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IOP Conference Series: Materials Science and Engineering PAPER • OPEN ACCESS Experimental Study on the Influences of Air Flow in an Integral Hydrocarbon Display Cabinet to its Temperature and Energy Performances To cite this article: I N Suamir et al 2019 IOP Conf. Ser.: Mater. Sci. Eng. 494 012017 View the article online for updates and enhancements. This content was downloaded from IP address 180.249.116.232 on 31/03/2019 at 16:28 Experimental Study on the Influences of Air Flow in an Integral Hydrocarbon Display Cabinet to its Temperature and Energy Performances I N Suamir1,*, M E Arsana1, and K M Tsamos2 1Mechanical Engineering Department, Bali State Polytechnic, Bali, 80364, Indonesia 2Energy Efficient and Sustainable Technologies, Institute of Energy Futures, Brunel University, London, UB8 3PH, UK *Email: nyomansuamir@pnb.ac.id Abstract. This paper presents results on temperature energy performance tests of an integral refrigerated hydrocarbon (HC) display cabinet for retail food applications. Heat from the condensing unit of the cabinet is rejected to both ambient air and water/glycol mixture flowing in a closed water circuit. Air flow in the cabinet loaded with M-packages as test products was studied in order to analyze effects of air flow rate in the cabinet to its temperature and energy performances. The product and air temperatures as well as energy consumption of the cabinet were measured. The tests were conducted in a test chamber at climate class 3. It was found that the HC display cabinet with integral condensing unit was found to provide excellent energy

performance with an Energy Efficiency Index below the requirement to qualify for enhanced capital allowances. The refrigeration system of the cabinet could also achieve a COP of 3.15. The study also found that higher air flow rate in the cabinet could make the product temperatures a little bit better, but the energy consumption increased approximately 7% when air flow rate was increased from 1200 m3 h-1 to 1800 m3 h-1. Air flow distribution in the cabinet was necessary to be optimized in order to comply with M0 classification cabinet. 1. Introduction Vertical refrigerated display cabinets are commonly used in retailed food stores to ensure safety of the food products. These cabinets keep and display food for the customers at different levels of temperature within the retail stores. Various types of vertical refrigerated display cabinets can be found in retail stores including the stand-alone or centralized systems. Stand-alone units are self- contained refrigeration systems. For the centralized applications, the display cabinet evaporators in sales area are feed by the centralized refrigeration system which located in the machinery room. With regards to their opening, there are two types of vertical refrigerated display cabinets: open-type and door type. The open-type refrigerated display cabinets are widely used in retail stores to attract the costumers and increase the sales. The absence of any physical obstacle like a glass door between the customer and product display area is preferred for commercial reasons. The main advantage of the open type refrigerated display cabinets over the door type ones is to allow consumers free access to food [1]. Retail refrigeration systems using HFC refrigerants are responsible for substantial greenhouse gas emissions from leakage of refrigerant to the ambient and indirect emissions from the electrical power
used by the compressors, fans and other ancillary equipment [2]. One way to significantly reduce or completely eliminate direct emission is through the use of natural refrigerants, such as hydrocarbons, CO2 and ammonia [3]. Considerable research has been carried out on the development and application of retail refrigeration systems employing natural refrigerants. Most systems are either trans-critical booster CO2 systems, cascade all CO2 systems, or subcritical CO2 systems cascaded with a hydrocarbon system on the high pressure side for heat rejection [4-6]. An interesting approach also developed and applied by some retail chains involves the use of integral or stand-alone hydrocarbon display cabinets with heat rejection to the air in the retail [7] and combination of heat rejection to the air and water in a closed loop system [8]. The heat in the water circuit can be either upgraded through a boiler or heat pump and used for domestic hot water and/or space heating, or rejected to the ambient through a dry cooler. This approach can provide energy integration between the refrigeration and space conditioning systems in the store and offers the potential for energy savings if the system is appropriately designed and controlled. Another way to reduce greenhouse gas emissions from retail refrigeration systems is by improving their energy efficiency. Sun et al. [9] reported the use of guiding strips at front face of the shelves of the open-type vertical refrigerated display cabinets could improve temperature performance and energy efficiency. Cooling capacity required to maintain the food product chilled decreased by 34%. Investigations on energy efficiency of retail cabinets have also been reported in [10,11,12]. They reported the amount of warm air entering open-type display cabinet was due the turbulence intensity, shape of the mean velocity profile at the discharge air grill and the Reynolds number. Furthermore, experimental results on energy performance of refrigerated display cabinets have been presented by [13,14]. They compared different patterns on the rear duct panel to improve the air distribution as well as to reduce heat extraction rate of the display cabinet. The authors reported optimum air distribution that could reduce heat extraction rate was achieved when 67% of the total air circulation to be delivered from the rear panel and the remaining 33% from the air curtain of

the display cabinet. This paper presents results of experimental investigations carried out for the development of a 3.81 meter low front open multi-deck chilled food display cabinet with 37% back flow ratio. The results indicated that regulating air flow rate could not make an open-type display cabinet comply with the M0 classification of product temperature range from -1°C to +4°C as described in BS EN ISO 23953- 2 [15]. Further optimization on air flow distribution of the display cabinet would be required as discussed in [14]. 2. Cabinet Description, Test Conditions and Methods 2.1. Cabinet Description The cabinet tested was a vertical multi-deck display cabinet with compression type and built-in condensing units. The cabinet is a 3.81 m long low front cabinet originally designed for R-404A refrigerant. The height of the cabinet is 2.22 m and the depth 1.14 m. The cabinet has a Total Display Area (TDA) of 6.9 m2. The evaporator coil and circulation fans are located in the rear flow tunnel. In the conversion to an integral Hydrocarbon (HC) system, the condensing units are located at the top of the cabinet. The cabinet uses hydrocarbon (HC) refrigerant, R1270. The refrigerant is flammable and carries an A3 safety classification [16,17] which limits the concentration of the refrigerant in an occupied space, in the event of leakage, to below its lower flammability limit. To minimize the refrigerant charge in each refrigeration circuit, the cabinet was designed with two completely independent condensing units and evaporator coils. Each circuit was charged with 0.72 kg R1270. This charge is within the safety limit specified by [16]. 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. Heat rejection from the condensing unit takes place through two heat exchangers, an air cooled heat exchanger rejecting heat to the ambient air for direct retail food store space heating, and water cooled heat exchangers rejecting heat to water/glycol for centralized thermal energy management. A horizontal scroll compressor is used to keep the height of the condensing unit to the minimum. To facilitate testing and development in the laboratory, a water/glycol heat rejection system was developed which enables control of flow rate and temperature to the condensing units. A schematic diagram of the heat rejection system together with the refrigeration system of the cabinet is shown in Figure 1. Air cooled HX Water cooled HX Temperature T: 18oC AC Expansion 240 V tank ` 3 controller 2 ~ Capillary R404A chiller tube Compressor 4 1 V T Chilled fluid With integrated pump controller 5 V Evaporator Storage tank 100L with V Flow-meter 12 kW cooling coil and Ball valve Water cooled HX of Cooling fluid 6 kW electric heater Non-return valve 2nd circuit T pump Temperature sensor a) Cabinet refrigeration system b) Heat rejection system Figure 1. Schematic diagram of heat rejection system 2.2. Test Conditions The tests were carried out in a test room conforming to [15]. 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. 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 meter above floor level. Ambient conditions in the test room were tightly controlled by a proportional-differential 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. Mean horizontal air velocity (cross flow) was in the range between 0.1 and 0.2 m s -1. The room conditions were set to Climate Class 3 with dry bulb temperature of 25°C and 60% RH as shown in Figure 2. a) Test-1 Temperature RH b) Test-2 Temperature RH Temperature (°C) RH (%) Temperature (°C) RH (%) Time (hours) Time (hours) Figure 2. Room conditions (Temperature and RH) during the test 2.3. Methods The tests were performed according to [15] which comprised two tests: (i) Test-1 Cabinet with lower air flow rate (1200 m3 h-1); (ii) Test-2 Cabinet with higher air flow rate (1800 m3 h-1). Air flow in the cabinet is shown in Figure

3. The tested display cabinet had a original back panel from manufacturer with perforated ratio 1.25% and could provide back flow ratio of 37%. The remaining 63% of air flow was for the air curtain. Lower air flow Higher air flow Top shelf Mid. shelf Fans Evaporator coils Mid. bottom shelf Back flow Air flow Air flow 1200 m3/h 1800 m3/h Base deck Figure 3. Air flow in the cabinet applied for the tests In order to comply with the standard, two measurement systems were applied. The first one measured parameters of the refrigeration systems (pressure, temperature and mass flow rate of the cooling fluid), parameters of air, M-packages in the cabinet and parameters of the test room (temperature and RH). The measurement 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 flow meter (accuracy ±1%) and air velocity meter with accuracy 10%; data logging system (Labtech software and Datascan modules) and recording 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). 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 3. The positions of the sensors were placed in accordance with [15]. All measurements were recorded every 10s. This interval provided possibilities to check all temperature measurements at every 60s, mass flow rate and pressure measurements at every 20s as specified in [15]. Recorded data from the measurement systems were processed and analyzed. Performance parameters such as mean, the overall mean of the M-packages temperatures and energy consumption were calculated. M-packages represented foods that are being stored in the cabinet. EES (Engineering Equation Solver) software was applied to calculate refrigerant mass flow rate from the energy balance of the water-cooled condenser. The software 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 flow rate. Further calculations and graphs manipulation were processed by using spread sheet program. 3. Results and Discussion 3.1. Temperature Performance Temperature variation of the warmest and the coldest M-packages for Test -1 is presented in Figure 4a. 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. 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. Temperature of Products a) Test-1 b) Test-2 Warmest Coldest Arithmetic mean BWota_FrLmUest TCoop_ldBCeLst AOvreirathllmmeeatnic mean 7 ϴah = 5.2 °C 6 ϴah = 5.4 °C Temperature (°C) 5 4 ϴm = 1.7 °C 3 ϴm = 2.3 °C 2 1 ϴb = -1.5 °C TT ee m mppeerraattu urree((° oC C)) 0 ϴb = -1.3 °C -1 -2 0 7220 14440 21660 28880 361000 413220 510440 517660 614880 7200 729220 826440 Time (hours) TimTimee(hours) ϴah = highest temperature of warmest M-package ϴm = Overall mean temperature of M-packages ϴb = Lowest temperature of coldest M-packages Figure 4. Variation of the warmest, the coldest and the arithmetic mean temperature of M-packages for Test-1 and Test-2 Time based curve of the temperature of the warmest and the coldest M-packages for Test-2 is shown in Figure 4b. The highest temperature of the warmest M-package was +5.4°C and the lowest temperature of the coldest M-package was -1.3°C. The overall mean temperature of the all M- packages was found to be 2.3°C. Similar with the results of the Test-1, for 24-hour test some M- packages on the middle shelf and on the base deck laid above +4°C. In addition, some M-packages on the top shelf were below -1°C. Based on the temperature of the M-packages, results of the Test-1 and Test-2 indicated that the cabinet with lower and higher air flow rate could not comply with the standard for M0 classification cabinet. Further optimization on the air flow rate distribution inside the

cabinet would be required. 3.2. Energy Performance Total Energy Consumption (TEC) of the cabinet was calculated according to [15]. For the cabinet equipped with integral condensing unit, TEC equals to Direct Energy Calculation (DEC) which can be calculated from: n?Nmax TEC ? DEC ? ?Wn x ?t (kWh) (1) n ?1 Wn = instant power consumption of the cabinet (kW) over 24 hours (Wn = 0 during stopping and defrost time), Δt = period of measurement (h). Table 1. Operational time of the cabinet during the tests Operational time Test-1 Test-2 Compressor ON/OFF frequency in 24 (h) Running time trun (h) Defrost time tdeft (h) Stopping time tstop (h) Percentage of the running time trr (%) 27 21.4 1.0 1.6 93.0 1 21.8 2.0 0.17 99.2 Operational parameters of the both tests include compressor On and OFF frequency, running, defrost, stopping and percentage of running time is presented in Table 1. It can be seen that Test-1 with lower air flow rate, number of compressor switching ON and OFF due to thermostat setting is much higher than it is in Test-2. This indicated that the refrigeration system of the cabinet stopped in every 50 minutes which make any frost accumulated in the evaporator melt. Therefore for the cabinet with lower air flow rate, frost would not be a problem. Power consumption including total energy consumption (TEC) of the cabinet can be seen in Table 2. TEC of the cabinet was found to be 57.61 kWh.day-1 for Test-1 and 62.24 kWh.day-1 for Test-2. This results showed that the cabinet with lower air flow rate is more energy efficient compared to the cabinet with higher air flow rate. Table 2. Power consumption and TEC of the cabinet Power and Energy consumption Test-1 Test-2 Maximum power (kW) Minimum power (kW) Average power (kW) TEC (kWh.day-1) 3.00 1.52 2.69 57.61 2.99 1.50 2.85 62.24 The variation of instant power consumptions of the cabinet are shown in Figure 5a and 5b respectively for Test-1 and Test-2. From the figure can be seen compressor cycles in both tests. For Test-2 most of the compressor cycle due to defrost which was set in every 3 hours. This showed that higher air flow rate caused higher infiltration load and the system run continuously which could make problems with frost accumulation in the evaporator. a) Test-1 b) Test-2 Compressor power Overall power Compressor power Overall power Power (kW) Power (kW) Time (hours) Time (hours) Figure 5. Power consumption of the cabinet for Test-1 and Test-2 An ECA (Enhanced Capital Allowance) performance criterion of a refrigerated display cabinet is expressed as Energy Efficiency Index (EEI) which can be calculated from: EEI ? TDA TEC (kWh day-1 m-2) (2) The energy efficiency index of the cabinet and arithmetic mean coefficient of performance (COP) of the refrigeration systems of both tests are presented in Table 3. Table 3. EEI and COP of the cabinet Test-1 Test-2 Energy efficiency index (EEI) kWh day-1 m-2 8.28 8.95 Coefficient of performance (COP) 3.17 3.03 The EEI threshold for M0 classification cabinet with integral condensing unit is 12.50 (kWh.day-1.m-2) [18] The Energy Efficiency Index (EEI) of the cabinet at for lower air flow rate is found to be 8.28 kWh day-1m-2 and 8.95 kWh day-1m-2 the higher air flow rate. This EEI value is far below the enhanced capital allowances (ECA) threshold of 12.50 kWh day-1m-2 [18]. 4. Conclusions The HC cabinet with integral condensing unit was found to provide excellent energy performance with an Energy Efficiency Index below the requirement to qualify for enhanced capital allowances. The refrigeration system of the cabinet could also achieve a COP of 3.15 at climate class 3 conditions. Higher air flow rate in the cabinet could make the product temperatures a little bit better, but the energy consumption increased approximately 7% (from 58 kWh day-1 to 62 kWh day-1). Higher air flow rate caused higher infiltration load and the system run continuously which could make problems with frost. For the lower air flow rate frost was not a problem due to the system switching ON and OFF every 50 minutes. Total fans capacity from 1400 to 1500 m3 h-1 would be ideal for this cabinet. However, air flow distribution in the cabinet is necessary to be optimized in order to comply with M0 classification cabinet. 5. Acknowledgements The authors would like to acknowledge the technical and financial contributions of WR Refrigeration and Arneg SPA to the project. 6. References [1] Chen Y G and Yuan X L 2005 Experimental study of the performance of single-band air curtains for a

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