Test Report UTR - 171

Performance and Efficiency Testing THERMAL-XR coil coating

Graphene Manufacturing Group

01/06/2023

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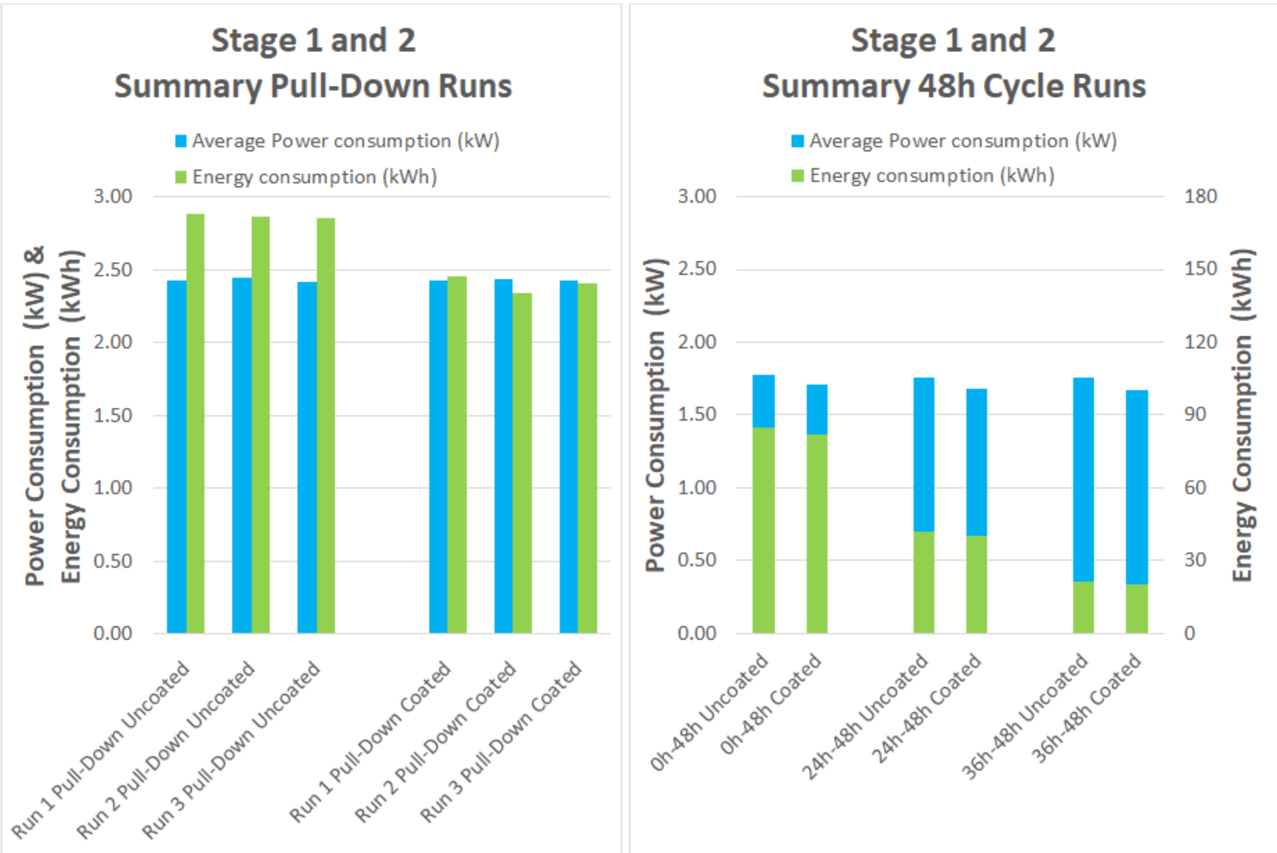
Executive summary

A new typical cold room refrigeration system was tested to investigate the effect of THERMAL-XR coil coating on the system power consumption in two steps: the time to temperature pull-down runs (step 1) and the continuous 48h cycle run (step 2).

The results are summarised below:

- Repeatable test results were achieved in both stages 1 and 2, and steps 1 and 2.
- Improvement in power consumption was seen in both stages (see Graph 1).
- The average pull-down time in stage one step 1 was 1:10:41, with an average power consumption of 2.43 kW, which results in about 2.86 kWh of energy consumption (Graph 2, Graph 3 and Table 3).
- The average pull-down time in stage two step 1 was 0:59:17, with an average power consumption of 2.44 kW, which results in about 2.41 kWh of energy consumption (Graph 6, Graph 7 and Table 6).
- The step 1 pull-down tests show a 15.9% reduction in the system's overall energy consumption.
  Note: During the analysis of the results, there was an irregularity found in the suction SuperHeat during the time to temperature pull-down runs in stage 1 and 2. Further information can be found in Section 5.1.
- Comparing step 2 of stage 1 and 2 of the continuous 48h runs shows up to a 4.7% energy consumption reduction.
  Note: During the analysis of the results, there was an irregularity found in the suction SuperHeat during the cycles of the continuous 48h runs in stage 1 and 2. Further information can be found in Section 5.2.



Graph 1: Summary results Stage 1 and Stage 2.

Nomenclature

Table 1: Abbreviation table

Abbreviation	Definition
h	Hour
min	Minutes
kWh	KiloWatt-hour
kW	KiloWatt
EEV	Electronic expansion valve
V	Volts
Hz	Hertz
°C	Degree Celsius
KTD	Kelvin temperature difference
DBT	Dry bulb temperature
RH	Relative humidity
kg	Kilograms

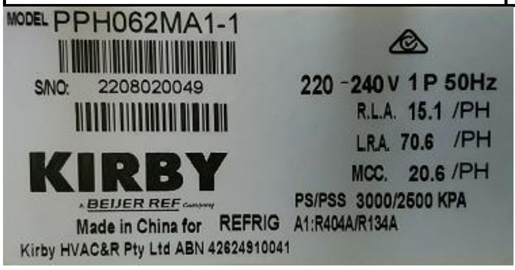
1. Introduction

This Test Report document provides the results and analysis of the power consumption comparison tests between an OEM factory coated condenser coil and a THERMAL-XR coated condenser coil used on the same condensing unit. The test procedure completed according to the processes and procedures detailed and accepted by the customer are provided in Test Description UTD-171 dated 20th March 2023.

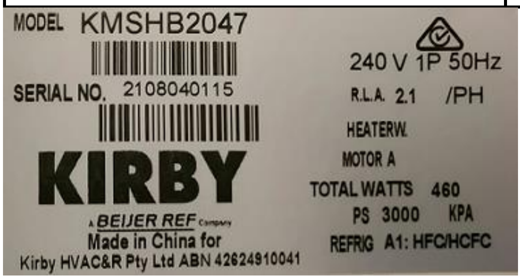
2. Testing equipment general information

Table 2: System information.

Condensing unit with a factory coated coil	
Brand	KIRBY
Model No.	PPH062MA1-1
Serial No.	2208020049
Type (family)	Polar Pack
Description	Condensing unit
Rated Voltage	220-240V 1 phase
Rated frequency	50Hz
Displacement (m3/h)	10.52
Refrigerant	R134a



Evaporator unit	
Brand	KIRBY
Model No.	KMSHB2047
Serial No.	2108040115
Type (family)	9000 Series
Description	Evaporator unit
Fan motor data	240V 50Hz 1 phase
Total power	460W
Refrigerant	R134a



3. Stage 1 – OEM factory coated condenser coil test

This stage consists of two steps:

1. Time to temperature test
2. Continuous 48h cycle test

3.1 Step 1 – Time to temperature test

3.1.1 General testing conditions

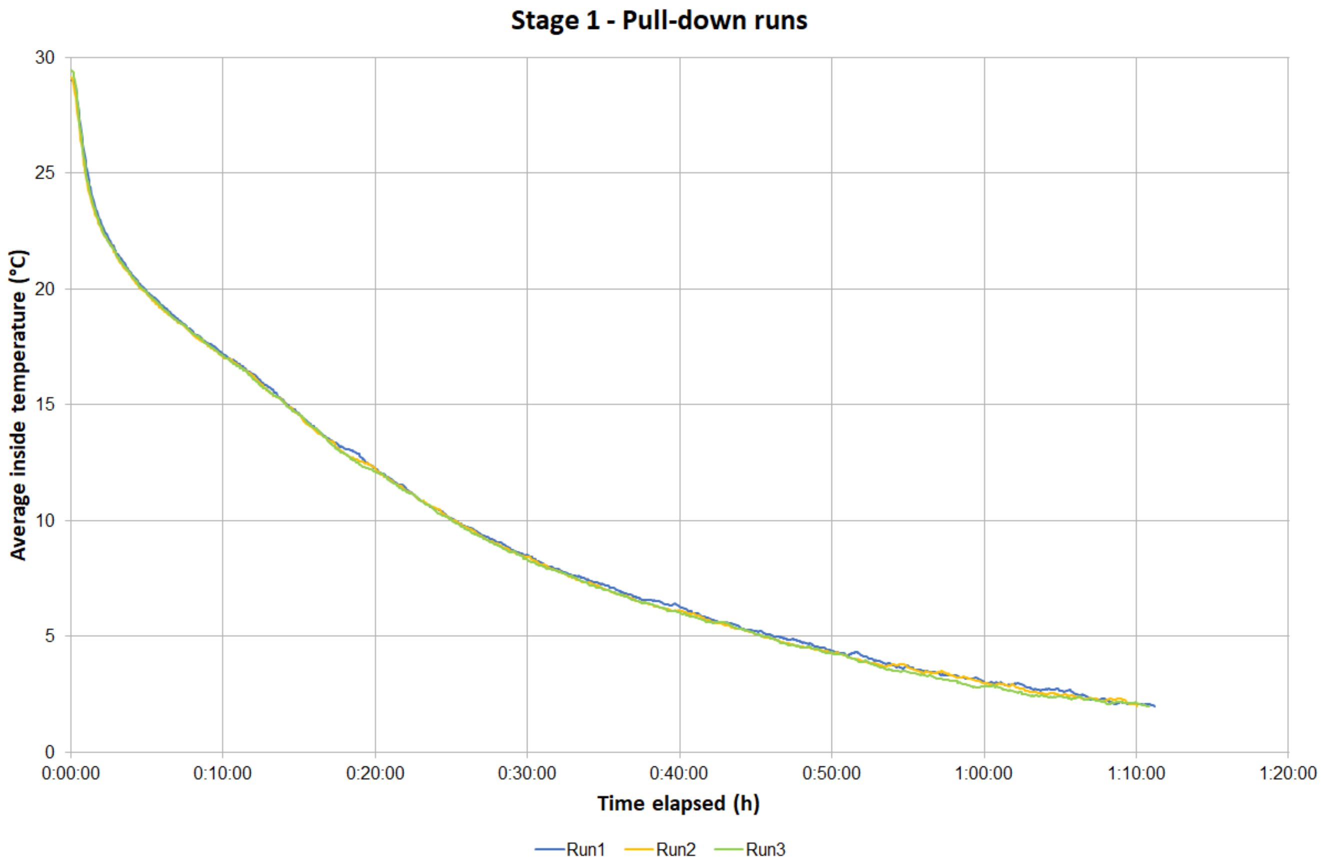
- Outside room DBT 35°C
- Inside room DBT 30°C
- Indoor room set point temperature 2°C
- 20min stabilisation at 30°C before start test

3.1.2 Results

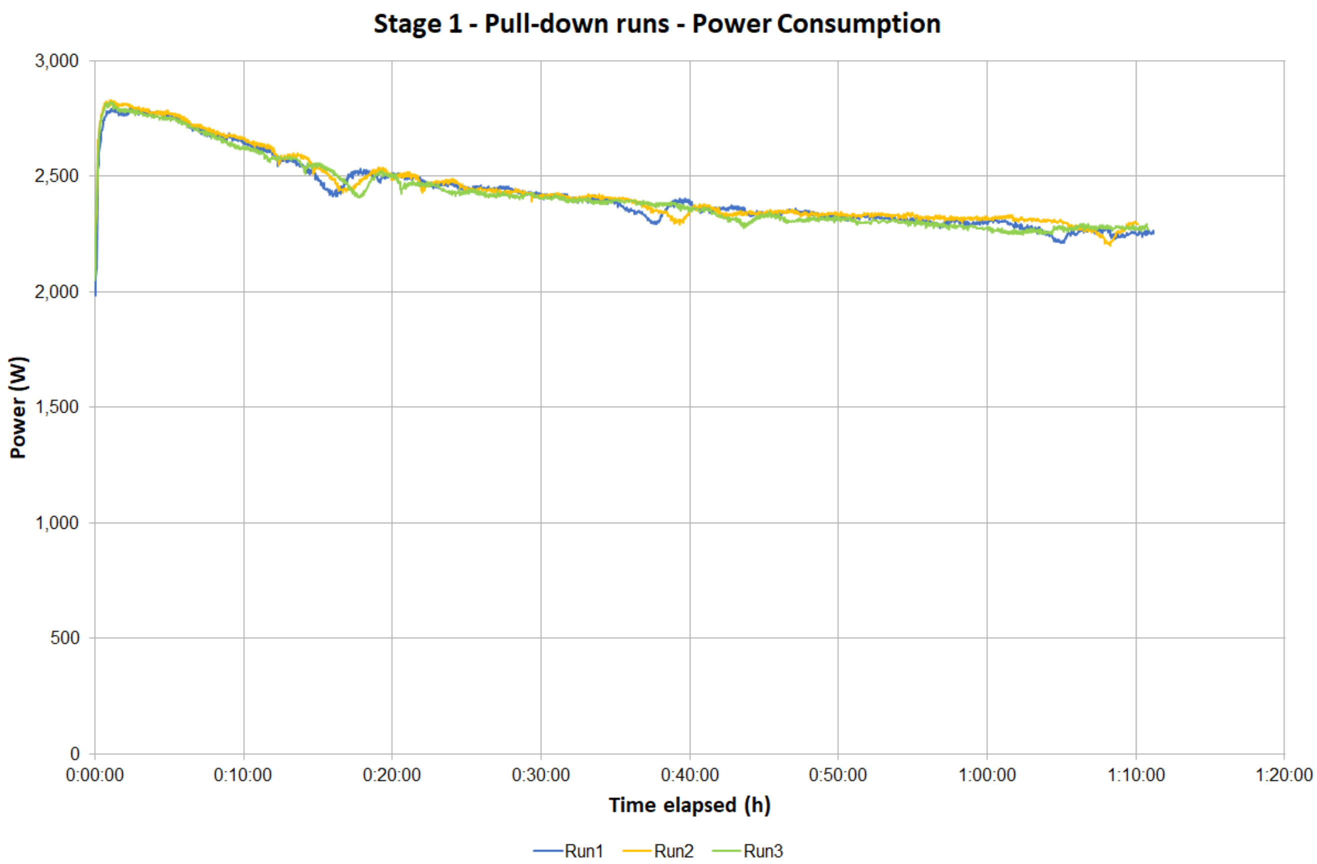
The purpose of the time to temperature (pull-down) runs in stage 1 is to investigate the required time and power consumption to cool down the inside room from 30°C to the 2°C set point using an OEM factory coated condenser coil. For the pull-down tests, three runs have been carried out for the purpose of showing consistency in the results. Table 3 shows that the energy difference between the three runs is within 1%. Graph 2 shows that the overall temperature decrease over time is nearly identical between the runs. Graph 3 provides the power consumption used by the unit over time. The power consumption between the runs is also very similar.

Table 3: Stage 1 – Time to temperature runs comparison – Duration and power consumption.

Power Consumption				
	Duration	**Average power (kW)**	**Energy (kWh)**	**Energy difference**
Run1	1:11:12	2.43	2.88	
Run2	1:10:04	2.45	2.86	0.79%
Run3	1:10:48	2.42	2.85	0.85%
Average	1:10:41	2.43	2.86	



Graph 2: Stage 1 – Time to temperature runs comparison.



Graph 3: Stage 1 – Time to temperature runs comparison.

3.2 Step 2 – Continuous 48h cycle test

3.2.1 General testing conditions

- Outside room DBT 35°C
- Inside room set point temperature 2°C
- Inside room heater 100W
- Inside room fan 275W
- 22h stabilisation at 2°C setpoint before the start of the test

3.2.2 Results

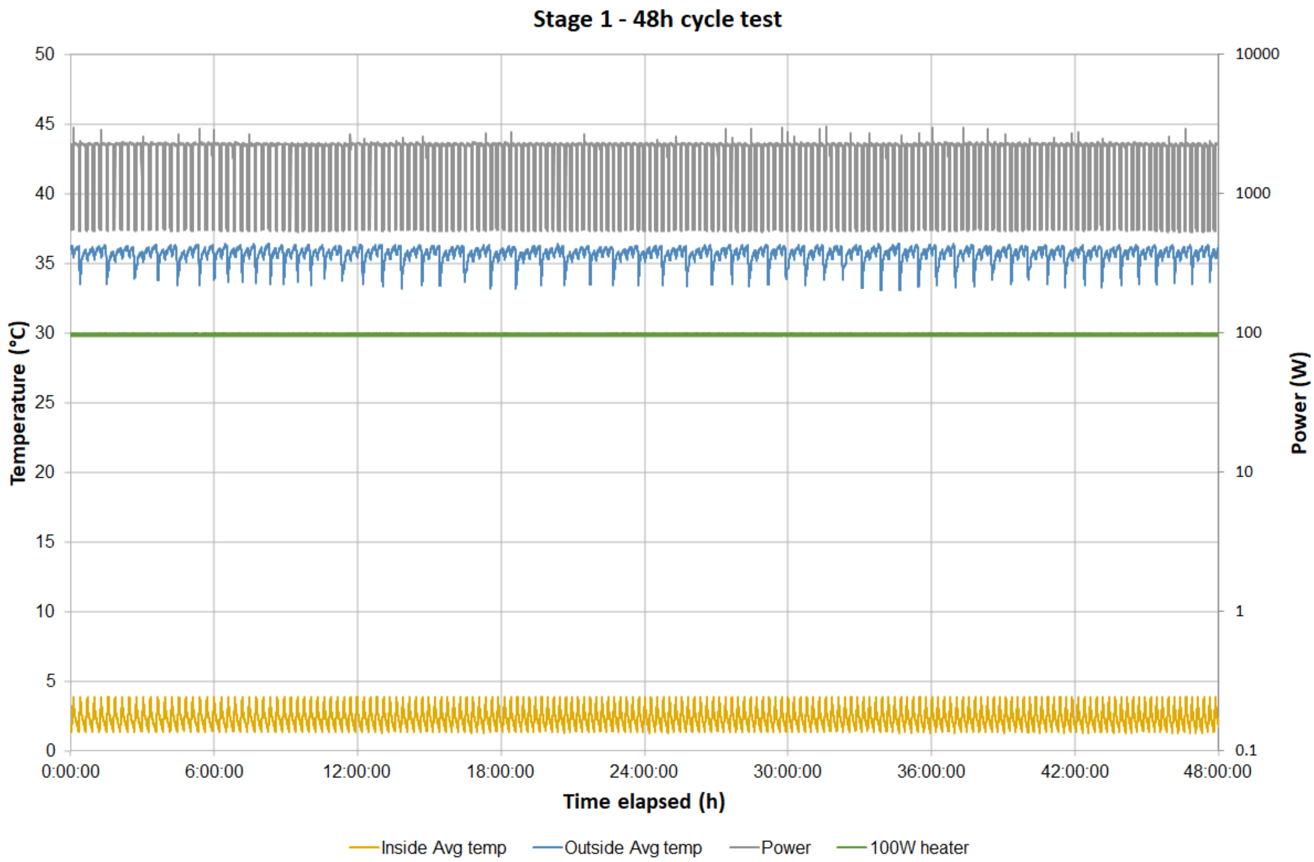
The purpose of the continuous 48h cycle test in stage 1 is to investigate the power consumption when the system is in cycling mode using an uncoated condenser coil. Prior to the start of the 48h test, a 22h stabilisation period at the 2°C setpoint was set to reject the majority of the heat from the room to ensure similar cyclic behaviour during the 48h test. Table 4 shows that the power consumption over the 48h time is stable with asymptotic behaviour towards the last 12h of the run. Table 4 provides more detail about the cycling time during the run. The cycle off time is consistent throughout the run, showing the heat load's consistency. Graph 4 shows consistent cyclic behaviour, with Graph 5 providing a detailed timeframe of the last 12 hours of the run.

Table 4: Stage 1 – Continuous 48h cycle test – Power consumption.

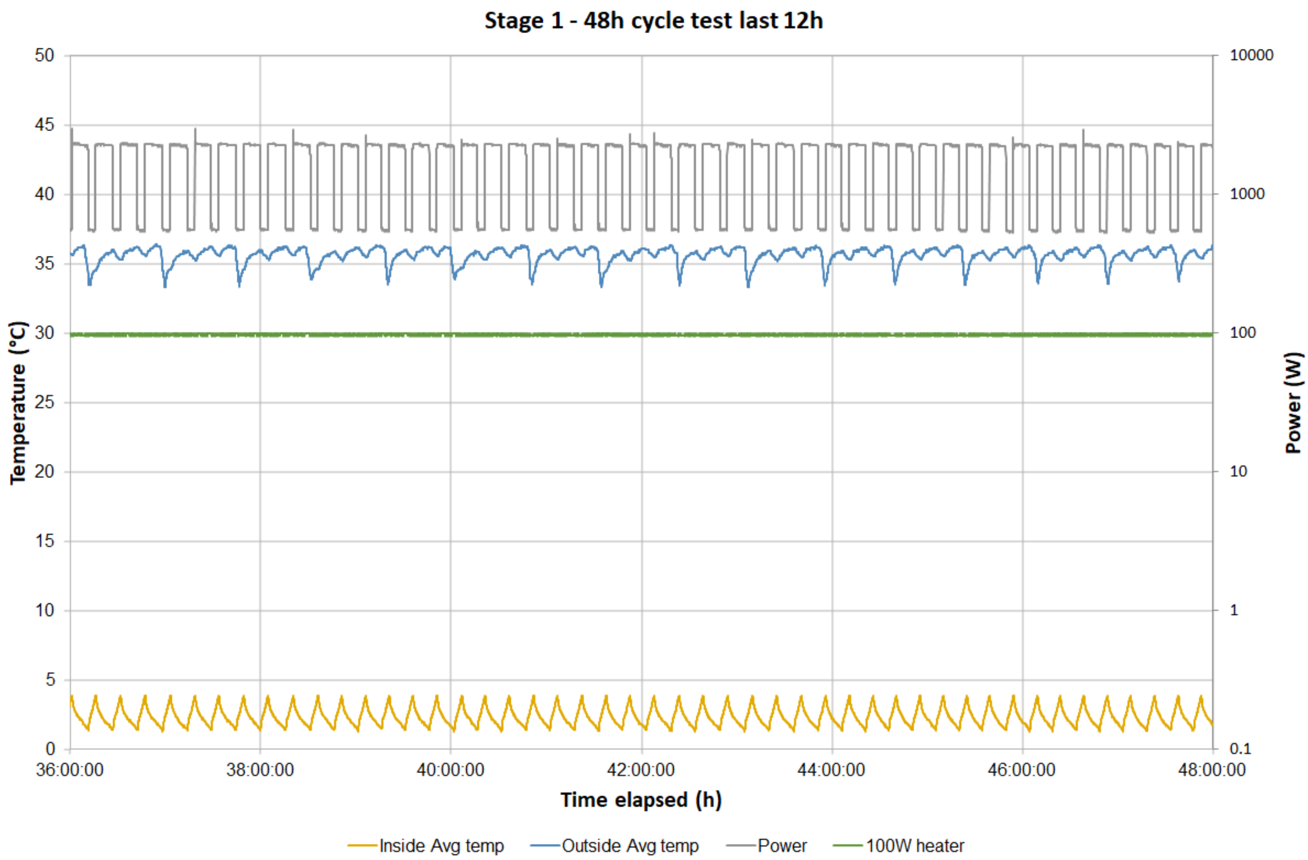
Power consumption cycle test		
	Average power (kW)	**Energy (kWh) per 24h**
Between 0h-48h	1.77	42.55
Between 24h-48h	1.76	42.14
Between 36h-48h	1.76	42.18

Table 5: Stage 1 – Continuous 48h cycle test – Cycle duration.

Average cycle duration			
	Time cycle ON	**Time cycle OFF**	**Cycle time complete**
Between 0h-48h	0:11:14	0:04:40	0:15:53
Between 24h-48h	0:10:42	0:04:40	0:15:22
Between 36h-48h	0:10:26	0:04:40	0:15:06



Graph 4: Stage 1 – Continuous 48h cycle test – Temperature and power consumption.



Graph 5: Stage 1 – Continuous 48h cycle test – Temperature and power consumption of the last 12h.

4. Stage 2 – THERMAL-XR coated condenser coil test

This stage consists of two steps:

1. Time to temperature test
2. Continuous 48h cycle test

In stage 2, the OEM factory coated condenser coil used in stage 1 was coated with THERMAL-XR by GMG. Product, process and procedure of the applied THERMAL-XR coating are not disclosed in this report.

4.1 Step 1 – Time to temperature test

4.1.1 General testing conditions

- Outside room DBT 35°C
- Inside room DBT 30°C
- Indoor room set point temperature 2°C
- 20min stabilisation at 30°C before start test

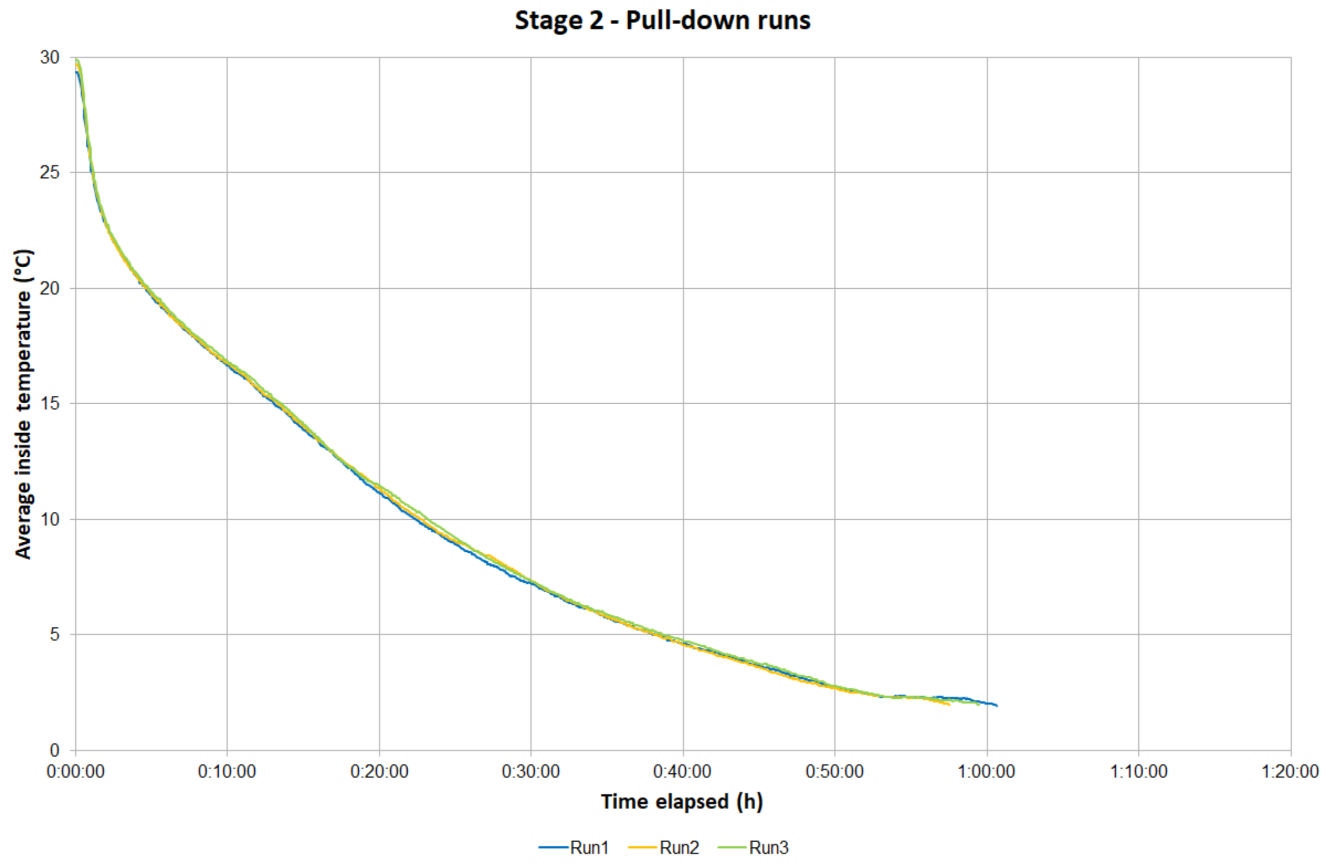
4.1.2 Results

The purpose of the the time to temperature (pull-down) runs in stage 2 is to compare the power consumption with stage 1 to investigate the potential energy reduction when using a THERMAL-XR coil coating on the condenser. As in stage 1, three runs have been carried out to show the repeat of the results. Table 6 shows that the energy difference between the three runs is slightly more significant than in stage 1 with 2-5%.

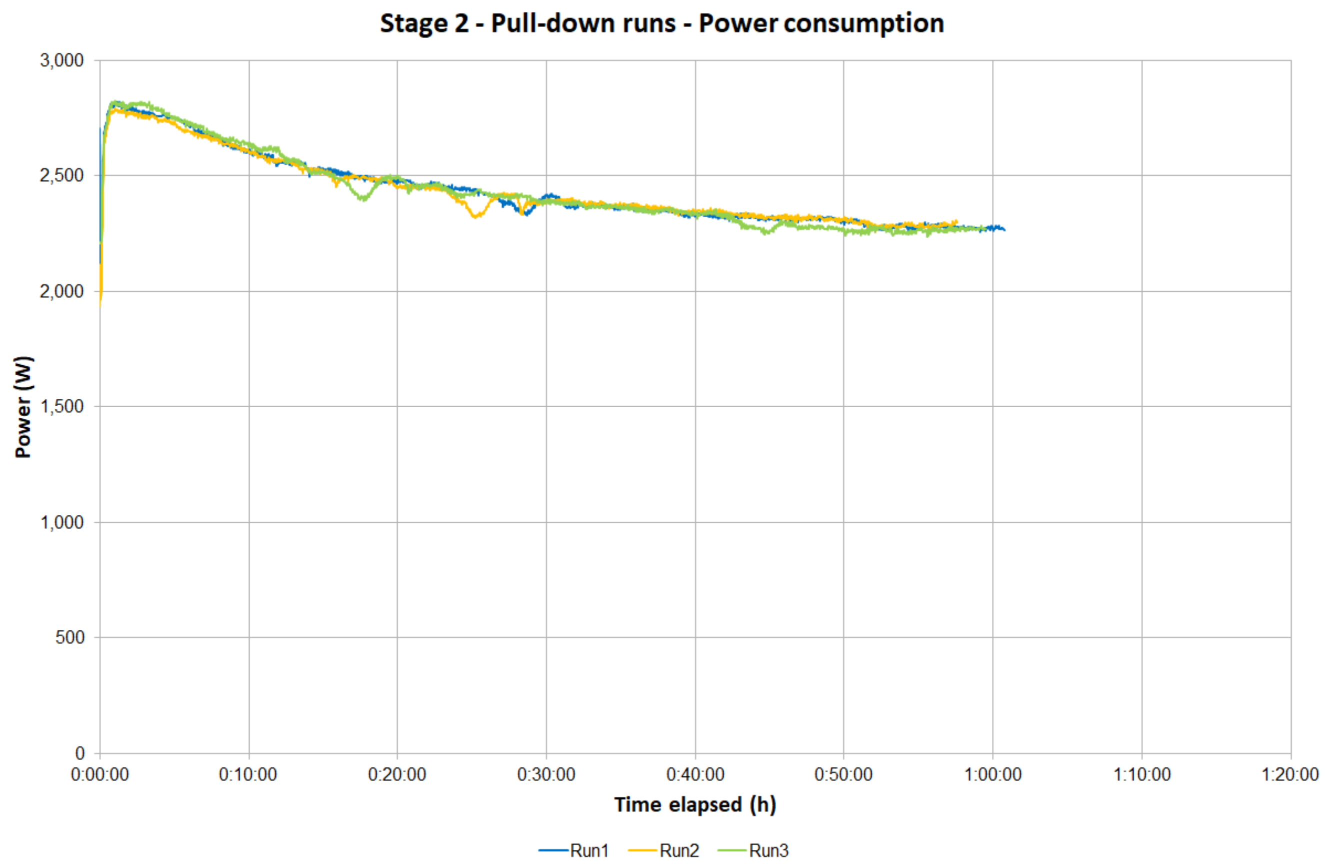
Graph 6 shows that the overall temperature decrease over time is nearly identical between the runs, with the main difference occurring in the last five minutes of the run. Graph 7 provides the power consumption used by the unit over time. The power consumption between the runs is also very similar.

Table 6: Stage 2 – Time to temperature runs – Duration and power consumption.

Power Consumption				
	Duration	**Average power (kW)**	**Energy (kWh)**	**Energy difference**
Run1	1:00:44	2.43	2.46	
Run2	0:57:35	2.44	2.34	4.93%
Run3	0:59:32	2.43	2.41	2.02%
Average	0:59:17	2.44	2.41	



Graph 6: Stage 2 – Time to temperature runs comparison.



Graph 7: Stage 2 – Time to temperature runs comparison.

4.2 Step 2 – Continuous 48h cycle test

4.2.1 General testing conditions

- Outside room DBT 35°C
- Inside room set point temperature 2°C
- Inside room heater 100W
- Inside room fan 275W
- 22h stabilisation at 2°C setpoint before the start of the test

4.2.2 Results

The purpose of the continuous 48h cycle test in stage 2 is to compare the power consumption with stage 1 to investigate the potential energy reduction of using a THERMAL-XR coil coating on the condenser. Prior to the start of the 48h run, a 22h stabilisation period at the 2°C setpoint was set to reject the majority of the heat from the room to ensure comparability between the two stages.

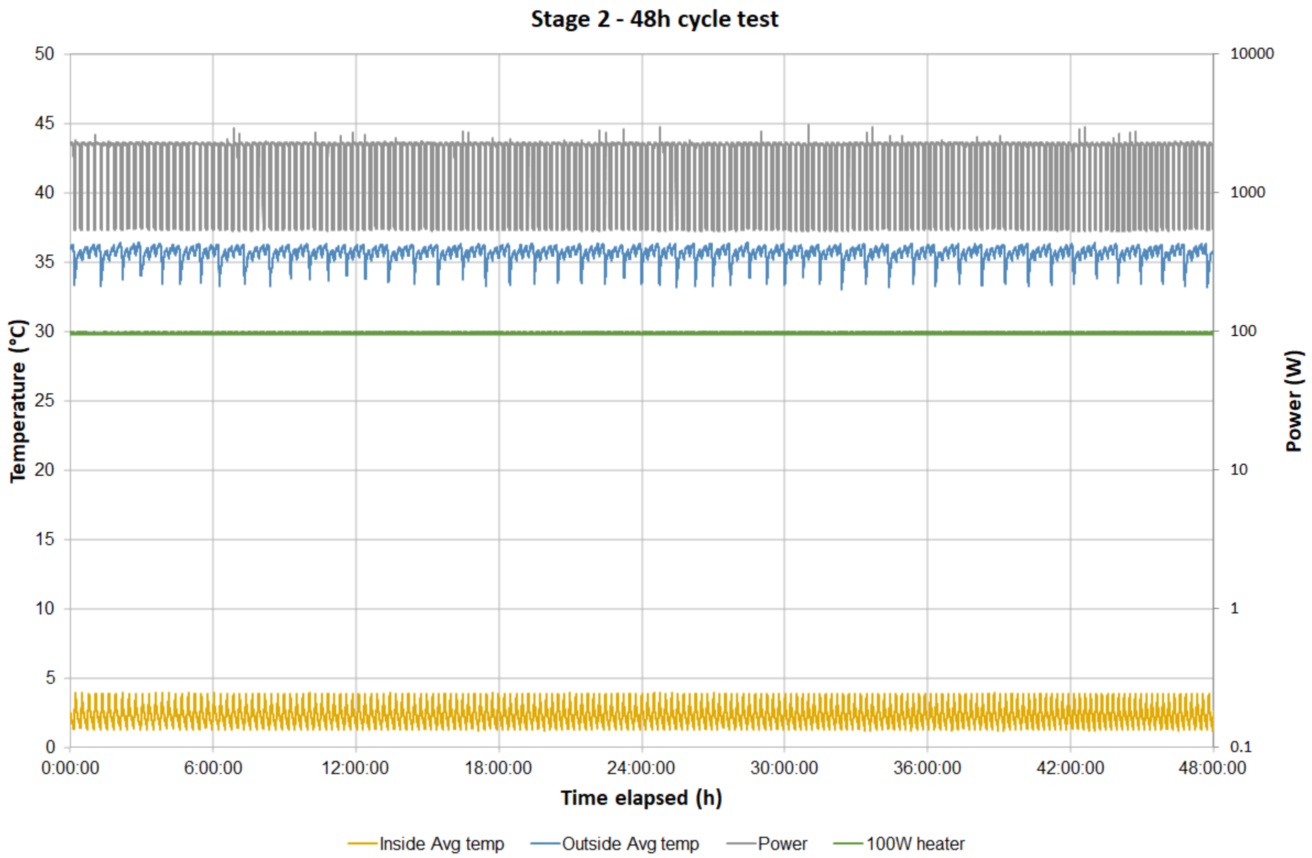
Table 7 shows that the power consumption over the 48h time is stable with asymptotic behaviour towards the last 12h of the run. Table 8 provides more detail about the cycling time during the run. The cycle off time is consistent throughout the run, showing the heat load's consistency. Graph 8 shows consistent cyclic behaviour, with Graph 9 providing a detailed timeframe of the last 12 hours of the run.

Table 7: Stage 2 – Continuous 48h cycle test – Power consumption.

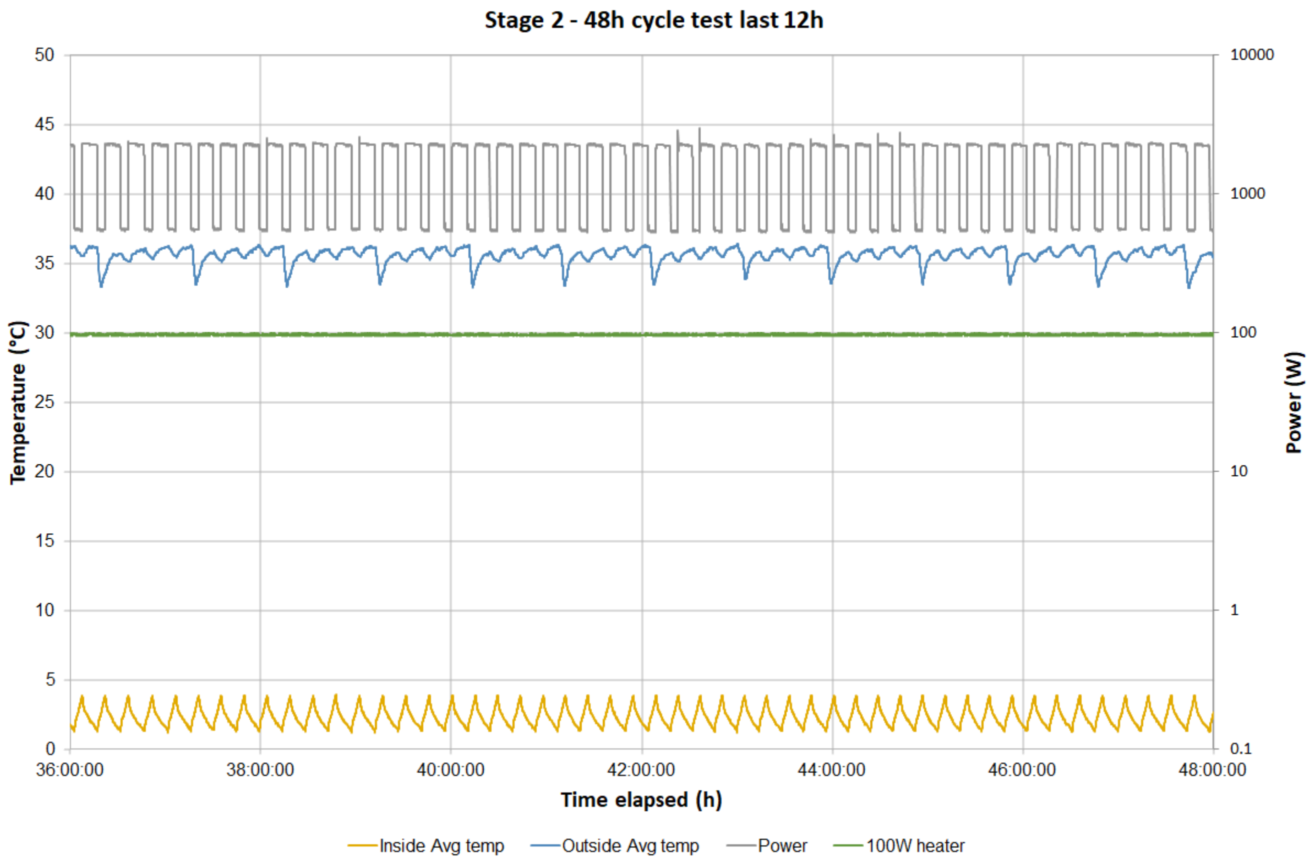
Power consumption cycle test		
	Average power (kW)	Energy (kWh) per 24h
Between 0h-48h	1.71	40.97
Between 24h-48h	1.68	40.39
Between 36h-48h	1.68	40.20

Table 8: Stage 2 – Continuous 48h cycle test – Cycle duration.

Average cycle duration			
	Time cycle ON	Time cycle OFF	Cycle time complete
Between 0h-48h	0:10:13	0:04:50	0:15:03
Between 24h-48h	0:09:43	0:04:50	0:14:33
Between 36h-48h	0:09:29	0:04:48	0:14:18



Graph 8: Stage 2 – Continuous 48h cycle test – Temperature and power consumption.



Graph 9: Stage 2 – Continuous 48h cycle – Temperature and power consumption of the last 12h.

5. Results and discussions

5.1 Step 1 – Time to temperature test

Repeatable test results were achieved in both stages 1 and 2. The energy reduction between stage 1 (using an OEM factory coated condenser coil) and stage 2 (using a THERMAL-XR coated coil) during the pull-down runs is 15.9% (Table 9). Graph 10 shows the difference between the pull-down runs from stage 1 and 2. It has to be noted that the relative humidity in the outside room had about 10 percent points difference between stage 1 and stage 2 (Table 10). This may have impacted the accuracy of the energy reduction percentage.

Table 9: Comparison between stage 1 and 2 – Pull-down runs.

Pull-down runs - Power consumption (averages)				
	Duration	**Average power (kW)**	**Energy (kWh)**	**Energy reduction**
Stage 1	1:10:41	2.43	2.86	
Stage 2	0:59:17	2.44	2.41	15.9%

Table 10: Comparison between stage 1 and 2 – Average room temperatures and relative humidity.

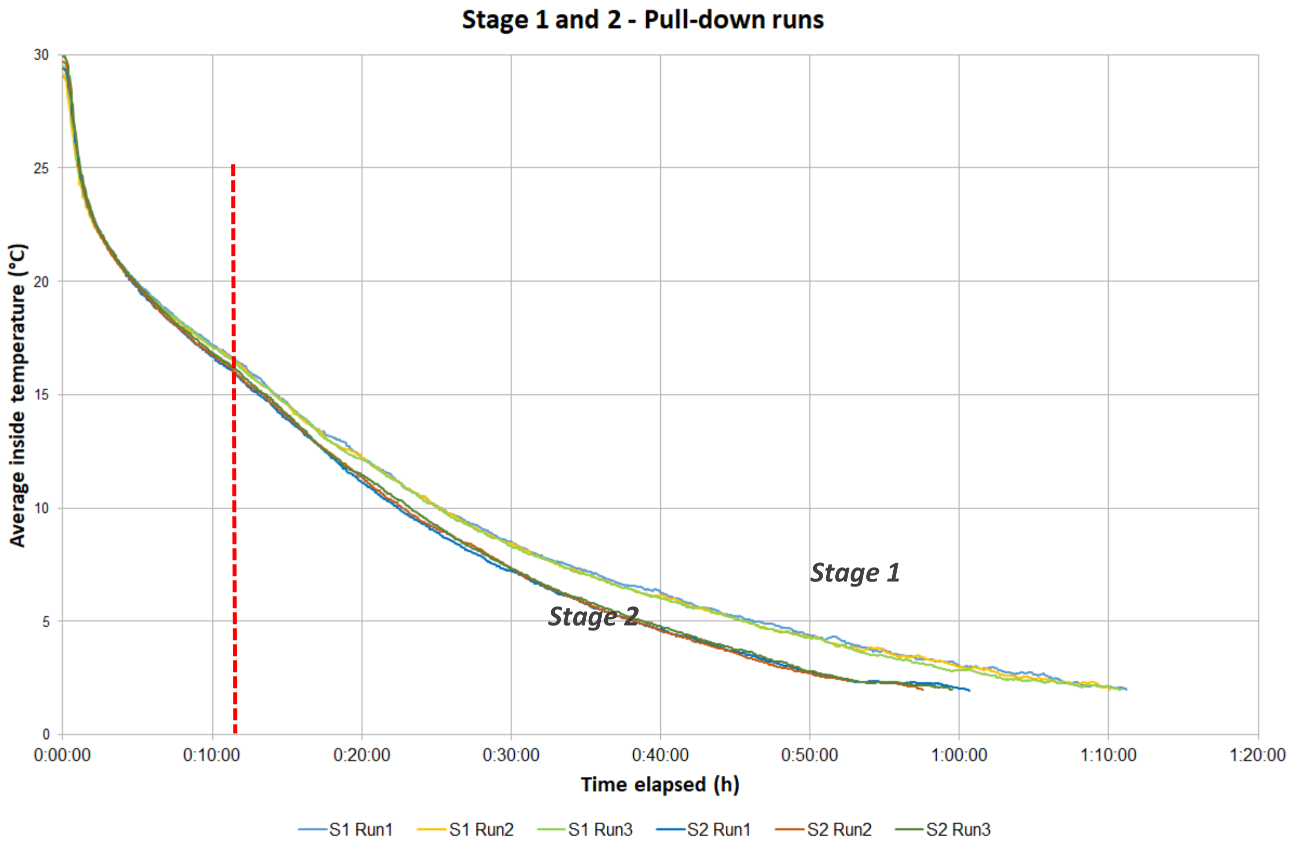
	Inside temp		Inside RH		Outside temp		Outside RH	
	Start	**End**	**Start**	**End**	**Start**	**End**	**Start**	**End**
Stage 1	29.20 °C	1.98 °C	51.9 %H	67.8 %H	35.00 °C	35.50 °C	**26.9 %H**	**25.7 %H**
Stage 2	29.70 °C	1.97 °C	45.0 %H	69.1 %H	35.03 °C	36.13 °C	**16.0 %H**	**14.3 %H**

During the analysis of the results, there was an irregularity found in the suction SuperHeat during the pull-down runs in stage 1 and 2 (Graph 11). The result indicate that the electronic expansion valve (EEV) was not maintaining the 6KTD SuperHeat set point during the first 10-12 minutes. During this time, the discharge temperature also drops indicating the EEV is overfeeding the evaporator until the EEV starts to fluctuate at the 10-12min mark (red dotted line). A steady 6KTD SuperHeat should be expected throughout the pull-down runs. When comparing the runs up until the 10-12min mark, only a 5% reduction in energy consumption is observed (Table 11).

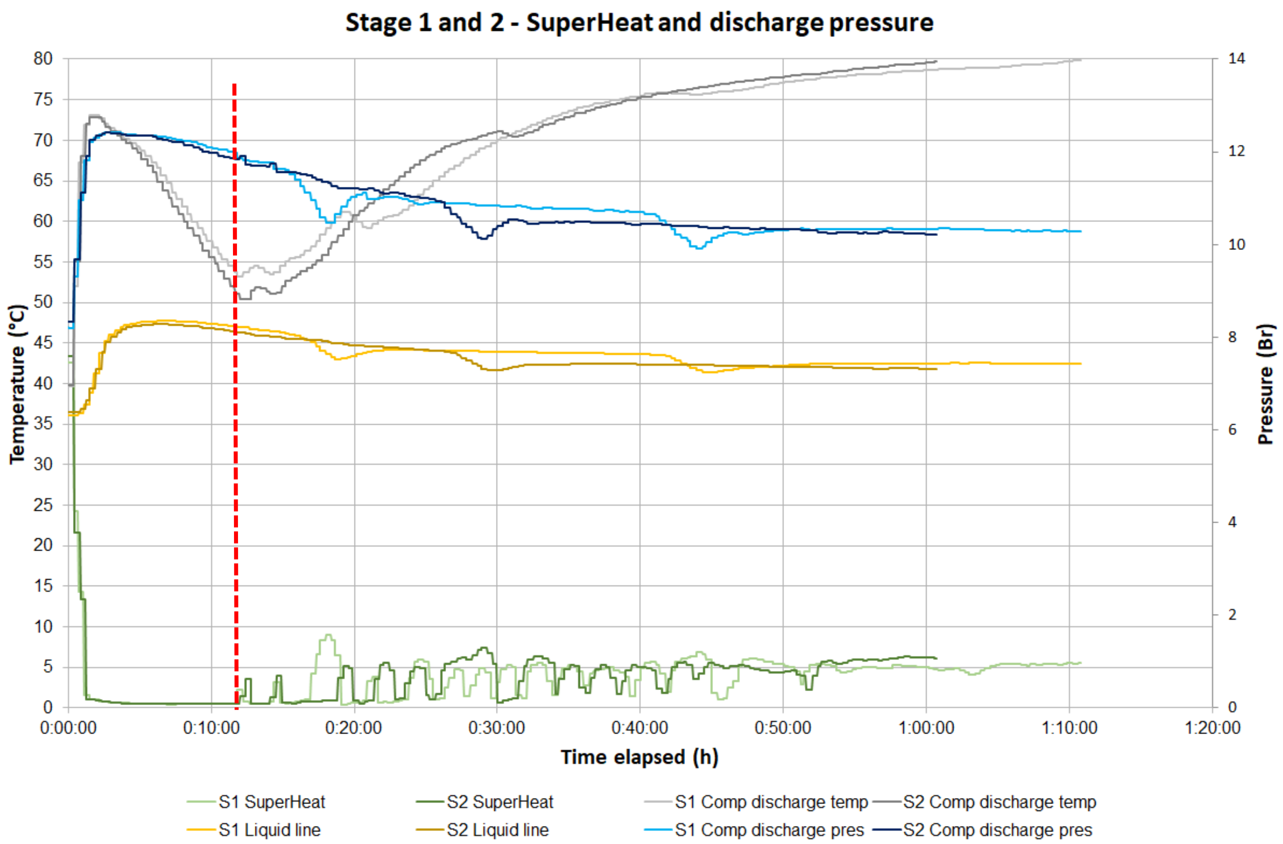
Table 11: Comparison between stage 1 and 2 – Pull-down runs 2 to 10°C.

Pull-down comparison – Until SuperHeat irregularities				
	Duration	**Average power (kW)**	**Energy (kWh)**	**Energy reduction**
Stage 1	0:10:56	2.72	0.50	
Stage 2	0:10:26	2.71	0.47	5.0%

While the test runs provide consistent and comparable data, the downward peaks in Superheat curves in Graph 11, occurring in both stage 1 and stage 2, are unusual and indicate that there may be a potential issue with the unit, perhaps with the EEV or with the EEV control unit. This may have also impacted the accuracy of the energy reduction percentage of the complete pull-down runs. It is recommended to investigate the matter further.



Graph 10: Comparison Stage 1 and 2 – Time to temperatures all pull-down runs.



Graph 11: Comparison Stage 1 and 2 – SuperHeat pull-down run1 of stage 1 and stage 2.

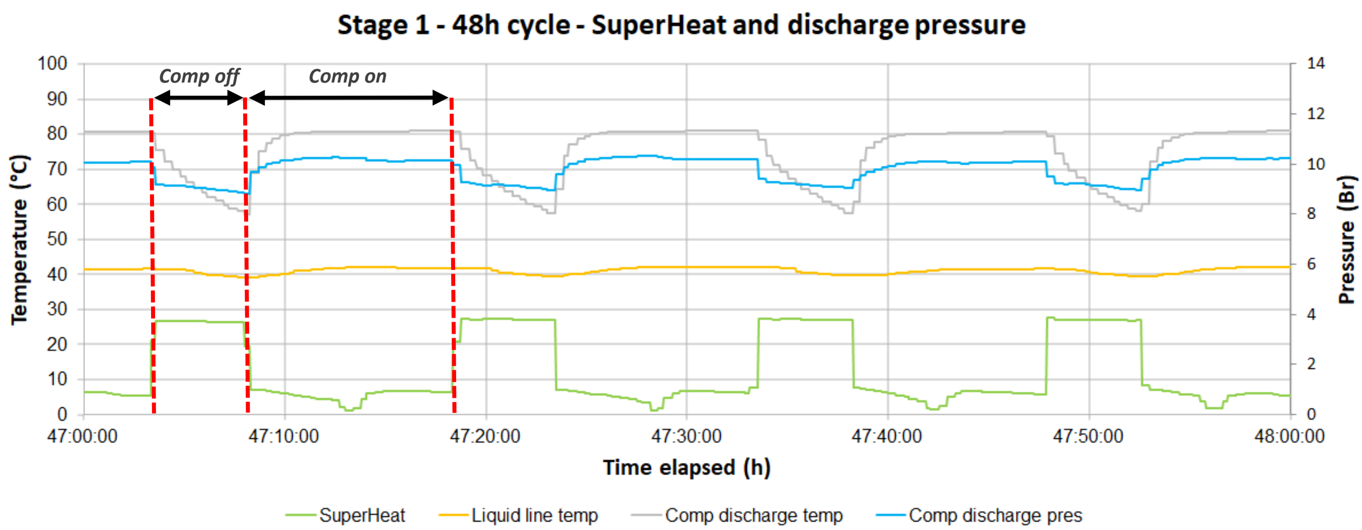
5.2 Step 2 – Continuous 48h cycle test

Repeatable test results were achieved in both stages 1 and 2. Before the 48h test runs, a 22h stabilisation period occurred to ensure more consistent cycle times. Between stage 1 and stage 2, the energy reduction over the total 48h is 3.71% and slowly increases to 4.69% (Table 12) as the system rejects more and more heat from the room. The percentage of energy reduction between the OEM factory and the THERMAL-XR coated condenser coil is within the same range as during the first part of the pull-down runs.

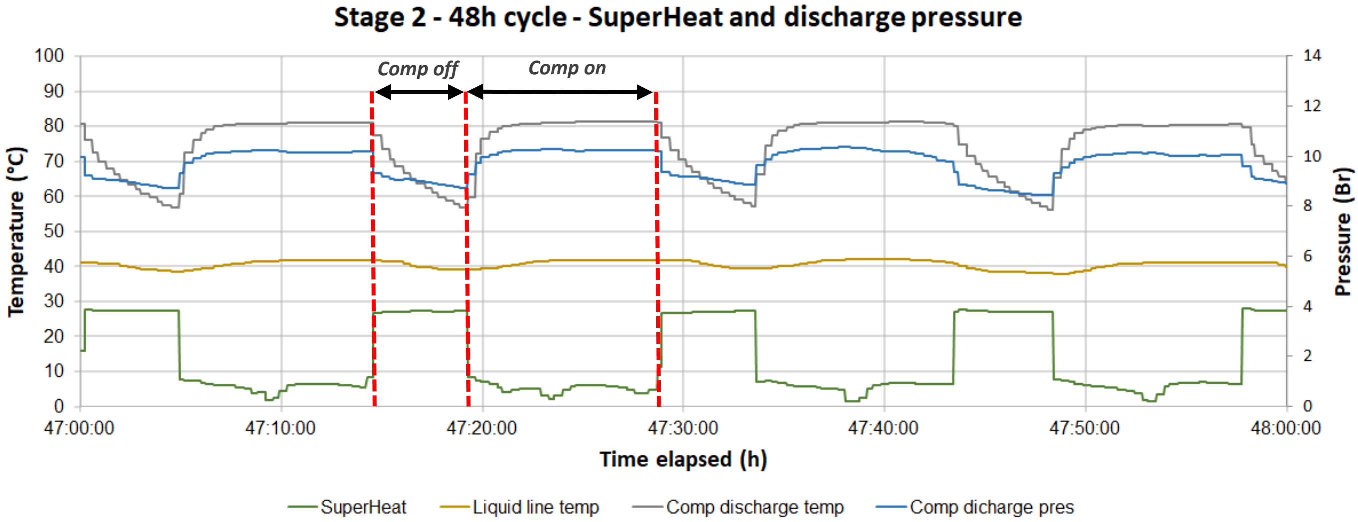
Table 12: Comparison between stage 1 and 2 – Temperature cycle test.

48h cycle test - Power consumption			
Between 0h-48h	**Average power (kW)**	**Energy kWh per 24h**	**Energy reduction**
Stage1	1.77	85.10	
Stage2	1.71	81.95	3.71%
Between 24h-48h			
Stage1	1.76	42.14	
Stage2	1.68	40.39	4.13%
Between 36h-48h			
Stage1	1.76	42.18	
Stage2	1.68	40.20	4.69%

Similar to step 1, there was an irregularity found in the suction SuperHeat during the step 2 continuous 48h cycle runs in stage 1 and 2. There is a repeatable drops during every cycle (Graph 12 and Graph 13). As with step 1, the result indicate that the EEV was not maintaining a steady 6KTD SuperHeat set point throughout the 48h cycles, while a steady 6KTD SuperHeat should be expected when the compressor is on.



Graph 12: Stage 1 – Continuous 48h cycle test – SuperHeat.



Graph 13: Stage 2 – Continuous 48h cycle test – SuperHeat.

END OF REPORT

Appendix 1: Test setup

Overview pictures:

Image 1: Overview of the test setup of the indoor room. Note: for the step 1 time to temperature pull-down tests the 100W heater was removed from the room.

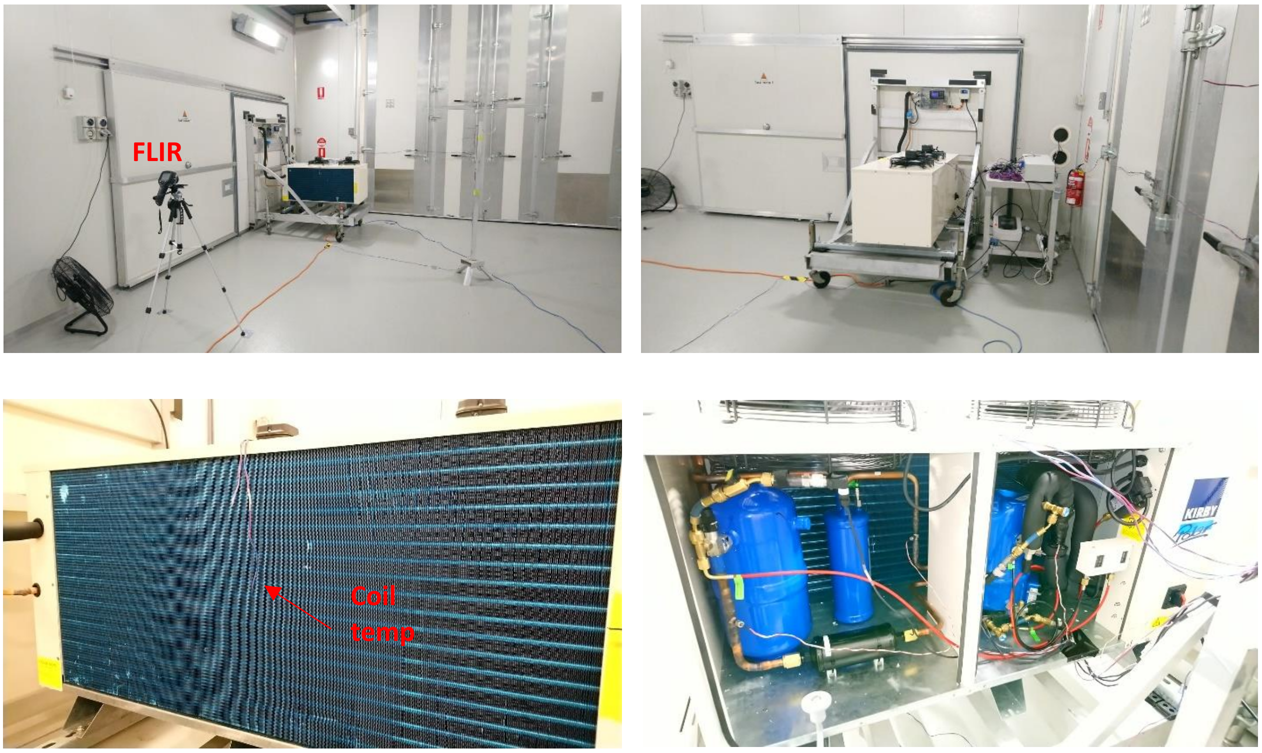


Image 2: Overview of the test setup of the 35°C outside room.

Appendix 2: Thermal images of the condenser coil

During the pull-down runs, two thermal images have been taken at time stamp 25min and 50min and the surface temperature of the coil has been recorded for each run. No consistent correlation between coil surface temperatures and power consumption reduction was found. Therefore, the influence of the condenser coil surface temperature and/or data from the thermal images remains inconclusive, and is shown in this Appendix as additional information only.

Stage 1 (OEM factory coated condenser coil) – Run1

Thermal image at 25min ($T_{coil\_surface}$ = 43.0°C):

Thermal image at 50min ($T_{coil\_surface}$ = 42.0°C):

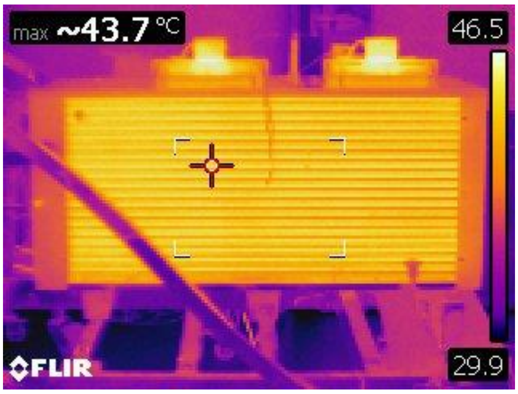
Stage 1 (OEM factory coated condenser coil) – Run2

Thermal image at 25min ($T_{coil\_surface}$ = 43.3°C):

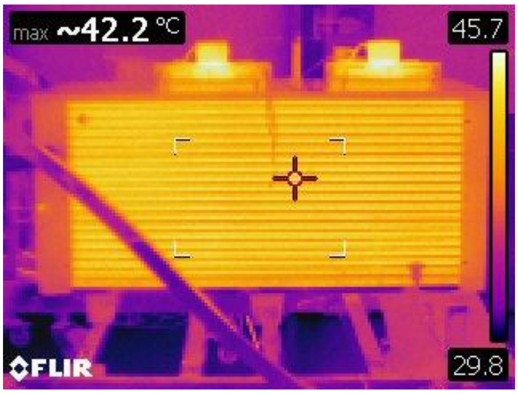
Thermal image at 50min ($T_{coil\_surface}$ = 42.0°C):

Stage 1 (OEM factory coated condenser coil) – Run3

Thermal image at 25min ($T_{coil\_surface}$ = 43.0°C):



Thermal image at 50min ($T_{coil\_surface}$ = 42.0°C):



Stage 2 (THERMAL-XR coated condenser coil) – Run1

Thermal image at 25min ($T_{coil\_surface}$ = 42.8°C):

Thermal image at 50min ($T_{coil\_surface}$ = 41.2°C):

Stage 2 (THERMAL-XR coated condenser coil) – Run2

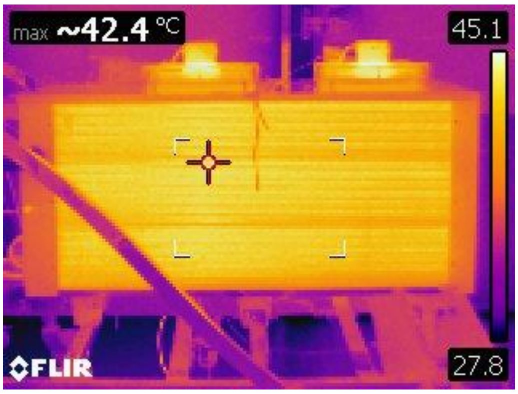
Thermal image at 25min ($T_{coil\_surface}$ = 40.9°C):

Thermal image at 50min ($T_{coil\_surface}$ = 41.4°C):

Stage 2 (THERMAL-XR coated condenser coil) – Run3

Thermal image at 25min ($T_{coil\_surface}$ = 42.4°C):

Thermal image at 50min ($T_{coil\_surface}$ = 41.4°C):



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