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TEST REPORT

TEMPERATURE AND ENERGY PERFORMANCE OF A VERTICAL MULTI-DECK DISPLAY CABINET

Model:
Berlino 3 LF M 110 H205
Redesigned for R-1270 with integral condensing units

Tested to:
BS EN ISO 23953 Standards
ECA Requirements

Test classification: **M0**

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Summary

This report presents 4 sets of test results of a vertical multi-deck display cabinet with integral condensing unit. The tests were carried out to evaluate temperature performance and energy consumption of the cabinet at different air flowrate and perforation ratio of its back panels to meet M0 specification.

Series of 48-hour period tests were carried out according to BS EN ISO 23953. Each test consisted of two stages. *First stage*; the cabinet was operated with night-covers OFF and lights switched ON for a period of 24 hours. *Second stage*; the cabinet was tested with night-covers OFF and lights switched ON for a period of 12 hours followed by 12 hours with night-covers ON and lights switched OFF. The result of each test was reported accordingly.

The conditions of the cabinet in four series of tests can be described as follows:

- Test-1: Cabinet with lower air flowrate and original back panels
- Test-2: Cabinet with lower air flowrate and modified back panels.
- Test-3: Cabinet with original air flowrate and back panels
- Test-4: Cabinet with original air flowrate and modified back

During the test the cabinet was loaded with test packages and M-packages according to BS EN ISO 23953-2: 2005. The temperatures of the M-packages were monitored and recorded. From temperature performance analyses were found the cabinet tested with modified back panels (Test-2 and Test-4) could maintain the M-package temperatures within the M0 classification (-1°C and +4°C) throughout the test. On the other hand temperature of some M-packages of Test-1 and Test-3 were beyond the range of M0 classification, but they may still be acceptable for class M1.

The energy efficiency index of the cabinet was below the EEI threshold specified for M0 integral cabinet by the UK ECA (Enhanced Capital Allowance) scheme for listing on the Energy Technology List. This showed that the cabinet with modified back panels could be listed on the UK ECA scheme Energy Technology List as M0 classification.

The test results can be summarised as below:

Temperature performance of the first stage tests:

M-packages temperature	**Test-1**	**Test-2**	**Test-3**	**Test-4**
Maximum temperature θ_{ah} (°C)	5.2	4.1	5.4	4.1
Overall mean θ_m (°C)	1.7	1.8	2.3	1.8
Minimum temperature θ_b (°C)	-1.5	-0.9	-1.3	-1.1

Temperature performance of the second stage tests:

M-packages temperature	**Test-1**	**Test-2**	**Test-3**	**Test-4**
Maximum temperature θ_{ah} (°C)	5.2	4.0	5.2	4.0
Overall mean θ_m (°C)	2.2	2.0	2.6	2.1
Minimum temperature θ_b (°C)	-1.4	-1.0	-1.2	-1.0

Energy consumption and heat extraction of the first stage tests: “The cabinet was operated with night-covers OFF and lights switched ON for a period of 24 hours”.

First stage test over 24-hour period	**Test-1**	**Test-2**	**Test-3**	**Test-4**
Compressor ON/OFF frequency in 24 (h)	27	38	1	7
Running time t_{run} (h)	21.4	20.87	21.83	21.4
Defrost time t_{deft} (h)	1.0	1.0	2.0	2.0
Stopping time t_{stop} (h)	1.6	2.13	0.17	0.6
Percentage of the running time t_{rr} (%)	93.0	90.7	99.2	97.5
Average power (kW)	2.69	2.65	2.85	2.80
TEC (kWh/day)	**57.61**	**55.38**	**62.24**	**60.06**
Total heat extraction; Q_{tot} (kWh)	182.51	174.64	188.71	187.47
Heat extraction in t_{run75} ; Q_{75} (kWh)	139.03	135.77	139.76	139.38
Heat extraction rate in t_{run} ; Φ_{run} (kW)	8.53	8.37	8.64	8.74
Heat extraction rate in t_{run75} ; Φ_{run75} (kW)	8.67	8.67	8.53	8.67
Heat extraction rate in t_{24} ; Φ_{24} (kW)	7.60	7.28	7.86	7.81
Heat extraction rate in $t_{24\text{-}deft}$; $\Phi_{24-deft}$ (kW)	7.94	7.59	8.58	8.52
Energy efficiency index (EEI) kWh/day.m^2	**8.28**	**7.96**	**8.95**	**8.63**
Coefficient of performance (COP)	3.17	3.15	3.03	3.12

Energy consumption and heat extraction of the second stage tests: “The cabinet was tested with night-covers OFF and lights switched ON for a period of 12 hours followed by 12 hours with night-covers ON and lights switched OFF”.

Second stage test over 24-hour period	**Test-1**	**Test-2**	**Test-3**	**Test-4**
Compressor ON/OFF frequency in 24 (h)	67	72	60	61
Running time t_{run} (h)	17.1	16.5	17.0	16.9
Defrost time t_{deft} (h)	1.0	1.0	2.0	2.0
Stopping time t_{stop} (h)	5.9	6.5	5.0	5.1
Percentage of the running time t_{rr} (%)	74.3	71.6	77.3	76.7
Average power (kW)	2.47	2.44	2.56	2.52
TEC (kWh/day)	**42.19**	**40.10**	**43.59**	**42.59**
Total heat extraction; Q_{tot} (kWh)	133.23	124.55	132.86	134.22
Heat extraction in t_{run75} ; Q_{75} (kWh)	104.86	99.05	102.25	103.71
Heat extraction rate in t_{run} ; Φ_{run} (kW)	7.81	7.57	7.81	7.95
Heat extraction rate in t_{run75} ; Φ_{run75} (kW)	8.20	8.02	8.01	8.19
Heat extraction rate in t_{24} ; Φ_{24} (kW)	5.55	5.19	5.54	5.59
Heat extraction rate in $t_{24\text{-}deft}$; $\Phi_{24-deft}$ (kW)	5.79	5.42	6.04	6.10
Energy efficiency index (EEI) kWh/day.m^2	**6.06**	**5.76**	**6.26**	**6.12**
Coefficient of performance (COP)	3.16	3.11	3.05	3.15

Performance parameters of the refrigeration system during first stage tests: “The cabinet was operated with night-covers OFF and lights switched ON for a period of 24 hours”.

First stage test over 24-hour period	**Test-1**	**Test-2**	**Test-3**	**Test-4**
Minimum evaporating temperature (^{o}C)	-8.4	-7.6	-9.8	-9.7
Mean evaporating temperature in 10% t_{run} (^{o}C)	-7.4	-6.6	-9.0	-8.6
Mean evaporating temperature in 75% t_{run} (^{o}C)	-7.1	-6.6	-7.1	-7.0
Mean evaporating temperature in t_{run} (^{o}C)	-6.8	-6.2	-6.5	-6.4
Mean air-ON temperature (^{o}C)	5.7	6.0	6.8	5.8
Mean air-OFF temperature (^{o}C)	-3.0	-2.5	-3.6	-3.6
Mean degree of superheat (^{o}C)	6.5	7.2	5.5	5.5
Mean degree of subcooled (^{o}C)	3.9	4.1	3.9	4.0
Mean condensing temperature (^{o}C)	28.9	29.1	29.2	29.2
Mean suction pressure (bar-g)	3.7	3.8	3.7	3.8
Mean discharge pressure (bar-g)	11.8	11.9	11.8	11.8
Mean refrigerant mass flowrate (kg/s)	0.029	0.029	0.028	0.028
Mean water/glycol mass flowrate (kg/s)	0.40	0.40	0.40	0.40

1. Introduction

Centre for Energy and the Built Environment Research, Brunel University, has been appointed to test a vertical multi-deck display cabinet by WR Refrigeration. The scope of tests included temperature performance and energy consumption which were carried out according to BS EN ISO 23953. The aim of the tests was to fulfil the requirements set out in the ECA (Enhanced Capital Allowance) energy technology criteria list for refrigerated equipment.

2. Cabinet Description

The cabinet tested was a vertical multi-deck display cabinet with compression type and built-in condensing units. It was, originally, a remote type display cabinet with R-404A refrigerant and then was redesigned to be working as an integral display cabinet utilising hydrocarbon refrigerant R-1270. The cabinet comprises two identical refrigeration systems which work in parallel. The evaporator coils of the refrigeration systems were fitted at the rear of back panels and the condensing units were installed on the top of the cabinet. For expansion devices, capillary tubes were used.

The cabinet consists of 5 shelves and 1 base (bottom) deck for loading the test packages. Ticket-bars are attached in the front edge of the 5 shelves. The selves are also completed with acrylic-risers which seat on the gap between the front edge and the ticket-bars. General information of the cabinet is shown in Table-1.

Table-1: General information of the tested cabinet

Manufacturer	Arneg S.p.A.
Model	Berlino 3 LF M 110 H205
Serial number	OJ13151601
Redesigned by	WR Refrigeration
Refrigerant	R-1270
Refrigerant charge @ system (kg)	0.720
Type of condensing unit	Air and water cooled
Number of shelves	6
Maximum load of the shelf (kg/m^2)	160
Number of blinds	3
Number of fans	6
Defrost type	Off-cycle
Temperature control method	Compressors on/off
Condenser cooling fluid	Propylene glycol and water mixture
Mass fraction glycol in water (%)	25
Cabinet dimensions external:	
Length (mm)	3810
Depth (mm)	1144
Height (mm)	2220
Cabinet dimensions internal:	
Length without ends (mm)	3750
Shelf depth (mm)	500
Base deck depth (mm)	712
Open height (mm)	1435

Figure-1 shows the sectional view of the tested display cabinet. From the figure can be seen the arrangement and number of the shelves, evaporator coils, fans and condensing units. It also shows linear dimensions used to determine TDA (Total Display Area) of the cabinet.

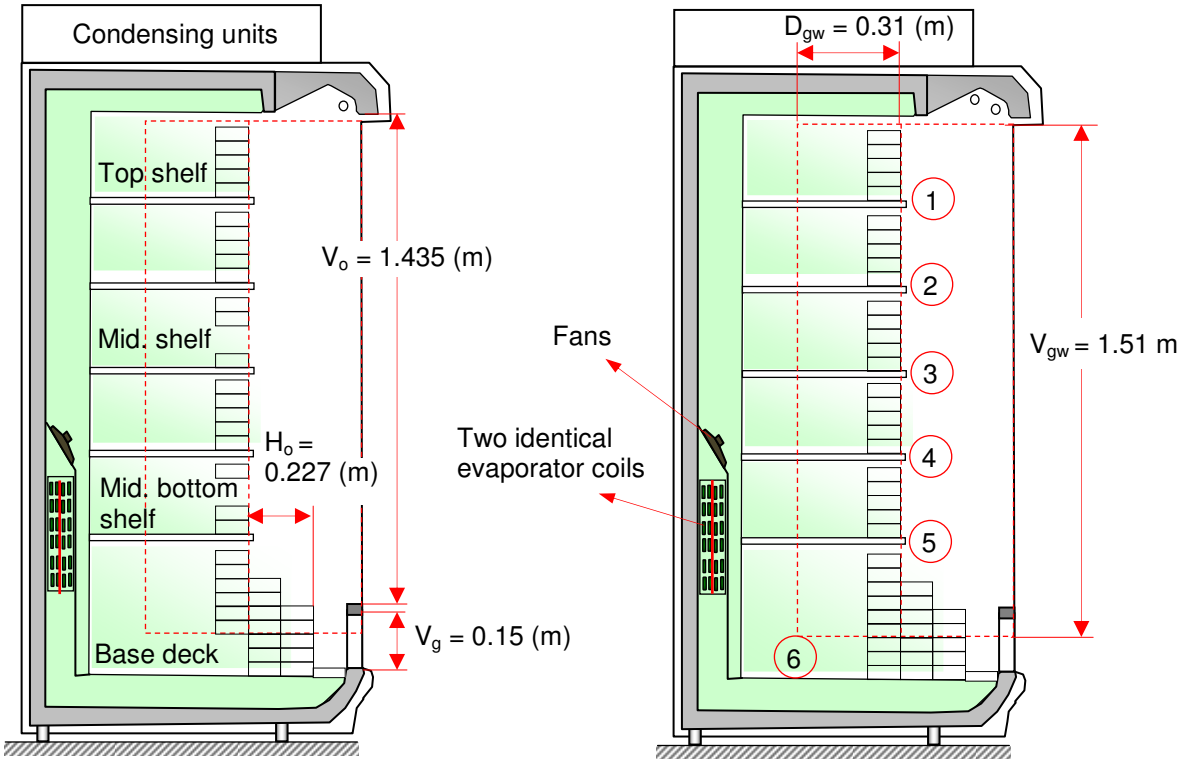


Figure-1: Tested display cabinet

TDA was determined according to BS EN ISO 23953-2 Annex A, Figure A.9 for vertical multi-deck cabinet with side transparency which can be calculated from:

$$TDA = (H_o \times L_{oh}) + (V_o \times L_{ov}) + (T_g \times V_{gv} \times L_{gv}) + (T_g \times V_{gw} \times D_{gw})$$

$$= \mathbf{6.96}\ m^2$$

Where:

Light transmission (T_g) through glazing surface (double glass) = 81 %
Open length horizontal projection: L_{oh} = 3.75 m
Open length vertical projection: L_{ov} = 3.75 m
Length of vertical transparency: L_{gv} = 3.69 m
Depth of end wall transparency: D_{gw} = 0.31 m
Open height: V_o = 1.435 m
Open horizontal projection: H_o = 0.227 m
Height of end wall transparency: V_{gw} = 1.51 m

3. Test Conditions and Methods

3.1 Test conditions

The tests were carried out in a test room conforming to BS EN ISO 23953-2: 2005 standard, subclause 5.3.1. The test room walls and ceiling are thermally insulated and are equipped with inner metal skin. The useful dimensions of the test room can accommodate overall dimensions of the tested cabinet in accordance with subclause 5.3.2.1 of the standard. The lighting in the test room was provided by fluorescent lights with lighting level in the range between 500 and 650 lux which complies with the standard of 600±100 lux at a height of 1 metre above floor level.

Ambient conditions in the test room were tightly controlled by a proportional-differential (PD) controller which modulates humidifier, heating system and the opening of three ways valve of the water chiller system. The ambient conditions were monitored by temperature and RH sensors linked to the measurement system and their measuring points were placed in accordance with subclause 5.3.2.3.2 Figure 5 of the standard.

Mean horizontal air velocity (cross flow) of the test room was measured in accordance with subclause 5.3.1.2 of the standard which was in the range between 0.1 and 0.2 m/s.

For all tests, the test room conditions were set to **Climate Class III** with dry bulb temperature of 25°C and 60% RH.

3.2 Measurement systems

Two measurement systems were applied during the tests. The first one measured parameters of the refrigeration systems (pressure, temperature and mass flow rate of the cooling fluid), parameters of air and M-packages in the cabinet (temperature and RH) and parameters of the test room (temperature and RH). This system consisted of some sensors which include temperature sensors with accuracy better than ±0.5°C, pressure transducers (accuracy ±1%), RH sensor (accuracy ±3 unit), mass flowmeter (accuracy ±1%) and air velocity meter with accuracy 10%; data logging system (Labtech software and Datascan modules); recording/display system (computer set and monitor). The second measurement system monitored and recorded power consumption of the cabinet which comprised a programmable power meter (HM8115-2 from Hameg Instrument; connected in series with the main supply) and a recording/display system.

Temperature sensors (T type thermocouples) in the M-packages were placed on 4 shelves: top shelf, middle shelf, mid-bottom shelf and bottom deck as identified in Figure-1 at positions in accordance with BS EN ISO 23953-2: 2005 subclause 5.3.2.3.3 Figure 21.

All measurements were recorded every 10s. This interval provided possibilities to check all temperature measurements at every 60s, mass flowrate and pressure measurements at every 20s as specified in BS EN ISO 23953-2: 2005 standard subclause 5.3.1.6.

3.3 Running in and Commissioning

Before steady-state tests were started, the cabinet was switched on and allowed to run for about 4 hours at the climate class III with no M-packages in the cabinet. This running-in was intended to find out if there was any erratic functioning of refrigeration system, control or defrosting operations. After running-in, the cabinet was commissioned to achieve its best performance. The main aim of the commissioning was to check whether the manufacturer operational setting was suitable enough to obtain M-packages temperatures as M0 classification (all M-packages temperatures during the test should range from -1 to +4^{o}C). Temperatures of the M-packages were monitored as close as possible to the requirements. The automatic controller of the cabinet has appropriately been reset.

The commissioning stage was also found that the refrigeration capacity of the refrigeration systems was unmatched with heat extraction of the cabinet. The cabinet was then modified to make it performed as close as design specifications. The modifications included replacement of some refrigeration components with bigger capacities, increase perforation ratio of the back panels and change air flowrate in the cabinet.

3.4 Methods

Tests were carried out after commissioning had been completed. The operational parameters of the cabinet were set at the optimum setting obtained from the commissioning. The tests were performed according to BS EN ISO 23953-2: 2005.

After modification of the cabinet, series of tests have been done which can be described as follows:

- **Test-1**: Cabinet with lower air flowrate and original back panels
- **Test-2**: Cabinet with lower air flowrate and modified back panels.
- **Test-3**: Cabinet with original air flowrate and back panels
- **Test-4**: Cabinet with original air flowrate and modified back panels.

Due to the cabinet are fitted with lighting and night-covers, each test was carried out in two stages for at least 48 hours as follows:

- *Stage a*: The cabinet with night-covers removed (OFF) and lights switched ON for a period of 24 hours.
- *Stage b*: The cabinet with night-covers OFF and lights switched ON for a period of 12 hours followed by 12 hours with night-covers ON and lights switched OFF.

Recorded data from the measurement systems were processed and analysed. Performance parameters such as mean, the overall mean of M-packages temperatures and energy consumption were calculated. EES model was made and was applied to calculate refrigerant mass flowrate from the energy balance of the water-cooled condenser. The model was also used to determine the state of refrigerant in the compression cycle and to check whether the energy balance equation of the water-cooled condenser was valid for calculating the refrigerant mass flowrate. Further calculations and graphs manipulation were processed by using spread sheet programme.

Test results were reported according to BS EN ISO 23953-2: 2005, subclause 6.3.

3.5 Cabinet Preparation

The tested cabinet is an open vertical cabinet designated as **IVC2S** (Incorporated condensing unit; Vertical; Chilled: Multi-deck; Self-service) according to BS EN ISO 23953-1: 2005, Annex A. The cabinet was positioned in the test room according to BS EN ISO 23953-2: 2005 subclause 5.3.2.1 Figure 9. Cross flow direction in the test room was from right to the left (referred to the front view of the cabinet).

The cabinet was loaded with test packages and M-packages according to BS EN ISO 23953-2: 2005 subclause 5.3.2.3 Figure 21. Each M-package had a calibrated T-type thermocouple inserted into the geometric centre of the package. Total number of the M-packages was 54 (12 each for the top, middle and mid-bottom shelves and 18 for the base (bottom) deck.

Temperature control method of the cabinet was compressors ON/OFF. The control parameters were set in an automatic controller and were modulated by temperature of air-ON and air-OFF.

Temperature sensors of the air-ON and air-OFF were respectively located in the inlet duct underneath base deck about 30 mm away from right side-wall and in the supply duct above the fans about 500 mm away from the left side-wall.

4. Results

4.1 Test-1: Cabinet with lower air flowrate and original back panels

4.1.1 Operational setting

Table-2 shows detailed operational setting of the cabinet in Test-1 obtained from the commissioning stage.

Table-2: Operational setting of the cabinet in Test-1

Thermostat setting:	
Cut in (^{o}C)	3
Differential (^{o}C)	2.2
Air ON/OFF weight (%)	50
Number of defrost per day	6
Defrost minimum time (minutes)	10
Defrost termination (^{o}C)	10
Condenser cooling fluid:	
Temperature IN (^{o}C)	18
Temperature OUT (^{o}C)	24

Display of the measurement system in a particular time during the test can be seen in Figure-2.

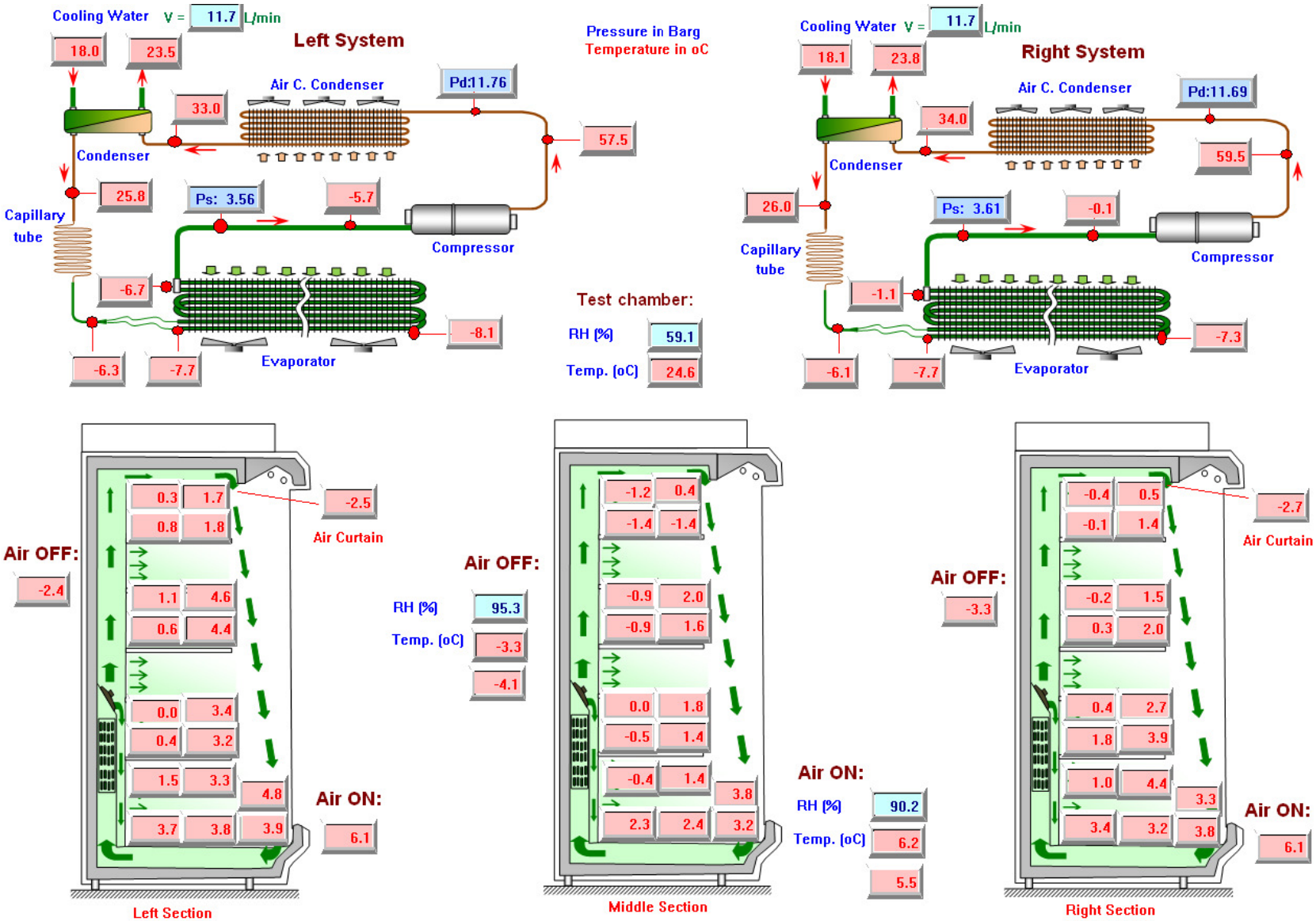


Figure-2: Display of the measurements system of Test-1

4.1.2 Temperature Performance

4.1.2.1 Test-1a: The cabinet tested with night-covers OFF and lights switched ON for a period of 24 hours.

Conditions of the test room during the Test-1a were maintained in the allowable range of Climate class III (25°C, 60%) as shown in Figure-3. Temperature variation of the warmest and the coldest M-packages is presented in Figure-4. The highest temperature of the warmest M-package was +5.2°C and the lowest temperature of the coldest M-package was -1.5°C. The overall mean temperature of the all M-packages was found to be 1.7°C. Variations of the M-package temperatures on the individual shelf are presented in Figures A-1 to A-4 of the Appendix.

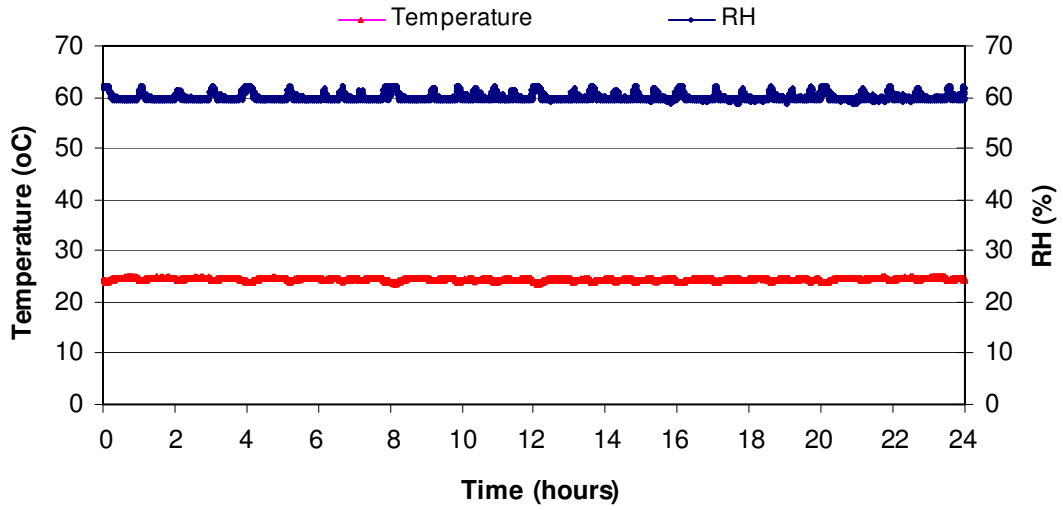
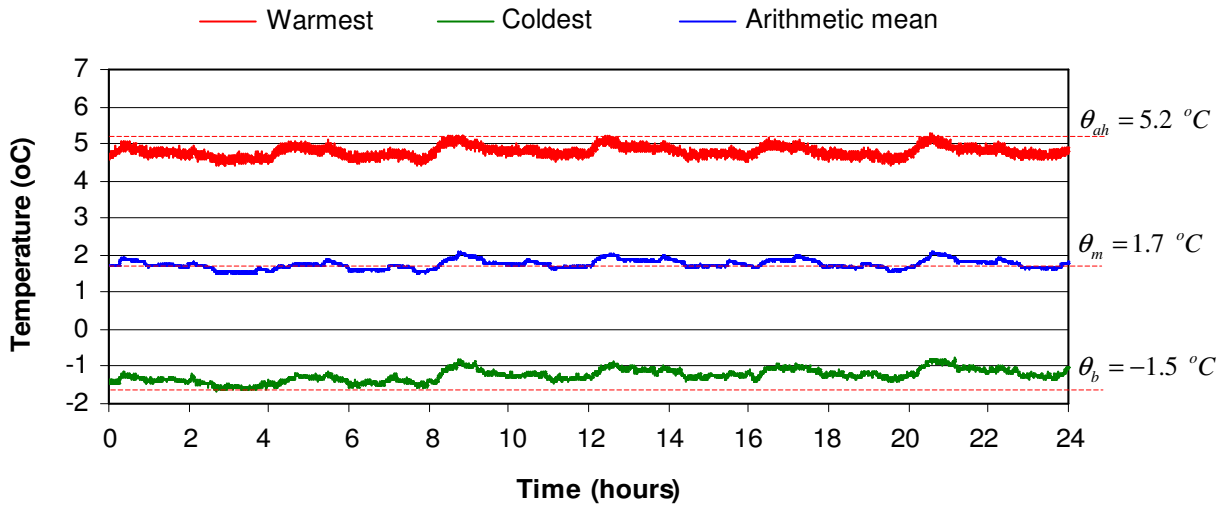


Figure-3: Test room conditions during the Test-1a



θ_{ah} = highest temperature of warmest M-package

θ_b = lowest temperature of coldest M-package

θ_m = overall mean temperature of M-packages

Figure-4: Time/temperature curves of warmest and coldest M-packages and arithmetic mean temperature of all M-packages in Test-1a

During the 24-hour test 2 M-packages on the middle shelf and 3 M-packages on the base deck laid above +4°C. All of the M-packages on the top shelf were below 3°C, but 2 of them were below -1°C.

Air-ON and air-OFF temperatures of the cabinet during the Test-1a are shown in Figure-5. Average air-ON and air-OFF temperatures in t_{run10} period were 5.7°C and -3.0°C respectively. These temperatures were achieved at evaporating temperatures as shown in Figure-6. Mean evaporating temperature, degree superheat, degree of subcooled and other parameters are presented in Table-3.

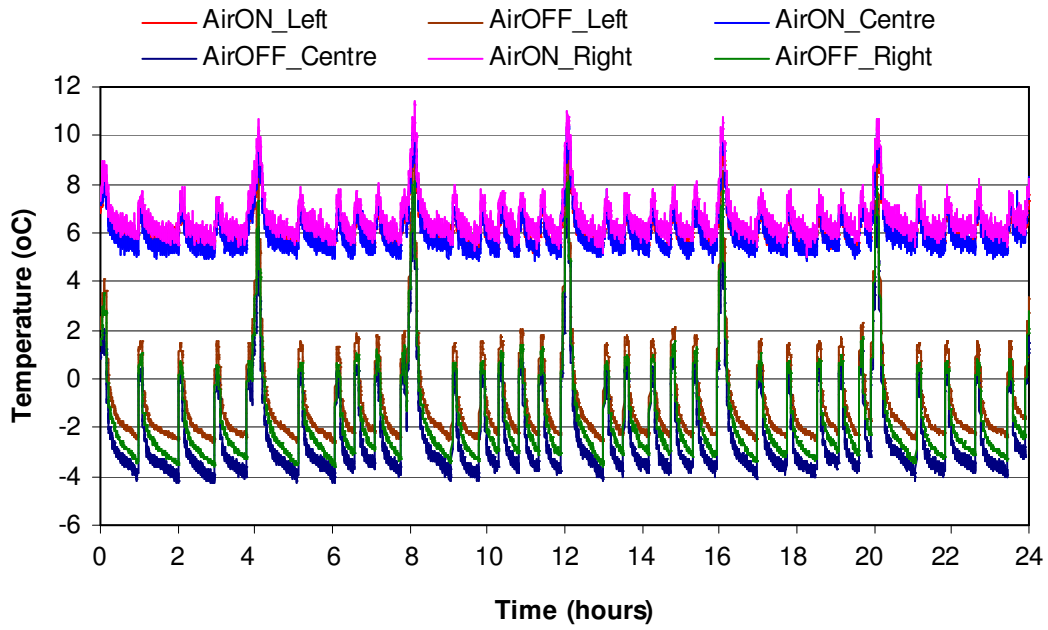


Figure-5: Time/temperature curves of air-ON and air-OFF of the cabinet in Test-1a

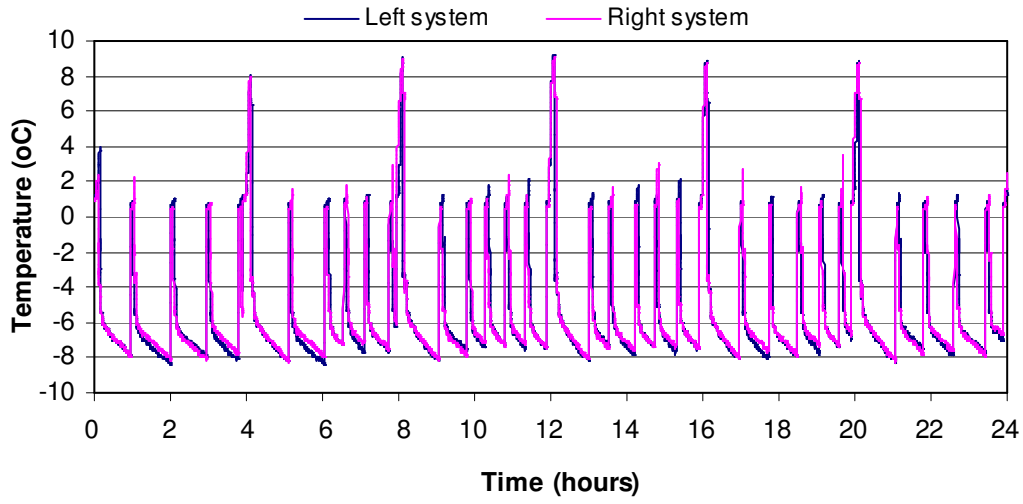


Figure-6: Time/temperature curves of evaporating temperature of the Test-1a

Table-3: Performance parameters of the refrigeration systems

Parameters	Left system	Right system	Overall
Minimum; $\theta_{e-\min}$ (°C)	-8.4	-8.3	-8.4
Mean t_{run10}; $\theta_{e-mrun10}$ (°C)	-7.4	-7.3	-7.4
Mean t_{run75}; $\theta_{e-mrun75}$ (°C)	-7.2	-7.0	-7.1
Mean t_{run}; θ_{e-mrun} (°C)	-6.8	-6.7	-6.8
Mean degree of superheat (°C)	4.5	8.4	6.5
Mean degree of subcooled (°C)	4.1	3.6	3.9
Mean condensing temperature (°C)	29.0	28.8	28.9
Mean suction pressure (bar-g)	3.7	3.7	3.7
Mean discharge pressure (bar-g)	11.8	11.7	11.8
Mean refrigerant mass flowrate (kg/s)	0.015	0.014	0.029
Mean water/glycol mass flowrate (kg/s)	0.20	0.20	0.40

t_{run10} = running time for reporting evaporator temperature of t_{run}.10%
t_{run75} = 75% running time (t_{run}.75%) excluding time after defrost
t_{run} = running time
θ_e = evaporating temperature

4.1.2.2 Test-1b: The cabinet tested with night-covers OFF and lights switched ON for a period of 12 hours followed by 12 hours with night-covers ON and lights switched OFF.

Temperature and RH of the test room during the Test-1b were maintained in the allowable range of the standard as shown in Figure-7. Temperature variation of the warmest and the coldest M-packages is presented in Figure-8. The highest temperature of the warmest M-package is the same as the Test-1, while the lowest temperature of the coldest M-package is slightly higher. The overall mean temperature of the all M-packages was 2.2°C.

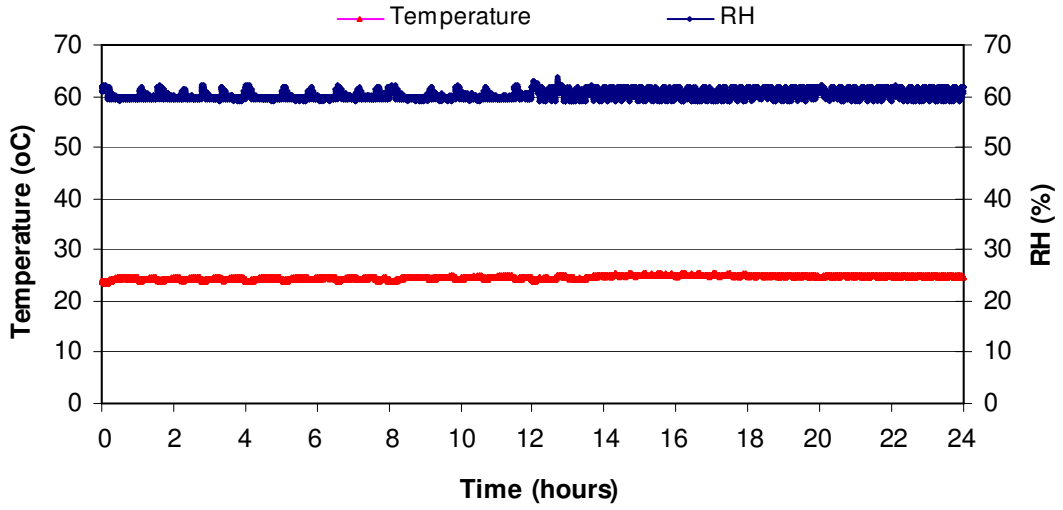


Figure-7: Test room conditions during the Test-1b

Temperature range of the M-packages during the second 12 hours of the test was very narrow of about 4°C which laid from 0 to +4°C. However in the first 12 hours of the test, the temperature range was still wider than class M0.

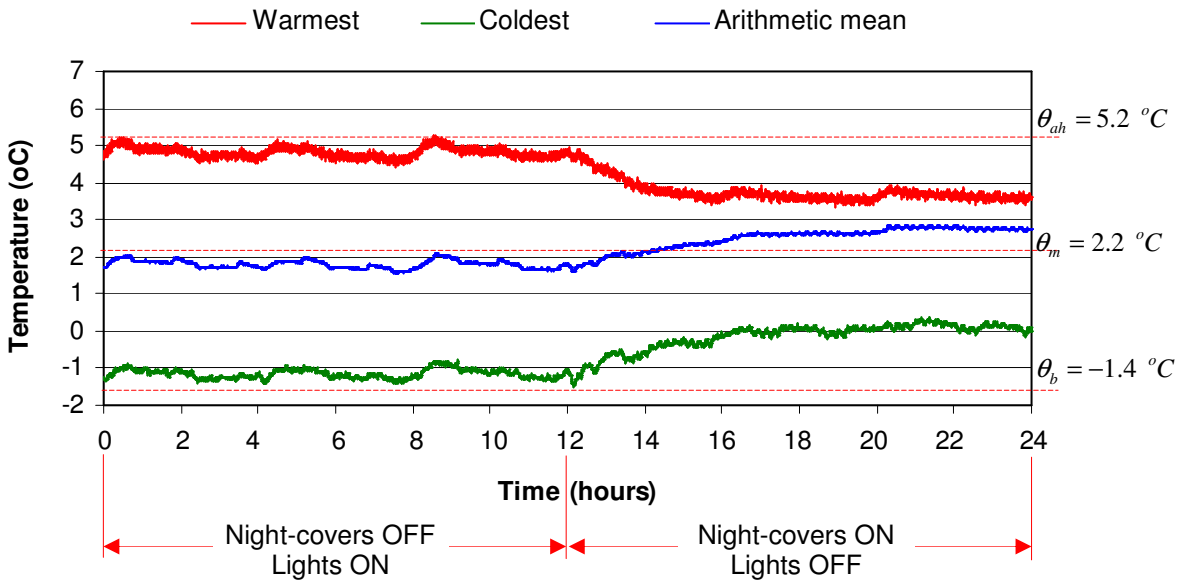


Figure-8: Time/temperature curves of warmest and coldest M-packages and arithmetic mean temperature of all M-packages in Test-1b

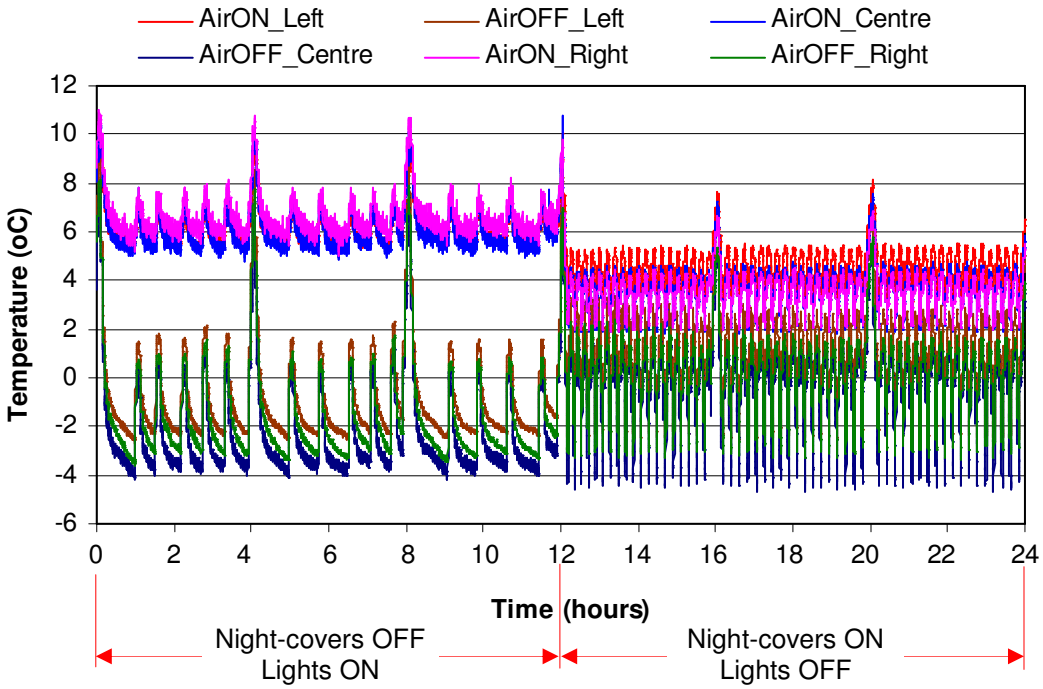


Figure-9: Time/temperature curves of air-ON and air-OFF of the cabinet in Test-1b

Air-ON and air-OFF temperatures of the cabinet during the Test-1b are shown in Figure-9. Air-ON temperature in the second 12 hours was much lower than the first one. Moreover the compressors were switching ON and OFF more frequently during

the period when the night-covers were closed (ON). Evaporating temperature during the Test-1b is shown in Figure-10.

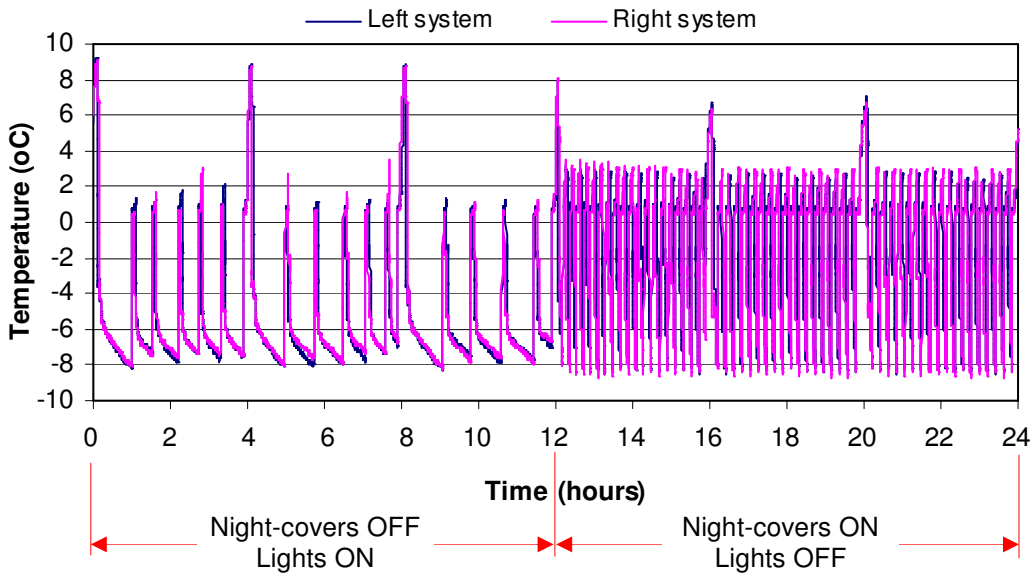


Figure-10: Time/temperature curves of evaporating temperature of the Test-1b

4.1.3 Water Vapour Condensation

Water vapour condensation was found on the external surfaces of the left and right glass-walls for both tests (Test-1a and Test-1b). The maximum area and degree of the condensation are shown in Figure-11 and 12. It can be seen the right side-wall, which was facing the cross flow, exhibited less water vapour condensation. The condensation remained in 24 hours of the period of observation.

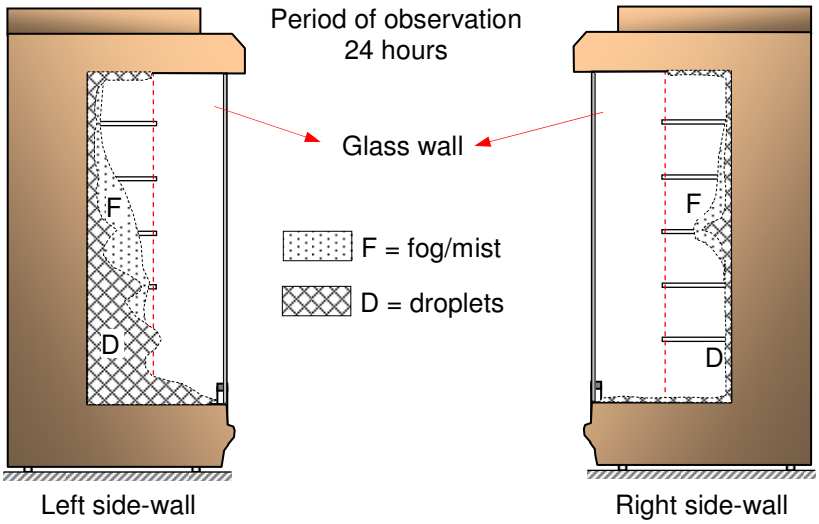


Figure-11: Water vapour condensation on the external surfaces of Test-1a

Figure-12 shows the side-walls in Test-1b which only exhibited droplets water. There was no fog on the external surfaces. The maximum area with water vapour condensation was also smaller due to infiltration air from the gap between the night-covers and the side wall replaced some of the cold air on the internal surface of the side-wall. The infiltration air made the side-walls a little bit warmer compared with them in Test-1a.

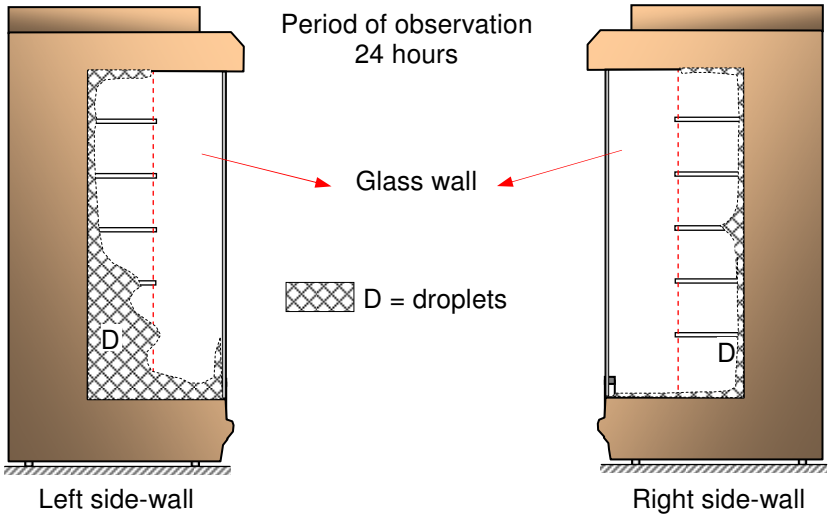


Figure-12: Water vapour condensation on the external surfaces of Test-1b

4.1.4 Electrical Energy Consumption

Total Energy Consumption (*TEC*) of the cabinet was calculated according to BS EN ISO 23953-2: 2005 subclause 5.3.5.2. For the cabinet fitted with integral condensing unit *TEC* equals to Direct Energy Calculation (*DEC*) which can be calculated from:

$$TEC = DEC = \sum_{n=1}^{n=N_{max}} W_n \, x \, \Delta t \qquad \text{(kWh)}$$

W_n = instant power consumption of the cabinet (kW) over 24 hours (W_n = 0 during stopping and defrost time), Δt = period of measurement (h).

Table-4: Operational time of the Test-1

Operational time	Test-1a	Test-1b
Compressor ON/OFF frequency in 24 (h)	27	67
Running time t_{run} (h)	21.4	17.1
Defrost time t_{deft} (h)	1.0	1.0
Stopping time t_{stop} (h)	1.6	5.9
Percentage of the running time t_{rr} (%)	93.0	74.3

The instant power consumptions of the cabinet during the tests are shown in Figure-13 and 14 respectively for Test-1a and Test-1b. Compressor switching ON/OFF frequency and operational time during the tests are presented in Table-4. Power

consumption including *TEC* of the cabinet can be seen in Table-5. *TEC* of the cabinet was found to be 57.61 kWh/day for Test-1a and 42.19 kWh/day for Test-1b.

Table-5: Power consumption and TEC of the cabinet in Test-1

Power and Energy consumption	Test-1a	Test-1b
Maximum power (kW)	3.00	2.93
Minimum power (kW)	1.52	1.41
Average power (kW)	2.69	2.47
TEC (kWh/day)	**57.61**	**42.19**

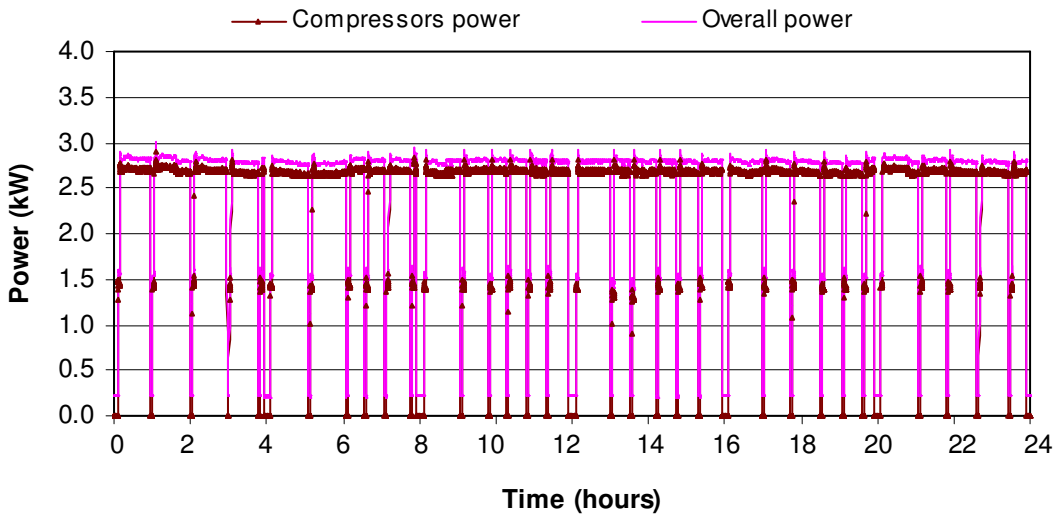


Figure-13: Power consumption of the cabinet during Test-1a

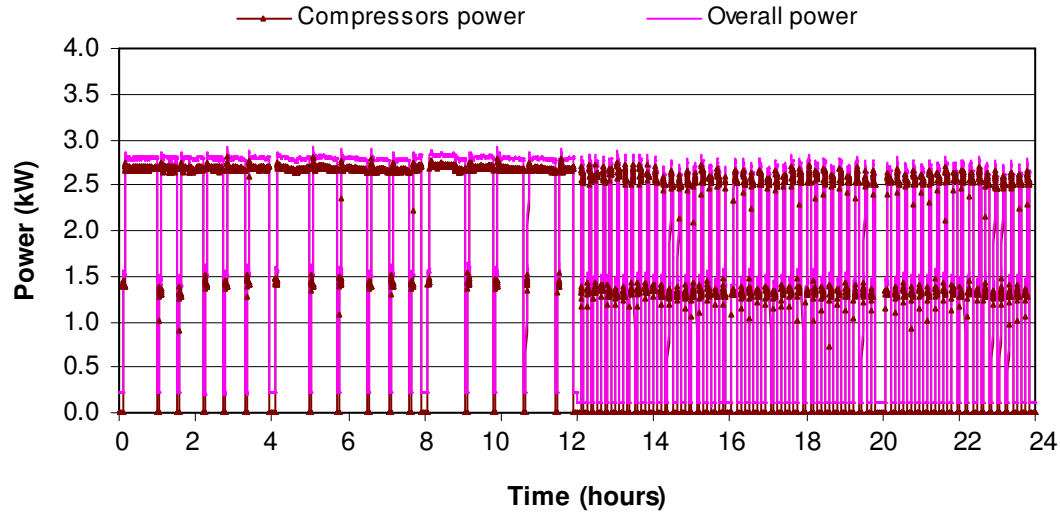


Figure-14: Power consumption of the cabinet during Test-1b

4.1.5 Heat Extraction Rate

Total heat extraction (Q_{tot}) of the cabinet was calculated according to BS EN ISO 23953-2: 2005 subclause 5.3.6.3.

$$Q_{tot} = \sum_{n=1}^{n=N_{max}} \Phi_n \, x \, \Delta t \qquad \text{(kWh)}$$

Φ_n = instant heat extraction rates of the cabinet (kW) over 24 hours (Φ_n = 0 during stopping and defrost time), Δt = period of measurement (h).

Table-6 presents the heat extraction and heat extraction rate of the cabinet. Table-7 shows heat extraction rates per 1 m length of the cabinet.

Table-6: Heat extraction and heat extraction rate of the Test-1

	Test-1a	Test-1b
Total heat extraction; Q_{tot} (kWh)	182.51	133.23
Heat extraction in t_{run75} ; Q_{75} (kWh)	139.03	104.86
Heat extraction rate in t_{run} ; Φ_{run} (kW)	8.53	7.81
Heat extraction rate in t_{run75} ; Φ_{run75} (kW)	8.67	8.20
Heat extraction rate in t_{24} ; Φ_{24} (kW)	7.60	5.55
Heat extraction rate in $t_{24\text{-}deft}$; $\Phi_{24-deft}$ (kW)	7.94	5.79

Table-7: Heat extraction rate per unit length of the cabinet

	Test-1a	Test-1b
Φ_{run} per unit length (kW/m)	2.28	2.08
Φ_{run75} per unit length (kW/m)	2.31	2.19
Φ_{24} per unit length (kW/m)	2.03	1.48
$\Phi_{24-deft}$ per unit length (kW/m)	2.12	1.54

4.1.6 Energy efficiency index

An ECA performance criterion of a refrigerated display cabinet is expressed as Energy Efficiency Index (EEI) which can be calculated from:

$$EEI = \frac{TEC}{TDA} \qquad \text{(kWh/day.m}^2\text{)}$$

The energy efficiency index of the cabinet and arithmetic mean coefficient of performance (COP) of the refrigeration systems in Test-1 are presented in Table-8.

Table-8: EEI and COP of the Test-1

	Test-1a	Test-1b
Energy efficiency index (EEI) kWh/day.m^2	8.28	6.06
Coefficient of performance (COP)	3.17	3.16

The EEI threshold for M0 classification cabinet with integral condensing unit is **12.50** (kWh/day.m^2).

4.2 Test-2: Cabinet with lower air flowrate and modified back panels

4.2.1 Operational setting

Table-9 shows detailed operational setting of the cabinet in Test-2 obtained from the commissioning stage. Display of the measurement system in a particular time during the Test-2 is shown in Figure-15.

Table-9: Operational setting of the cabinet in Test-2

Thermostat setting:	
Cut in (°C)	3
Differential (°C)	2.2
Air ON/OFF weight (%)	50
Number of defrost per day	6
Defrost minimum time (minutes)	10
Defrost termination (°C)	10
Condenser cooling fluid:	
Temperature IN (°C)	18
Temperature OUT (°C)	24

4.2.2 Temperature Performance

4.2.2.1 Test-2a: The cabinet tested with night-covers OFF and lights switched ON for a period of 24 hours.

Conditions of the test room during the Test-2a were maintained in the allowable range of Climate class III (25°C, 60%) as shown in Figure-16. Temperature variation of the warmest and the coldest M-packages is presented in Figure-17. The highest temperature of the warmest M-package was +4.1°C, while the lowest temperature of the coldest M-package is -0.9°C. The overall mean temperature of the all M-packages was 1.8°C. Variations of the M-package temperatures on the individual shelf are presented in Figures A-5 to A-8 of the Appendix.

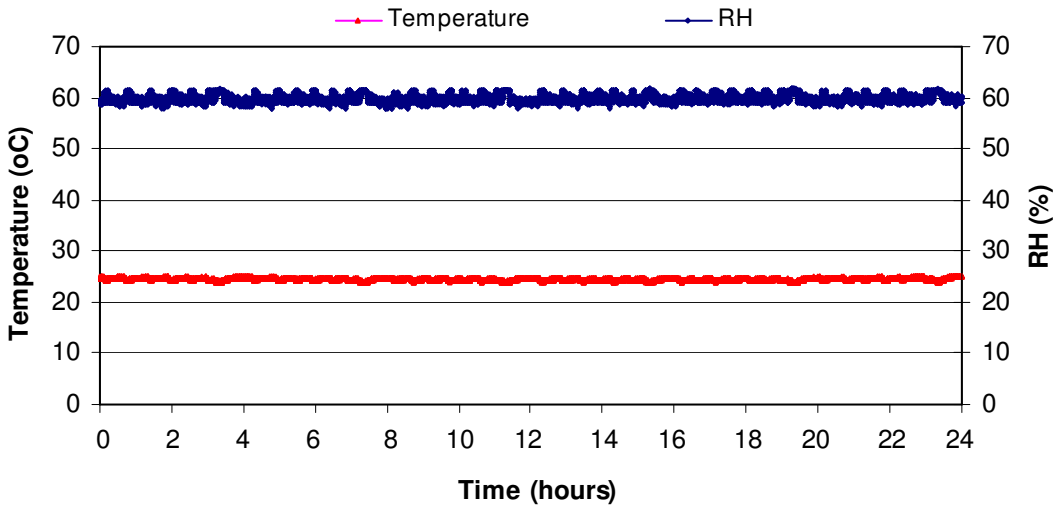


Figure-16: Test room conditions during the Test-2a

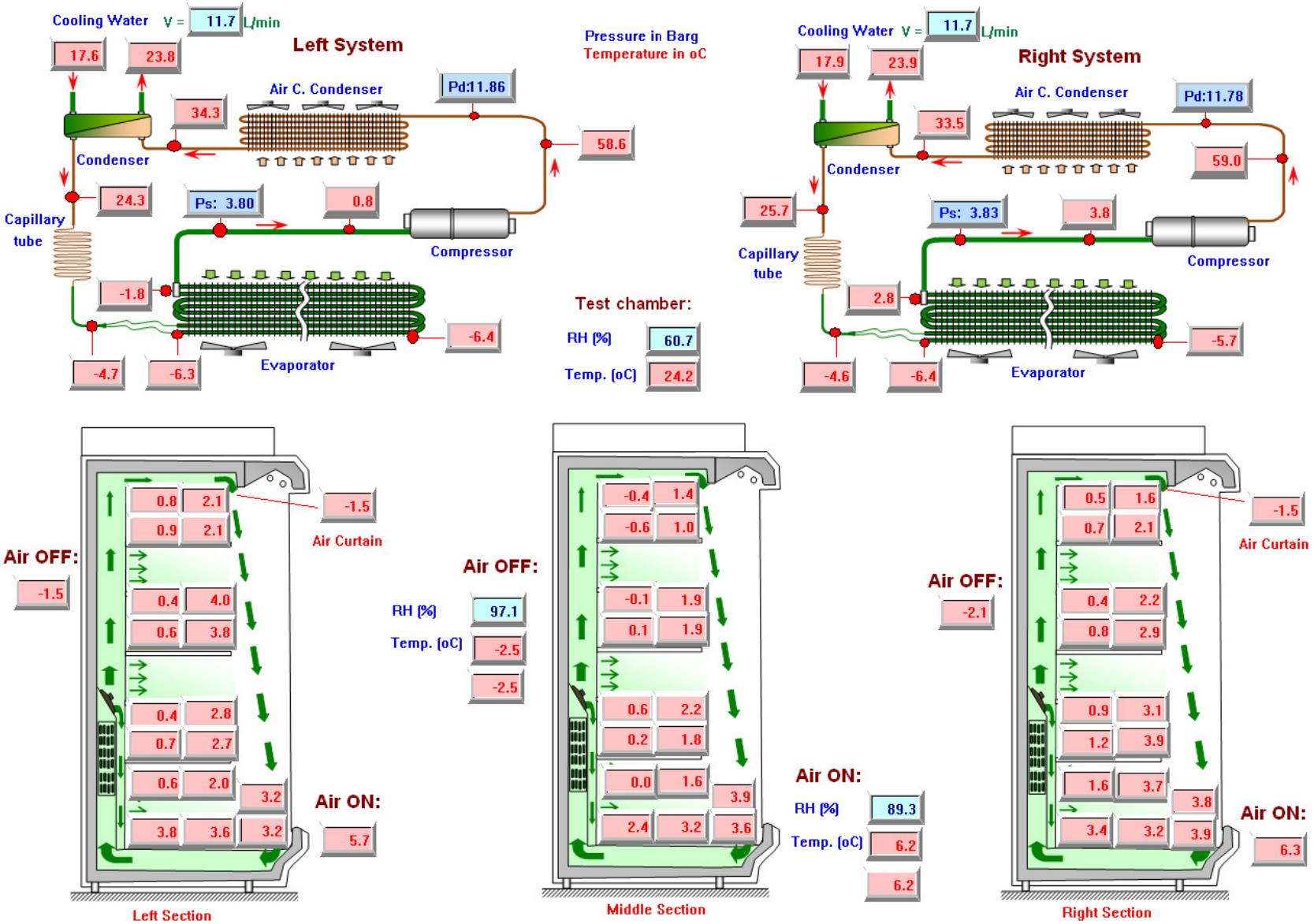
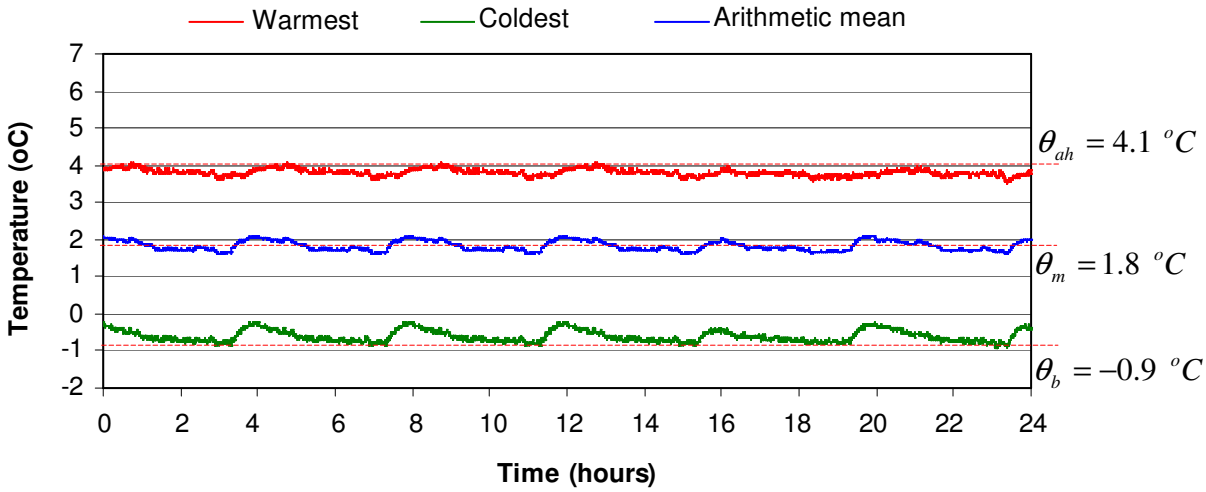


Figure-15: Display of the measurements system of Test-2



θ_{ah} = highest temperature of warmest M-package

θ_b = lowest temperature of coldest M-package

θ_m = overall mean temperature of M-packages

Figure-17: Time/temperature curves of warmest and coldest M-packages and arithmetic mean temperature of all M-packages in Test-2a

Air-ON and air-OFF temperatures of the cabinet during the Test-2a are shown in Figure-18. Average air-ON and air-OFF temperatures in t_{run10} period were 6.0°C and -2.5°C respectively. These temperatures were achieved at evaporating temperatures as shown in Figure-19. Mean evaporating temperature, degree superheat, degree of subcooled and other parameters are presented in Table-10.

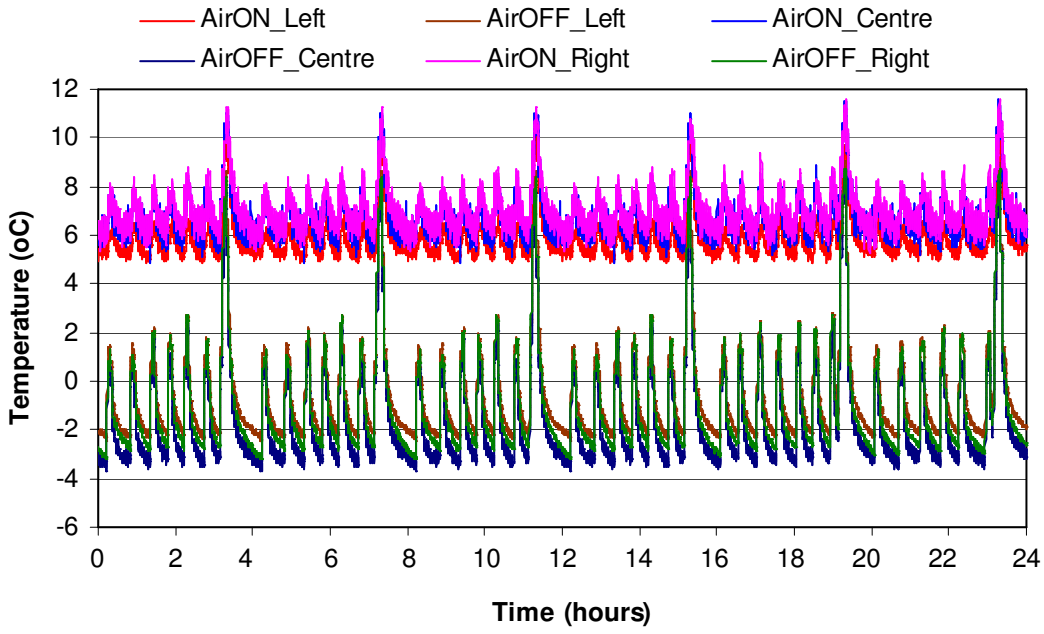


Figure-18: Time/temperature curves of air-ON and air-OFF of the cabinet in Test-2a

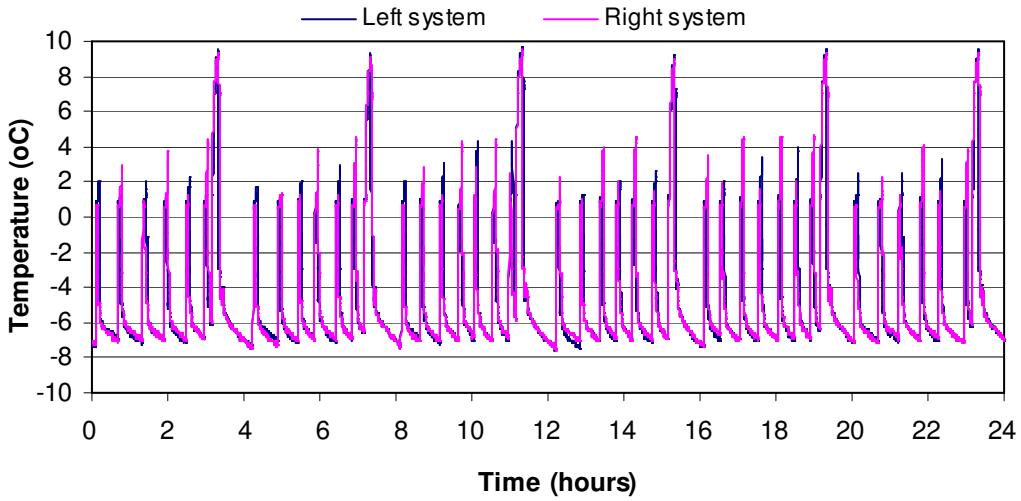


Figure-19: Time/temperature curves of evaporating temperature of the Test-2a

Table-10: Performance parameters of the refrigeration systems

Parameters	Left system	Right system	Overall
Minimum; $\theta_{e-\min}$ (°C)	-7.6	-7.6	-7.6
Mean t_{run10}; $\theta_{e-mrun10}$ (°C)	-6.6	-6.6	-6.6
Mean t_{run75}; $\theta_{e-mrun75}$ (°C)	-6.6	-6.5	-6.6
Mean t_{run}; θ_{e-mrun} (°C)	-6.2	-6.1	-6.2
Mean degree of superheat (°C)	5.5	8.8	7.2
Mean degree of subcooled (°C)	4.3	3.8	4.1
Mean condensing temperature (°C)	29.3	28.9	29.1
Mean suction pressure (bar-g)	3.8	3.8	3.8
Mean discharge pressure (bar-g)	11.9	11.8	11.9
Mean refrigerant mass flowrate (kg/s)	0.015	0.014	0.029
Mean water/glycol mass flowrate (kg/s)	0.20	0.20	0.40

t_{run10} = running time for reporting evaporator temperature of t_{run}.10%
t_{run75} = 75% running time (t_{run}.75%) excluding time after defrost
t_{run} = running time
θ_e = evaporating temperature

4.2.2.2 Test-2b: The cabinet tested with night-covers OFF and lights switched ON for a period of 12 hours followed by 12 hours with night-covers ON and lights switched OFF.

Temperature and RH of the test room during the Test-2b are shown in Figure-20, while time/temperature curves of the warmest and the coldest M-packages including the arithmetic mean temperature of all M-packages are presented in Figure-21. The temperature range of the M-packages in this test could meet M0 classification with overall mean temperature of the M-packages was 2.0°C.

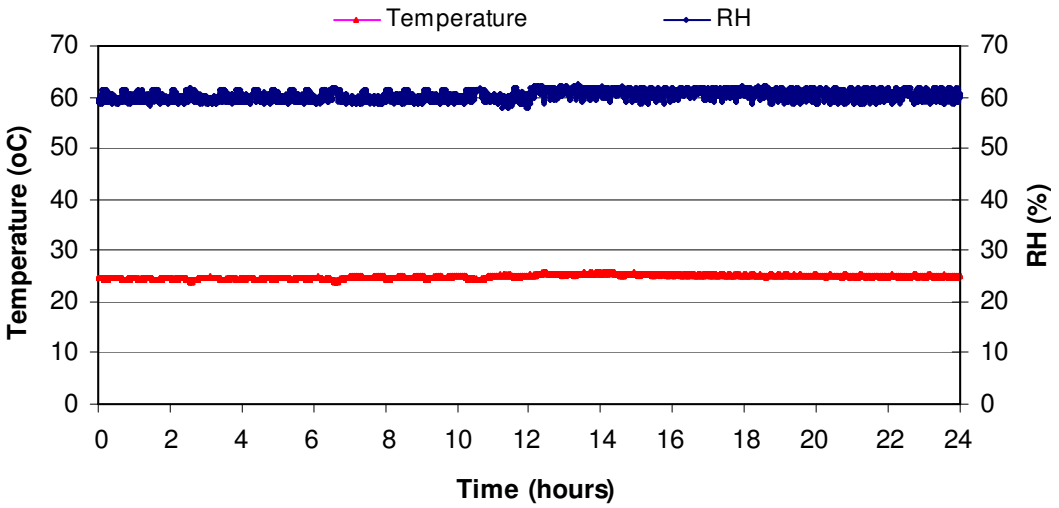


Figure-20: Test room conditions during the Test-2b

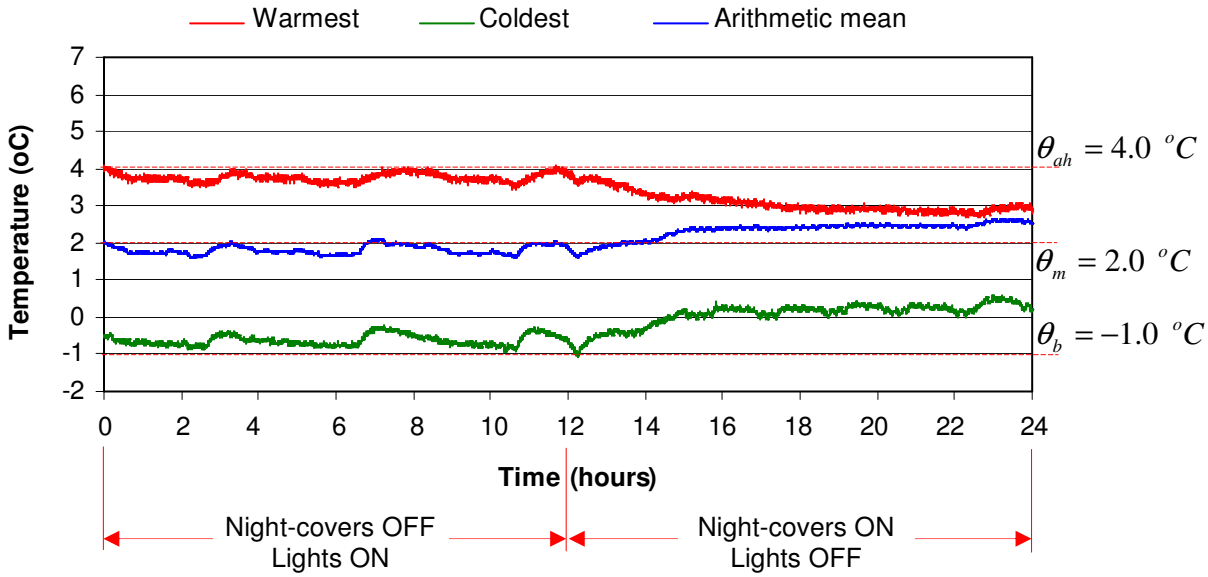


Figure-21: Time/temperature curves of warmest and coldest M-packages and arithmetic mean temperature of all M-packages in Test-2b

Air-ON and air-OFF temperatures of the cabinet during the Test-2b are shown in Figure-22. Air-ON temperature in the second 12 hours was much lower than the first one. Moreover the compressors were switching ON and OFF more frequently during the period when the night-covers were closed (ON). Time/temperature curve of the evaporator during the Test-2b is shown in Figure-23. It can be seen the evaporating temperature of the cabinet with modified back panels was higher in order to keep the M-packages temperature in the M0 classification compared with it was in the Test-1.

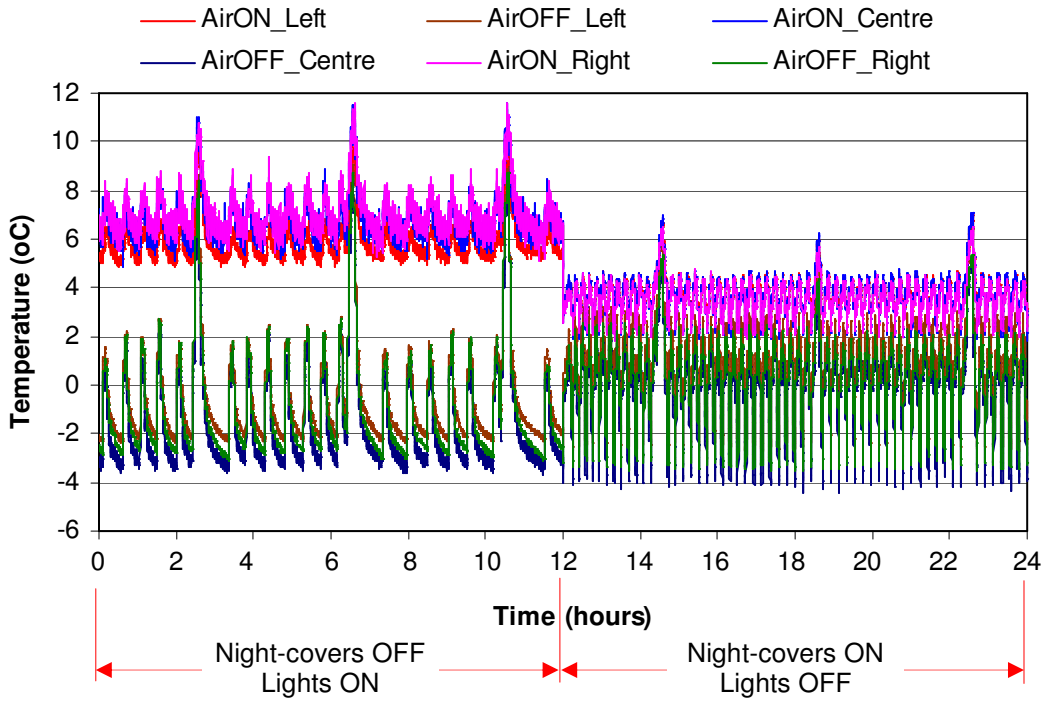


Figure-22: Time/temperature curves of air-ON and air-OFF of the cabinet in Test-2b

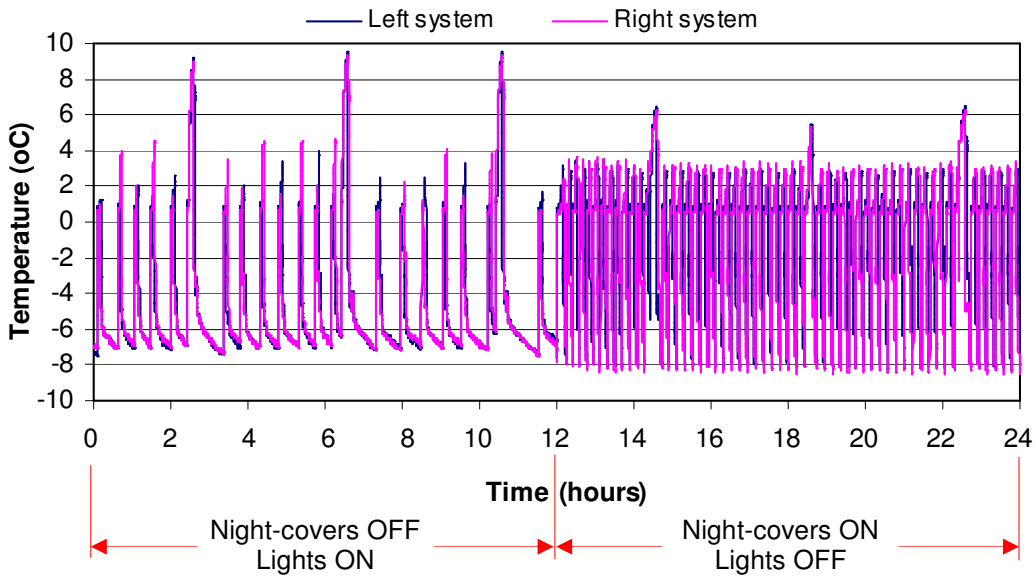


Figure-23: Time/temperature curves of evaporating temperature of the Test-2b

4.2.3 Water Vapour Condensation

Water vapour condensation was found on the external surfaces of the left and right glass-walls for both tests (Test-2a and Test-2b). The maximum area and degree of the condensation are shown in Figure-24 and 25. In this test the surface area covered by water condensation is larger than the Test-1. The side wall which was

facing to the cross flow exhibited less water vapour condensation. The condensation remained in 24 hours of the period of observation.

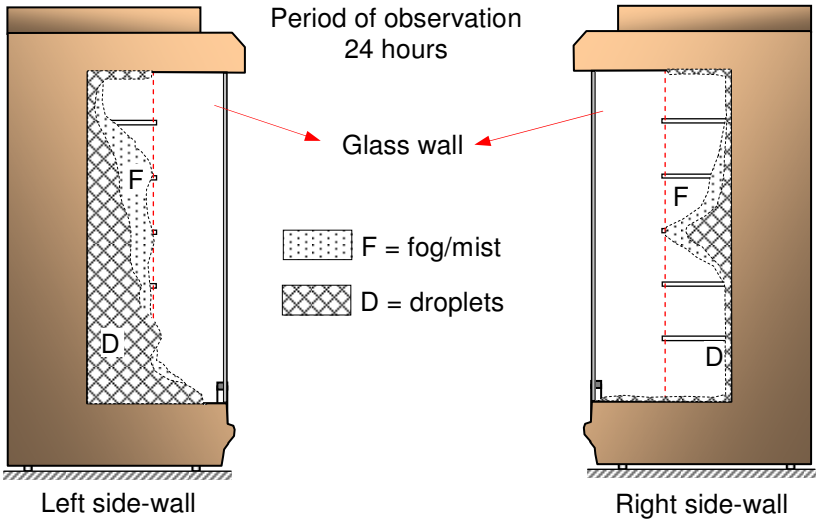


Figure-24: Water vapour condensation on the external surfaces of Test-2a

Figure-25 shows the side-walls in Test-2b which only exhibited droplets water. There was no fog on the external surfaces. The maximum area with water vapour condensation was smaller due to infiltration air from the gap between the night-covers and the side wall replaced some of the cold air on the internal surface of the side-wall. The infiltration air made the side-walls a little bit warmer compared with them in the Test-2a.

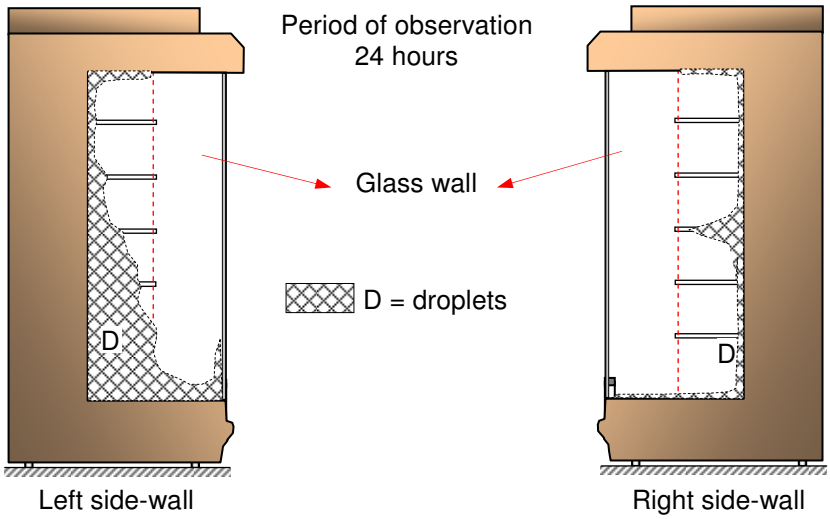


Figure-25: Water vapour condensation on the external surfaces of Test-2b

4.2.4 Electrical Energy Consumption

Total Energy Consumption (*TEC*) of the cabinet was calculated according to BS EN ISO 23953-2: 2005 subclause 5.3.5.2. For the cabinet fitted with integral condensing unit *TEC* equals to Direct Energy Calculation (*DEC*) which can be calculated from:

$$TEC = DEC = \sum_{n=1}^{n=N_{max}} W_n \, x \, \Delta t \qquad \text{(kWh)}$$

W_n = instant power consumption of the cabinet (kW) over 24 hours (W_n = 0 during stopping and defrost time), Δt = period of measurement (h).

Table-11: Operational time of the Test-2

Operational time	Test-2a	Test-2b
Compressor ON/OFF frequency in 24 (h)	38	72
Running time t_{run} (h)	20.87	16.5
Defrost time t_{deft} (h)	1.0	1.0
Stopping time t_{stop} (h)	2.13	6.5
Percentage of the running time t_{rr} (%)	90.7	71.6

The instant power consumptions of the cabinet during the tests are shown in Figure-26 and 27 respectively for Test-2a and Test-2b. Compressor switching ON/OFF frequency and operational time during the tests are presented in Table-11. Power consumption including *TEC* of the cabinet can be seen in Table-12. *TEC* of the cabinet was found to be 55.38 kWh/day for Test-2a and 40.10 kWh/day for Test-2b.

Table-12: Power consumption and TEC of the cabinet in Test-2

Power and Energy consumption	Test-2a	Test-2b
Maximum power (kW)	2.95	2.94
Minimum power (kW)	1.48	1.40
Average power (kW)	2.65	2.44
TEC (kWh/day)	**55.38**	**40.10**

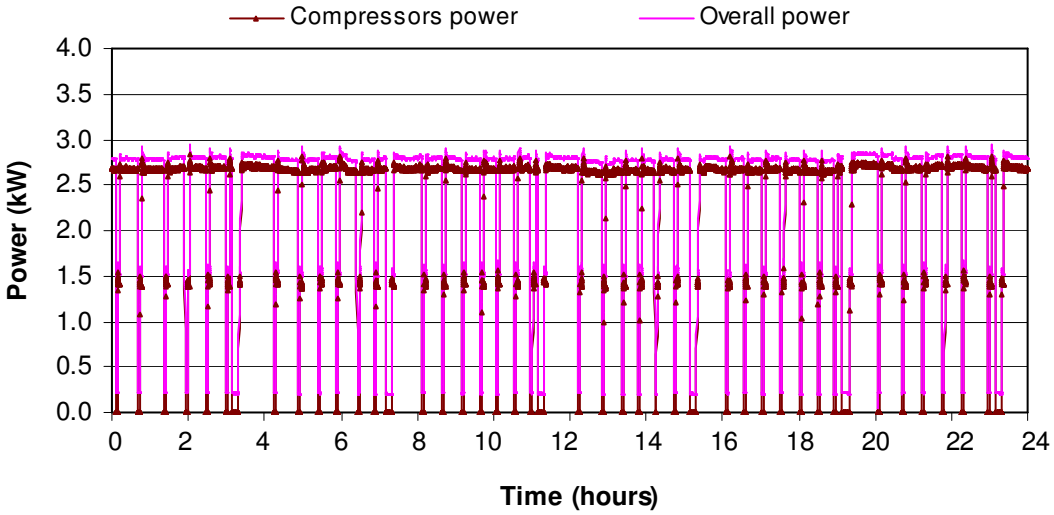


Figure-26: Power consumption of the cabinet during Test-2a

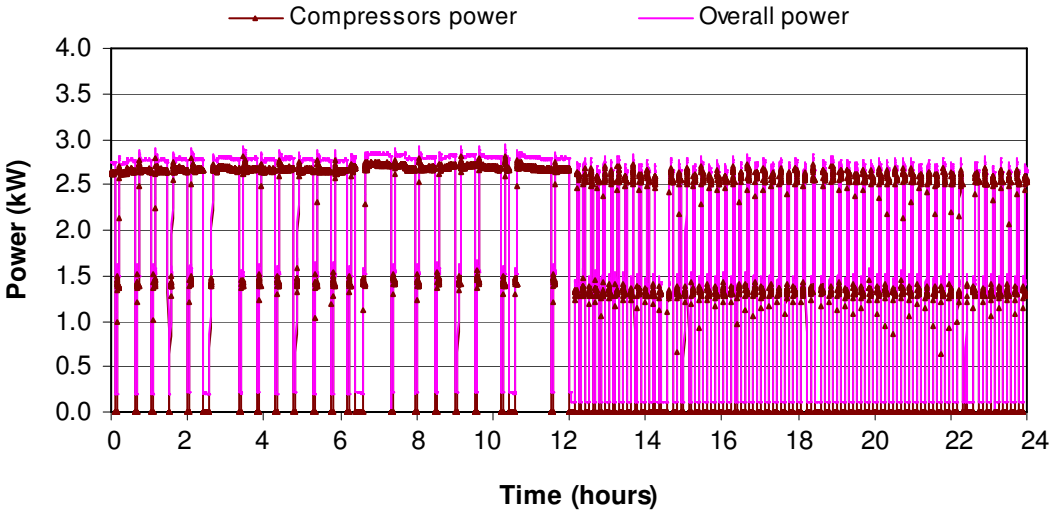


Figure-27: Power consumption of the cabinet during Test-2b

4.2.5 Heat Extraction Rate

Total heat extraction (Q_{tot}) of the cabinet was calculated according to BS EN ISO 23953-2: 2005 subclause 5.3.6.3.

$$Q_{tot} = \sum_{n=1}^{n=N_{max}} \Phi_n \, x \, \Delta t \qquad \text{(kWh)}$$

Φ_n = instant heat extraction rates of the cabinet (kW) over 24 hours (Φ_n = 0 during stopping and defrost time), Δt = period of measurement (h).

Table-13 presents the heat extraction and heat extraction rate of the cabinet. Table-14 shows heat extraction rates per 1 m length of the cabinet.

Table-13: Heat extraction and heat extraction rate of the Test-2

	Test-2a	Test-2b
Total heat extraction; Q_{tot} (kWh)	174.64	124.55
Heat extraction in t_{run75} ; Q_{75} (kWh)	135.77	99.05
Heat extraction rate in t_{run} ; Φ_{run} (kW)	8.37	7.57
Heat extraction rate in t_{run75} ; Φ_{run75} (kW)	8.67	8.02
Heat extraction rate in t_{24} ; Φ_{24} (kW)	7.28	5.19
Heat extraction rate in $t_{24\text{-}deft}$; $\Phi_{24-deft}$ (kW)	7.59	5.42

Table-14: Heat extraction rate per unit length of the cabinet

	Test-2a	Test-2b
Φ_{run} per unit length (kW/m)	2.23	2.02
Φ_{run75} per unit length (kW/m)	2.31	2.14
Φ_{24} per unit length (kW/m)	1.94	1.38
$\Phi_{24-deft}$ per unit length (kW/m)	2.02	1.44

4.2.6 Energy efficiency index

An ECA performance criterion of a refrigerated display cabinet is expressed as Energy Efficiency Index (EEI) which can be calculated from:

$$EEI = \frac{TEC}{TDA} \qquad (kWh/day.m^2)$$

The energy efficiency index of the cabinet and arithmetic mean coefficient of performance (COP) of the refrigeration systems in Test-2 are presented in Table-15.

Table-15: EEI and COP of the Test-2

	Test-2a	Test-2b
Energy efficiency index (EEI) kWh/day.m^2	7.96	5.76
Coefficient of performance (COP)	3.15	3.11

The EEI threshold for M0 classification cabinet with integral condensing unit is **12.50** (kWh/day.m^2).

4.3 Test-3: Cabinet with original air flowrate and back panels

4.3.1 Operational setting

Table-16 shows detailed operational setting of the Test-3 obtained from the commissioning stage. The defrost cycle was set in every 3 hours which was shorter than it was in the Test-1 and Teast-2. At longer defrost cycle the cabinet showed a problem with frost which significantly reduced the air flow to the evaporator coil and resulted in the M-packages temperature increased. Display of the measurement system in a particular time during the Test-3 is presented in Figure-28.

Table-16: Operational setting of the cabinet in Test-3

Thermostat setting:	
Cut in (^{o}C)	3
Differential (^{o}C)	2.2
Air ON/OFF weight (%)	50
Number of defrost per day	8
Defrost minimum time (minutes)	15
Defrost termination (^{o}C)	10
Condenser cooling fluid:	
Temperature IN (^{o}C)	18
Temperature OUT (^{o}C)	24

4.3.2 Temperature Performance

4.3.2.1 Test-3a: The cabinet tested with night-covers OFF and lights switched ON for a period of 24 hours.

Conditions of the test room during the Test-3a were shown in Figure-29. Time based curve of the temperature of the warmest and the coldest M-packages is presented in Figure-30. The M-package temperatures on the individual shelf are presented in Figures A-9 to A-12 of the Appendix.

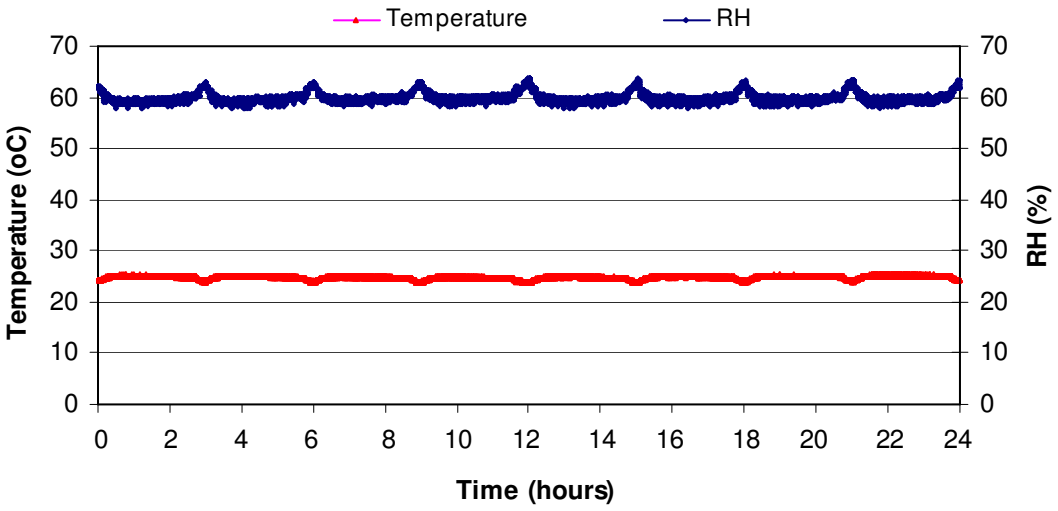


Figure-29: Test room conditions during the Test-3a

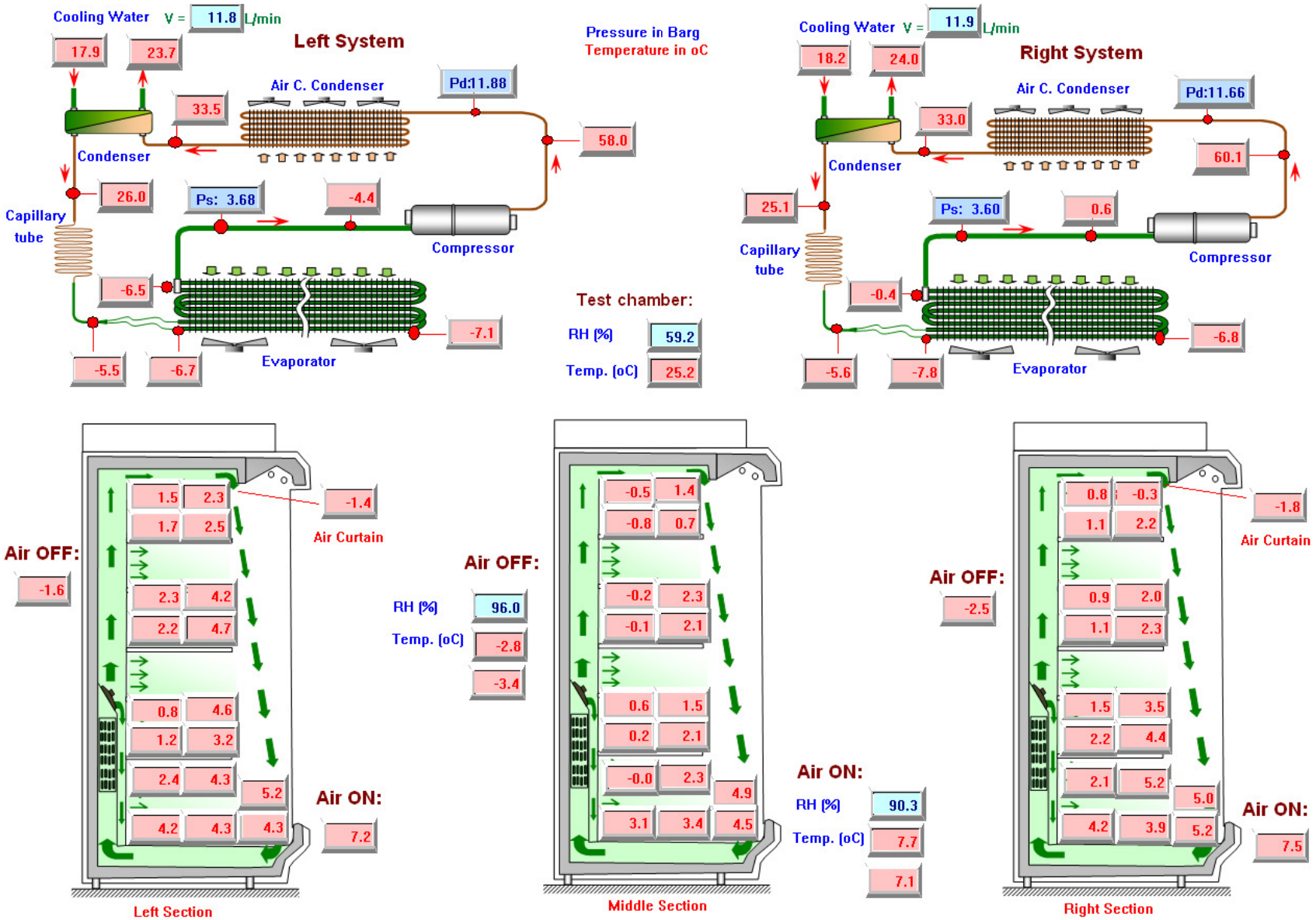
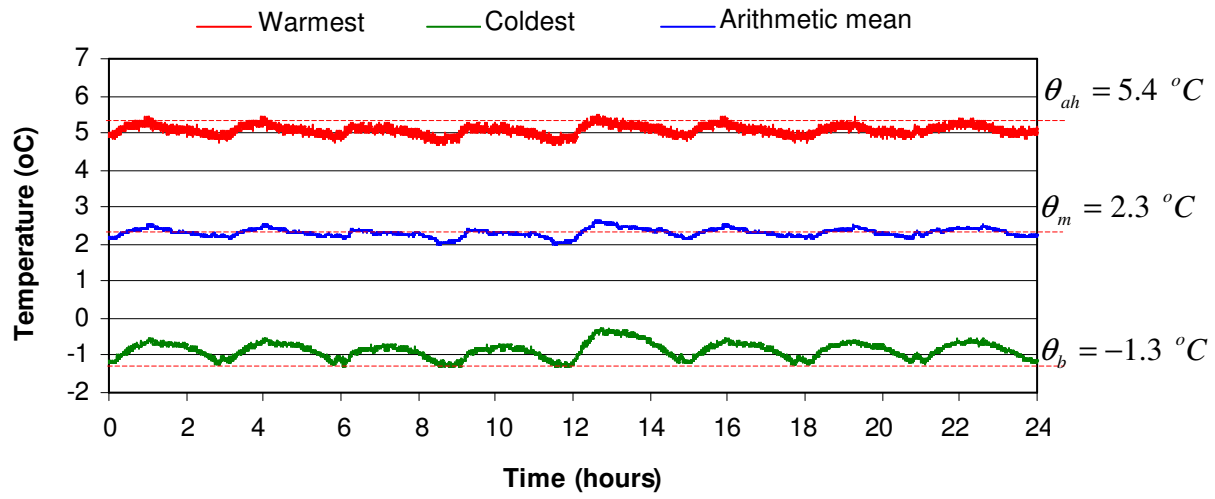


Figure-28: Display of the measurements system of Test-3



θ_{ah} = highest temperature of warmest M-package θ_b = lowest temperature of coldest M-package

θ_m = overall mean temperature of M-packages

Figure-30: Time/temperature curves of warmest and coldest M-packages and arithmetic mean temperature of all M-packages in Test-3a

Temperatures of Air-ON and air-OFF during the Test-3a are shown in Figure-31. Arithmetic mean of air-ON and air-OFF temperatures over t_{run10} period was 6.8°C and -3.6°C respectively. These temperatures were achieved at evaporating temperatures as shown in Figure-32. Mean evaporating temperature, degree superheat, degree of subcooled and other parameters are presented in Table-17.

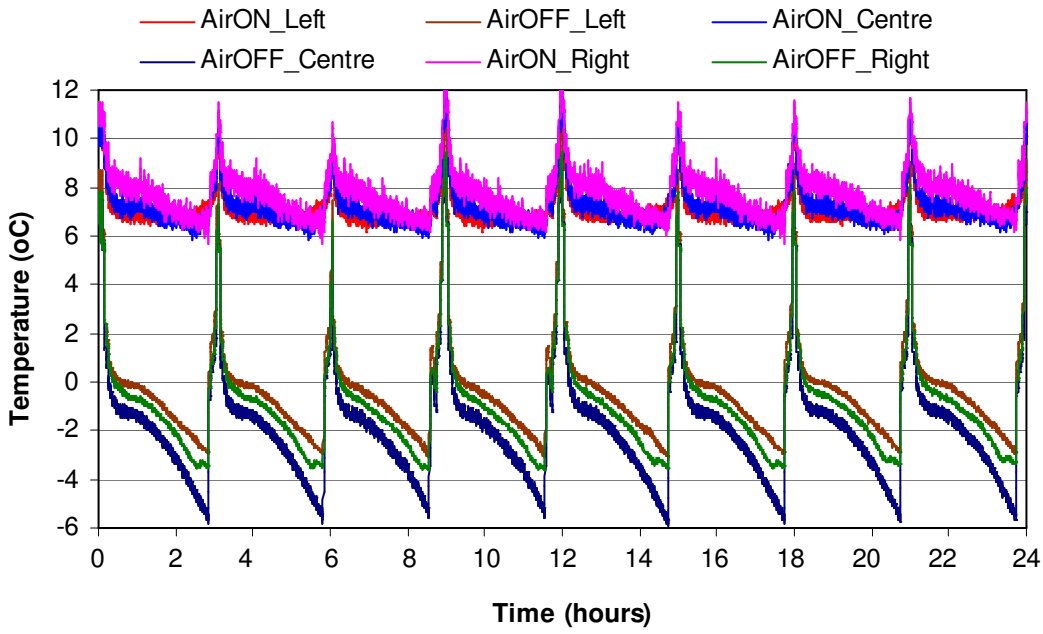


Figure-31: Time/temperature curves of air-ON and air-OFF of the cabinet in Test-3a

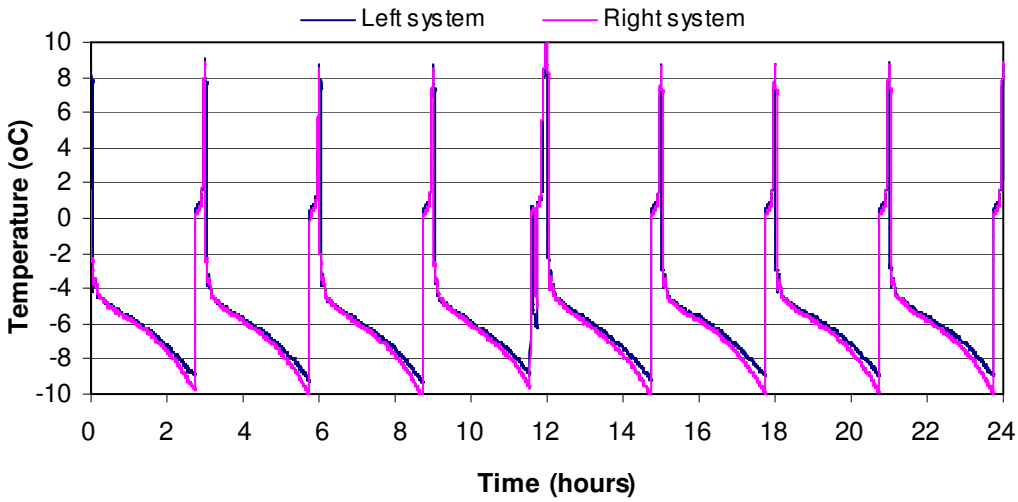


Figure-32: Time/temperature curves of evaporating temperature of the Test-3a

Table-17: Performance parameters of the refrigeration systems

Parameters	Left system	Right system	Overall
Minimum; $\theta_{e-\min}$ (°C)	-9.3	-10.2	-9.8
Mean t_{run10}; $\theta_{e-mrun10}$ (°C)	-8.6	-9.4	-9.0
Mean t_{run75}; $\theta_{e-mrun75}$ (°C)	-6.9	-7.2	-7.1
Mean t_{run}; θ_{e-mrun} (°C)	-6.3	-6.6	-6.5
Mean degree of superheat (°C)	3.3	7.7	5.5
Mean degree of subcooled (°C)	4.3	3.5	3.9
Mean condensing temperature (°C)	29.5	28.9	29.2
Mean suction pressure (bar-g)	3.7	3.7	3.7
Mean discharge pressure (bar-g)	11.9	11.7	11.8
Mean refrigerant mass flowrate (kg/s)	0.014	0.014	0.028
Mean water/glycol mass flowrate (kg/s)	0.20	0.20	0.40

t_{run10} = running time for reporting evaporator temperature of t_{run}.10%
t_{run75} = 75% running time (t_{run}.75%) excluding time after defrost
t_{run} = running time
θ_e = evaporating temperature

4.3.2.2 Test-3b: The cabinet tested with night-covers OFF and lights switched ON for a period of 12 hours followed by 12 hours with night-covers ON and lights switched OFF.

Temperature and RH of the test room during the Test-3b were presented in Figure-33 and time/temperature curves of the warmest and the coldest M-packages were presented in Figure-34. The highest temperature of the warmest M-package was 5.2°C and the lowest temperature of the coldest M-package was -1.2°C. This temperature range indicated that the cabinet in the Test-3 conditions could not meet the M0 classification.

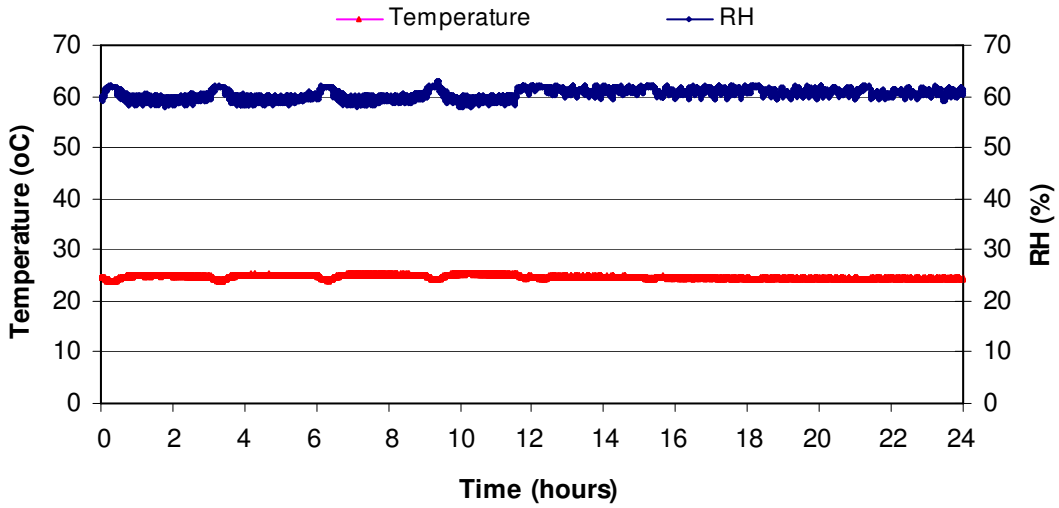


Figure-33: Test room conditions during the Test-3b

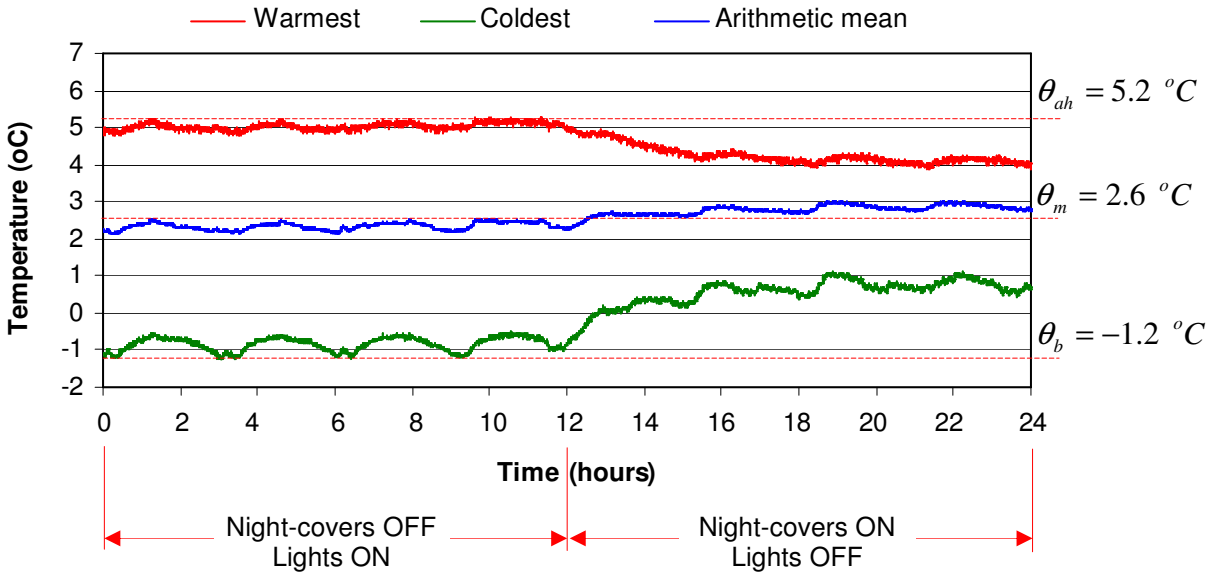


Figure-34: Time/temperature curves of warmest and coldest M-packages and arithmetic mean temperature of all M-packages in Test-3b

Air-ON and air-OFF temperatures of the cabinet during the Test-3b are shown in Figure-35. Air-ON temperature in the second 12 hours was much lower than the first one. As also shown in other previous tests, the compressors were switching ON and OFF more frequently during the period when the night-covers were closed (ON). Evaporating temperature during the Test-3b is shown in Figure-36.

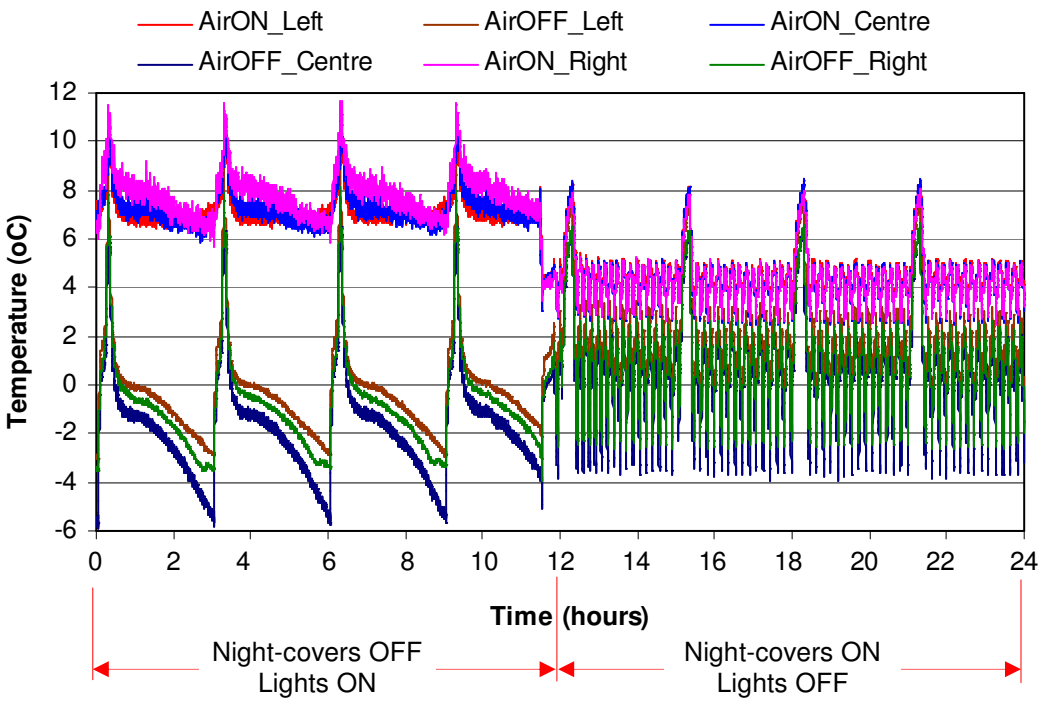


Figure-35: Time/temperature curves of air-ON and air-OFF of the cabinet in Test-3b

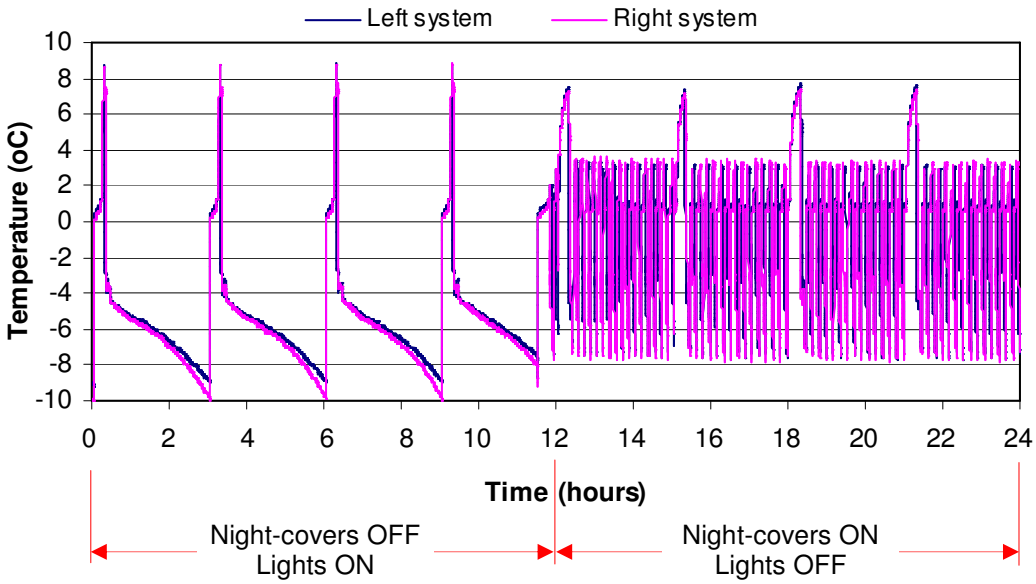


Figure-36: Time/temperature curves of evaporating temperature of the Test-3b

4.3.3 Water Vapour Condensation

Water vapour condensation was found on the external surfaces of the left and right glass-walls for both tests (Test-3a and Test-3b). The maximum area and degree of the condensation are shown in Figure-37 and 38. The coverage area of the water condensation during these tests was quite similar with the Test-1. The wall which was facing the cross flow exhibited less water vapour condensation.

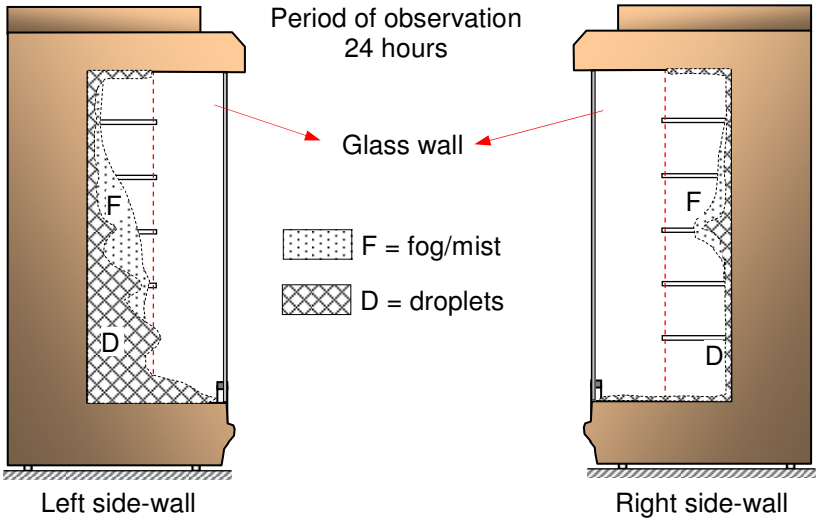


Figure-37: Water vapour condensation on the external surfaces of Test-3a

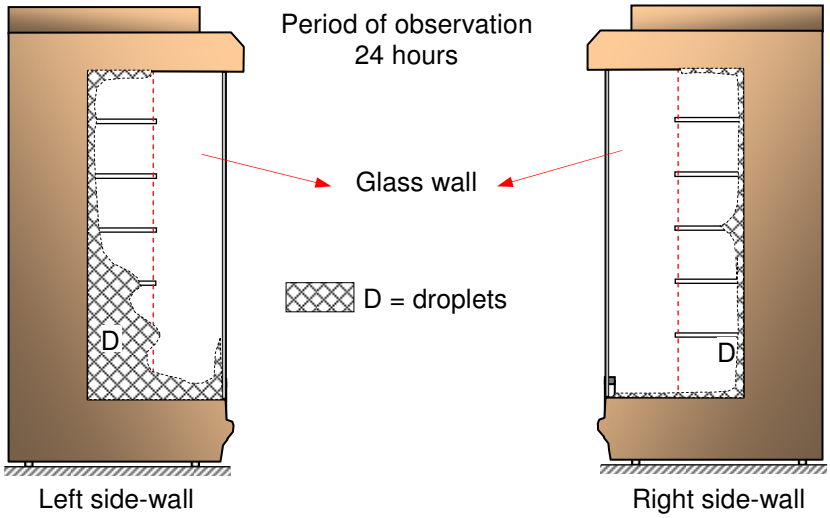


Figure-38: Water vapour condensation on the external surfaces of Test-3b

4.3.4 Electrical Energy Consumption

Total Energy Consumption (*TEC*) of the cabinet was calculated according to BS EN ISO 23953-2: 2005 subclause 5.3.5.2. For the cabinet fitted with integral condensing unit *TEC* equals to Direct Energy Calculation (*DEC*) which can be calculated from:

$$TEC = DEC = \sum_{n=1}^{n=N_{max}} W_n \, x \, \Delta t \qquad \text{(kWh)}$$

W_n = instant power consumption of the cabinet (kW) over 24 hours (W_n = 0 during stopping and defrost time), Δt = period of measurement (h).

Table-18: Operational time of the Test-3

Operational time	Test-3a	Test-3b
Compressor ON/OFF frequency in 24 (h)	1	60
Running time t_{run} (h)	21.83	17.0
Defrost time t_{deft} (h)	2.0	2.0
Stopping time t_{stop} (h)	0.17	5.0
Percentage of the running time t_{rr} (%)	99.2	77.3

Compressor switching ON/OFF frequency and operational time are presented in Table-18. Power consumption including *TEC* of the cabinet can be seen in Table-19. *TEC* of the cabinet was found to be 62.24 kWh/day for Test-3a and 43.59 kWh/day for Test-3b. The instant power consumptions of the cabinet during the tests are shown in Figure-39 and 40 respectively for Test-3a and Test-3b.

Table-19: Power consumption and TEC of the cabinet in Test-3

Power and Energy consumption	Test-3a	Test-3b
Maximum power (kW)	2.99	2.95
Minimum power (kW)	1.50	1.39
Average power (kW)	2.85	2.56
TEC (kWh/day)	**62.24**	**43.59**

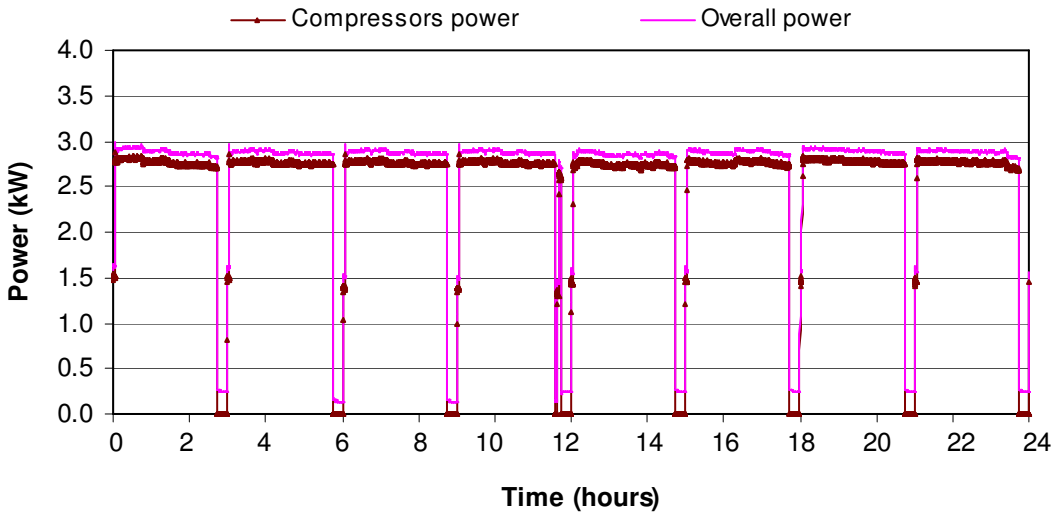


Figure-39: Power consumption of the cabinet during Test-3a

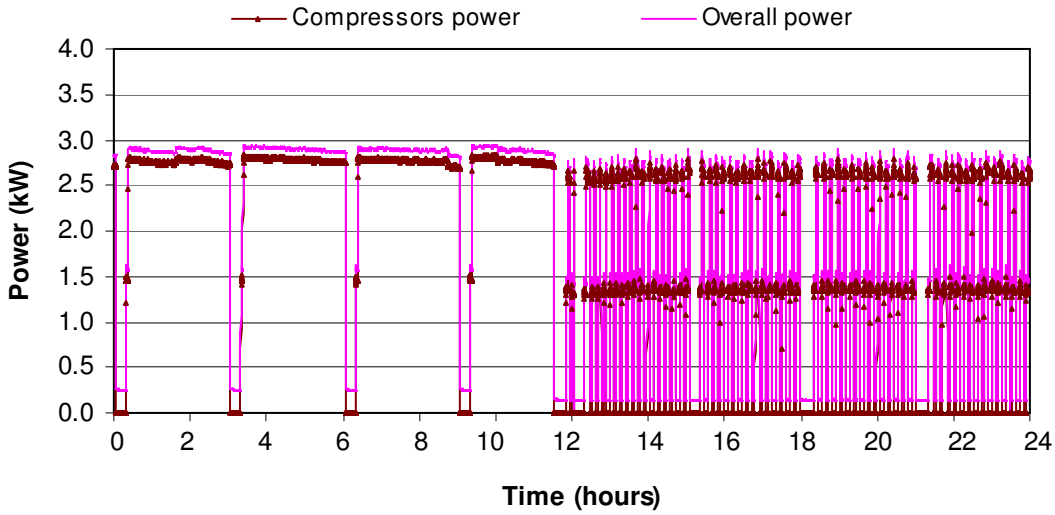


Figure-40: Power consumption of the cabinet during Test-3b

4.3.5 Heat Extraction Rate

Total heat extraction (Q_{tot}) of the cabinet was calculated according to BS EN ISO 23953-2: 2005 subclause 5.3.6.3.

$$Q_{tot} = \sum_{n=1}^{n=N_{max}} \Phi_n \, x \, \Delta t \qquad \text{(kWh)}$$

Φ_n = instant heat extraction rates of the cabinet (kW) over 24 hours (Φ_n = 0 during stopping and defrost time), Δt = period of measurement (h).

Table-13 presents the heat extraction and heat extraction rate of the cabinet. Table-14 shows heat extraction rates per 1 m length of the cabinet.

Table-20: Heat extraction and heat extraction rate of the Test-3

	Test-3a	Test-3b
Total heat extraction; Q_{tot} (kWh)	188.71	132.86
Heat extraction in t_{run75} ; Q_{75} (kWh)	139.76	102.25
Heat extraction rate in t_{run} ; Φ_{run} (kW)	8.64	7.81
Heat extraction rate in t_{run75} ; Φ_{run75} (kW)	8.53	8.01
Heat extraction rate in t_{24} ; Φ_{24} (kW)	7.86	5.54
Heat extraction rate in $t_{24\text{-}deft}$; $\Phi_{24-deft}$ (kW)	8.58	6.04

Table-21: Heat extraction rate per unit length of the cabinet

	Test-3a	Test-3b
Φ_{run} per unit length (kW/m)	2.30	2.08
Φ_{run75} per unit length (kW/m)	2.28	2.14
Φ_{24} per unit length (kW/m)	2.10	1.48
$\Phi_{24-deft}$ per unit length (kW/m)	2.29	1.61

4.3.6 Energy efficiency index

An ECA performance criterion of a refrigerated display cabinet is expressed as Energy Efficiency Index (EEI) which can be calculated from:

$$EEI = \frac{TEC}{TDA} \qquad \text{(kWh/day.m}^2\text{)}$$

The energy efficiency index of the cabinet and arithmetic mean coefficient of performance (COP) of the refrigeration systems in Test-3 are presented in Table-22.

Table-22: EEI and COP of the Test-3

	Test-3a	Test-3b
Energy efficiency index (EEI) kWh/day.m^2	8.95	6.26
Coefficient of performance (COP)	3.03	3.05

The EEI threshold for M0 classification cabinet with integral condensing unit is **12.50** (kWh/day.m^2).

4.4 Test-4: Cabinet with original air flowrate and modified back panels

4.4.1 Operational setting

The operational setting of the Test-3 was also applied as shown in Table-23. Display of the measurement system in a particular time during the Test-4 is presented in Figure-41.

Table-23: Operational setting of the cabinet in Test-4

Thermostat setting:	
Cut in (°C)	3
Differential (°C)	2.2
Air ON/OFF weight (%)	50
Number of defrost per day	8
Defrost minimum time (minutes)	15
Defrost termination (°C)	10
Condenser cooling fluid:	
Temperature IN (°C)	18
Temperature OUT (°C)	24

4.4.2 Temperature Performance

4.4.2.1 Test-4a: The cabinet tested with night-covers OFF and lights switched ON for a period of 24 hours.

Conditions of the test room during the Test-4a are shown in Figure-42. Temperature variation of the warmest and the coldest M-packages is presented in Figure-43. Time/temperature curves of the M-packages on the individual shelf are presented in Figures A-13 to A-16 of the Appendix.

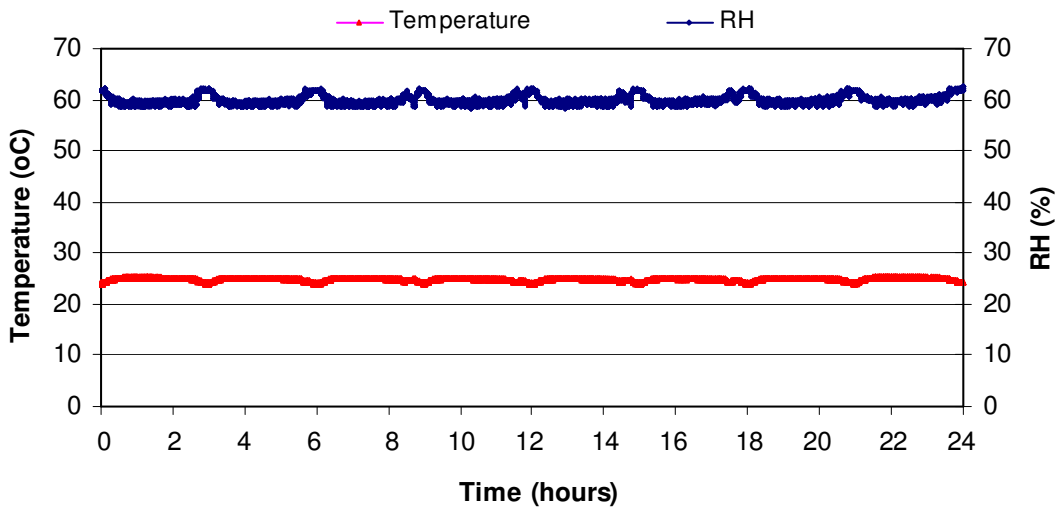


Figure-42: Test room conditions during the Test-4a

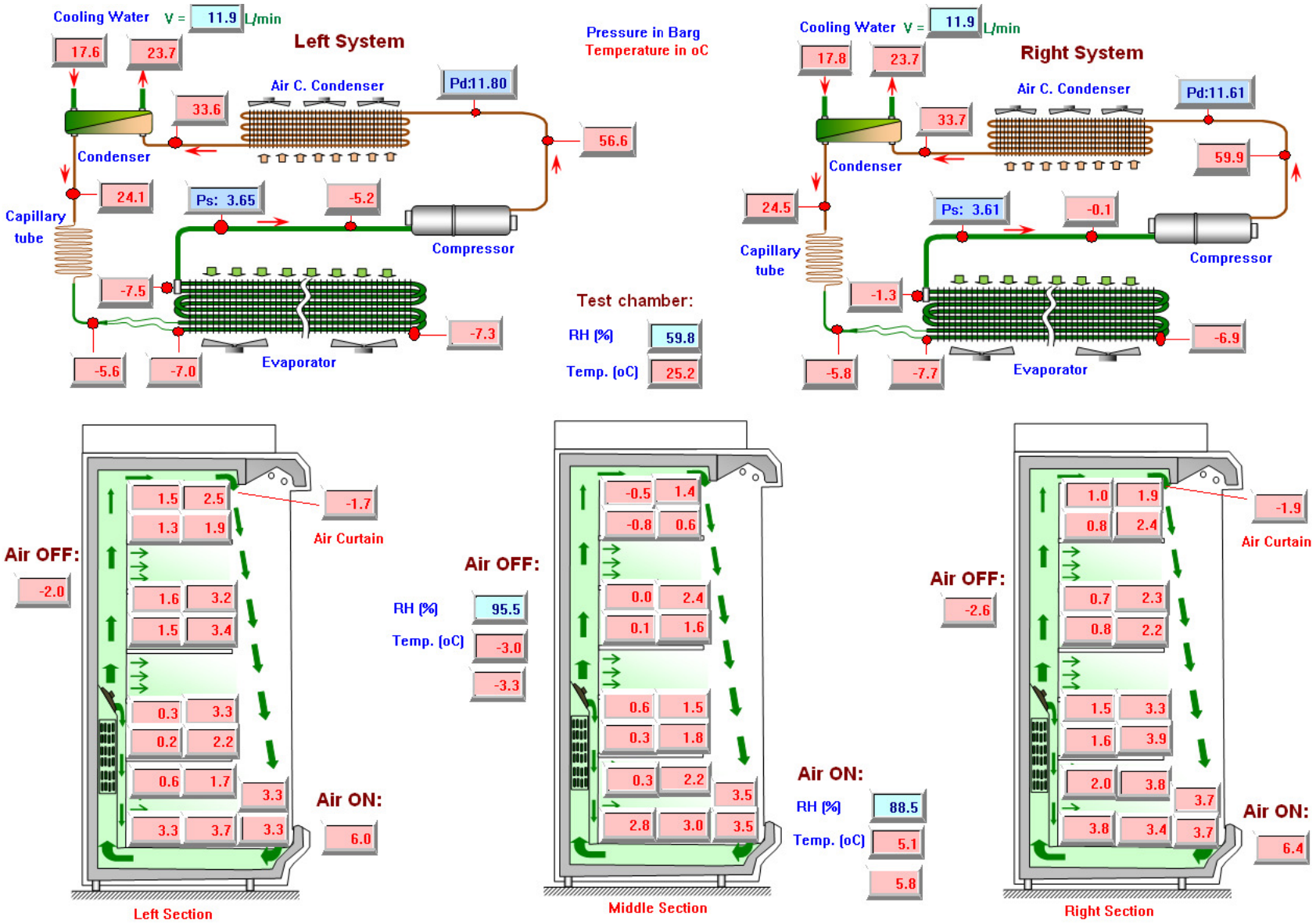
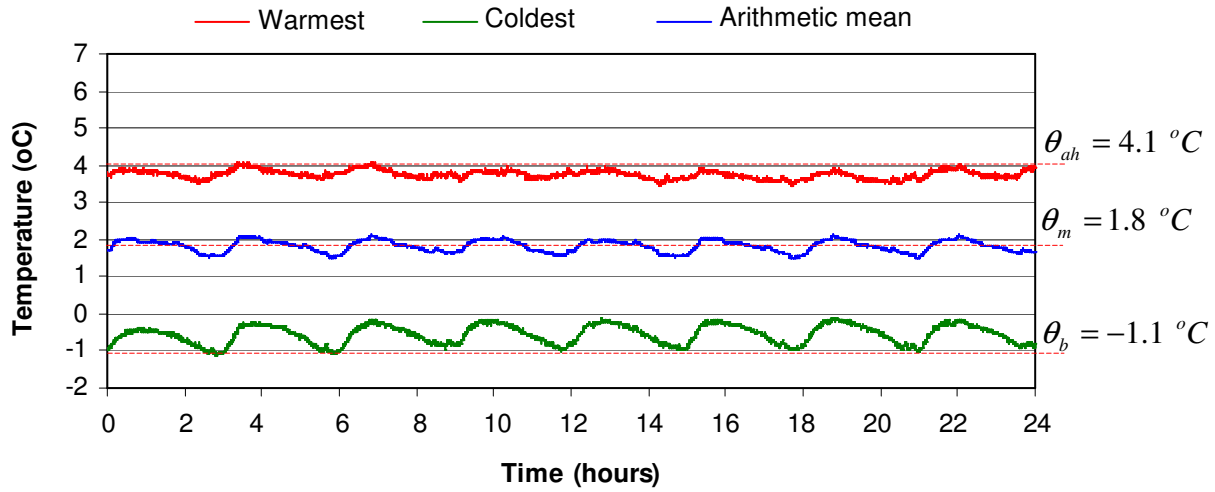


Figure-41: Display of the measurements system of Test-4



θ_{ah} = highest temperature of warmest M-package

θ_b = lowest temperature of coldest M-package

θ_m = overall mean temperature of M-packages

Figure-43: Time/temperature curves of warmest and coldest M-packages and arithmetic mean temperature of all M-packages in Test-4a

Air-ON and air-OFF temperatures of the cabinet during the Test-4a are shown in Figure-44. Arithmetic mean of air-ON and air-OFF temperatures over t_{run10} period was 5.8°C and -3.6°C respectively. These temperatures could be achieved at evaporating temperatures as shown in Figure-45. Mean evaporating temperature, degree superheat, degree of subcooled and other parameters are presented in Table-24.

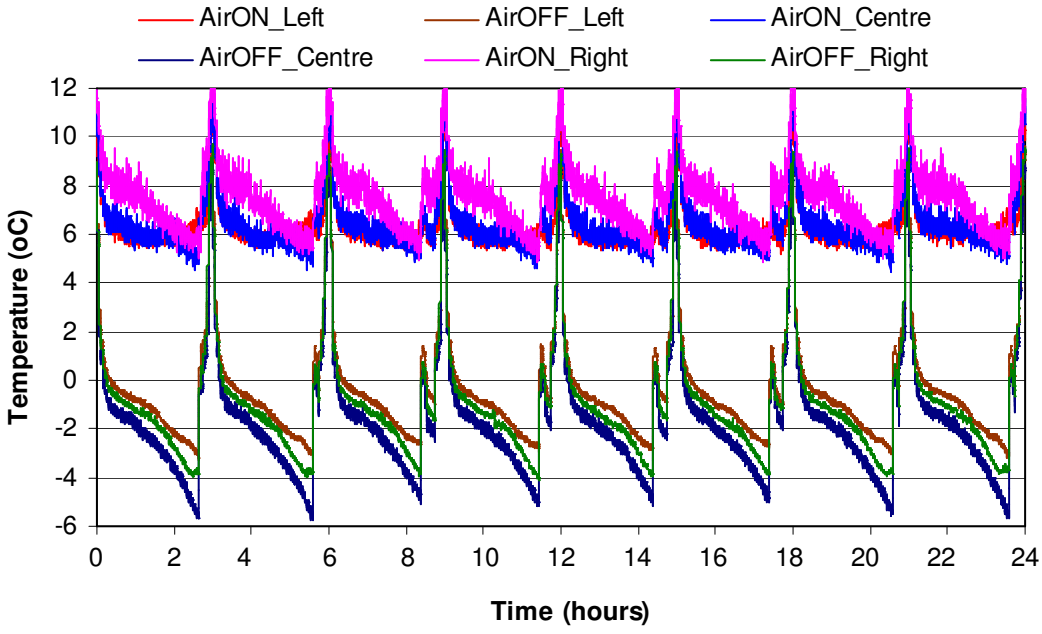


Figure-44: Time/temperature curves of air-ON and air-OFF of the cabinet in Test-4a

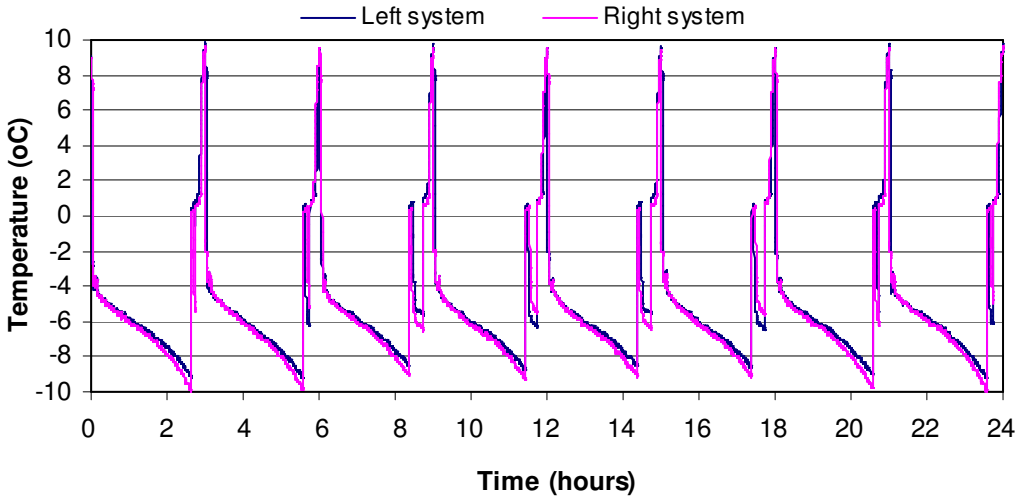


Figure-45: Time/temperature curves of evaporating temperature of the Test-4a

Table-24: Performance parameters of the refrigeration systems

Parameters	Left system	Right system	Overall
Minimum; $\theta_{e-\min}$ (°C)	-9.3	-10.1	-9.7
Mean t_{run10}; $\theta_{e-mrun10}$ (°C)	-8.3	-8.8	-8.6
Mean t_{run75}; $\theta_{e-mrun75}$ (°C)	-6.8	-7.1	-7.0
Mean t_{run}; θ_{e-mrun} (°C)	-6.3	-6.5	-6.4
Mean degree of superheat (°C)	3.4	7.5	5.5
Mean degree of subcooled (°C)	4.3	3.6	4.0
Mean condensing temperature (°C)	29.4	28.9	29.2
Mean suction pressure (bar-g)	3.8	3.7	3.8
Mean discharge pressure (bar-g)	11.9	11.7	11.8
Mean refrigerant mass flowrate (kg/s)	0.014	0.014	0.028
Mean water/glycol mass flowrate (kg/s)	0.20	0.20	0.40

t_{run10} = running time for reporting evaporator temperature of t_{run}.10%
t_{run75} = 75% running time (t_{run}.75%) excluding time after defrost
t_{run} = running time
θ_e = evaporating temperature

4.4.2.2 Test-4b: The cabinet tested with night-covers OFF and lights switched ON for a period of 12 hours followed by 12 hours with night-covers ON and lights switched OFF.

Temperature and RH of the test room during the Test-4b is shown in Figure-46. Time/temperature curves of the warmest and the coldest M-packages including arithmetic mean temperature of all M-packages are presented in Figure-47.

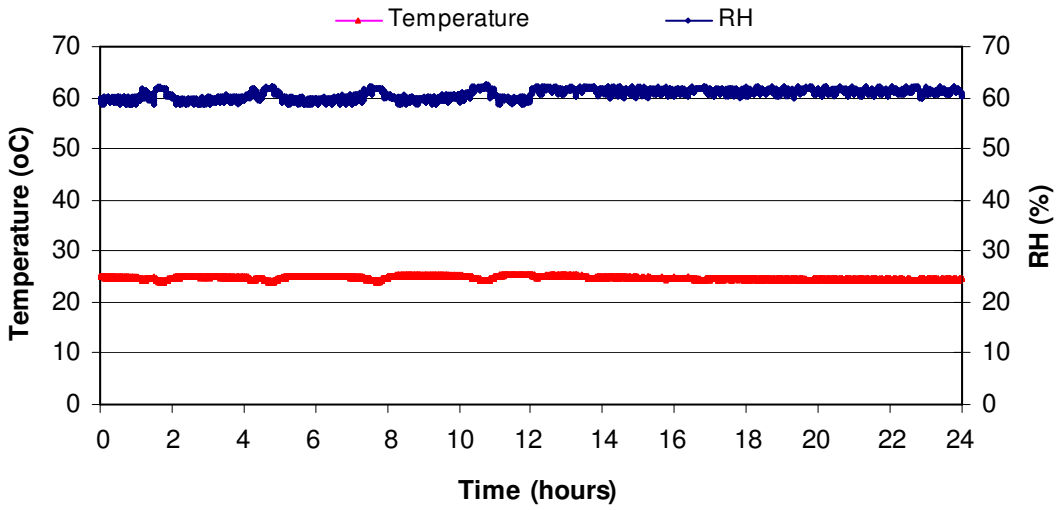


Figure-46: Test room conditions during the Test-4b

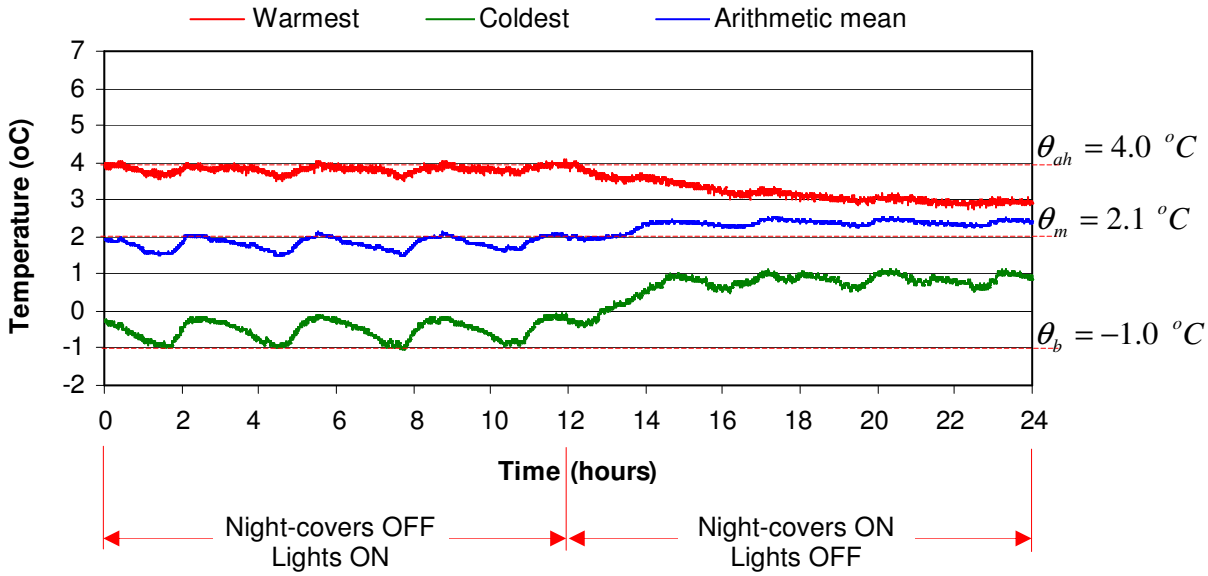


Figure-47: Time/temperature curves of warmest and coldest M-packages and arithmetic mean temperature of all M-packages in Test-4b

Air-ON and air-OFF temperatures of the cabinet during the Test-4b are shown in Figure-48. Air-ON temperature in the second 12 hours was much lower than the first one. Moreover the compressors were switching ON and OFF more frequently during the period when the night-covers were closed (ON). Evaporating temperature during the Test-4b is shown in Figure-49.

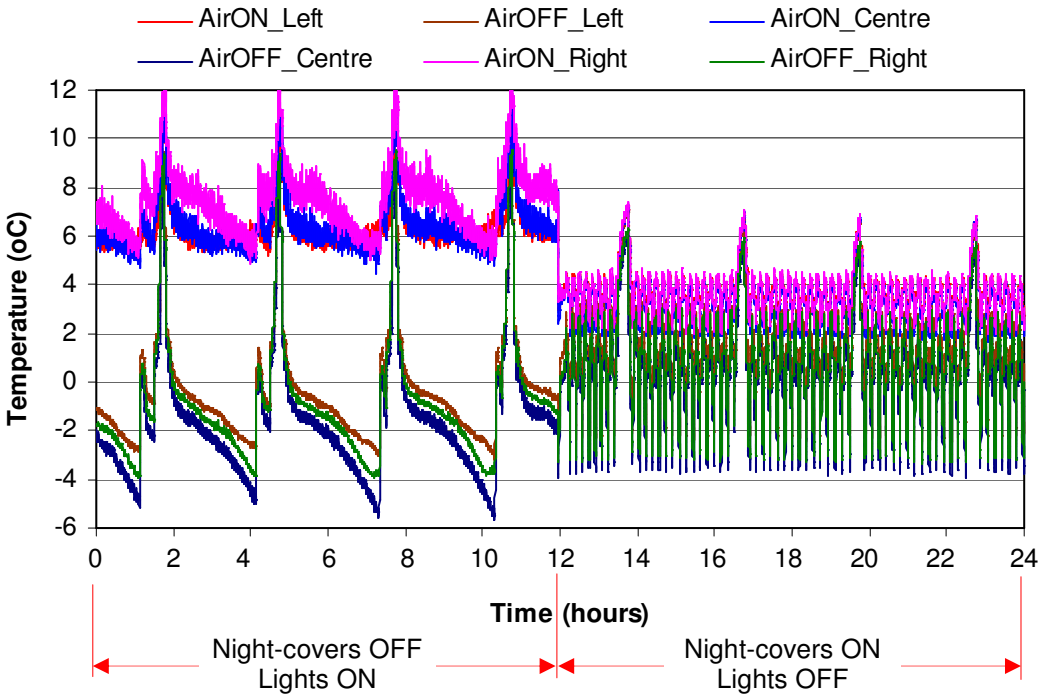


Figure-48: Time/temperature curves of air-ON and air-OFF of the cabinet in Test-4b

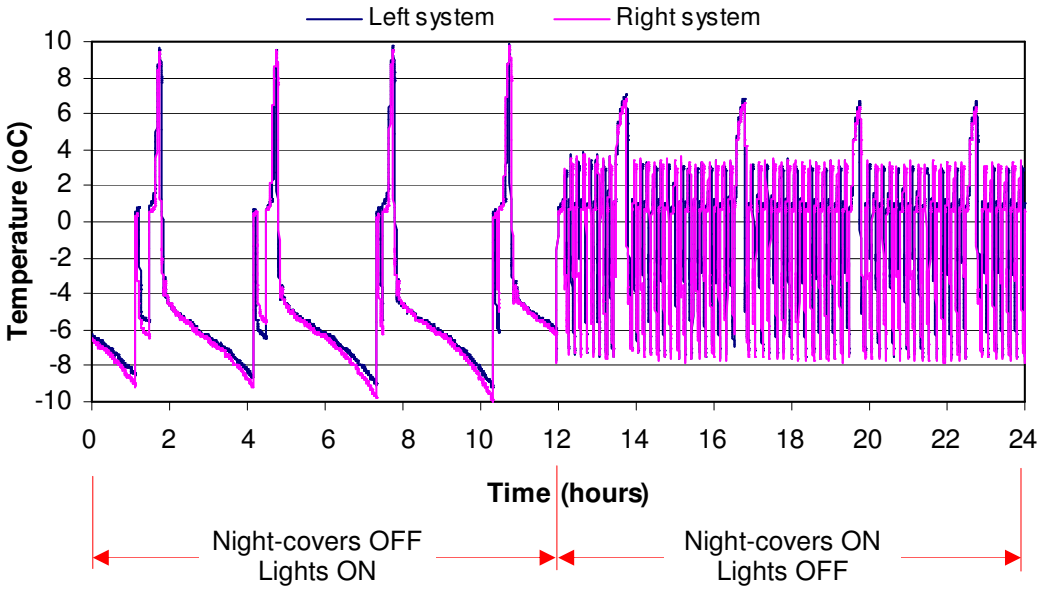


Figure-49: Time/temperature curves of evaporating temperature of the Test-4b

4.4.3 Water Vapour Condensation

In this test, water vapour condensation was also found on the external surfaces of the left and right glass-walls for both tests (Test-4a and Test-4b). The maximum area and degree of the condensation are very much similar with the Test-2 which shown in Figure-50 and 51.

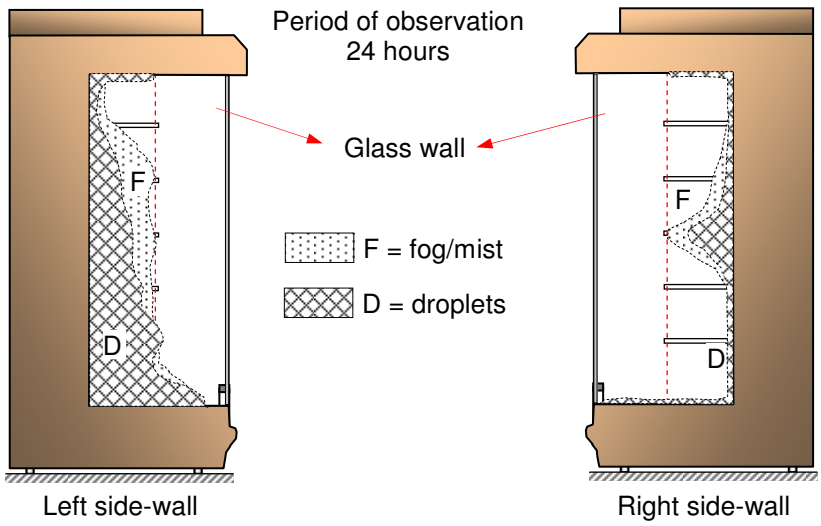


Figure-50: Water vapour condensation on the external surfaces of Test-4a

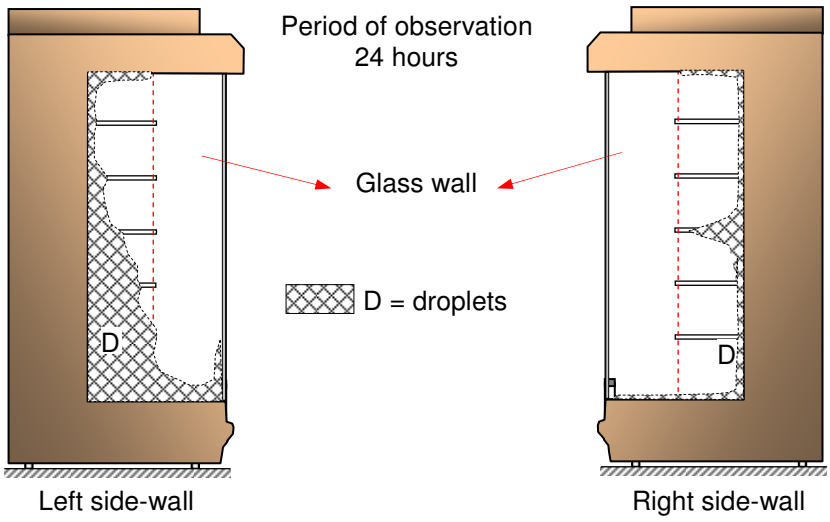


Figure-51: Water vapour condensation on the external surfaces of Test-4b

4.4.4 Electrical Energy Consumption

Total Energy Consumption (*TEC*) of the cabinet was calculated according to BS EN ISO 23953-2: 2005 subclause 5.3.5.2. For the cabinet fitted with integral condensing unit *TEC* equals to Direct Energy Calculation (*DEC*) which can be calculated from:

$$TEC = DEC = \sum_{n=1}^{n=N_{max}} W_n \, x \, \Delta t \qquad \text{(kWh)}$$

W_n = instant power consumption of the cabinet (kW) over 24 hours (W_n = 0 during stopping and defrost time), Δt = period of measurement (h).

Table-25: Operational time of the Test-4

Operational time	Test-4a	Test-4b
Compressor ON/OFF frequency in 24 (h)	7	61
Running time t_{run} (h)	21.4	16.9
Defrost time t_{deft} (h)	2.0	2.0
Stopping time t_{stop} (h)	0.6	5.1
Percentage of the running time t_{rr} (%)	97.5	76.7

Compressor switching ON/OFF frequency and operational time are presented in Table-25. Power consumption including *TEC* of the cabinet can be seen in Table-26. The instant power consumptions of the cabinet during the tests are shown in Figure-52 and 53 respectively for Test-4a and Test-4b.

Table-26: Power consumption and TEC of the cabinet in Test-4

Power and Energy consumption	Test-4a	Test-4b
Maximum power (kW)	2.99	2.97
Minimum power (kW)	1.50	1.40
Average power (kW)	2.80	2.52
TEC (kWh/day)	**60.06**	**42.59**

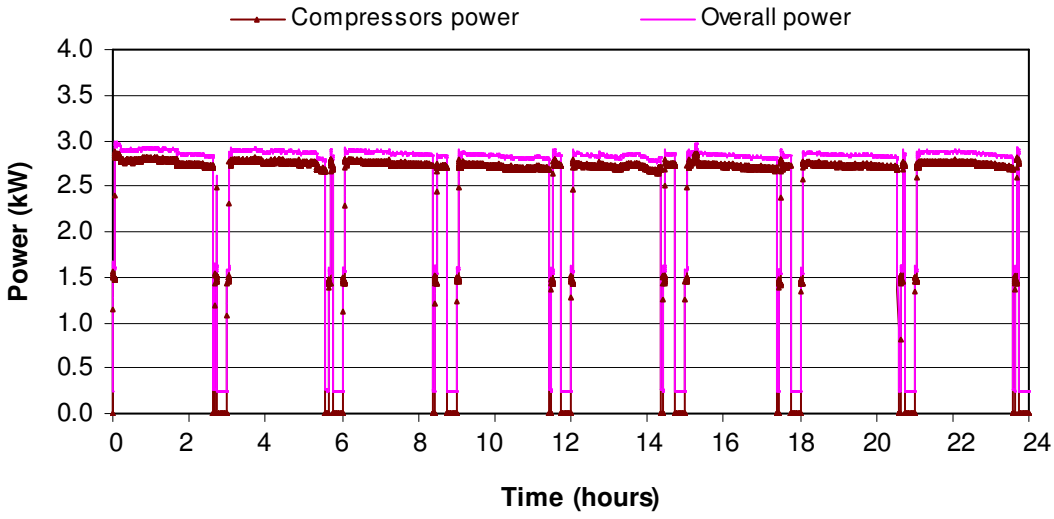


Figure-52: Power consumption of the cabinet during Test-4a

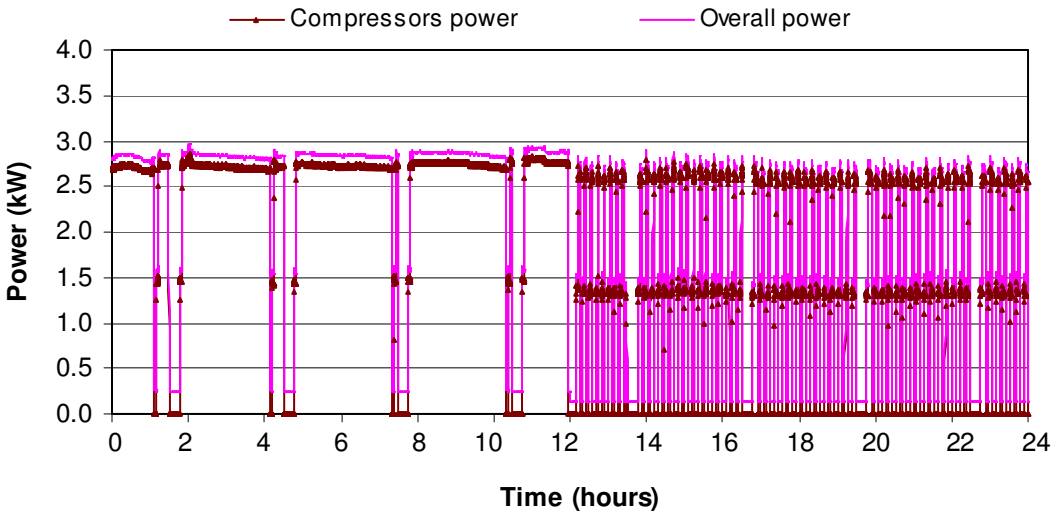


Figure-53: Power consumption of the cabinet during Test-4b

4.4.5 Heat Extraction Rate

Total heat extraction (Q_{tot}) of the cabinet was calculated according to BS EN ISO 23953-2: 2005 subclause 5.3.6.3.

$$Q_{tot} = \sum_{n=1}^{n=N_{max}} \Phi_n \, x \, \Delta t \qquad \text{(kWh)}$$

Φ_n = instant heat extraction rates of the cabinet (kW) over 24 hours (Φ_n = 0 during stopping and defrost time), Δt = period of measurement (h).

Table-27 presents the heat extraction and heat extraction rate of the cabinet. Table-28 shows heat extraction rates per 1 m length of the cabinet.

Table-27: Heat extraction and heat extraction rate of the Test-4

	Test-4a	Test-4b
Total heat extraction; Q_{tot} (kWh)	187.47	134.22
Heat extraction in t_{run75} ; Q_{75} (kWh)	139.38	103.71
Heat extraction rate in t_{run} ; Φ_{run} (kW)	8.74	7.95
Heat extraction rate in t_{run75} ; Φ_{run75} (kW)	8.67	8.19
Heat extraction rate in t_{24} ; Φ_{24} (kW)	7.81	5.59
Heat extraction rate in $t_{24\text{-}deft}$; $\Phi_{24-deft}$ (kW)	8.52	6.10

Table-28: Heat extraction rate per unit length of the cabinet

	Test-4a	Test-4b
Φ_{run} per unit length (kW/m)	2.33	2.12
Φ_{run75} per unit length (kW/m)	2.31	2.18
Φ_{24} per unit length (kW/m)	2.08	1.49
$\Phi_{24-deft}$ per unit length (kW/m)	2.27	1.63

4.4.6 Energy efficiency index

An ECA performance criterion of a refrigerated display cabinet is expressed as Energy Efficiency Index (EEI) which can be calculated from:

$$EEI = \frac{TEC}{TDA} \qquad \text{(kWh/day.m}^2\text{)}$$

The energy efficiency index of the cabinet and arithmetic mean coefficient of performance (COP) of the refrigeration systems in Test-4 are presented in Table-29.

Table-29: EEI and COP of the Test-4

	Test-4a	Test-4b
Energy efficiency index (EEI) kWh/day.m^2	8.63	6.12
Coefficient of performance (COP)	3.12	3.15

The EEI threshold for M0 classification cabinet with integral condensing unit is **12.50** (kWh/day.m^2).

5. Conclusions

Total display area (TDA) of the cabinet was found to be 6.96 m^2.

The terms used for the cabinet and test conditions were estimated by using CFD model as follows:

- Original air flowrate was 1719 m^3/h
- Lower air flowrate was 1173 m^3/h
- Original back panels referred to perforated ratio of the back panels of the cabinet of about 1.25% or equivalent to ratio of backflow to the total air flow of about 37%.
- Modified back panels was the back panels with perforated ratio of 5.0% or equivalent to a ratio of backflow to the total air flow of the cabinet in the range between 60% and 70%.

Temperature of M-packages for the tests with night-covers OFF and lights switched ON for a period of 24 hours:

Cabinet conditions	θ_{ah} (°C)	θ_b (°C)
1. Lower air flowrate and original back panels	5.2	-1.5
2. Lower air flowrate and modified back panels	4.1	-0.9
3. Original air flowrate and original back panels	5.4	-1.3
4. Original air flowrate and modified back panels	4.1	-1.1

Temperature of M-packages for the tests with night-covers OFF and lights switched ON for a period of 12 hours followed by 12 hours with night-covers ON and lights switched OFF:

Cabinet conditions	θ_{ah} (°C)	θ_b (°C)
1. Lower air flowrate and original back panels	5.2	-1.4
2. Lower air flowrate and modified back panels	4.0	-1.0
3. Original air flowrate and original back panels	5.2	-1.2
4. Original air flowrate and modified back panels	4.0	-1.0

The cabinet with modified back panels (Cabinet 2 and 4) could maintain the M-package temperatures within the M0 classification (-1°C and +4°C) throughout the test. However, temperatures of some M-packages of the cabinet with original back panels (Cabinet 1 and 3) were beyond the range which indicated the cabinet with original back panels could not comply with the M0 classification.

Total energy consumption and energy efficiency index of the cabinet for the tests with night-covers OFF and lights switched ON for a period of 24 hours:

Cabinet conditions	TEC (kWh/day)	EEI (kWh/day.m^2)
1. Lower air flowrate and original back panels	57.61	8.28
2. Lower air flowrate and modified back panels	55.38	7.96
3. Original air flowrate and original back panels	62.24	8.95
4. Original air flowrate and modified back panels	60.06	8.63

Total energy consumption and energy efficiency index of the cabinet for the tests with night-covers OFF and lights switched ON for a period of 12 hours followed by 12 hours with night-covers ON and lights switched OFF:

Cabinet conditions	TEC (kWh/day)	EEI (kWh/day.m^2)
1. Lower air flowrate and original back panels	42.19	6.06
2. Lower air flowrate and modified back panels	40.10	5.76
3. Original air flowrate and original back panels	43.59	6.26
4. Original air flowrate and modified back panels	42.59	6.12

The Energy Efficiency Index (EEI) threshold for M0 classification with integral condensing unit is 12.50 kWh/day/m^2. We can conclude the cabinet with modified back panels complies with the ECA scheme criteria for M0 classification.

Appendix

1. Time/temperature curves of M-packages on the individual shelf of the Test-1a

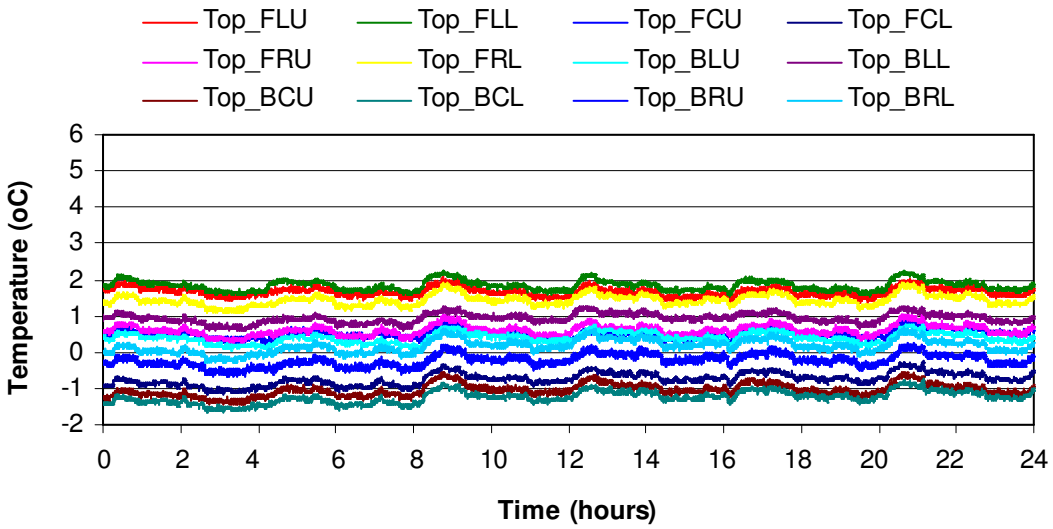


Figure-A.1: Time/temperature curves of the M-packages on the top shelf

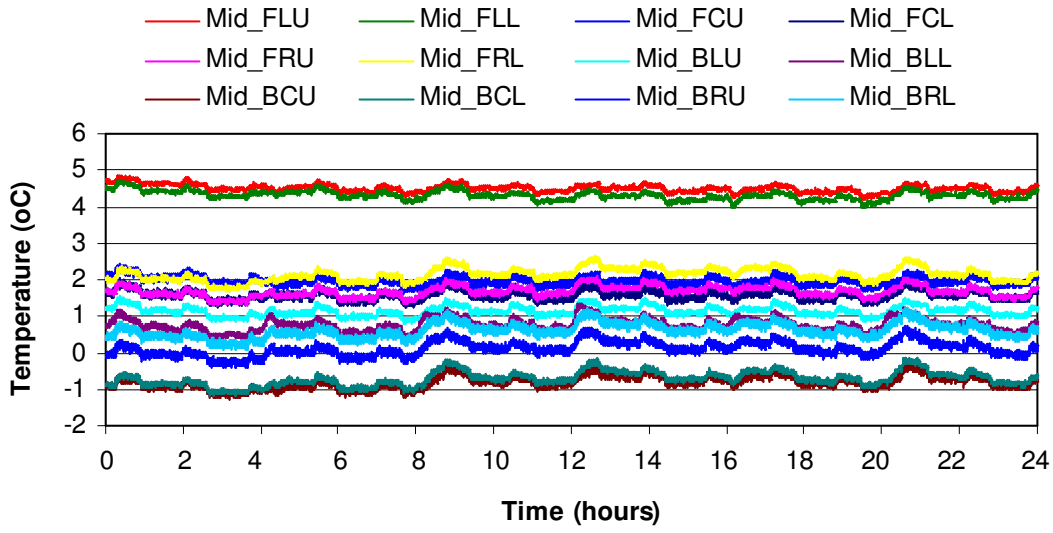


Figure-A.2: Time/temperature curves of the M-packages on the middle shelf

Legend:
(M-packages positions on the shelf)

FLU = front left upper	FCU = front centre upper	FRU = front right upper
FLL = front left lower	FCL = front centre lower	FRL = front right lower
BLU = front left upper	BCU = front centre upper	BRU = front right upper
BLL = front left lower	BCL = front centre lower	BRL = front right lower

Air cross flow direction in the test room was from right to the left of the cabinet

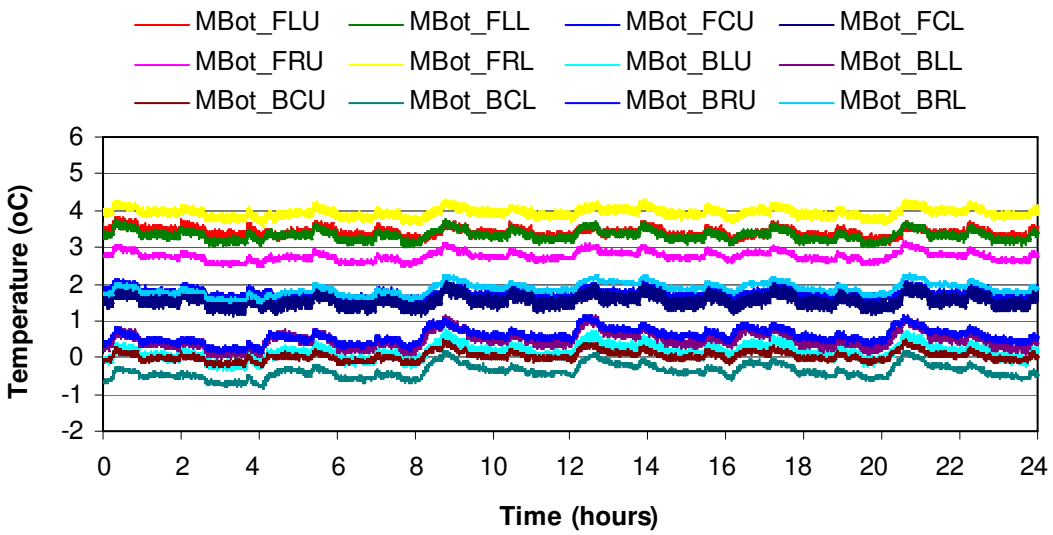


Figure-A.3: Time/temperature curves of the M-packages on the middle-bottom shelf

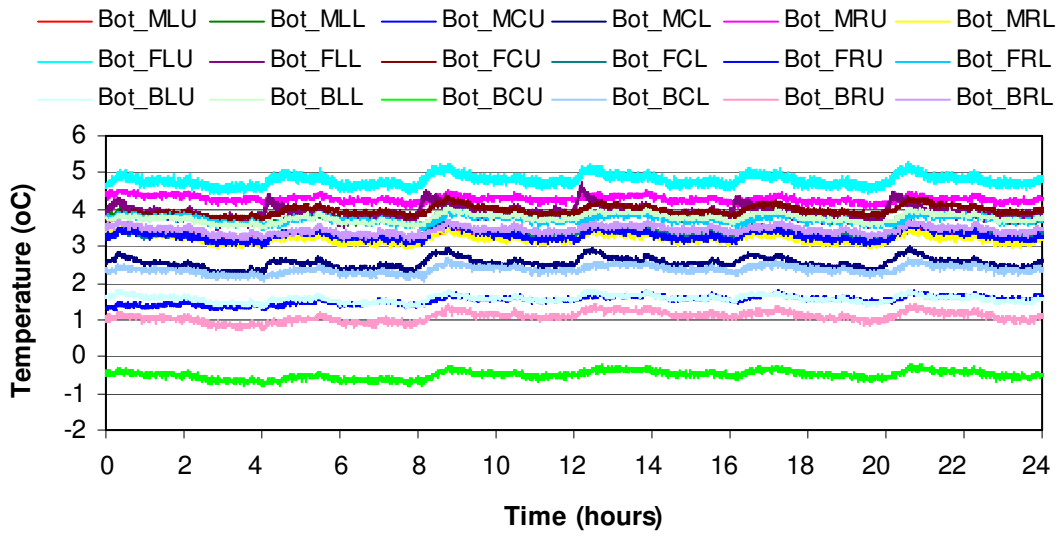


Figure-A.4: Time/temperature curves of the M-packages on the bottom deck

Legend for additional M-packages positions on the bottom deck:

MLU = middle left upper	MCU = middle centre upper	MRU = middle right upper
MLL = middle left lower	MCL = middle centre lower	MRL = middle right lower

Air cross flow in the test room was from right to the left of the cabinet

2. Time/temperature curve of M-packages on the individual shelf of the Test-2a

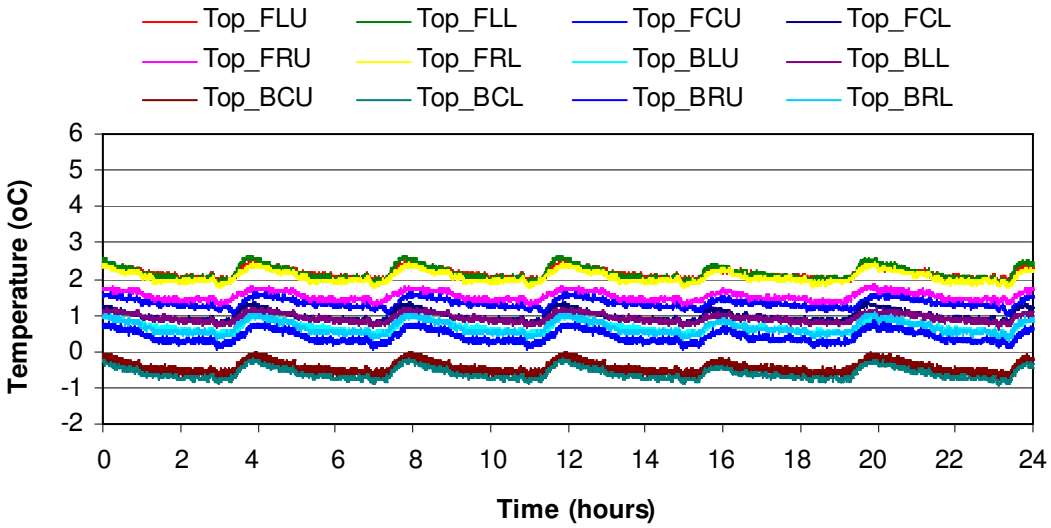


Figure-A.5: Time/temperature curves of the M-packages on the top shelf

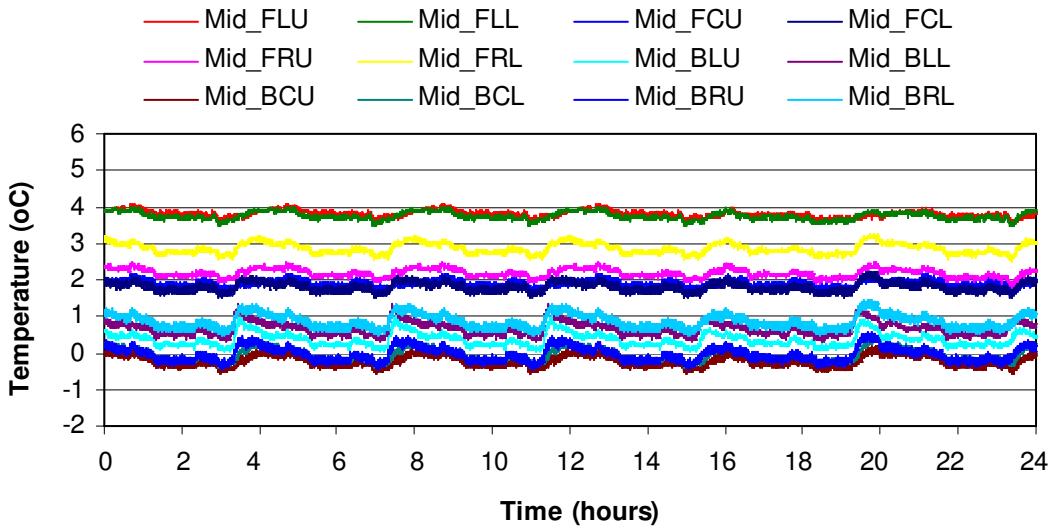


Figure-A.6: Time/temperature curves of the M-packages on the middle shelf

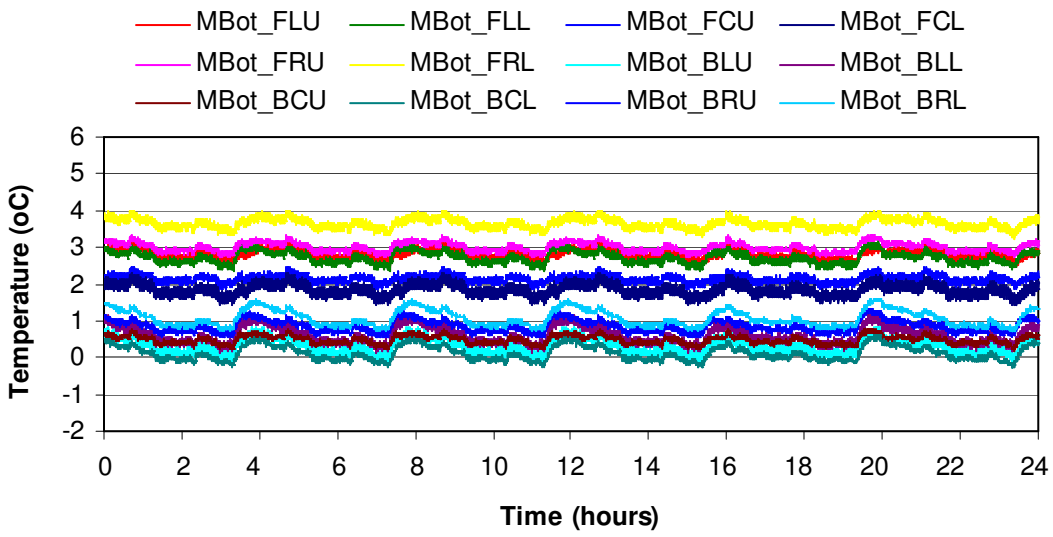


Figure-A.7: Time/temperature curves of the M-packages on the middle-bottom shelf

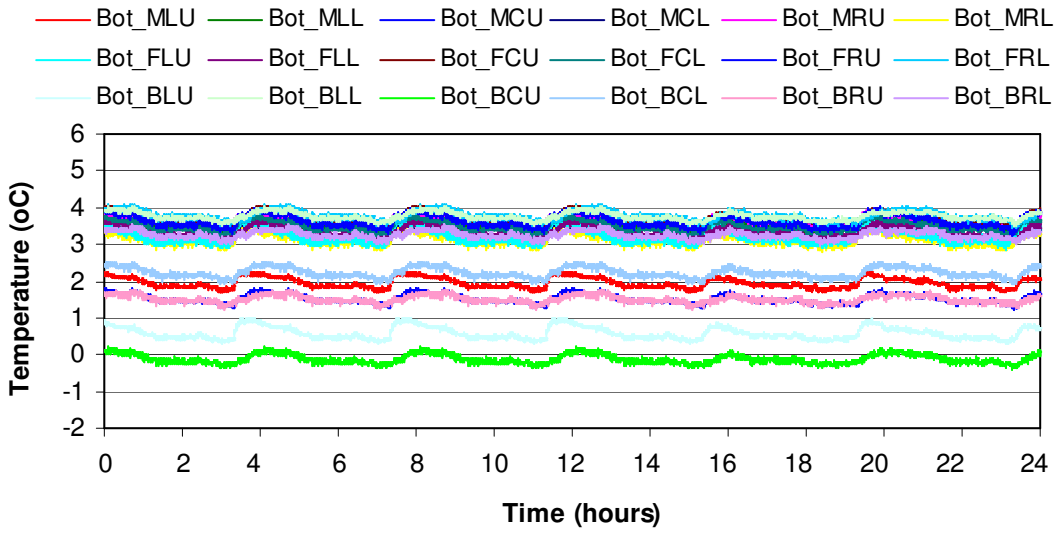


Figure-A.8: Time/temperature curves of the M-packages on the bottom deck

3. Time/temperature curve of M-packages on the individual shelf of the Test-3a

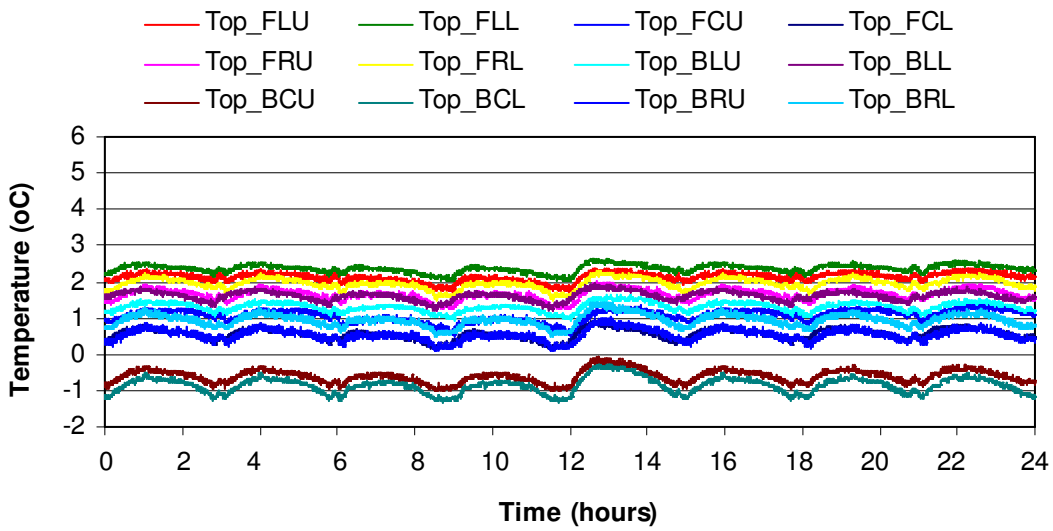


Figure-A.9: Time/temperature curves of the M-packages on the top shelf

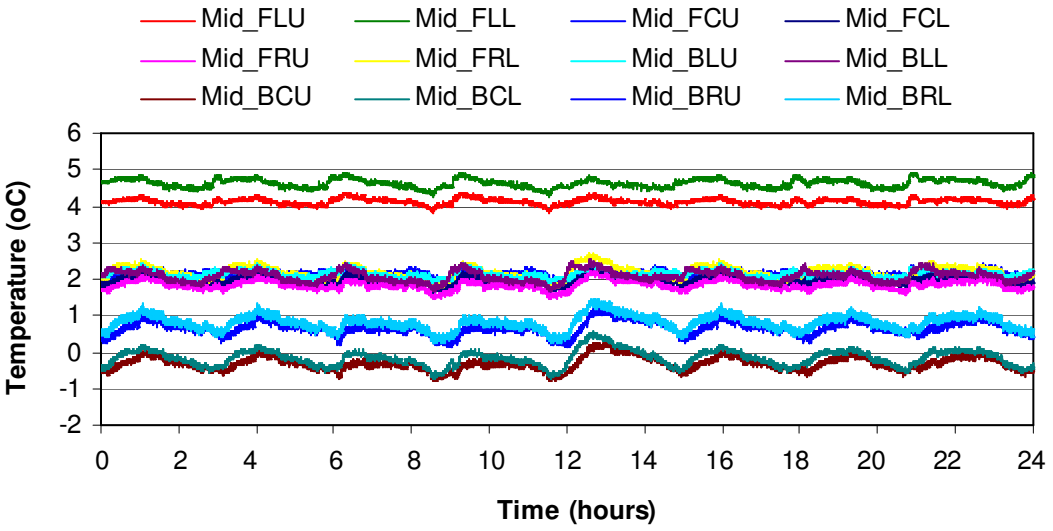


Figure-A.10: Time/temperature curves of the M-packages on the middle shelf

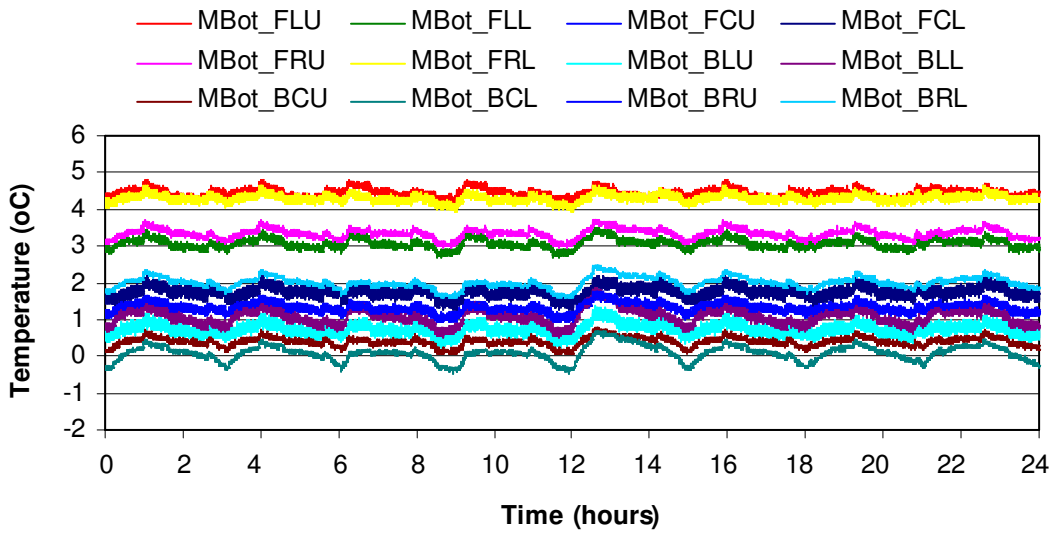


Figure-A.11: Time/temperature curves of the M-packages on the middle-bottom shelf

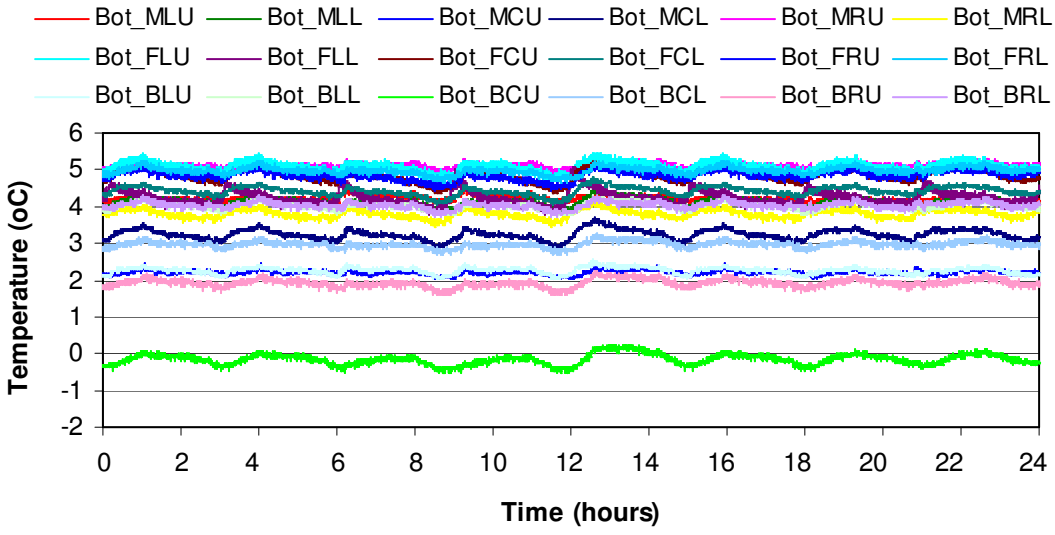


Figure-A.12: Time/temperature curves of the M-packages on the bottom deck

4. Time/temperature curve of M-packages on the individual shelf of the Test-4a

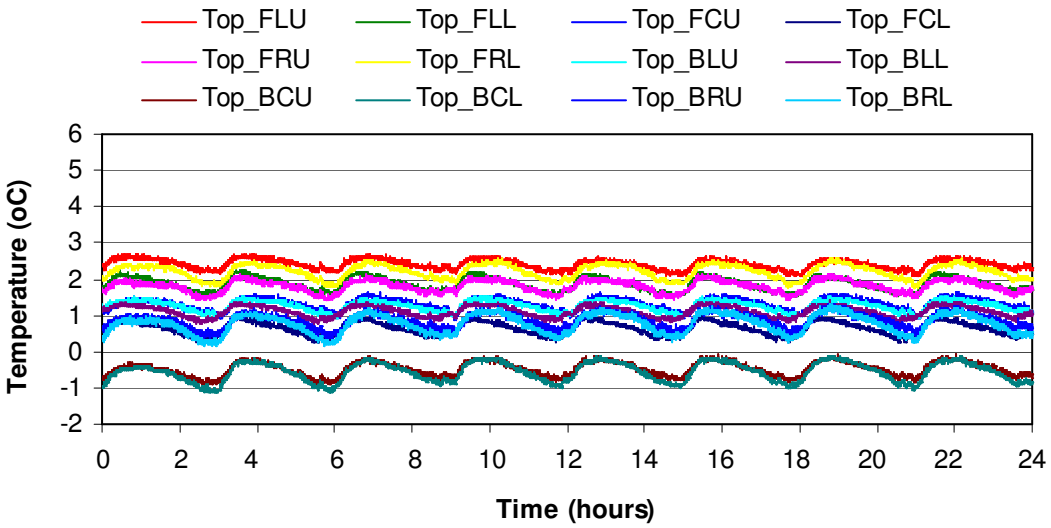


Figure-A.13: Time/temperature curves of the M-packages on the top shelf

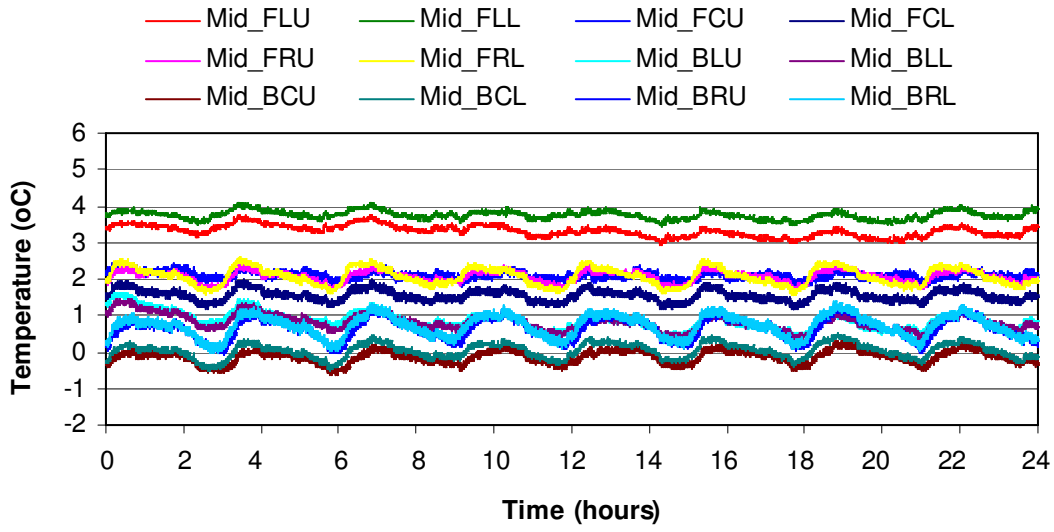


Figure-A.14: Time/temperature curves of the M-packages on the middle shelf

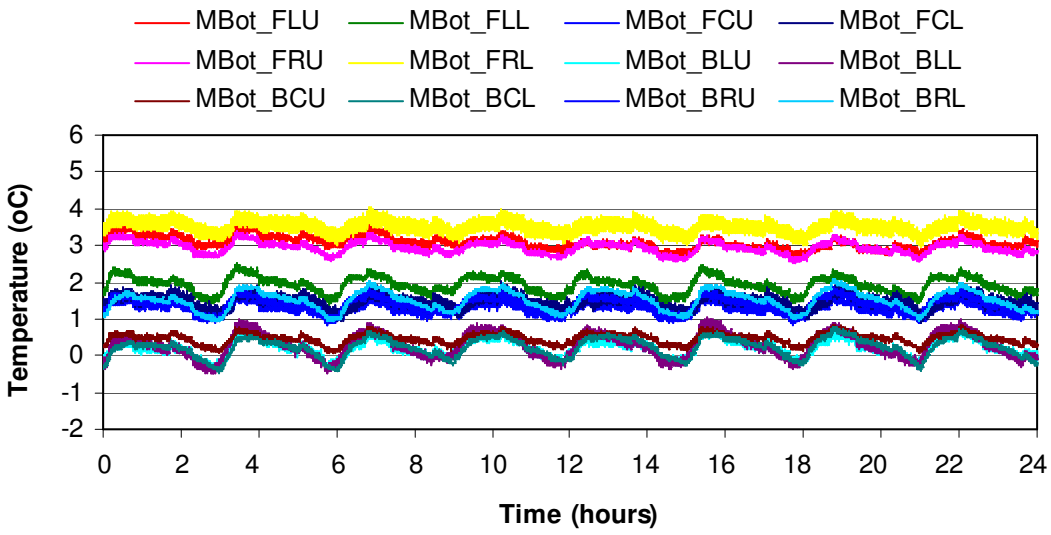


Figure-A.15: Time/temperature curves of the M-packages on the middle-bottom shelf

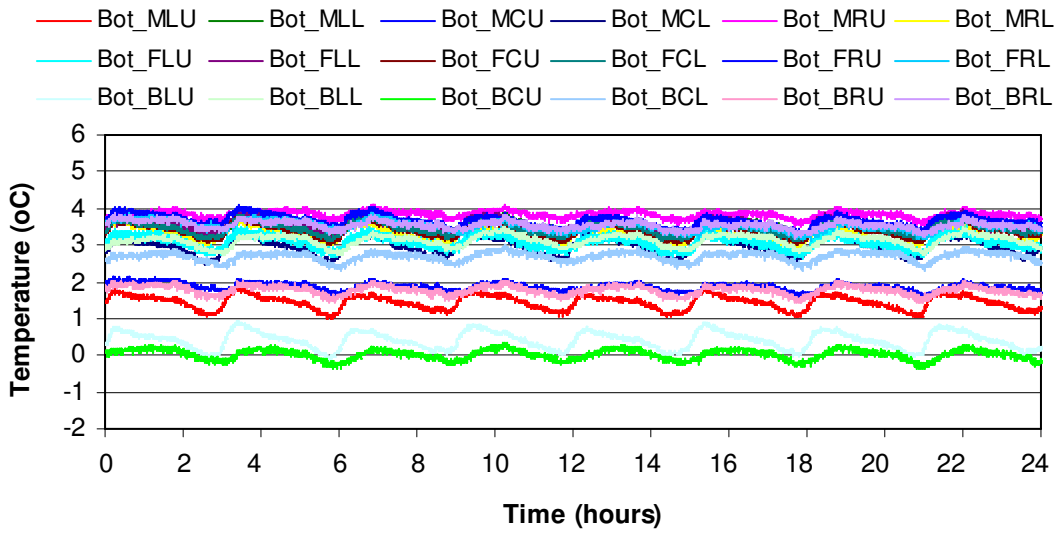


Figure-A.16: Time/temperature curves of the M-packages on the bottom deck