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# Combined Heating and Power: Control Documentation and Efficiency Measurement

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University of Plymouth

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### Appendix A – Overall Thermal Efficiency Full Data Recording

Time (s)	W <sub>Elec</sub> (kW)	η <sub>elec</sub> %	Vol. Flow (l/s)	Flow Rate (m/s)	T <sub>2</sub> (°C)	T <sub>1</sub> (°C)	ΔT <sub>1,2</sub> (°C)	T <sub>4</sub> (°C)	T <sub>5</sub> (°C)	ΔT <sub>4,5</sub> (°C)	T <sub>R</sub> (°C)	T <sub>S</sub> (°C)	ΔT <sub>S,R</sub> (°C)	W <sub>heat</sub> PU (kW)	W <sub>heat</sub> (ΔT <sub>4,5</sub> ) (kW)	W <sub>heat</sub> (ΔT <sub>S,R</sub> ) (kW)	W <sub>heat</sub> Efficiency %	W <sub>heat</sub> Efficiency %	W <sub>heat</sub> Efficiency %	η <sub>th</sub> % (PU)	η <sub>th</sub> % (ΔT <sub>4,5</sub> )	η <sub>th</sub> % (ΔT <sub>S,R</sub> )
0	13.4	28.4	0.542	0.674	51	70	60.5	55	46	9	43.4	48.9	5.5	30.8	20.1	12.3	65.3	42.5	26.0	93.7	71.0	54.4
60	13.2	28.0	0.547	0.68	51	70	60.5	57	47	10	44.4	50.6	6.2	30.5	22.5	13.9	64.7	47.7	29.4	92.6	75.7	57.4
120	13.3	28.2	0.559	0.682	51	70	60.5	58	48	10	45.8	51.9	6.2	30.1	23.0	14.2	63.8	48.8	30.0	92.0	77.0	58.2
180	13.2	28.0	0.552	0.687	51	71	61.0	59	49	10	46.9	53.2	6.3	30.3	22.7	14.3	64.2	48.1	30.3	92.2	76.1	58.3
240	13.2	28.0	0.550	0.685	52	71	61.5	60	50	10	47.8	54.2	6.4	30.4	22.6	14.4	64.5	48.0	30.6	92.4	76.0	58.6
300	13.3	28.2	0.546	0.678	52	71	61.5	60	51	9	48.3	54.8	6.5	30.6	20.2	14.6	64.9	42.9	31.0	93.1	71.1	59.2
360	13.2	28.0	0.545	0.682	53	72	62.5	61	51	10	48.7	55.7	7.0	30.4	22.4	15.7	64.5	47.5	33.3	92.4	75.5	61.2
420	13.3	28.2	0.552	0.684	54	73	63.5	62	52	10	49.2	56.0	6.7	30.5	22.7	15.3	64.7	48.1	32.4	92.9	76.3	60.6
480	13.4	28.4	0.439	0.525	54	74	64.0	62	53	9	49.5	56.9	7.5	30.3	16.3	13.5	64.2	34.5	28.6	92.6	62.9	57.0
540	13.2	28.0	0.259	0.321	53	75	64.0	61	53	8	47.9	56.8	9.0	30	8.5	9.5	63.6	18.1	20.2	91.6	46.0	48.2
600	13.2	28.0	0.258	0.318	51	75	63.0	59	52	7	45.2	56.3	11.2	30.4	7.4	11.9	64.5	15.8	25.1	92.4	43.7	53.1
660	13.3	28.2	0.432	0.549	50	73	61.5	58	50	8	44.1	54.8	10.7	29.9	14.2	18.9	63.4	30.1	40.2	91.6	58.3	68.4
720	13.3	28.2	0.533	0.663	50	72	61.0	59	48	11	46.2	52.9	6.7	30.1	24.1	14.6	63.8	51.2	31.0	92.0	79.4	59.2
780	13.3	28.2	0.534	0.666	51	71	61.0	60	49	11	47.1	53.6	6.4	30.4	24.2	14.2	64.5	51.2	30.0	92.6	79.4	58.2
840	13.2	28.0	0.536	0.664	52	71	61.5	61	50	11	47.9	54.6	6.7	29.9	24.2	14.7	63.4	51.4	31.2	91.4	79.4	59.2
900	13.4	28.4	0.515	0.627	53	72	62.5	62	51	11	48.6	55.4	6.8	30.3	23.3	14.4	64.2	49.4	30.6	92.6	77.8	59.0
960	13.2	28.0	0.331	0.388	54	73	63.5	63	52	11	48.0	56.4	8.4	30.5	15.0	11.4	64.7	31.7	24.2	92.6	59.7	52.2
1020	13.3	28.2	0.313	0.387	51	74	62.5	59	52	7	46.1	55.7	9.6	30.3	9.0	12.3	64.2	19.1	26.1	92.4	47.3	54.3
1080	13.4	28.4	0.309	0.384	50	74	62.0	60	51	9	45.1	54.5	9.4	30.2	11.4	12.0	64.0	24.2	25.4	92.6	52.6	53.8
1140	13.3	28.2	0.484	0.61	50	73	61.5	59	49	10	45.8	53.7	7.9	30.2	19.9	15.7	64.0	42.2	33.3	92.2	70.4	61.5
1200	13.2	28.0	0.524	0.646	51	71	61.0	59	49	10	47.0	54.1	7.1	30.1	21.5	15.2	63.8	45.7	32.3	91.8	73.6	60.3
1260	13.3	28.2	0.523	0.649	52	71	61.5	61	50	11	47.8	54.5	6.7	30.3	23.7	14.5	64.2	50.1	30.8	92.4	78.3	59.0
1320	13.2	28.0	0.489	0.603	53	72	62.5	61	51	10	48.6	55.6	6.9	30.2	20.1	14.0	64.0	42.6	29.6	92.0	70.6	57.6
1380	13.4	28.4	0.361	0.451	53	73	63.0	63	53	10	47.5	55.4	7.9	29.9	14.9	11.7	63.4	31.5	24.8	91.8	59.9	53.2
1440	13.2	28.0	0.331	0.409	51	74	62.5	59	52	7	46.1	54.9	8.7	30.2	9.5	11.9	64.0	20.2	25.2	92.0	48.2	53.2
1500	13.3	28.2	0.326	0.407	50	74	62.0	59	51	8	45.3	54.3	9.0	30.3	10.7	12.1	64.2	22.7	25.6	92.4	50.9	53.8
1560	13.3	28.2	0.431	0.585	49	74	61.5	59	50	9	45.9	53.4	7.6	29.9	16.0	13.4	63.4	33.8	28.5	91.6	62.0	56.7
1620	13.2	28.0	0.501	0.6266	50	73	61.5	60	49	11	46.7	53.6	6.9	30.6	22.7	14.2	64.9	48.1	30.1	92.9	76.0	58.0
1680	13.2	28.0	0.504	0.621	52	72	62.0	60	50	10	47.5	54.4	6.9	30.3	20.7	14.3	64.2	44.0	30.3	92.2	72.0	58.2
1740	13.3	28.2	0.500	0.621	52	71	61.5	61	51	10	47.9	54.7	6.8	30.1	20.6	14.0	63.8	43.6	29.7	92.0	71.8	57.9
1800	13.3	28.2	0.408	0.555	53	73	63.0	62	51	11	48.3	55.7	7.4	30.2	18.5	12.4	64.0	39.1	26.2	92.2	67.3	54.4
	<b>13.3</b>	<b>28.1</b>	<b>0.459</b>	<b>0.6</b>	<b>51.6</b>	<b>72.4</b>	<b>62.0</b>	<b>60.0</b>	<b>50.4</b>	<b>9.6</b>	<b>46.9</b>	<b>54.4</b>	<b>7.5</b>	<b>30.3</b>	<b>18.5</b>	<b>13.7</b>	<b>64.2</b>	<b>39.2</b>	<b>29.1</b>	<b>92.3</b>	<b>67.3</b>	<b>57.2</b>
60	5.6	19.6	0.503	0.625	47	53	50.0	56	47	9	43.4	48.0	4.5	20.1	18.6	9.3	70.2	65.1	32.7	89.81	84.7	52.2
120	5.8	20.3	0.530	0.659	51	55	53.0	58	45	13	41.9	46.8	4.9	20.4	28.3	10.6	71.3	99.0	37.0	91.55	119.3	57.3
180	5.8	20.3	0.539	0.669	51	59	55.0	58	47	11	42.6	49.9	7.3	20	24.4	16.1	69.9	85.2	56.3	90.16	105.5	76.5
240	5.7	19.9	0.543	0.677	51	62	56.5	58	50	8	46.1	52.3	6.2	19.9	17.9	13.8	69.5	62.4	48.4	89.46	82.3	68.3
300	5.7	19.9	0.544	0.674	51	65	58.0	57	50	7	46.5	52.1	5.6	19.8	15.7	12.5	69.2	54.8	43.6	89.11	74.7	63.5
360	5.6	19.6	0.539	0.67	51	65	58.0	57	50	7	46.5	51.8	5.3	19.7	15.5	11.8	68.8	54.2	41.3	88.41	73.8	60.9
420	5.6	19.6	0.543	0.676	51	65	58.0	58	50	8	46.5	52.0	5.5	20	17.9	12.3	69.9	62.5	42.9	89.46	82.0	62.5
480	5.7	19.9	0.544	0.676	51	65	58.0	58	50	8	46.5	51.6	5.2	19.9	17.9	11.5	69.5	62.5	40.3	89.46	82.4	60.3
540	5.6	19.6	0.543	0.675	51	65	58.0	57	50	7	46.5	51.9	5.3	19.8	15.6	11.9	69.2	54.6	41.5	88.76	74.2	61.1
600	5.6	19.6	0.546	0.681	51	65	58.0	57	50	7	46.5	51.8	5.4	19.7	15.7	12.0	68.8	54.9	42.0	88.41	74.5	61.6
	<b>5.7</b>	<b>19.8</b>	<b>0.537</b>	<b>0.7</b>	<b>50.6</b>	<b>61.9</b>	<b>56.3</b>	<b>57.4</b>	<b>48.9</b>	<b>8.5</b>	<b>45.3</b>	<b>50.8</b>	<b>5.5</b>	<b>19.9</b>	<b>18.8</b>	<b>12.2</b>	<b>69.6</b>	<b>65.5</b>	<b>42.6</b>	<b>89.5</b>	<b>85.3</b>	<b>62.4</b>

## Nomenclature

A	Actuator	-
AAV	Automatic Air Vent	-
BV	Buffer Vessel	-
BSI	British Standards Institute	-
CCUF	Cross Correlation Ultrasonic Flow Meter	-
$C_v$	Calorific Value	J/kg
CHP	Combined Heating and Power	-
CP	Circulation Pump	-
$C_p$	Specific Heat Capacity	J/KgK
DHW	Domestic Hot Water	-
DUF	Doppler Ultrasonic Flow Meter	-
ECL	Electronic Control Unit	-
H/X	Heat Exchanger	-
EU	European Union	-
EV	Expansion Vessel	-
FCU	Fan Coil Unit	-
ICE	Internal Combustion Engine	-
ISO	International Organization for Standardization	-
PAT	Portable Appliance Testing	-
$P_n$	Rated Power	W
PRV	Pressure Release Valve	-
PU	Power Unit	-
Q	Volumetric Flow	m <sup>3</sup> /s
SHL	Space Heating Loop	-
SMART	Specific Measurable Assignable Realistic Time-bound	-
T	Temperature (Gauge/ Sensor)	-
TC	Thermocouple	-
TTUF	Transit Time Ultrasonic Flow Meter	-
V	Valve	-
$W_{heat}$	Heating Power Output	W
$W_{elec}$	Electrical Power Output	W
$\eta_{th}$	Overall Thermal Efficiency	%
$\rho$	Density	Kg/m <sup>3</sup>