Mohammad Hamad Buhamadi, et. al. International Journal of Engineering Research and Applications
www.ijera.com
ISSN: 2248-9622, Vol. 11, Issue 2, (Series-V) February 2021, pp. 59-70

RESEARCH ARTICLE OPEN ACCESS

Effect of Refrigerant Types in Cooling Loads Calculations and Refrigeration Cycle Performance Used in a Cold Room Building Located in Kuwait

Eng. Mohammad Hamad Buhamadi
Eng. Abdullah Faisal Aldaijani

ABSTRACT:
In the present study, there is a cold room building in Kuwait that contains three cold rooms; two rooms are used to store union and one for watermelon. A cold room is used to store perishable goods such as meat and vegetables to slow down their deterioration and preserve them as fresh as possible for as long as possible. The studied heating loads that have to be considered in cold room are transmission, product, occupants, lighting, air change, and equipment or motor loads. Simple refrigeration cycle is designed with certain pressures, refrigerant capacity, and compressor power. The selected used refrigerants are ammonia R717, R22, and R134a. Coefficient of performance (COP) and the proper refrigerant capacity are calculated for each type. Finally, it is concluded that the proper refrigerant is R22 with total cooling capacity 152 Kw and 35 KW compressor power.
Key words: Heating loads, simple refrigeration cycle, R22 refrigerant, Ammonia R717, R134a refrigerant, refrigerant capacity, coefficient of performance, and compressor power.

Date of Submission: 13-02-2021 Date of Acceptance: 27-02-2021

I. INTRODUCTION

A cold rooms are designed and constructed in order to keep the goods such as chickens, meat, fruits and vegetables to decrease the deterioration and keep them as the fresh goods as long as possible. The heat generated in the storeroom can accelerate the good's deterioration so the goods have to be cooled by cooling in cold rooms. Heating loads have to be calculated to design the cooling load generated by the refrigerators. The cooling loads changes along the day depending on several factors. Most of harvested fruits and vegetables cannot be kept at normal temperature.

Cold storing rooms are the most suitable method to handle the goods between the production phase and market phase as shown in figure 1.1. Cold room design determine the suitable temperatures and relative humidity. Each product has to be kept in a certain temperature to keep it from deterioration; for example, onions has to be kept at zero, and watermelon has to be kept at 10 degree centigrade. Also, higher relative humidity is more favorable for long storing.

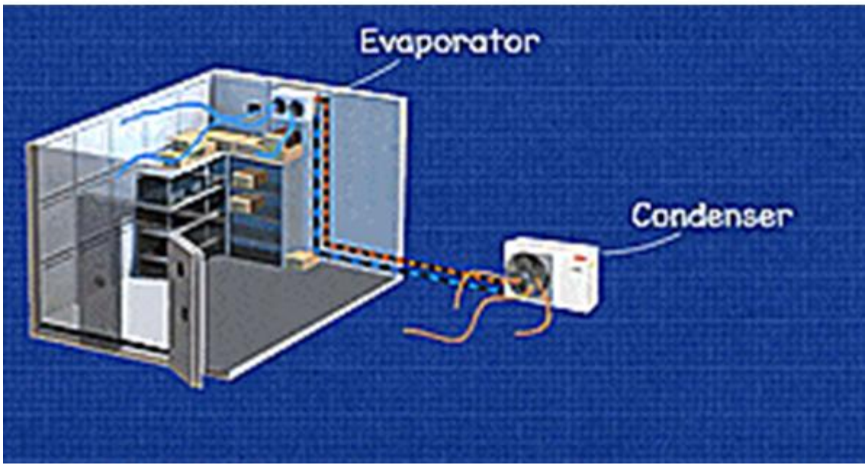

Figure I-1 Cold Storage Room.

Suitable postharvest cooling or freezing perform the following factors:

- Decrease the deterioration produced by enzymes.
- Decrease water loss by higher relative humidity in cold room
- Decrease the produced natural ripening.

In addition to keep the goods quality, postharvest cooling increase the flexibility for the seller to sell the product in the proper time. This cold rooms facilitate the growing process who supply the fruits and vegetables to restaurants in the highest possible quality. Cold rooms can add the carbon dioxide and dry the vegetables and fruits to maintain vitamin C.

There are some kinds of fruits or vegetables that cannot be stored with each other due to incompatibility.
For example, we can store apples with oranges but we cannot do with bananas. Apples are incompatible with the bananas. Hence, foodstuffs are devided in to three categories depending on the temperature

1. Most animal products (or) vegetable produce, not sensitive to cold (0-4°C) E.g. Apple, grape, carrot and onion.
2. Vegetable produce moderately sensitive to cold (4-8°C) E.g. Mango, orange, potato and tomato (ripened).
3. Vegetable produce sensitive to cold (>8°C) like watermelon and banana.

Generally, the refrigeration cycle is the primary content of the cold rooms. It contains four major components: the compressor, condenser, expansion device, and evaporator.
Cycle description starts with the compressor. The hot gas refrigerant is compressed through the compressor and pushed to the condenser coil. The condenser have a coil series the exposed to the worm air in the atmosphere to cool and condense the hot gas refrigerant to make it in liquid phase by releasing the heat energy inside the refrigerant. Heat transfer process is implemented at almost constant pressure and heat loss is latent heat “change in phase”.

Then, the hot liquid pass through the capillary tube throttle valve as an expansion device to decrease the pressure at constant enthalpy theoretically. Now, the refrigerant is a combination of cold liquid and vapor. In some refrigeration cycle; turbine is used as an expansion device in order to decrease the pressure at constant entropy and increase the evaporator cooling capacity. Finally, the combined phase refrigerant passes through the evaporator that has the a similar series coils of the condenser. Warm air draws across the evaporator as cold refrigerant moves through the coils. The low-pressure liquid refrigerant cools the warm air blown across it through heat transfer and heads back to the compressor. The cycle is ready to begin again as shown in figure 1.2.

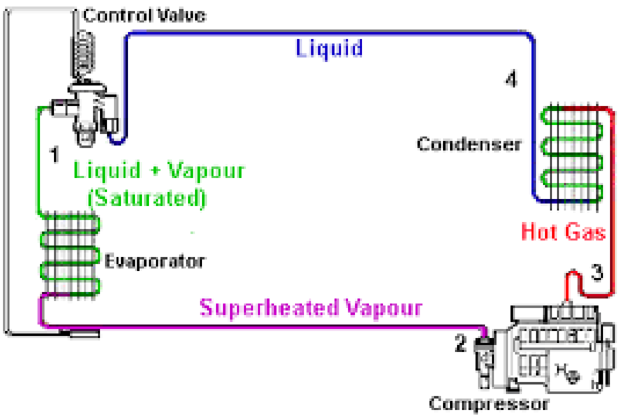

Figure I-2 Refrigeration cycle loop

It is required to design a simple refrigeration cycle with the previous principle of operation and select the proper refrigerant type and capacity to have the highest possible coefficient of performance in cold room located in Kuwait city that used in union and watermelon storage.

II. MATERIAL AND METHODS

2.1. Cold Rooms Description

There are three cold rooms that are located in Kuwait. It is used to cool and store onion and watermelon. Two cold rooms are used for onion storage with dimension (Length = 25m, Width = 13m, and

Height = 4m). In addition to one cold room is used room for watermelon storage with the same dimension of onion rooms.

The rooms; back and front walls in addition to roof are exposed directly to sun light along the day. There are two workers who are working in product handling area. The cold room building plan view is shown in figure 2.1 as below.

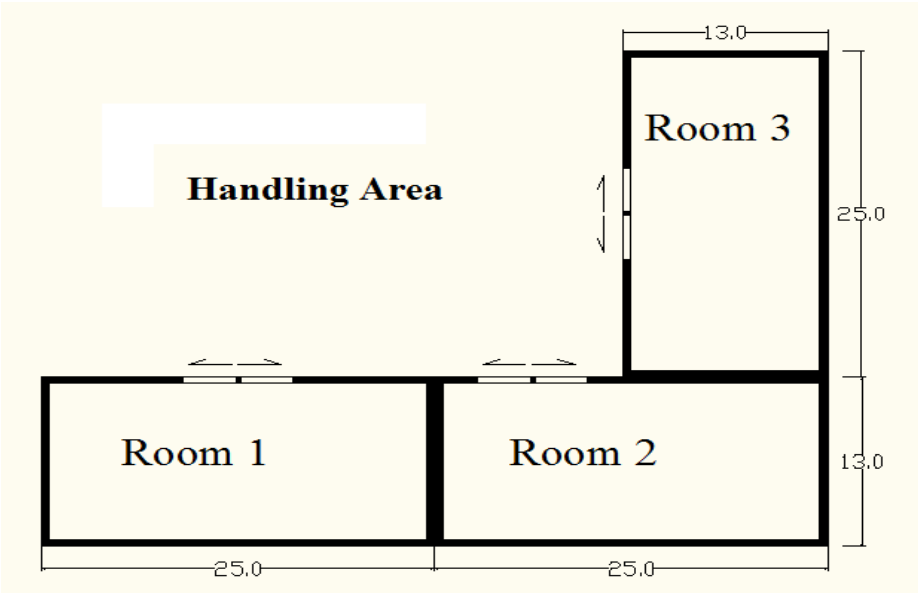

Figure 2-1 Cold Storage Description.

2.2. Designation of refrigeration cycle for cold rooms

A simple refrigeration cycle is designed which include the following parts:

- Low pressure compressor (compressor#1)
- High pressure compressors(compressor#2)
- Condenser
- Expansion device
- Onion evaporator 1, 2
- Watermelon evaporator 3

The liquid phase refrigerants enter the three evaporators to cool the product at different pressures. Hence, it is boiled and vaporize at the compressor inlet. Two compressors are used to compress the refrigerant to the condenser that cool the refrigerant once again to its hot liquid condition. Finally, the expansion devices decrease its pressure to extract the heat from the product through the evaporator.

There are two different refrigerant mass flow rate in the cycle shown in figure 2.2. The first one is M1 that used to cool room 1 and room 2. M1 is devided into two similar streams enter to each evaporator of onion cold rom. On the other hand, M2 is used to cool room 3. The total refrigerant mass flow rate are the sum of M1, M2.

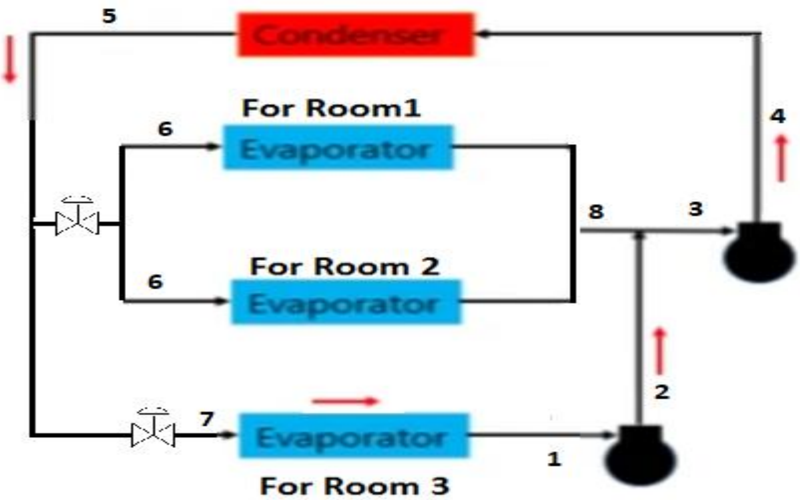

Figure 2-2 Refrigeration Cycle Diagram

Each refrigerant type has its p-h chart with its characteristics such as enthalpy, entropy, and pressure. The cycle is presented in ph- chart as below:

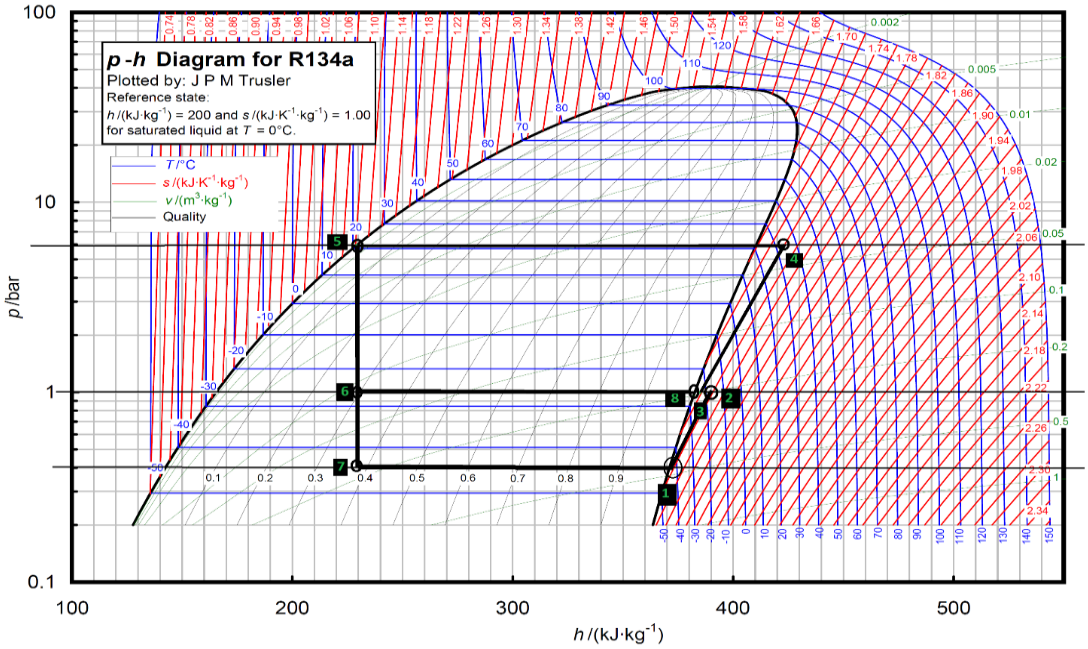

Figure 2-3 Refrigeration Cycle on p-h chart

2.3. Heating Loads Calculations

Rooms will be discussed separately. For each room; all the following loads are calculated as a heating loads to be removed by the refrigeration cycle. The loads are shown in figure 2.4 and indicated as below:

1. Transmission load (the load produced from temperature difference between the outside and required temperatures)
2. Product load (the load that produced from the storage vegetables or fruits)
3. Occupants load (the load produced from the workers themselves during working inside)
4. Lighting load (the load produced from the lighting intensity)
5. Air change load (the load produced from the bad insulation of the windows and doors)
6. Motor load (the load produced from the refrigerators machines)

Figure II-4 Heating loads acting on the cold room walls, roof, and floor

2.3.1. Study of Room 1 (onion)

The following parameters are considered in the cooling loads calculations:

- Onion storage temperature is 1°C (Tin = 1°C)
- Maximum Kuwait atmospheric temperature in summer is 50°C (Tout = 50°C)
- The ground temperature is 20°C.
- Bricks are used in construction with the following specifications; thickness 0.32m and k=0.15 W/m.K
- Roof and floor are all insulated with 70mm polyurethane k=0.07 W/m.C
- The mass of the stored onion can be calculated by equation 2.1. as below

Mass (Kg) = Density (Kg/m3) x Volume (m3) ------ (2.1)

Knowing that the onion density is 1250 Kg/m3 and the onion volume is equivalent to 75% of the room volume. Hence;

$$\mathbf{M_{onion} = 1250 \times 25 \times 13 \times 4 \times 0.75 = 1200\ Ton}$$

a. Transmission load

The transmission load is calculated from equation 2.2 as below:

Q = U x A x (Temp out – Temp in) ÷ 1000 ------- (2.2)

- Q= kWh/day heat load
- U = Overhaul heat transfer coefficient (W/m2.K)
- A = surface area of walls roof and floor (m2)
- Temp in = The air temperature inside the room (°C)
- Temp out = The ambient or outside air temperature (°C)

Area of each wall, roof and floor.

- Side 1 = 13m x 4m = 52m^2
- Side 2 = 13m x 4m = 52m^2
- Side 3 = 25m x 4m = 100m^2
- Side 4 = 25m x 4m = 100m^2
- Roof = 25m x 13m = 325m^2
- Floor = 25m x 13m = 325m^2

Total area without floor is 629 m^2 without the floor.

The overhaul heat transfer coefficient is calculated from equation 2.3 as below:

$$U=1 \div \left(\frac{1}{ho}+\frac{Xbreak}{kbreak}+\frac{Xins}{Kins}+\frac{1}{hi}\right) \text{ ---- (2.3)}$$

Where:

- hi: convection heat transfer coefficient for the air inside the cold room (2 W/m^2 C)

- ho: convection heat transfer coefficient for the air outside the cold room (10 W/m^2 C)
- X: thickness of brick or insulation (m)
- K: Convection heat transfer coefficient (W/m C)

From equation 2.3; the overhaul heat transfer coefficient is (U=0.27 W/m2.C)
With Substitution in equation 2.2; the transmission load from walls and roof is:

$$Q_{t\ walls} = 8.32\ KW$$

Floor

The transmission load from the floor is calculated from equation 2.2 as below:
Q = 0.27 x (25 x 13) x (20-1)

$$Q_{t\ floor} = 1.7\ KW$$

$$\mathbf{Q_{total\ trans.} = 10\ Kw}$$

b. Product load

There are 10% of new onions that arrive each day at a temperature of 25°C and a specific heat capacity of 3.77 Kj/Kg. C. The product load is calculated from equation 2.4 as below:

Q = m x Cp x (Temp enter – Temp store) / (3600) ------ (2.4)

$$\mathbf{Q_p = 12\ KWh}$$

c. Occupants load

There are 2 workers who are working in the store for 4 hours a day. 278 Watts of heat per hour inside. The occupant load is calculated from equation 2.5 as below:

Q = people x time x heat / 1000 ------ (2.5)

$$\mathbf{Q_o = 2.2\ KWh/day}$$

d. Lighting load

Four Lamps are used for 4 hours per day. Power of each is 100 watt. The Heat generated by the lighting is calculated from equation 2.6 as below

Q= lamps x time x wattage / 1000 ----- (2.6)

$$\mathbf{Q_L = 1.6kWh/day}$$

e. Air change load

Due to windows and doors infiltration; there are 5 volume air changes per day that circulated from outside to inside. Each cubic meter of new air provides 2kJ/°C heat generated inside the cold room. Equation 2.7 formulate the air change heating load as below:

Q = changes x volume x energy x (Temp out – Temp in) / 3600 ------ (2.7)

$$\mathbf{Q_a = 7.4\ kWh/day}$$

f. Motor load

Equipment or fan motor load describe the heating loads that produced from the evaporator fan. Equation 2.8 describe the heat load calculation.

Q =fan power x running time per day ------ (2.8)

In the cold room; 300 watt fan is running for 14 hours per day. So, with substitution in equation 2.8; the heat load is:

$$\mathbf{Q_m = 4.2\ KWh/day}$$

Total Load Calculation in Room#1

Total heating load n room #1 is calculated from equation 2.9 as below:
$Q = Q_t + Q_p + Q_o + Q_L + Q_a + Q_m$

Total Heat Load in Room # 1 = 37.4 KW

2.3.2. Study of Room 2 (onion)

Room #1 is identical to room #2 regarding to the area and the applied heating load. Hence,

Total Heat Load in Room # 2 = 37.4 KW

2.3.3. Study of Room 3 (Watermelon)

The following parameters are considered in the cooling loads calculations for watermelon room:

- Watermelon storage temperature is 10°C (Tin = 10°C)
- All other parameters are the same for onion cold room.
- The mass of the stored watermelon can be calculated by equation 2.1.

Knowing that the watermelon density is 960 Kg/m3 and the volume is equivalent to 60% of the room volume. Hence;

$$\mathbf{M_{watermelon} = 960\ x\ (25\ x\ 13\ x\ 4)\ x\ 0.6 = 750\ Ton}$$

a. Transmission load

The transmission load is calculated from equation 2.2 and 2.3 as discussed before. From equation 2.3; the overhaul heat transfer coefficient is (U=0.27 W/m2.C)

With Substitution in equation 2.2 for watermelon; the transmission load from walls and roof is:
Q = 0.27 x 629 x (50-10)

$$\mathbf{Q_{t\ walls} = 6.8\ KW}$$

Floor

The transmission load from the floor is calculated from equation 2.2 as below:
Q = 0.27 x (25 x 13) x (20-10)

$$\mathbf{Q_{t\ floor} = 0.8\ KW}$$
$$\mathbf{Q_{total\ trans.} = 7.6\ Kw}$$

b. Product load

There are 10% of new watermelons that arrive each day at a temperature of 25°C and a specific heat capacity of 3.94 Kj/Kg. C. The product load is calculated from equation 2.4 as below:

Q = m x Cp x (Temp enter – Temp store) / (24*3600) ------ (2.4)

$$\mathbf{Q_p = 4.7\ KWh}$$

c. Occupants, Lighting, Motor loads

Occupants, lighting, and motor loads in watermelon cold room 3 are equivalent to room 1 and 2 as below:

$$\mathbf{Q_L = 1.6 kWh/day}$$
$$\mathbf{Q_m = 4.2\ KWh/day}$$
$$\mathbf{Q_o = 2.2\ KWh/day}$$

d. Air change load

Due to windows and doors infiltration; there are 5 volume air changes per day that circulated from outside to inside. Each cubic meter of new air provides 2kJ/°C heat generated inside the cold room. From equation 2.7; the air change load is as below

$$\mathbf{Q_a = 6\ kWh/day}$$

Total Load Calculation in Room#3

Total heating load in room #3 is calculated from equation 2.9 as below:
$Q = Q_t + Q_p + Q_o + Q_L + Q_a + Q_m$

Total Heat Load at room#3 = 26.3 KW

2.4. Cooling Loads Calculations

It is recommended to take factor of safety in the calculation to be more conservative for any cold room disturbance. The selected factor of safety if 1.5.
Heating loads are recorded in table 2.1 for each room as below:

Table 3-1 Loads calculated on each room

Room	Heating Load	Designed Cooling loads	To	Ti
Room1	37.4 KW	56 KW	50°C	1°C
Room2	37.4 KW	56 KW	50°C	1°C
Room3	26.3 KW	40 KW	50°C	10°C

III. RESULTS AND DISCUSSION

It is designed to operate at 0.7 bar, 2bar, and 7 bar as low, medium, and high pressure for all types of selected refrigerant. Refrigerant mass flow rate is calculated in each room evaporator. Then, coefficient of performance will be calculated and compared to select the most proper refrigerant with highest coefficient of performance.
The schematic cycle diagram is represented in figure 3.1.

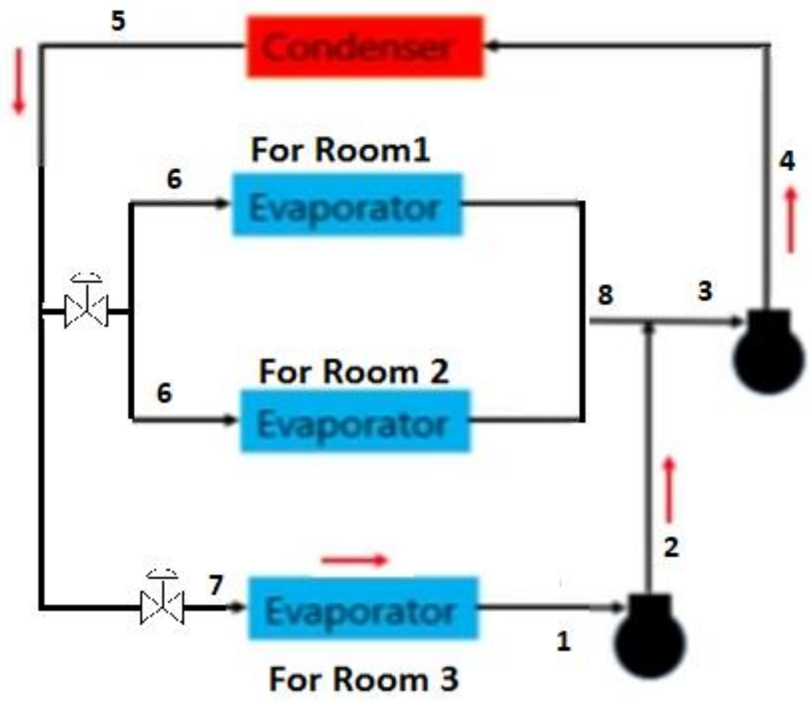

Figure 3.1. Schematic diagram cold room

The refrigerant mass flow rate contains $M_{ref\ 1}$ that circulate in room 1 and room 2, while $M_{ref\ 2}$ circulates in room3. Total mass flow rate of refrigerant M_{ref} is $M_{ref\ 1} + M_{ref\ 2}$.
Onion evaporator cooling capacity in room 1 and 2 is calculated from equation 3.1 and 3.2 as below:

$$\mathbf{Q_{eo} = M_{ref1}\,(h_1 - h_7)} \qquad \text{------ (3.1)}$$

$$\mathbf{Q_{ew} = M_{ref\ 2}\,(h_8 - h_7)} \qquad \text{------ (3.2)}$$

Compressors power are calculated from equation 3.3 and 3.4 as below:

$$\mathbf{P_o = (M_{ref\ 1} + M_{ref\ 2})\ (h_4 - h_3)} \qquad \text{------ (3.3)}$$

$$\mathbf{P_w = M_{ref\ 2}\,(h_2 - h_1)} \qquad \text{------ (3.4)}$$

Where: Q: the cooling duty produced from the evaporator (KW)
M_{ref}: Refrigerant mass flow rate (Kg/sec)
P: compressor power (Kw)
h: enthalpy (KJ/Kg)

3.1. Cycle on Ammonia

The ammonia refrigerator p-h chart is represented as shown in figure 3.2.

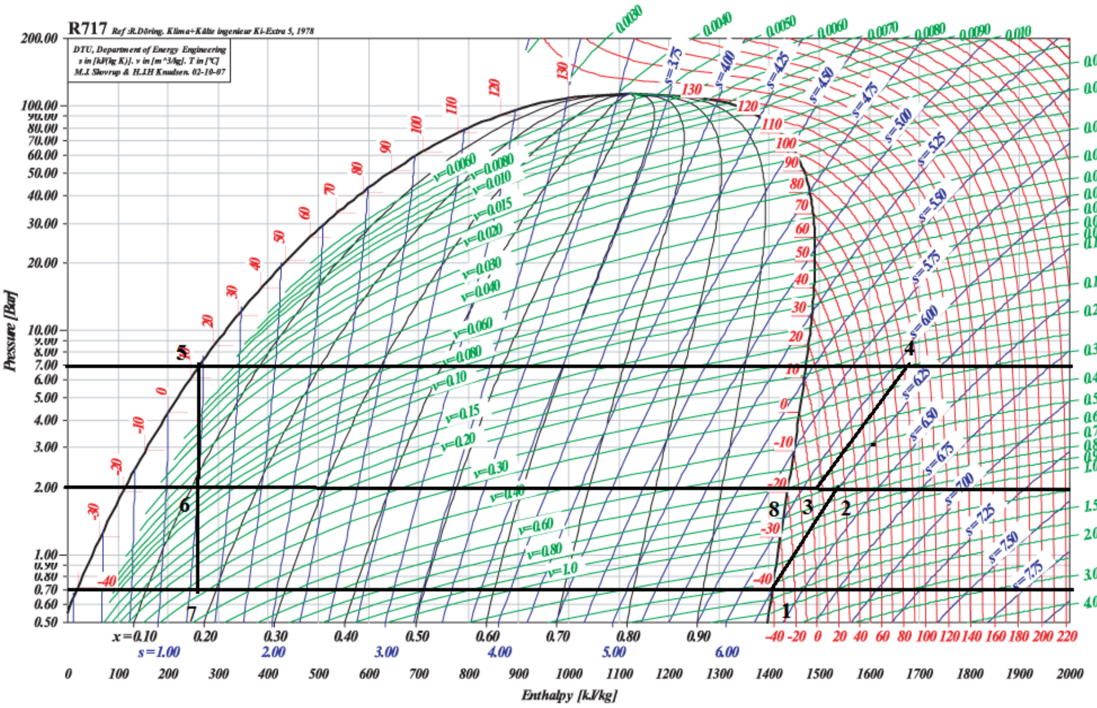

Figure 3.2. Cycle on P-h chart for Ammonia refrigerant

3.2. Cycle on R22

R22 refrigerator p-h chart is represented as shown in figure 3.3.

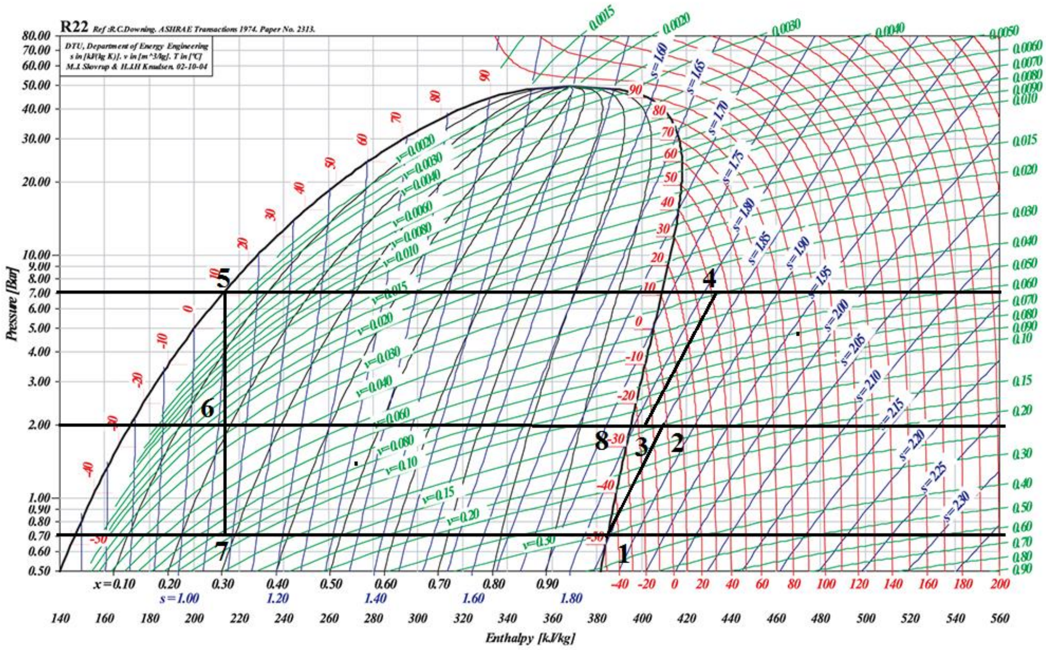

Figure 3.3. Cycle on P-h chart for R22 refrigerant

3.3. Cycle on R134a

R134a refrigerator p-h chart is represented as shown in figure 3.4.

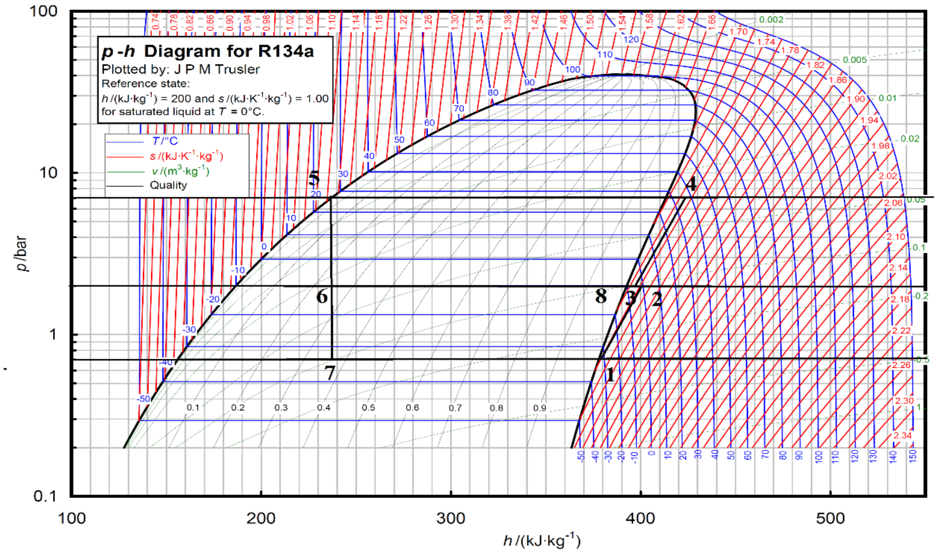

Figure 3.4. Cycle on P-h chart for R134a refrigerant

All enthalpy values are obtained from p-h chart and recorded in table 3.2 for all refrigerant types. From equations 3.1, 3.2, 3.3 and 3.4; refrigerants mass flow rate and consumed power are calculated and recorded in table 3.3.

Table 3-2 Enthalpy values for each refrigerant

Enthalpy (Kj/Kg)	Ammonia Refrigerant	R22	R134a
h1	1400	385	380
h2	1580	410	400
h3	1500	405	398
h4	1700	435	428
h5	260	210	240
h6	260	210	240
h7	260	210	240
h8	1450	395	395

Table 3-3 Refrigerant mass flow rate and compressor power

Parameters	Ammonia Refrigerant	R22	R134a
Mref1 (Kg/sec)	0.10	0.64	0.80
Mref2 (Kg/sec)	0.03	0.22	0.26
Compressor power 1 (Kw)	26.4	25.7	31.7

Compressor power 2 (Kw)	6.0	5.4	5.2

The cycle coefficient of performance is calculated from equation 3.5 as below

$$\textbf{COP} = \frac{Cooling\ Capacity\ (Kw)}{Total\ Compressor\ Power\ (Kw)} \qquad \textbf{------ (3.5)}$$

COP is calculated and recorded in table 3.4 for each type of refrigerant.

Table 3-4 Refrigerant COP

Parameters	**Ammonia Refrigerant**	**R22**	**R134a**
Total Compressor power (Kw)	32.42	31.1	36.9
Total cooling load (Kw)	152	152	152
Coefficient of Performance	4.68	4.88	4.12

The highest coefficient of performance is the most proper refrigerant due to low power consumption with the same cooling loads for watermelon and onions.

Hence, the most proper and selected refrigerant is R22 for cold rooms application located on Kuwait city. So, there is a significant effect of the refrigerant type on the compressor power and refrigeration cycle performance.

IV. CONCLUSION

A cold room is used to store perishable goods such as meat and vegetables to slow down their deterioration and preserve them as fresh as possible for as long as possible. Heat accelerates their deterioration so the products are cooled down by removing the heat. To remove the heat we need to know what the cooling load will be.

It is planned to design a three cold rooms in Kuwait city to store onion in two rooms and watermelon in one room. The room's area are equal. Onion has to be stored in 1°C while the watermelon has to be stored at 10°C. Maximum ambient temperature in Kuwait reaches to 50°C. All heating loads are calculated for each room such as transmission, occupation, motor, product, ventilation, and lighting loads.

Total heating loads were calculated with 1.5 factor of safety and recorded 56 Kw for each onion's room and 40 Kw for watermelon's room. For each refrigerant types; ammonia, R22, or R134a; it was designed to operate at 0.7 bar, 2bar, and 7 bar as low, medium, and high pressure. Refrigerant mass flow rate, consumed power, and coefficient of performance were calculated for each room.

The highest coefficient of performance is the most proper refrigerant due to low power consumption with the same cooling loads for watermelon and onions. Hence, the most proper and selected refrigerant is R22 for cold rooms application located on Kuwait city. Consequently, it was proven that there is a significant effect of the refrigerant type on the compressor power and refrigeration cycle performance

REFERENCES

[1]. Harmati N, Jakšić Z, Vatin N. 2015 Energy consumption modelling via heat balance method for energy performance of a building. Procedia Eng vol. 117 pp. 79–90. doi:10.1016/j.proeng.2015.08.238.

[2]. Harmathy N, Kontra J, Murgul V, Magyar Z. 2018 Energy Performance Simulation and Evaluation of Various Construction Types for a Residential Building (International ODOO Project) vol. 692 pp. 63–76. doi:10.1007/978-3-319-70987-1_60.

[3]. Vatin N, Gamayunova O, Nemova D. 2014 An energy audit of kindergartens to improve their energy efficiency. Adv Civ Eng Build Mater IV - Sel Peer Rev Pap from 2014 4th Int Conf Civ Eng Build Mater CEBM vol. 305 p. 8.

[4]. Tarasova DS, Petritchenko MR. 2017 Buildings quasi-stationary thermal behavior. Mag Civ Eng vol. 72 pp. 28–35. doi:10.18720/MCE.72.4.

[5]. Gorshkov A, Vatin N, Nemova D, Shabaldin A, Melnikova L, Kirill P. 2015 Using life-cycle analysis to assess energy

savings delivered by building insulation. vol. 117 p. 85–94. doi:10.1016/j.proeng.2015.08.240.

[6]. Tanic M, Stankovic D, Nikolic V, Nikolic M, Kostic D, Milojkovic A, et al. 2015 Reducing energy consumption by optimizing thermal losses and measures of energy recovery in preschools. Procedia Eng vol. 117 vol. 24–37. doi:10.1016/j.proeng.2015.08.179.

[7]. Murgul V. 2016 Methodology to Improve Energy Efficiency of Residential Historic Buildings in St. Petersburg. MATEC Web Conf., vol. 53. doi:10.1051/matecconf/20165301046.

[8]. Castro JCL, Zaborova DD, Musorina TA, Arkhipov IE. 2017 Indoor environment of a building under the conditions of tropical climate. Mag Civ Eng vol. 76 pp. 5–7. doi:10.18720/MCE.76.5.

[9]. Nefedova A, Chernyshev D, Tseytin D. 2015 Multi-comfort school analysis. vol. 117 p. 1112–9. doi:10.1016/j.proeng.2015.08.243.

[10]. ASHRAE. Chapter 18. 2009 Nonresidential cooling and heating load calculations. ASHRAE Handb. Fundam., p. 52.

[11]. Kreider JF, Curtiss PS, Rabl A. 2010 Heating and cooling of buildings: design for efficiency. (Rev. 2nd ed.). CRC Press.

[12]. Spitler JD, Fisher DE, 1997 Pedersen CO. Radiant time series cooling load calculation procedure. ASHRAE Trans., vol. 103 p. 503–15.

[13]. Mitalas GP. 1972 TRANSFER FUNCTION METHOD OF CALCULATING COOLING LOADS, HEAT EXTRACTION & SPACE TEMPERATURE. ASHRAE J vol. 14 pp. 4–6.

[14]. Feng J, Bauman F, Schiavon S. 2014 Experimental comparison of zone cooling load between radiant and air systems. Energy Build; vol. 84 pp. 2–9. doi:10.1016/j.enbuild.2014.07.080.