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Design and Analysis of Vertical Evaporator Refrigerator without Freezer Compartment

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ABSTRACT

The aim of this paper is to design analysis of Regular 190L household direct cool vertical evaporator refrigerator with refrigerant 134a. In this household refrigerator. The usable cabinet space is improved by 25~30 % with roll bond vertical evaporator by instead of conventional c or o type roll bond evaporator. This improvement in usable space is based on the volume of existing evaporator ie. freezer section of house hold a direct cool refrigerator. The design finalization of cooling circuit and internal volume of the vertical evaporator is done based on 43° no load pull-down test and 32°C energy test. Based on 43°C pull-down test, freezer section becomes warmer by approximately 9°C~12°C so it can be considered as a refrigerator without a freezer compartment. A further extension this vertical evaporator, one perforated cover is added to this bare roll bond panel of vertical evaporator from customer safety and aesthetic point of view and this vertical evaporator refrigerator with 1 perforated cover then compared with baseline refrigerator. The energy improvement found with vertical evaporator refrigerator with 1 perforated cover when compared to baseline refrigerator is 9~10 %.

Keywords: Vertical Evaporator, Roll Bond Evaporator, Direct Cool Refrigerator, R134a.

1. INTRODUCTION

The usable cabinet space of household direct cool refrigerator is improved by use of roll bond vertical evaporator instead of conventional c or o type roll bond evaporator.

This usable space decided based on the volume of existing evaporator i.e. freezer compartment and refrigerator compartment however in this project freezer compartment is converted into the refrigerator compartment.

In this project for R190L refrigerator 3 cooling circuits based on their internal volumes 120CC, 140CC & 170CC are designed and analyzed. The energy improvement found in R190L 170CC vertical evaporator refrigerator is 3~6 % compared to its 120CC & 140CC vertical evaporator refrigerators, so based on 43°C NLPD and 32°C energy tests 170CC internal volume circuit is considered as a final cooling circuit.

As per Bureau of energy efficiency (BEE) guidelines, in 43°C NLPD test freezer compartment temperature should be colder than -8°C temperature, which is not reaching in case of vertical evaporator refrigerator so it can be registered under 'refrigerator without freezer compartment' category.

Further perforated sheets are added to cover bare roll bond panel ie evaporator, in which 170CC cooling circuit with 1 perforated cover found the most energy efficient. Then comparative 43°C NLPD and 32°C energy tests are done on baseline R190L refrigerator and R190L 170CC cooling circuit with 1 perforated cover ie vertical evaporator refrigerator. The energy improvement found in vertical evaporator refrigerator is 9~10 % compared to baseline refrigerator.

2. LITERATURE REVIEW

A first-principles mathematical model developed to investigate the thermal behavior of a plate-type, roll-bond evaporator by Christian J. L Hermesa, et.al [1]. The refrigerated cabinet was also taken into account in order to supply the proper boundary conditions to the evaporator model. The mathematical model was based on the mass, momentum, and energy conservation principles applied to each of the following domains: (i) refrigerant flow through the evaporator channels; (ii) heat diffusion in the evaporator plate; and (iii) heat transmission to the refrigerated cabinet. Empirical correlations were also required to estimate the shear stresses,

and the internal and external heat transfer rates. The governing partial differential equations were discretized through the finite volume approach and the resulting set of algebraic equations was solved by successive iterations. Validation of the model against experimental steady-state data showed a reasonable level of agreement: the cabinet air temperature and the evaporator cooling capacity were predicted within error bands of 1.5 C and 6%, respectively. This paper helps to investigate the thermal behavior of a plate-type, roll-bond evaporator. This paper doesn't give any idea regarding design and analysis of a vertical roll bond evaporator.
In international engineering research journal paper by Ashish Matkar, et.al [2] the design and analysis of direct cool refrigerator with vertical evaporator is studied. In this paper effect of vertical evaporator on performance in the household refrigerator instead of conventional O or C type evaporator is studied but the experimentation and analysis are done with R134a refrigerant whereas impact with R600a refrigerant is not discussed.

The investigation was done by Erik Bjo rk, et.al [3] for the flow boiling heat transfer in a typical domestic refrigerator evaporator with horizontal flow, frequent bends, and a non-circular cross-section. The mass flux was varied between 21 and 43 kg/m2 s, the heat flux between 1 and 5 kW/m2 and the vapor quality between 0.2 and 0.8. In spite of a predicted stratified to wavy-stratified flow pattern complete tube perimeter wetting was believed to occur except for the lowest mass flux and for positions upstream of the first bend. It was concluded that the bends helped to wet the tube perimeter. The experimental data revealed heat transfer coefficients higher than predicted with conventional correlations. This was suggested to be explained by thin film evaporation at a perimeter repeatedly wetted by liquid slugs. A simple correlation based on the pure convective part of the Shah correlation was derived from the experimental data. The mean deviation of this was 16.9% compared to Shah's 54.7%. This paper helps to investigate the flow boiling heat transfer in a typical domestic refrigerator evaporator with horizontal flow, frequent bends, and a non-circular cross-section. This paper doesn't give any idea regarding design and analysis of a vertical roll bond evaporator.

A study is presented on the influence of the air flow rate and surface geometry on the thermal-hydraulic performance of commercial tube-fin 'no-frost' evaporators by Jader R. Barbosa JR. et.al [4]. A specially constructed wind-tunnel calorimeter was used in the experiments from which data on the overall thermal conductance, pressure drop, Colburn j-factor and Darcy friction factor f were extracted. Eight different evaporator samples with distinct geometric characteristics, such as the number of tube rows, number of fins and fin pitch were tested. Semi-empirical correlations for j and f are proposed in terms of the air-side Reynolds number and the finning factor. A discussion is presented on the performance of the evaporator with respect to specific criteria such as the pumping power as a function of heat transfer capacity and the volume of material in each evaporator. This paper helps to study influence of the air flow rate and surface geometry on the thermal-hydraulic performance of commercial tube-fin 'no-frost' evaporators. This paper doesn't give any idea regarding design and analysis of a vertical roll bond evaporator.

The presentation of a new model for fin-and-tube evaporators, focusing on the solid core simulation and its integration with a quasi-homogeneous two-phase flow model for the in- tube refrigerant flow was done by C. Oliet, et.al [5]. Special attention is given to separate in-tube flow patterns (stratified, stratified- wavy), because of their importance in liquid overfeed and domestic refrigerator evaporators and the impact on the solid core temperature distribution. The paper presents the solid core formulation and numerical method, the in-tube two-phase flow model, and describes the proposed integration algorithm between them. A selected single-tube baseline case is analysed in full detail, showing the impact of stratified flow on the fin-and-tube temperature distributions. Additional studies are finally presented analysing different flow transitions (single phase to stratified flow, stratified-wavy flow to annular flow, and annular flow to partial dry-out) and several operating parameters (flow regime, tube material, and tube thickness). This paper is devoted to the presentation of a new model for fin-and-tube evaporators, focusing on the solid core simulation and its integration with a quasi-homogeneous two-phase flow model for the in- tube refrigerant flow. This paper doesn't give any idea regarding design and analysis of a vertical roll bond evaporator.

The study was done by Anand M. Shelke, et.al [6] on the design of solar sterilizer assisted with aqua ammonia solar vapour absorption system. The projects deal with the fulfillment of sterilized safe drinking water at cheap & reliable cost as well as usage of nonconventional solar energy source. It consists of a combined system having water sterilizer that usage evacuated tubes and aqua ammonia vapour absorption system.

The study was done by Sandip S. Sisat, et.al [7] on performance and evaluation of blends of hydrocarbon (R134a/R290 and R134a/R600a) in the household refrigerator as hydrocarbon are the best-suited fluid for alternatives to conventional refrigerants. The study was done for usage of blends of R134a/R290 and R134a/R600a for experimentation at the different mass percentage of refrigerants for different load conditions.

3. HEAT LOAD CALCULATIONS FOR DIRECT COOL REFRIGERATOR WITHOUT FREEZER COMPARTMENT

Below are the steps defined to make the design calculations for the refrigerator. All the design calculation for the refrigerator is based on heat and mass transfer fundamentals.
Step 1- Calculation of outside Heat Transfer Coefficient (ho)
Step 2- Calculation of Internal Heat Transfer Coefficient (hi)
Step 3 -Wall Heat Load Calculations
Step 4 - Air Change Load Calculations
Step 5 - Calculations for Commodity Load for Refrigerator Compartment
Step 6 - Calculations for Commodity Load for Freezer Compartment
Step 7 - Calculation of Water Load for RC

Step 8 - Calculations for Water Load for FC
Step 9 - Total Heat Load with freezer compartment
Step 10 - Total Heat Load without freezer compartment
Step 11 –Comparison of Total Heat Load with and without freezer

Detail explanation of each step:

Step 1- Calculation of outside Heat Transfer Coefficient (ho) On Condenser Coil
For outside heat transfer calculation, outer wall temperature is considered based on air-cooled condenser temperature and ambient temperature. For calculating heat transfer coefficient calculated Grasoff No as per given formula. Value of Prandtl No (Pr) is taken from property table and calculated outside heat transfer coefficient based on below formula. Table 3.1 shows the calculated values of outside heat transfer coefficient.

$\mathrm{Gr} = \frac{g\times\beta\times\theta\times L^3}{\vartheta^2}$ ------------3.1
$\mathrm{Nu} = 0.548(\mathrm{Gr}\times\mathrm{Pr})^{1/4}$ ----------3.2
When $10^5 < \mathrm{Gr.Pr} > 10^{11}$
$\mathrm{Nu} = \mathrm{ho}\times \mathrm{L/K}$ -----------3.3

Table 3.1: Calculation of outside Heat Transfer Coefficient (ho)
Twall = 47°C
Tamb = 43°C
Tmean = 45°C

Taking properties of air at 45°C
ho = 3.6

Step 2- Calculation of Internal Heat Transfer Coefficient (hi)
For inside heat transfer calculation inside wall, temperature is considered based on evaporator temperature and inside surface temperature. For calculating heat transfer coefficient Reynolds No (Re) and Prandtl No (Pr) is taken from property table and calculated inside heat transfer coefficient based on below formula.
g=acceleration due to Earth gravity
β=volumetric thermal expansion coefficient (equal to approximately 1/T, for ideal gases,
Where
This absolute temperature)
Ts= Surface temperature
T∞= bulk temperature
L=characteristic length
D=diameter
V=kinetic viscosity

$$\mathrm{Nu} = 0.548\times\frac{(\mathrm{Gr}\times\mathrm{Pr})1}{4} \quad \ldots\ldots\ldots \text{for } 105 < Gr\times\mathrm{Pr} < 1011$$
--------3.5

Internal Heat Transfer Coefficient (hi) based on natural convection.

T liner FC = -13°C
T in FC = -12°C
T mean FC = -12.5°C
T liner RC = +2°C
T in RC = +1°C
T mean RC = +1.5°C

Taking properties at -12.5 mean air temperature.

hi for FC = 1.423
hi for RC = 1.391

Step 3 -Wall Heat Load Calculations
Wall load calculations are finalized on the basis of required refrigerator capacity, performance, and energy requirement for the refrigerator. As shown in Table 3.1 inside and outside surface area of each refrigerator and freezer walls is calculated. The thermal resistance considering inside and outside convection and conduction for the each surface of refrigerators like liner, insulation and sheet metal part for each wall of the refrigerator and freezer compartment is calculated. The total thermal resistance of each refrigerator and the freezer wall is calculated. Then heat transfer of each wall of refrigerator and freezer compartment is calculated.

$R1 = 1/(ho \times Ao)$ --------3.5
$R2 = b_{CRCA}/(K_{CRCA} \times A_{CRCA})$ ------3.6
$R3 = b_{Insulation}/(K_{Insulation} \times A_{Insulation})$ ----3.7 $R4 = b_{Liner}/(K_{Liner} \times A_{Liner})$ -----3.8
$R5 = 1/(hi \times Ai)$ ----3.9

$Rt = R1 + R2 + R3 + R4 + R5$ -----3.10
$Q = (To - Ti)/Rt$ -----3.11

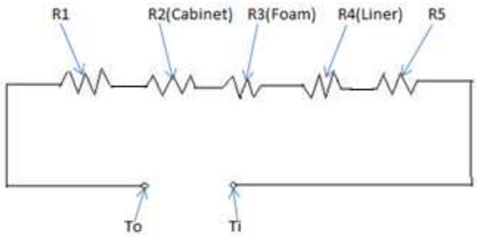

Figure 3.1: Resistance circuit

Table 3.1: Wall Heat Load Calculations

Walls	To	Ti	hi	ho	Ao
RC Side Wall LHS	43	+2	1.3912	3.06	0.62
RC Side Wall RHS	48	+2	1.3912	3.06	0.62
RC Back Wall	48	+2	1.3912	3.06	0.88
RC Door	43	+2	1.3912	3.06	0.71
RC Bottom Wall	43	+2	1.3912	3.06	0.23
Comp. Deck-Depth	43	+2	1.3912	3.06	0.10
Comp. Deck-Height	43	+2	1.3912	3.06	0.12
FC Top Wall	43	-12	1.423	3.06	0.34
FC Side Wall LHS	48	-12	1.423	3.06	0.33
FC Side Wall RHS	48	-12	1.423	3.06	0.33
FC Back Wall	53	-12	1.423	3.06	0.36
FC Door	43	-12	1.423	3.06	0.29

Table 3.2: Wall Heat Load Calculations

Walls	R total	Q (watts)
RC Side Wall LHS	5.17	9.48
RC Side Wall RHS	5.22	10.35
RC Back Wall	5.12	10.54
RC Door	5.26	9.31
RC Bottom Wall	12.69	3.86
Comp. Deck-Depth	34.27	1.43
Comp. Deck-Height	29.70	1.65
FC Top Wall	11.02	5.53
FC Side Wall LHS	13.34	4.95
FC Side Wall RHS	13.34	4.95
FC Back Wall	14.08	5.04
FC Door	15.13	4.03

Total Thermal Wall Heat Load (W) = 69.54 Watts.

Step 4 - Air Change Load Calculations

Air change load is calculated based on outside and inside humidity ratio and also considered sensible heat and latent heat. Table 3.4 shows the input values of temperatures and calculated values of inside humidity, outside humidity, sensible heat transfer, latent heat transfer and the total heat transfer due to air change. Eqs.(3.12) and Eqs. (3.13) Shows the formula to calculate sensible heat transfer and latent heat transfer respectively.

$Q_s = \rho * Q_{Air} * C_p(T_o - T_i)$ -------3.12
$Q_l = \rho * Q_{Air} * C_p(W_o - W_i)$ ------ 3.13

For FC
Air change Load = V x Air x 0.75 x (hi –ho) /24
= 3 x 36 x 0.75 x (5.66-3.06) /24
=8.7 BTU/hr
Air change Load = 2.54 Watts

For RC
Air change Load = V x Air x 0.75 x (hi –ho) /24
= 9 x 36 x 0.75 x (5.66-3.06) /24
=3.84 BTU/hr
Air change Load = 6.38 Watts.

Step5- Calculations for commodity load for Refrigerator compartment

Q= {weight of commodity (lb) x delta T°C x Sp. Heat ((btu/lb)/F) } / 24
= 9.027 Watts ---------3.14

Table 3.3 shows the commodities taken in Consideration based on consumer's normal usage and its weight based on storage space available in the refrigerator compartment. The normal temperature of a commodity is considered as 30°C and storage temperature of each type of commodity defined based on dew point temperature. Then the specific heat of each commodity calculated as shown in the formula in Eqs. (3.14). Then heat transfer rate of each commodity for refrigerator compartment is calculated.

For RC:

Table 3.3: Commodity Load for RC

Sr No	Commodity	Q Watts
1	cabbage	0.994967
2	carrots	0.762102
3	cucumber	0.363782
4	tomatoes	0.867735
5	Apples	0.857768
6	coconut	0.585869
7	Lemon	0.314878
8	Grapes	0.868702
9	water	1.681739
10	milk	0.910289
11	fish	0.819421

Total Commodity load in RC (W) = 9.02725 Watts.
----3.14

Step 6 - Calculations for Commodity Load for Freezer Compartment.
Table 3.4 shows the commodities taken in consideration based on consumer's normal usage and its weight based on storage space available in the freezer compartment. The normal temperature of a commodity is considered as 30 °Cand storage temperature of each type of commodity is defined based on dew point temperature. Then the specific heat of each commodity is calculated as shown in the formula in Eqs. (3.15). Then latent heat conversion is considered since in freezer compartment phase change happens at 0°C. Then heat transfer rate of each commodity for freezer compartment is calculated.

Q= { weight of commodity (lb) x delta T°C x Sp. Heat ((Btu/lb)/F) +Lt. heat (Btu/lb) } / 24
= 923.10 Watts ---------3.15

For FC:

Table 3.4: Commodity Load for FC

Sr No	Commodity	Watts
1	Meat	1.854577
2	Chicken	2.39398
3	Ice cream	5.798294
4	Ice	13.05632

Step 7 - Calculation of Water Load for RC

Water load for refrigerator compartment is calculated based on the normal water temperature of 30℃ to the drinkable water temperature of 13℃. The amount of water quantity considered based on storage space available and normal usage pattern of the consumer. The total heat transfer rate for water in refrigerator compartment is calculated

Q= {weight of water (lb) x delta T°C x Sp. Heat ((Btu/lb)/F) } / 24
= 14.76 Watts ---------3.16

Step 8 - Calculations for Water Load for FC

Water load for freezer compartment is calculated based on the normal water temperature of 30℃ to the ice temperature of -5℃. The amount of water quantity considered based on storage space available and normal usage pattern of the consumer. Then latent heat conversion is considered since in freezer compartment phase change happens at 0℃. The total heat transfer rate for water in the freezer compartment is calculated.

Q= {weight (lb) x delta T°C x Sp. Heat ((Btu/lb)/F) x weight of water (lb) x Lt. Heat (Btu/lb)} / 24
---------3.17

For FC

Q = (wt x delta T x Sp) + (wt x latent heat) / 24 3.18
= { 7.04 × [30 - (-4)] × 1 + 7.04 × 144 } /24 = 15.28 W

For RC

Q = (wt x delta T x Sp) + (wt x latent heat) / 24 3.19
= { 31.9 × [30 - (13)] × 1 + 31.9 × 144 } /24 = 6.612 W

For Chiller

Q = { 4.4 × [30 - (1.5)] × 1 + 4.4 × 144 } /24 = 1.52 W 3.20
Total water commodity load = 23.42 Watts.

Step 9 - Total Heat Load (W) with freezer compartment

The total heat load to be handled in the refrigerator is the sum of heat from sources as:
Heat load from walls
Heat load from entering air i.e. Air change load
Heat load from commodity load
Heat load from water and ice

Table 3.5 shows the total thermal load of freezer and refrigerator compartment. Total thermal load for the 190L conventional refrigerator is 137.08 watts.

Table 3.5: Total Thermal Load for Refrigerator (with freezer compartment)

Sr. No	Parameters	Q-FC (W)	Q –RC (W)	Q Total (W)
1	Thermal Wall Load	6.14	63.12	69.26
2	Air Change Load	2.54	3.84	6.38
3	Commodity Load	23.10	9.02	32.12
4	Water Load	15.28	14.76	30.04
Total heat Load (W)				137.08

As per heat load for given platform size, we can select the compressor from compressor manufactures catalogs to achieve cooling performance as per requirement and energy target for that cooling target, next we select the condenser and evaporator for given data of heat load.
In this project, focus is on condenser selection and improvement in condenser performance improvement from given data by keeping all parameter constant like compressor, platform size, evaporator, capillary length, heat load.

Step 10 - Total Heat Load (W) without freezer compartment
The total heat load to be handled in the refrigerator is the sum of heat from sources as:
Heat load from walls
Heat load from entering air i.e. Air change load
Heat load from commodity load
Heat load from water and ice

Table 3.6 shows the total thermal load of freezer and refrigerator compartment. Total thermal load for the 190L conventional refrigerator is 96.88 watts.

Table 3.6: Total Thermal Load for Refrigerator (without freezer compartment)

Sr.s No	Parameters	Q-FC (W	Q –RC (W)	Q Total (W)
1	Thermal Wall Load	6.14	63.12	69.26
2	Air Change Load	0	3.84	3.84
3	Commodity Load	0	9.02	9.02
4	Water Load	0	14.76	14.76
Total heat Load (W)				96.88

Step 11 – Comparison Total Heat Load (W) without freezer compartment
As from step 10 and Step 11 it is clear that, total heat load of the refrigerator without freezer compartment is less than total heat load of the refrigerator without freezer compartment so no need to change compressor specification in terms of cooling capacity and COP.
Step 12 – Selection of R134a compressor
Based on table 3.7, selected LGE MA42LPJG R134a compressor model for testing.

Table 3.7: R134a compressor details

Compressor	R134a Compressor
Make & Model	LGE R134a MA42LPJG
Cooling Capacity	107 W
COP (W/W)	1.18 COP
Displacement	4.2 CC

4. Cooling circuit diagrams of vertical evaporator

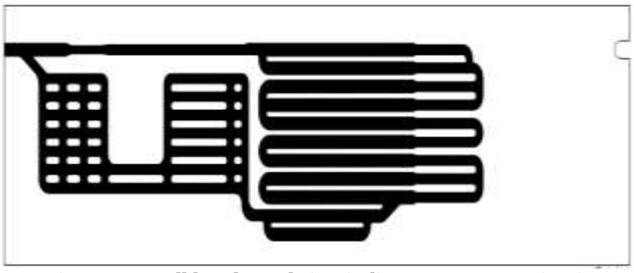

Figure 4.1: Roll bond panel circuit diagram _ 120CC circuit

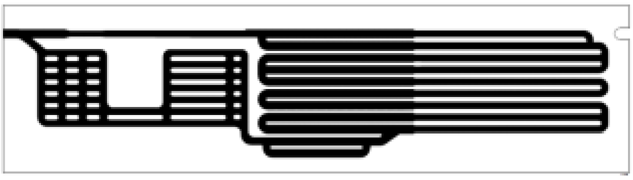

Figure 4.2: Roll bond panel circuit diagram _ 140CC circuit

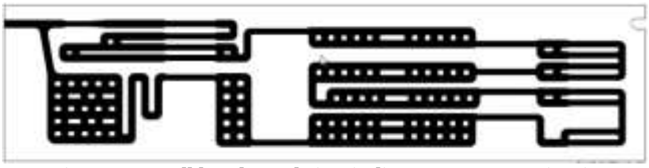

Figure 4.3: Roll bond panel circuit diagram _ 170CC circuit

5. Experimental setup:

In the proposed scenario, freezer section is removed and it is converted into usable refrigerator compartment as shown in figure 5.1.

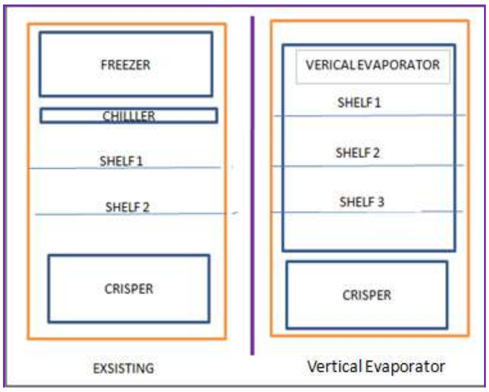

Figure 5.1: Vertical evaporator

In this project for performance evaluation of vertical evaporator refrigerator, temperature measurement scheme is as shown in figure 5.2

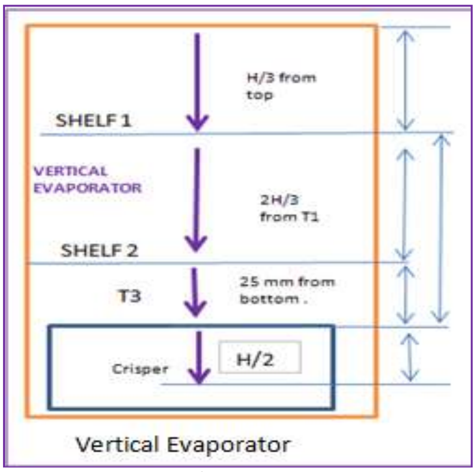

Figure 5.2: block diagram of Temperature measurement scheme

The temperature is measured with the help of thermocouple. The sensitive part of which is inserted in the center of a tinned copper cylinder, weighing 25 gm and having a minimum external area (diameter = height = about 15.2 MM).

Temperature measuring instruments shall be accurate ±0.3°C .K type's thermocouples are used to measure temperature inside cabinets

6. Test matrix:

The tests as per mentioned in Indian Std. S1476 are performed on R190L vertical evaporator and R190L baseline refrigerator. Based on functional & subject matter experience, 43°C NLPD and 32°C energy tests are selected for experimentation from the above mentioned standard.

Table 6.1: Experimentation test matrix

Sr. No	Variation in cooling circuit selected for experimentation			
1	R190L 120CC	R190L 140CC	R190L 170CC	***
2	R190L 170CC W/O perforated cover	R190L 170CC with 1 P. cover	R190L 170CC with 2 P. covers	R190L 170CC with 3 P. covers
3	R190L Baseline product	R190L 170CC W/O P. cover	R190L 170CC with 1 P. cover	***

7. RESULTS & DISCUSSION

In this chapter, results are discussed from cooling circuit selection based on its internal volume for vertical evaporator up as per mentioned in test matrix table no.6.1.

7.1.1 43°C no load pull-down test

43°C no load pull-down test helps to select the refrigerant type based on compartment's temperature.
The internal volume of R190L baseline refrigerator roll bond panel ie o type evaporator is 165CC, which is taken into consideration for below-mentioned comparison testing.

Table 7.1: 43°C NLPD test results

Circuit Volume and Gas charging qty.	R190L Vertical Evaporator 120CC (~30% less than final)	R190L Vertical Evaporator 140CC (~20% less than final)	R190L Vertical Evaporator 170CC (Final circuit)
	R134a : 50 gm	R134a : 60 gm	R134a : 70 gm
Freezer Avg. 6 hr. (°C)	NA	NA	NA
Refrigerator Avg. 6 hr. (°C)	-0.9	-1.7	-3.9

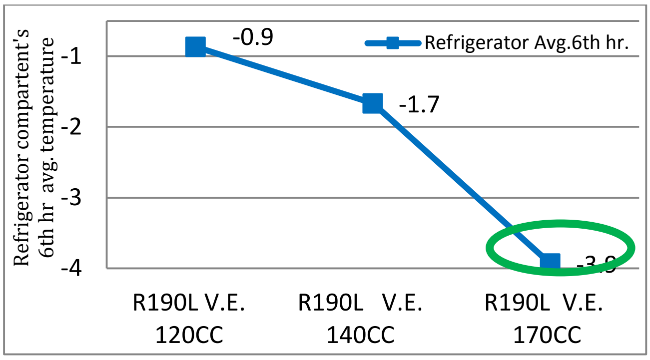

Figure 7.1: 43°C NLPD comparison to select internal volume of cooling circuit based on refrigerator compartment's temperature

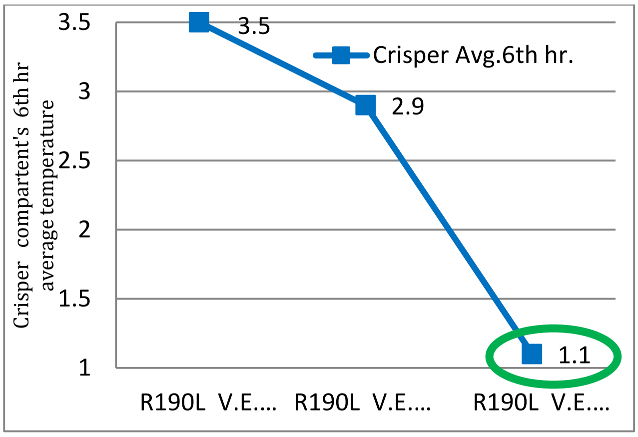

Figure 7.2: 43°C NLPD comparison to select internal volume of cooling circuit based on crisper compartment's temperature

1) In R134a R190L 170CC internal volume vertical evaporator refrigerator, overall refrigerator compartment's 6th-hour temperature is drifted to -3.9°C which is colder compared to 120CC & 140CC internal volume vertical evaporator refrigerators.
2) In R134a R190L 170CC internal volume vertical evaporator refrigerator, crisper compartment's 6th-hour temperature is drifted to +1.1°C which is colder compared to 120CC & 140CC internal volume vertical evaporator refrigerators.

7.1.2 32°C Energy test comparison

32°C energy test helps to select energy efficient product on basis of per year energy consumption between R134a & R600a refrigerant products.

Table 7.2: 32°C Energy Test Results

Cooling circuits	120CC (30% Less)		140CC(20% less)		170CC (Final circuit)	
Test	W.pt.	C.pt.	W.pt.	C.pt.	W.pt	Cpt.
Individual Energy/ Year (Kwh)	250	279	245	272	240	265
Final Energy/ Year (Kwh)	275		266		258	

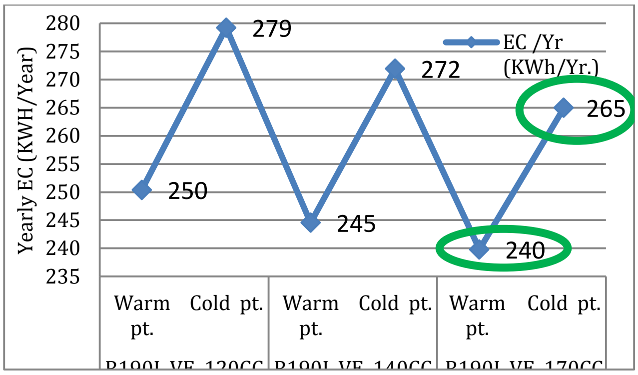

Figure 7.3: 32°C warm & cold pt. energy comparison test to select the internal volume of the cooling circuit

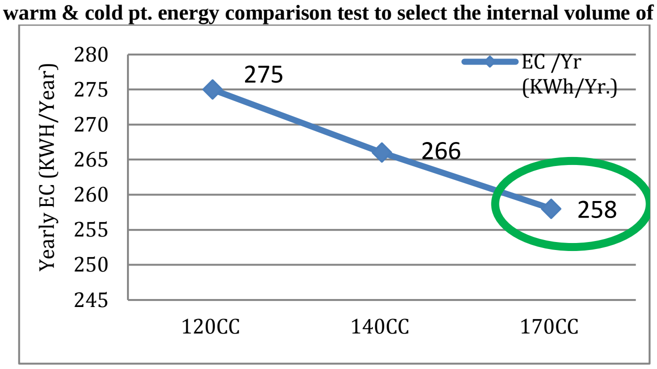

Figure 7.4: 32°C final energy comparison test to select internal volume of cooling circuit

1) In 32°C energy test, R134a R190L vertical evaporator refrigerator with 170CC internal volume circuit consumes less energy ie 258 KWH/year compared to 275 KWH/ year in 120 CC circuit and 266 KWH/ year in140 CC circuit.
2) So based on 43°C NLPD & 32°C energy test 170CC internal volume cooling circuit is considered for further experimentation as it most efficient compared to other 2 cooling circuits.

7.2 Comparison to select addition of perforated covers

Perforated covers are added to cover bare roll bond panel cooling circuit ie evaporator from aesthetic & customer safety point. This is to select addition of perforated covers ie thickens to cover vertical evaporator.
The material used for Perforated cover = HIPS with sheet thickness 1.2 MM.

7.2.1 43°C No load pull down comparison

43°C no load pull-down test helps to select perforated cover thickness over vertical evaporator based on compartment's temperature.

Table 7.3: 43°C NLPD test results

Circuit Volume and Gas charging qty.	R190L 170CC circuit V.E. W/O P. cover	R190L 170CC circuit V.E with 1 P. cover	R190L 170CC circuit V.E. with 2 P. covers	R190L 170CC circuit V.E. with 3 P. covers
	R134a : 70 gm	R134a : 70gm	R134a : 70gm	R134a : 70gm
Freezer Avg. 6 hr. (°C)	NA	NA	NA	NA
Refrigerator Avg. 6 hr. (°C)	-3.9	-3.2	-2.2	-1.3

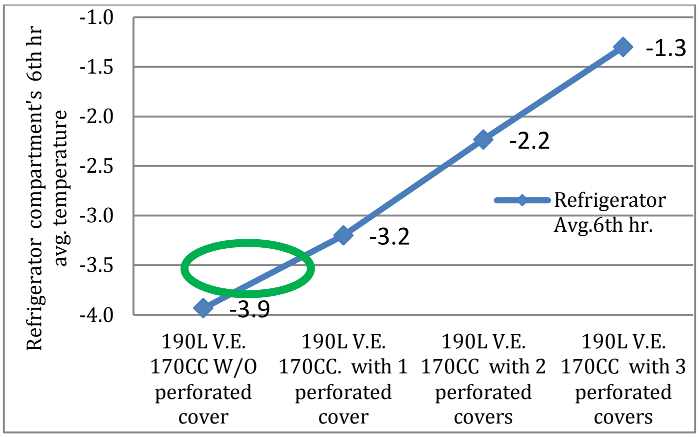

Figure 7.5: 43°C NLPD comparison to select addition of perforated covers based on refrigerator compartment's temperature

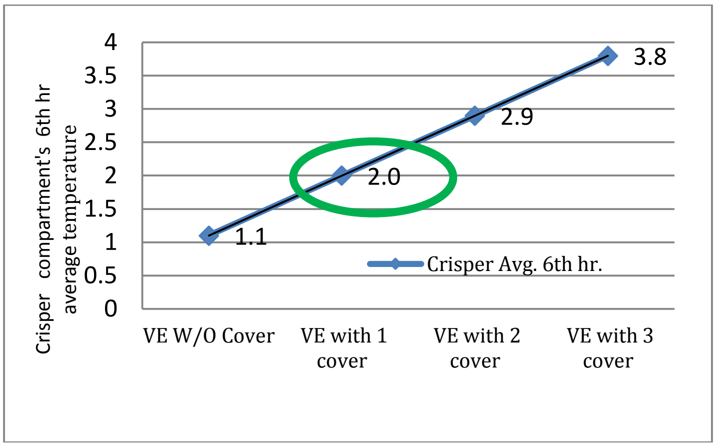

Figure 7.6: 43°C NLPD comparison to select addition of perforated covers based on crisper compartment's temperature

1) In R134a R190L 170CC vertical evaporator, overall refrigerator compartment's 6th-hour temperature is drifted to -3.2°C which is colder compared to 2 & 3 perforated cover refrigerators with 1 perforated cover refrigerator
2) In R134a R190L 170CC vertical evaporator with 1 perforated cover refrigerator, crisper compartment's 6th-hour temperature is drifted to +2°C which is colder compared to 2 & 3 perforated cover refrigerators.
3) As both, refrigerator compartment's & crisper compartment's 6 hr. avg. temperatures are colder in the 170CC vertical evaporator with 1 perforated cover refrigerator compared to other 2 perforated cover options so only 1 perforated cover option is further considered for 32°C energy test.

7.4 Comparison of baseline product vs vertical evaporator with 1 perforated cover

This is to compare baseline product vs vertical evaporator with 1 perforated cover.

7.4.1 43°C No laod pull down comparison

Table 7.4: 43°C NLPD test results

Circuit Volume and Gas charging qty.	R190L Base Line product with (175 CC) O Type evaporator	R190L 170CC circuit vertical evaporator without perforated cover	R190L 170CC circuit vertical evaporator with 1 perforated cover
	R134a : 75gm	R134a : 70gm	R134a : 70gm
Freezer Avg. 6 hr. (°C)	-14.7	NA	NA
Refrigerator Avg. 6 hr. (°C)	-1.7	-3.9	-3.2

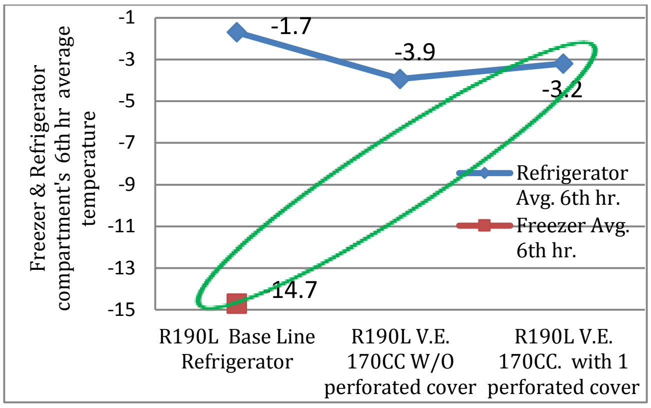

Figure 7.7: 43°C NLPD test comparison of R190L baseline refrigerator vs R190L 170CC vertical evaporator refrigerator based on freezer & refrigerator compartment temperature

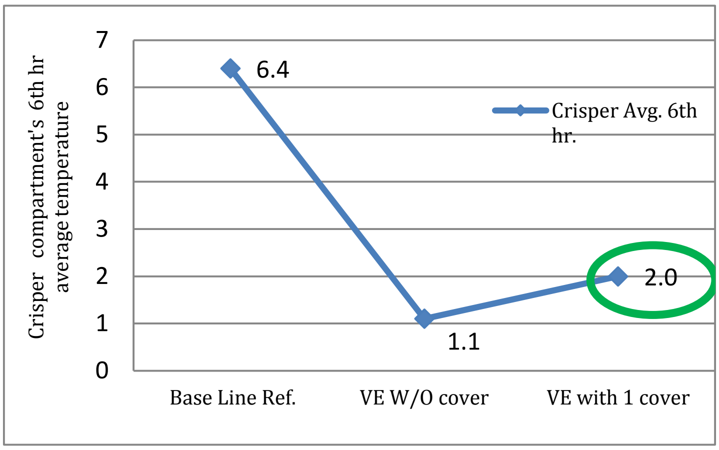

Figure 7.8: 43°C NLPD test comparison of R190L baseline refrigerator vs R190L 170CC vertical evaporator refrigerator based on crisper compartment temperature

1) In R134a R190L 170CC vertical evaporator with 1 perforated cover refrigerator, overall refrigerator compartment's 6th-hour temperature is drifted to -3.2°C which is colder compared to R134a R190L baseline refrigerator.
2) In R134a R190L 170CC vertical evaporator with 1 perforated cover refrigerator, crisper compartment's 6th-hour temperature is drifted to +2.0°C which is colder compared to R134a R190L baseline refrigerator.
3) In R134a R190L baseline refrigerator, the coldest compartment's temperature recorded is of freezer compartments ie -14.7°C. But whereas in R134a R190L 170CC vertical evaporator refrigerator with 1 perforated cover, the coldest compartment's temperature recorded is of refrigerator compartment's ie -3.2°C.
So the mean shift in vertical evaporator refrigerator's compartment temperature is at -14.7°C to -3.2°C.
As per BEE guidelines, In 43°C NLPD test freezer compartment temperature should be colder than -8°C temperature, which is not reaching in case of vertical evaporator refrigerator so it is considered as a refrigerator without a freezer compartment.

7.4.2 32°C energy test comparison

Table 7.5: 32°C Energy Test results

Cooling circuits	R190L Base Line product with O Type evaporator		R190L 170CC vertical evaporator with 1 perforated cover	
Test	W.pt.	C.pt.	W.pt	Cpt.
Individual Energy/ Year (Kwh)	268	293	240	267
Final Energy/ Year (Kwh)	295		265	

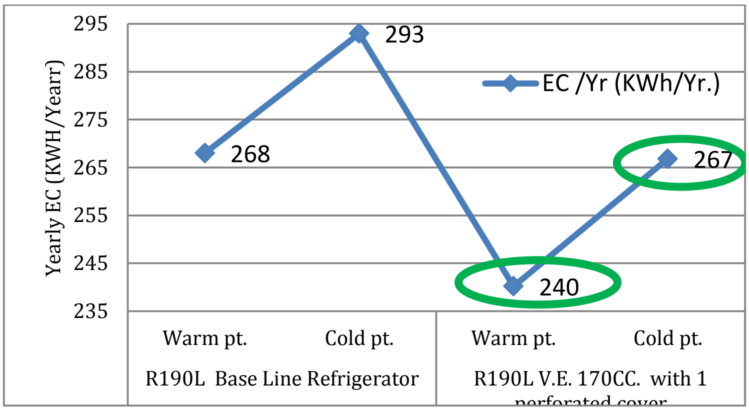

Figure 7.9: 32°C warm & cold pt. energy test comparison of R190L baseline refrigerator vs R190L 170CC vertical evaporator refrigerator with 1 perforated cover

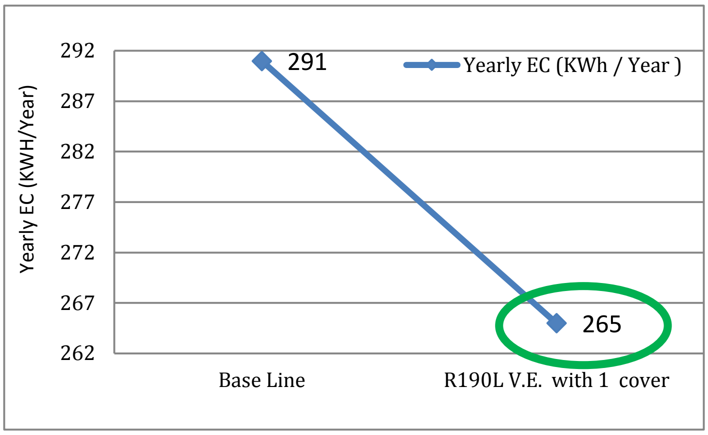

Figure 5.10: 32°C final energy test comparison of R190L baseline refrigerator vs R190L 170CC vertical evaporator refrigerator with 1 perforated cover

1) R134a R190L 170CC vertical evaporator refrigerator with 1 perforated cover consumes less energy ie 265 kWh/year compared to R134a R190L baseline product ie 291 kWh/year.
2) As per BEE table 2.2 The year 2015 given in annexure table no B2 & B3, R134a R190L 170CC vertical evaporator refrigerator with 1 perforated cover shall be treated as 4 stars whereas R134a R190L baseline product shall be treated as 3 Star.
So energy improvement is 1 star in case of vertical evaporator refrigerator.
3) Based on 43°C NLPD & 32°C energy test R134a R190L 170CC vertical evaporator refrigerator with 1 perforated cover is more efficient than R190L baseline refrigerator.

CONCLUSION

1) Freezer to refrigerator compartment volume ratio is 30:: 70%. As in R190L vertical evaporator refrigerator, freezer compartment is converted into refrigerator compartment so it gives an improvement in refrigerator usable space by 25~30% which means larger food storage area.
2) Based on 43°C pull-down test, as freezer section becomes warmer by 9~12°C in R190L vertical evaporator refrigerator compared to R190L baseline refrigerator. And as per Bureau of energy efficiency (BEE) guidelines, in 43°C NLPD test freezer compartment temperature should be colder than -8°C temperature, which is not reaching in case of vertical evaporator refrigerator so it is considered as a refrigerator without a freezer compartment.
3) In 32°C energy test, R134a R190L vertical evaporator refrigerator with 170CC internal volume circuit consumes 3~6 % less energy consumption compared to R190L vertical evaporator refrigerator with 120CC & 140CC internal volume circuit options.
4) In R134a R190L 170CC vertical evaporator with 1 perforated cover refrigerator, overall refrigerator compartment's 6th-hour temperature is drifted to -3.2°C which is colder compared to 2 & 3 perforated cover refrigerators.
5) In R134a R190L 170CC vertical evaporator with 1 perforated cover refrigerator, crisper compartment's 6th-hour temperature is drifted to +2.0°C which is colder compared to 2 & 3 perforated cover refrigerators.
6) In 32°C energy consumption test, R134a R190L 170CC vertical evaporator refrigerator with 1 perforated cover consumes 9~10 % less energy compared to R190L baseline refrigerator. As per guidelines are given by BEE, this vertical evaporator refrigerator can be registered in 'refrigerator without freezer compartment' category for star rating programme.

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