Performance Analysis of Vertical Evaporator Refrigerator with Refrigerant R134a and R600a

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Abstract - The aim of this paper is to study comparative analysis of household direct cool vertical evaporator refrigerator with 134a and R1600a refrigerant. In this household refrigerator, 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 volume of existing evaporator ie freezer section of house hold direct cool refrigerator .Based on 43°C pull down test , freezer section becomes warmer by approximately 9°C~-12°C so it can be considered as refrigerator without freezer compartment. Further extension to above experiment R134a compressor and refrigerant is replaced by R600a compressor and refrigerant. Based on 32°C energy consumption test, vertical evaporator refrigerator with R600a refrigerant consumes 7~8 % less energy than vertical evaporator refrigerator with R134a refrigerant.

Keywords: Vertical Evaporator, Roll Bond Evaporator, Direct Cool Refrigerator, R600a,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 volume of existing evaporator ie freezer compartment and refrigerator compartment however in this project freezer compartment is converted into refrigerator compartment.
In this project for R190L refrigerator 3 cooling circuits based on their internal volumes 120CC, 140CC & 170CC are 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 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 most energy efficient. Then comparative 43°C NLPD and 32°C energy tests are done on base line 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.

This vertical evaporator refrigerator ie R190L 170CC cooling circuit with 1 perforated cover is further analyzed by changing refrigerant from R134a to R6000a to understand the energy improvement. The energy improvement found 7~8 % by changing R600a refrigerant compared to R134a refrigerant and 15~16 % when compared with R134a base line refrigerator.
 The measurement uncertainty is also calculated based on 32°C energy results to understand the accuracy of testing method. The calculated measurement uncertainty is 2 Kwh/year which is significantly less.

2. LITERATURE REVIEW:

In international engineering research journal paper by Ashish Matkar,et.al [1] the design and analysis of direct cool refrigerator with vertical evaporator is studied. In this paper effect of vertical evaporator on performance in household refrigerator instead of conventional O or C type evaporator is studied but the experimentation and analysis is done with R134a refrigerant where as impact with R600a refrigerant is not discussed.

The first reasonably successful air- cooled unit was Isko. Fred W. Wolf designed and marketed a household system called DOMELRE, a contraction of Domestic _Electric Refrigerator. The Wolf system was marketed by Mechanical Refrigerator Company and later by Isko until absorbed by Frigidaire in 1922. The paper regarding 'Domestic refrigerators – recent developments' which was published by R. Rademacher, et.al [2] throws light on the study and research done on domestic refrigerators and its recent developments. This paper doesn't give any idea regarding design and analysis of a vertical roll bond evaporator.

The determination of the theoretical and experimental performance analysis, cooling capacity and overall heat transfer coefficient of evaporators was discussed in paper by Horuz, et.al [3]. The experimental evaporator was analyzed with correlations together with the parameters of air velocity, fin spacing, tube diameter, evaporator temperature, refrigerant type and frost height. It is concluded that when the experimental and theoretical overall heat transfer coefficients were compared with those from the manufacturing catalogues (for the same working conditions), the latter was to be15-30% higher than the former one. The theoretical and experimental performance analysis, cooling capacity and overall heat transfer coefficient of evaporators studied and predicted in this paper. This paper doesn't give any idea

regarding design and analysis of a vertical roll bond evaporator.

A distributed parameter model for prediction of the transient performance of an evaporator is presented in the paper by S.Porkhial, et.al [4]. The model is capable of predicting the refrigerant temperature distribution, tube wall temperature, quality of refrigerant, inventory mass of refrigerant as a function of position and time. An efficient two-level iteration method is proposed to obtain the numerical solution of the model without solving a large set of non-linear equations simultaneously. A round bound evaporator of 12 cubic feet refrigerator with R12 as working fluid were chosen as a sample and some tests were carried out to determine its transient response. The results indicate that the theoretical model provides a reasonable prediction of dynamic response compared with the experimental data. Transient behavior of temperature, pressure, mass flow rate, mass of liquid and vapour of refrigerant, quality, heat transfer in household refrigerators have been presented. Also time dependent displacement of interface between saturated and superheated regions has been shown. Extensive investigation of theoretical and experimental results shows that with a controllable compressor, power consumption can be reduced. This model predicts transient behavior of temperature, pressure, mass flow rate, mass of liquid and vapor of refrigerant, quality, heat transfer in household refrigerators. This paper doesn't give any idea regarding design and analysis of a vertical roll bond evaporator.

A set of equations, which can be used to predict the performance parameters of an evaporator, when there is an oblique angle between the inlet air velocity and frontal face of the evaporator was studied by by Nan Chen, et.al [5]. In order to calculating the performance, a simulation model for predicting the performance of a plate-fin tube evaporator, on which frost formation occurs, has been presented. This model adopts different numerical algorithms according to different flow conditions including laminar, transitional and turbulent flow patterns. An experimental setup is built to verify the validity of this model. Then a comparison between the model's predictions and laboratory test data is provided. After correction, the numerical program based on this model is used to predict relationship between the oblique angel of the inlet air velocity and performance parameters (including frost weight, pressure drop and refrigerating capacity of the evaporator). At the end of this paper, the degree of performance degradation is described by a set of equations that is obtained through regression analysis. This paper helps with the sets of equations to predict the performance parameters of an evaporator, when there is an oblique angle between the inlet air velocity and frontal face of the evaporator. This paper doesn't give any idea regarding design and analysis of a vertical roll bond evaporator.

In most domestic and commercial refrigeration systems, frost forms on the air-side surface of the air-to-refrigerant heat exchanger. Frost-tolerant designs typically employ a large fin spacing in order to delay the need for a defrost cycle. Unfortunately, this approach does not allow for a very high air-side heat transfer coefficient, and the performance of these heat exchangers is often air-side limited. This was studied by A. D. Sommers, et.al [6]. Longitudinal vortex generation is a proven and effective technique for thinning the thermal boundary layer and enhancing heat transfer, but its efficacy in a frosting environment is essentially unknown. In this study, an array of delta-wing vortex generators is applied to a plain-fin-and-tube heat exchanger with a fin spacing of 8.5 mm. Heat transfer and pressure drop performance are measured to determine the effectiveness of the vortex generator under frosting conditions. For air-side Reynolds numbers between 500 and 1300, the air-side thermal resistance is reduced by 35–42% when vortex generation is used. Correspondingly, the heat transfer coefficient is observed to range from 33 to 53 W mK2 KK1 for the enhanced heat exchanger and from 18 to 26 W mK2 KK1 for the baseline heat exchanger. This paper helps to measure heat transfer and pressure drop performance to determine the effectiveness of the vortex generator under frosting conditions. This paper doesn't give any idea regarding design and analysis of a vertical roll bond evaporator.

A comparable evaluation of R600a (isobutene), R290 (propane), R134a, R22, R410A, and R32 in an optimized finned-tube evaporator, and analyzes the impact of evaporator effects on the system coefficient of performance (COP) was done by by Piotr. A. Domanski, et.al [7]. The study relied on a detailed evaporator model derived from NIST's EVAP-COND simulation package and used the ISHED1 scheme employing a non-Darwinian learnable evolution model for circuitry optimization. In the process, 4500 circuitry designs were generated and evaluated for each refrigerant. The obtained evaporator optimization results were incorporated in a conventional analysis of the vapor compression cycle. For a theoretical cycle analysis without accounting for evaporator effects, the COP spread for the studied refrigerants was as high as 11.7%. For cycle simulations including evaporator effects, the COP of R290 was better than that of R22 by up to 3.5%, while the remaining refrigerants performed approximately within a 2% COP band of the R22 baseline for the two condensing temperatures considered. This paper helps in comparable evaluation of R600a (isobutene), R290 (propane), R134a, R22, R410A, and R32 in an optimized finned-tube evaporator, and analyzes the impact of evaporator effects on the system coefficient of performance (COP). This paper doesn't give any idea regarding design and analysis of a vertical roll bond evaporator.

The study was done by Derya Burcu Ozkan, et.al [8] on parameters affecting the frost formation on the evaporator of a refrigerator and the structure of frost were examined. Air velocity measurements both at the air inlet and outlet channels of the evaporator were performed, and the effect of air velocity on frost formation was examined. The rate of evaporation of water inside the refrigerator cabin was also recorded. This paper helps to study parameters affecting the frost formation on the evaporator of a refrigerator and the examination of the effect of air velocity on frost formation. This paper doesn't give any idea regarding design and analysis of a vertical roll bond evaporator.

A first-principles mathematical model developed to investigate the thermal behavior of aplate-type, roll-bond evaporator by Christian J.L Hermesa, et.al [9]. 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 aplate-type, roll-bond evaporator. 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 [10] on design of solar sterilizer assisted with aqua ammonia solar vapour absorption system. The projects deals with fulfillment of sterilized safe drinking water at cheap & reliable cost as well as usage of nonconventional solar energy source. It consist of 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 [11] on performance and evaluation of blends of hydrocarbon (R134a/R290 and R134a/R600a) in 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 different mass percentage of refrigerants for different load conditions.

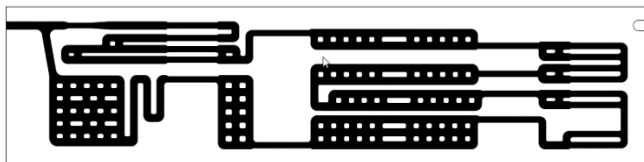## 3. COOLING CIRCUIT DIAGRAM OF VERTICAL EVAPORATOR

Figure 3.1: Roll bond panel circuit diagram _ 170CC circuit
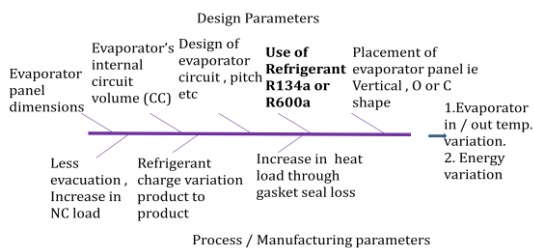
4. DESIGN FACTORS AFFECTING ON PERFORMANCE

Figure 4.1 : Fish bone diagram of design factors affecting on performance

The change in refrigerant from R134a to R600a, which is a design factor affects on energy parameter.

5. NOMENCLATURE

Table 5.1: Compressor details R134a & R600a

Compressor	R134a Compressor	R600a Compressor
Make & Model	LGE R134a MA42LPJG	AMCC R600a PZ59E1D-9
Cooling Capacity	107 W	100 W
COP (W/W)	1.18 COP	1.62 COP
Displacement	4.2 CC	5.9 CC

6. THEROTICAL CALCULATIONS FOR MEASUREMENT UNCERTAINTY :

Based on 32°C energy test of direct cool vertical evaporator with 1 perforated cover and with R134a circuit & refrigerant. The below data is tested for colder point of 32°C energy test when checked by Technician 1.
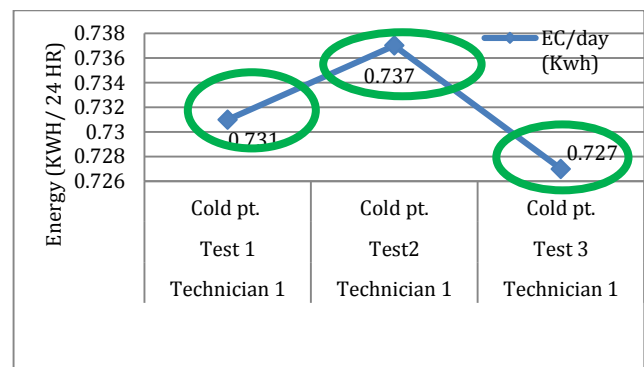

Figure 6.1 : Measurement uncertainty for 32°C energy test

Table 6.1 : Calculation for type A uncertainty

No	Readings Observed	Average	Standard deviation	Ua
1	0.731			
2	0.737	0.73	0.005	0.0023
3	0.727			
Total	2.195	0.73	0.005	0.0023

Mean value of the reading taken X1 ….. X10
0.73 KWH
Ua = $\sigma n\text{-}1/\sqrt{n}$

$\sigma n\text{-}1 = \sqrt{(\sum (Xi\text{-}Xbar)^2 / (\sqrt{n}\text{-}1)}$
0.0050 Kwh
$= \sqrt{(\sum (X1\text{-}Xbar)^2 + (X2 + Xbar)^2 + (X3\text{-}Xbar)^2 + \text{----} (Xn\text{-}Xbar)^2) / (\sqrt{n}\text{-}1)}$

Ua = $\sigma n\text{-}1/\sqrt{n}$ = 0.00225093
Type A uncertainty

Type B uncertainty :
Ub1 : Source : Std. uncertainty due to energy

Taken from the calibration certificate
% b1= 0.0380 % Divsier – K : 1.96
Assuming Normal distribution , Ub1 = b / k = a1/2
0.019388 %

Ub1=
0.0001419 kwh
Degree of freedom v2 ∞
Ub2 : Sorce : Specification accuracy of energy meter
Taken from the manufacturer 's spec.
 b 2 = 0.5 %
0.003658 Kwh
Assuming rectangular distribution Ub2 = a2/ sqrt(3) =
0.0021122 0 Kwh
%Ub2 = 0.288684 %
Degree of freedom V3= ∞
Ub3 : Source : uncertainty due to resolution of energy meter

Table 6.2: Calculation for uncertainty due to resolution

Resolution	Divide	A4	Divisor Sqrt (3)	Ub3
0.0001	2	0.00005	1.732	0.0000289

Uncertainty Ub3= a4/√3 = 0.0000289 Kwh
% Ub3 = 0.00395 %
Degree of freedom V4 = ∞
Combined uncertainty Uc = √ ((Ua^2) +(U1^2) +(U2^2) +(U3^2)+ (U4^2))

Table 6.3: Calculation for combined uncertainty

Ua	Ub1	Ub2	Ub3	Uc
0.002251	0.0001418537	0.00211220	0.000029	0.003

Expanded uncertainty at 95% confidence level

Table 6.4: Calculation for expanded uncertainty

Combined uncertainty	Coverage factor	Expanded Uncertainty
Uc	k	Ue = Uc * K
0.003	2	0.006

Effective degree of freedom
Veff = Vc^4(y) / (∑Ui^4 (y-Vi) = 0.00000000009 /
0.00223939960 = 0.000000040718
Final result = 0.73 ±0.006 Kwh /24 hrs
With coverage factor K= 2 at 95% CL

7. EXPERIMENTAL SET UP:
In proposed scenario, freezer section is removed and it is converted into usable refrigerator compartment as shown in figure 7.1.
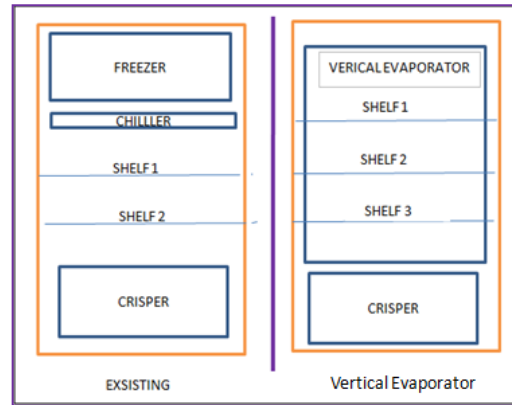

Figure 7.1: Vertical evaporator

In this project for performance evaluation of vertical evaporator refrigerator, temperature measurement scheme is as shown in figure 7.2
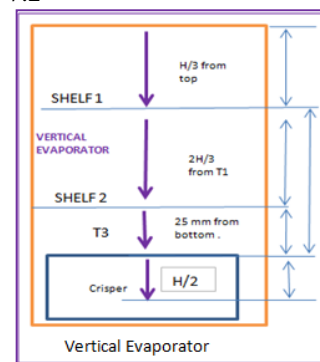

Figure 7.2 :Block diagram of Temperature measurement scheme

The temperature is measured with the help of thermocouple. The sensitive part of which are inserted in the centre of a tined copper cylinder, weighing 25 gm and having minimum external area (diameter = height = about 15.2 MM) .
Temperature measuring instruments shall be accurate ±0.3°C .K types thermocouples are used to measure temperature inside cabinets

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

Table 8.1: Experimentation test matrix

Sr. No	Test Name	Option 1	Option 2	Option 3
1	Meas. Uncertainty calculation 32°C Energy comparison	R190L 170CC VE with 1 P. cover Ref.: Cold point energy Test 1	R190L 170CC VE with 1 P. cover Ref.: Cold point energy Test 2	R190L 170CC VE with 1 P. cover Ref.: Cold point energy Test 3
2	43°C NLPD Comparison	R190L Baseline Ref. : R134a gas	R190L 170CC VE with 1 P. cover Ref. : R134a gas	R190L 170CC VE with 1 P. cover Ref. : R600a gas
3	32°C Energy comparison	R190L Baseline Ref. : R134a gas	R190L 170CC VE with 1 P. cover Ref. : R134a gas	R190L 170CC VE with 1 P. cover Ref. : R600a gas

9 .RESULTS & DISCUSSION :

In this chapter results are discussed from cooling circuit selection based on it's internal volume for vertical evaporator up to the use of R600a refrigerant for vertical evaporator refrigerator as per mentioned in test matrix table no.4.2.

9.1 43°C no load pull down test

43°C no load pull down test helps to select 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 9.1: 43°C NLPD test results

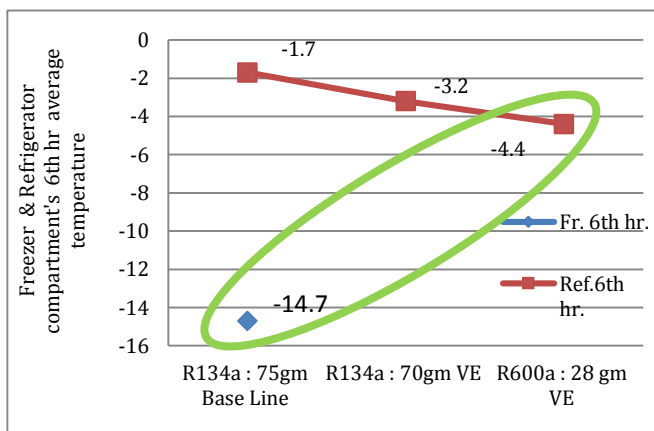| Parameters	R190L Base line refrigerator	R190L 170CC vertical evaporator Refrigerator 1 perforated cover	
Gas Charging	R134a : 75 gm	R134a : 70 gm	R600a : 28 gm
Freezer Avg. 6 hr. (°C)	-14.7	NA	NA
Refrigerator Avg. 6 hr. (°C)	-1.7	-3.2	-4.4

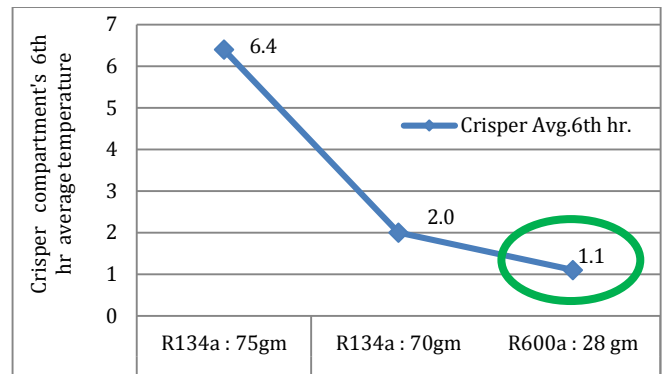Figure 9.1: 43°C NLPD comparison with R134a and R600a refrigerant based on refrigerator compartment's temperature

Figure 9.2: 43°C NLPD comparison with R134a and R600a refrigerant based on crisper compartment's temperature

1) In R600a R190L 170CC vertical evaporator refrigerator with 1 perforated cover, overall refrigerator compartment's 6th hour temperature is drifted to -4.4°C which is colder compared to R134a R190L baseline refrigerator and R134a R190L 170CC vertical evaporator refrigerator with 1 perforated cover.
2) R600a R190L 170CC vertical evaporator refrigerator with 1 perforated cover, crisper compartment's 6th hour temperature is drifted to +1.1°C which is colder compared to R134a R190L baseline refrigerator and R134a R190L 170CC vertical evaporator refrigerator R134a R190L baseline refrigerator with 1 perforated cover.
3) In R134a R190L baseline refrigerator, the coldest compartment's temperature recorded is of freezer compartments ie -14.7°C. But whereas in R600a R190L 170CC vertical evaporator refrigerator with 1 perforated cover, the coldest compartment's temperature recorded is of refrigerator compartment's ie -4.4°C.

So the mean shift in vertical evaporator refrigerator's compartment temperature is from -14.7°C to -4.4°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 refrigerator without freezer compartment.
4) Vertical evaporator product with R600a refrigerant circuit is colder than vertical evaporator product with R134a refrigerant circuit .

9.2 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 9.1: 32°C energy test results

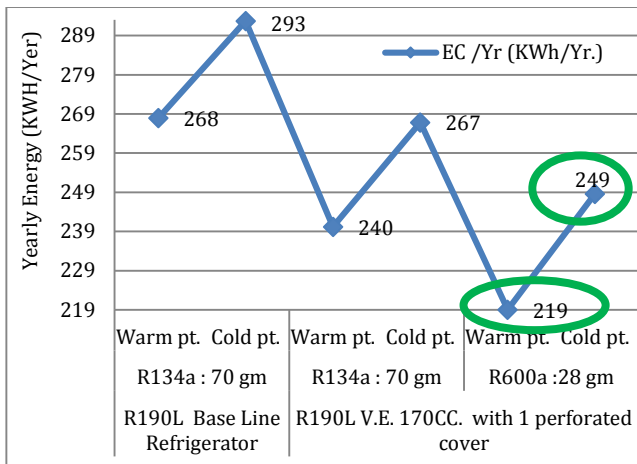| Parameters	R190L Base Line Refrigerator		R190L 170CC vertical evaporator Refrigerator with 1 perforated cover			
Gas Charging	R134a : 75 gm		R134a : 70 gm		R600a : 28 gm	
Test	W.pt.	C.pt.	W.pt.	C.pt.	W.pt	Cpt.
Individual Energy/ Year (Kwh)	268	293	240	267	219	249
Final Energy/ Year (Kwh)	291		265		246	

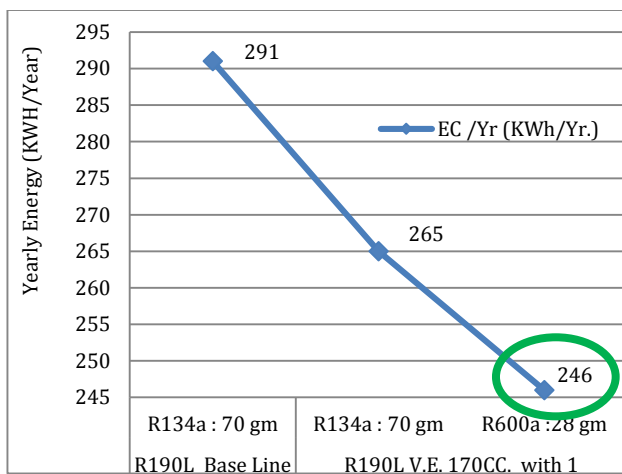Figure 9.3: 32°C warm pt. & cold pt. energy test comparison with R134a and R600a refrigerant

Figure 9.4: 32°C final energy test comparison with R134a and R600a refrigerant

1) In 32°C energy consumption test R600a R190L 170CC vertical evaporator refrigerator with 1 perforated cover, consumes less energy ie 246 KWH/Year compared to R134a R190L base line refrigerator ie 291 KWH/Year & R134a R190L 170CC vertical evaporator refrigerator with 1 perforated cover ie 265 KWH/Year.

2) The refrigerator with R600a refrigerant is colder so total run percentage is less than compared to the refrigerator with R134a refrigerant which finally results into less energy consumption.

3) The Molecular weight of R600a refrigerant is 58.1 kg/mol which is less than that of R134a refrigerant which is 102 kg/mol so amount of refrigerant qty. required to balance the cooling system is less in case of refrigerator with R600a refrigerant.

10.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 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 refrigerator without freezer compartment.

3) The measurement uncertainty in 32°C energy testing for Technician 1 is 2 KWH/Year which is significantly less.

4) In R600a R190L 170CC vertical evaporator with 1 perforated cover refrigerator, overall refrigerator compartment's 6th hour temperature is drifted to -4.4°C which is colder compared to R134a R190L baseline refrigerator and R134a R190L 170CC vertical evaporator with 1 perforated cover refrigerator.

5) In R600a R190L 170CC vertical evaporator with 1 perforated cover refrigerator, overall crisper compartment's 6th hour temperature is drifted to +1.1°C which is colder compared to R134a R190L baseline refrigerator and R134a R190L 170CC vertical evaporator with 1 perforated cover refrigerator.

6) In 32°C energy consumption test, R600a R190L 170CC vertical evaporator refrigerator with 1 perforated cover product consumes 7~8 % less energy compared to R134a R190L base line refrigerator.

7) In 32°C energy consumption test, R600a R190L 170CC vertical evaporator refrigerator with 1 perforated cover consumes 15~16 % less energy compared to R134a R190L 170CC vertical evaporator refrigerator with 1 perforated cover.

11. REFERENCES

[1] Ashish Devidas Matkar, Prof.R.D. Shelke, Prof.H.N.Deshpande 'Design and analysis of household direct cool refrigerator with vertical evaporator' International Engineering Research Journal (IERJ) Special Issue, pp.835-840, ISSN 2395-1621, June 2016.

[2] R.Rademacher, K.Kim 'Domestic refrigerator Recent developments' Int. J. Refrigeration, Vol 19, No.1, pp.1-9 1996.

[3] Horuz, E.Kuem , R.Yamankaradeinz. 'Experimental and theoretical performance analysis of air cooled plate finned tube evaporators' Int. comm. heat and mass transfer, Vol. 25, no.6, pp.787-798, 1998.

[4] S.P.Porkhial, B.khastoo , M saffar Avval. 'Transient response of dry expansion evaporator in household refrigerator' Applied Thermal Engineering 24, pp 1465–1480, 2004.

[5] Nan chen, Lie xu, Hai dong Feng,Chun guang yang. 'Performance investigation of a finned tube evaporator under the oblique frontal air velocity distribution' Applied Thermal Engineering 25, pp 113–125, 2005.

[6] A.D.Sommers, A.M.Jacobi 'Heat transfer enhancement of a refrigerator evaporator using vortex generation' Applied Thermal Engineering 28, pp 1006–1017, 2005.

[7] Piotr.A.Domanski, David Yashar, Misnung Kim 'Performance of a finned-tube evaporator optimized for different refrigerators and its effect on system efficiency' Applied Thermal Engineering 28, pp 820–827, 2005.

[8] Derya Burcu Ozkan, Erlap Ozil 'Experimental study on the effect of frost parameters on domestic refrigerator finned tube evaporator coils' Applied Thermal Engineering 26, pp 2490–2493, 2006.

[9] Christian J.L Hermesa, Cla'udio Meloa, Cezar O.R.Negra 'A numerical simulation model for plate-type, roll-bond evaporators' Int. J. Refrigeration 31, pp.335-347, 2008.

[10] Anand M.Joshi, Prof.R.D.Shelke , Prof.H.N.Deshpande 'Design of solar water sterilizer assisted with aqua ammonia solar vapour absorption system', international engineering research journal, pp. 801-805, 2016.

[11] Sandip S.Sisat, Prof.S.Y.Bhosale, Prof.H.N. Deshpande 'Experimental performance evaluation of blends of hydrocarbon (R134a/R290 and R134a/R600a) in household refrigerator, international engineering research journal, MECH PGCON 2017.

[12] ASHRAE, 1976. Thermo-physical Properties of Refrigerants.

[13] R S Khurmi and J K Gupta, 'A Textbook of Refrigeration and Air Conditioning' 3rd ed., S Chand and Company ltd, 2007, pp. 125-144.