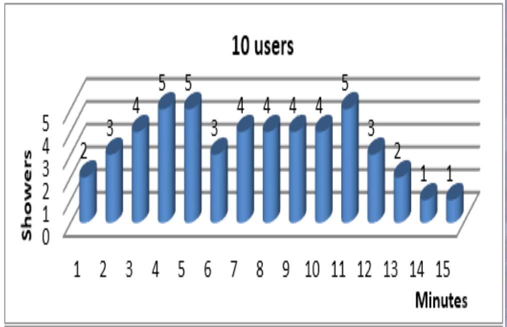
4 TEAMS: 2 Football, 2 Rugby (2 Trainings, 1 Match for each)

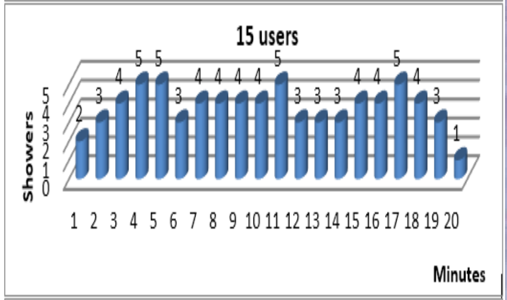
	M	T	W	T	F	S	S
1				R--10	R--10		R--15
2				R--15	R--15		R--15
3	F--15		F--15				R--15
4	F--10		F--10				R--15
5		R--10				R--15	F--20
6		R--15				R--15	F--20
7	F--10	R--15	F--15		F--20	R--15	
8	F--15	R--10	F--10		F--20	R--15	

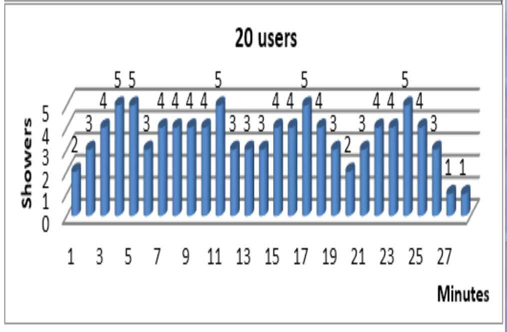
SCENARIO 4

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	







Results - measurements

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	/

Results – 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	

Results - payback

	Unit	Scenario			
		1	2	3	4
Annual savings @40 weeks	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 1 unit for 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

Conclusions

- Low water flow shower heads significantly reduced the expected energy savings
- Long payback despite operating under favourable user profiles and scenarios
- More effective to reduce the number of heat exchangers
- Dynamic heat transfer data are needed for more accurate performance prediction
- Modelling can help to optimise the design and to predict the life cycle environmental performance
- Long durability and low maintenance still makes this kind of device an attractive low carbon option

Further and on-going work

- Life cycle cost assessment
- Life cycle environmental impact assessment
- Develop application for system evaluation in new and refurbishment projects

Thank you for you attention

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