Appendix D

Calculations:

Case study 1

For Room Airconditioners (1.5 ton) with 3 star rating, consumption = \( \frac{3.517}{2.8} \times X \times 1.5 = 1.88 \text{KWH} \) (* because in the year 2010, in which these ACs were purchased the conversation factor for 3 star was 2.7 to 2.9 or in average 2.8 (HPMP2013)

Every day these Airconditioners run for about 8 hours. So,

2 numbers 2.0 ton AC without star rating consume = \( 3.2 \times 8 \times 2 = 51.2 \text{KWH/day} \)

59 numbers of 1.5 ton AC without star rating consume = \( 2.4 \times 8 \times 59 = 1132.8 \text{KWH/day} \)

If there are 24 working days average every month, then for 8 months (March to October), total consumption at this rate will be = \( 279953.8 \text{KWH} \)

For 14 numbers of 3 star Room ACs consumption is = \( 1.88 \times 14 \times 8 \times 24 \times 8 \times 8 \text{Months} = 40,427.5 \text{KWH} \)

For 2 numbers 1.5 ton RACs, of 5 star (year 2010), consumption = \( \frac{3.517}{3.1} \times 2 \times 1.5 \text{ton} \times 8 \text{hr} \times 24 \text{days} \times 8 \text{months} = 5227.85 \text{KWH} \)

For 2 numbers 2.0 ton RACs, of 5 star (year 2010), consumption = \( \frac{3.517}{3.1} \times 2 \times 2.0 \text{ton} \times 8 \text{hr} \times 24 \text{days} \times 8 \text{months} = 6970.46 \text{KWH} \)

So, total annual energy consumption in the Office due to existing Room Airconditioners = \( 227328 + 40,427.5 + 5227.85 + 6970.46 = 279953.8 \text{KWH} \)

On the other hand if all these Room Airconditioners are replaced by latest 5 Star RACs (year 2014-15) then the consumption would be

\[ \frac{3.517}{3.5} \times 1.5 \text{ton} \times 75 \text{numbers} \times 8 \text{Hrs} \times 24 \text{days} \times 8 \text{Months} = 1,73,639 \text{KWH} \]

Again, if all the four 2.0 ton 5 Star (year 2010) Room Airconditioners are replaced by latest 5 Star RACs (year 2012) then the consumption would be

\[ \frac{3.517}{3.5} \times 1.5 \text{ton} \times 2 \text{numbers} \times 8 \text{Hrs} \times 24 \text{days} \times 8 \text{Months} + \frac{3.517}{3.5} \times 2.0 \text{ton} \times 2 \text{numbers} \times 8 \text{Hrs} \times 24 \text{days} \times 8 \text{Months} = 4152 + 5536 = 10804.22 \text{KWH} \]

As such total consumption would be = \( 1,73,639 + 10804.22 = 1,84,443 \text{ KWH} \)

Pay back time
Price of one 5 Star RAC = Rs. 28,000/-
Cost for replacement of 79 RAC = 79 X 30000 = Rs. 22,12,000

Break even point = Rs. 22,12,000 / Rs. 5,38,679 = 4.1 say 4 years.
So, if all the existing room airconditioners of the ASEB HQ are replaced by new 5 Star marked AC, then the expense may be paid back within 4 years. By the saving in consumption of electricity

(i) Refer to Fig. 5.2.3 In the No-Star Refrigerator,
Power: 14281.5 + 35181.1 = 49462.6 watt.minute (in 6hrs)
Excluding 1st hr, 35181.1 watt.minute in 4.5 hrs, so in 24 hrs
Power consumption = (35181.1/4.5)X24 = 187632.53 watt.minute,
If we consider the additional (14281.5 - 11727*) = 2554.5 watt.minute (the excess amount required in the initial cooling) [* 35181.1 watt min. in 4.5 hrs, so 35181.1 /3=11727 watt min. in 1.5 hrs] 
Total Power consumption in 6 hrs = 35510.15 Watt Minute (without considering the effect of 1st 75 minutes required for initial cooling) i.e. 864 kWh per Annum
i.e. In 365 days = (2554.5 + (187632.53x365))/60 = 1141473.79 watt.hr = 1141 kWh (rounded to nearest integer)

(ii) Similarly, in the same refrigerator with compressor of a 5 star fridge,
Consumption in initial 60 minutes = 9026.25 watt.minutes
Power : 9026.25+26483.9 = 35510.15 watt.minute in 6hrs
Excluding 1st hr, 26483.9 watt.minute in 5hrs,
So in 24 hrs, power consumption = (26483.9/5)X24 = 127122.72 Watt.minute
If we consider the additional (9026.25-26483.9/5) = 3729.47 watt.minute,
Then, annual power consumption i.e. In 365 days
= (3729.47+ 127122.72 x365)/60 = 773392 watt.hr = 773 kWh (rounded to nearest integer)

For initial 60 minutes power consumption = 5440.9 watt.minutes
The consumption during 60 minutes to 360 minutes = 15978.15 watt minutes
Since the initial 60 minutes cooling time is required only once, it is calculated separately.

On the basis of power consumption during next 5 hours, the total consumption in one year = \((15978.15/5) \times 24 \times 365 = 27993718.8 \text{ watt} \times \text{minutes}\)

So, considering the additional power required for initial cooling = \((5440.9 - 15978.15/5) = 2245.27 \text{ watt} \times \text{minutes}\)

Thus the actual power consumption of 4-star refrigerator per year = \(2245.27 + 27993718 = 27995964 \text{ watt} \times \text{minutes} = 467 \text{ kWH}\)

In the experiment No.4 (Figure 5.5), the energy consumption by a 5 star refrigerator

For initial 60 minutes = \(4825.2 \text{ watt} \times \text{minutes}\)

For next 300 minutes = \(14762.28 \text{ watt} \times \text{minutes}\)

On the basis of power consumption during next 5 hours, the consumption per year = \((14762.28 / 5) \times 24 \times 365 = 25863514 \text{ watt} \times \text{minutes}\)

The additional power required in the initial hour = \((4825.2 - 14762.28/5) = 1872.75 \text{ watt} \times \text{minutes}\)

Actual consumption = \(1872.75 + 25863514 = 25865386.75 \text{ watt} \times \text{minutes} = 431 \text{ kWH}\).

15 minutes open in 60 minutes

Annual consumption on the basis of later 5 hours = \((22234.3/5) \times 24 \times 365 = 38954493.6 \text{ watt} \times \text{minutes}\)

Now adding the additional power in initial 60 minutes = \((5455.2 - 22234.3/5) + 38954493.6 = 38955501.6 \text{ watt} \times \text{minutes} = 649 \text{ KWH} \text{ (rounded to nearest integer)}\)

Increase in percentage of Energy Consumption = \((649-431)/431 \times 100\% = 50.58\%\)

When the door is kept open for 10 minutes after every 30 minutes:

Power during initial 60 minutes = \(5328.3 \text{ watt} \times \text{minutes}\)

Power during next 5 hours = \(26406.4 \text{ watt} \times \text{minutes}\)

Power consumption in 365 days = \((26406.4 / 5) \times 24 \times 365 = 46264012.8 \text{ watt} \times \text{minute}\)

Total power consumption including initial additional power = \((5328.3 - 26406.4/5) + 46264012.8 = 46264059.82 \text{ watt} \times \text{minutes} = 771 \text{ kWH/yr}\)
Increase in percentage of Energy consumption = \( \frac{(771-431)}{431} \times 100\% = 78.8\% \)

When the door is kept **open for 5 minutes after every 15 minutes**:

Power consumed during initial 60 minutes = 4965.2 watt.minutes

Power consumption during next 300 minutes = 27319.7 watt.minutes

On the basis of next 300 mins, energy consumption per annum = \( \frac{(27319.7 \times 24 \times 365)}{5} \) = 47864114.4 watt.minutes

Considering additional power consumed during initial 60 minutes, total power consumption = \( \frac{(4965.2-27319.7/5)}{5} + 47864114.4 \) = 798 KWH

Total Consumption When door is kept open for 5 minutes after every 15 minutes = 36112.4 Watt minute = 798 KWH per annum

When the door is kept **open for 90 minutes after every 135 minutes** from starting

Initial 60 minutes = 4825.2 watt.minutes

Next five hours = 30419.55 watt.minutes

On the basis of next five hours, consumption = \( \frac{(30419.55 \times 24 \times 365)}{5} \) = 53295051.6 watt.minutes

Considering initial 60 minutes, consumption = \( (4825.2 - 30419.55/5) + 53295051.6 \) = 53293792.89 watt.minutes = 888 KWH / annum

Increase in percentage of Energy Consumption = \( \frac{(888-431)}{431} \times 100\% = 106\% \)

Total No of refrigerators = 836907 (excluding Godrej refrigerators).

Total consumption per annum = 836907 \times 440 / 1000 = 368239 MWH

Total production of CO2 = 253888 ton per annum

Saving in Power = 468667 – 368239 = 100428 MWH

Saving in CO2 emission = 3329211 – 253888 = 79033 Metric ton

The above calculation is valid only when one considers the comparatively new refrigerators of 3, 4 and 5 star refrigerators are replaced by new 5 star refrigerators.

**1 minute open after every 3 minutes**

Since the opening started from very beginning, so there is no need to consider initial cooling time.

Hence, total power consumption in 6 hours = 37772.4 Watt minute = 919 kWh.

Percentage increase in power consumption = \( \frac{(919 - 431)}{431} \times 100\% = 113\% \)

123
### Analysis:

Number of Refrigerators sold by different major brands in Assam during last 6 years are shown in Table 5.5: (it is a projected figure based on actual sale of refrigerators in 3 years: 2008-09 to 2010-11)

#### Table 5.5 Sale of Refrigerators in Assam:

<table>
<thead>
<tr>
<th>YEAR</th>
<th>NO OF UNITS SOLD (GODREJ)</th>
<th>NO OF UNITS SOLD (LG)</th>
<th>NO OF UNITS SOLD (SAMSUNG)</th>
<th>NO OF UNITS SOLD (WHIRLPOOL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008-2009</td>
<td>15715</td>
<td>42290</td>
<td>23443</td>
<td>12120</td>
</tr>
<tr>
<td>2009-2010</td>
<td>23828</td>
<td>49760</td>
<td>28800</td>
<td>20190</td>
</tr>
<tr>
<td>2010-2011</td>
<td>28742</td>
<td>62195</td>
<td>41900</td>
<td>23800</td>
</tr>
<tr>
<td>2011-2012</td>
<td>33478</td>
<td>71233</td>
<td>62000</td>
<td>29100</td>
</tr>
<tr>
<td>2012-2013</td>
<td>39974</td>
<td>77644</td>
<td>68790</td>
<td>30200</td>
</tr>
<tr>
<td>2013-2014</td>
<td>44528</td>
<td>84322</td>
<td>72800</td>
<td>36320</td>
</tr>
<tr>
<td>TOTAL</td>
<td>186265</td>
<td>387444</td>
<td>297733</td>
<td>151730</td>
</tr>
</tbody>
</table>

Fig. 6.7 a & b Trend of sale of Refrigerators in Assam

On the basis of above Table, it is seen that (i) only 18% of sale is from Godrej, which uses HC (HydroCarbon) as refrigerant, while all other brands use HFC (Hydro-flouro carbon), a high GWP (Global Warming Potential) gas as refrigerant.
Table 6.6: ODP (Ozone Depleting Potential) and GWP of different refrigerants [24]

<table>
<thead>
<tr>
<th>Refrigerant</th>
<th>Atmospheric Lifetime (Years)</th>
<th>ODP</th>
<th>GWP (100 Year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CFC-11 (Baseline ODP)</td>
<td>50</td>
<td>1</td>
<td>4000</td>
</tr>
<tr>
<td>CFC-12</td>
<td>102</td>
<td>1</td>
<td>8500</td>
</tr>
<tr>
<td>CFC Blend</td>
<td>R-502</td>
<td>0.33</td>
<td>5260</td>
</tr>
<tr>
<td>HCFCs</td>
<td>HCFC-22</td>
<td>13.3</td>
<td>0.055</td>
</tr>
<tr>
<td></td>
<td>HCFC-123</td>
<td>1.4</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>HCFC-141b</td>
<td>9.4</td>
<td>0.11</td>
</tr>
<tr>
<td>HFCs</td>
<td>HFC-134a</td>
<td>14.6</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>HFC-152a</td>
<td>1.4</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>HFC-245fa</td>
<td>7.3</td>
<td>0</td>
</tr>
<tr>
<td>Natural Fluids</td>
<td>HC-290 (Propane)</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>HC-600a (Isobutane)</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>HC blend</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>R-744 Carbon Dioxide</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>HFC Blends</td>
<td>R-404A</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>R-407A</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>R-407C</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>R-410A</td>
<td>-</td>
<td>0</td>
</tr>
</tbody>
</table>

From the table 6.6, the GWP of different refrigerants can be found and the same can be used to calculate the TEWI.

Total 836907 number of refrigerators (LG, Whirlpool and Samsung) sold in Assam from 2008-09 to 2013-14 use the HFC based gas: primarily HFC134a. The amount of refrigerant in each refrigerator varies with the size and model of the same. However, on average about 150 gm of refrigerant is kept inside each unit. The expected life of the refrigerators are 15 years (average). Before that on average, a refrigerator is to be serviced/charged with refrigerant after 7/8 years. At the time of servicing most of the cases, the technicians release/vent the refrigerant into the atmosphere. Though lots of training has been being imparted to the technicians of the country under project NCCoPP (for refrigerators) and project HPMP (for Air-conditioners), but due to mainly non-availability of recovery units, about 60% of the gas is released into the atmosphere. As such, 836907 unit X 150 gm X 0.6 /1000 = 75322 Kg of refrigerant is emitted in 10 years or 7532 Kg per year.

125
Now its GWP = 7532 X 1300 (GWP of R134a) = 9791600 i.e it is equivalent to release of 9791 ton of CO\(_2\) into atmosphere per annum.

Secondly consumption of electricity of each refrigerator is about 560 KWhr per annum (considering 477 KWhr to 650 KWhr from 5 star to 3 star respectively in 2008-2011) i.e. for 836907 number of refrigerators the total consumption of electricity for 1 year will be 836907 X 560 = 468.667 X 10\(^3\) MWhr. The consequent release of CO\(_2\) into the atmosphere will be 468.667 X 10\(^3\) X 1.216 lbs CO\(_2\) per megawatt-hour generated × 1.25 MWh delivered/MWh generated × 1 metric ton/2,204.6 lb = 323130 Metric Ton of CO\(_2\) (considering all the power is generated from fossil fuel).

Emission of CO\(_2\) per annum by release of refrigerant (HFC) to atmosphere = 9791 ton
Emission of CO\(_2\) per annum due to production of electricity from fossil = 323130 ton
Total emission = 9791 + 323130 = 332921 Metric Ton of CO\(_2\)
It shows that about 97% of emission occurs due to production of electricity, while rest about 3% is due to release or vent of refrigerant from refrigerators by technicians.

![Fig. 6.8 Emission of CO\(_2\) from electricity and refrigerant](image)

In this context it may be mentioned that the supporters of HFCs, such as NRDC's David Goldstein, point out that the amount of HFCs in each fridge is relatively small, so that the entire effect of a refrigerator's HFCs on the climate is only 1% as great as the influence of its energy consumption. If a non-greenhouse substitute for HFCs
increased a fridge's energy use by more than 1%, he says, it would be a net loss for the climate. [King L, 2011]

In Assam total electricity demand: 850 MW (Off peak load) and 1200 MW (peak load); out of which the availability as on 23.12.2014 are 802 Mw and 1059 MW respectively as per data available from NERLDC & SLDC [www.apdcl.gov.in], giving a shortfall of 48 MW and 141 MW respectively. Out of this, about 479 MW is produced from fossil fuel and the rest from hydro power. (source: apdcl.com).

\[
\text{CO}_2 \text{ release due to production of this electricity} = 479 \text{ MW} \times 1,216 \text{ lbs CO}_2 \text{ per megawatt-hour generated} \times 1.25 \text{ MWh delivered/MWh generated} \times 1 \text{ metric ton/2,204.6 lb} = 330.25 \text{ metric tons CO}_2/\text{per hour}
\]
\[
\text{or } 330.25 \times 24 \times 365 = 2893.03 \times 10^3 \text{ Metric tons of CO}_2/\text{per annum}
\]
due to the production of electricity for Assam alone. There is large scope of reduction of emission of CO2 from production of electricity by converting most of the refrigerators and air-conditioners of Assam by new 5 star marked ones.

Now if all the refrigerators of Assam are replaced by new 5 Star (of 2014) refrigerators, the savings will be tremendous. Even if we consider only the comparatively new refrigerators (from 2008-2013) sold in Assam by different manufacturers (Table 5.5) and replace these by new refrigerators (5Star) of latest model (2014) the total savings will be as follows:

Total No of refrigerators = 836907 (excluding Godrej refrigerators).
Consumption of electricity per refrigerator per annum= 440 KWHr (average)
Total consumption per annum = 836907 X 440 /1000 = 368239 MWHr
Total production of CO2 = 253888 ton per annum

\[
\text{Saving in Power} = 468667 \text{ - } 368239 = 100428 \text{ MWHr}
\]

\[
\text{Saving in CO2 emission} = 332921 \text{ - } 253888 = 79033 \text{ Metric ton}
\]
The above calculation is valid only when one considers the comparatively new refrigerators of 3, 4 and 5 star refrigerators are replaced by new 5 star refrigerators.
To be more pragmatic the survey undertaken within this research activity may be explored as given below:

Table 6.7: No of Houses having Refrigerators with different Star Marking (Survey)

<table>
<thead>
<tr>
<th>Total No of houses visited</th>
<th>No of Houses having Refrigerators with following Star Marking</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5 Star</td>
</tr>
<tr>
<td>120</td>
<td>50</td>
</tr>
</tbody>
</table>

Fig. 6.11 Number of houses having refrigerators with different Star mark
Prospect of energy saving in Guwahati

According to 2011 Census Number of households in Guwahati = 2,03,456

Considering 50% of them have one Refrigerator i.e about 1.0 lakh, then on the basis of above fig 5.10, total 59% of them are not having 5Star marked refrigerators or in other words 41% or 41,000 have 5-Star, 37% or 37,000 have 4 Star, 17% or 17,000 have 3 Star and 5% or 5,000 have No-star marked refrigerators. If Government somehow manage to replace all these refrigerators especially non-5-star marked ones by new 5-star marked refrigerators then savings will be as follows:

Present consumption = 560 KWHr for each 4-Star marked refrigerator per annum (actual average)
And 600 KWHr for each 3-Star marked refrigerator per annum (actual average)
And 800 KWHr for each No-Star marked refrigerator per annum (actual average)
Total consumption = $37000 \times 560 + 17000 \times 600 + 5000 \times 800$ KWHr = 20720 + 10200 + 4000 = 34920 MWHr per annum

On the other hand replacing these 59000 by 5-Star (new) refrigerator will lead to consumption = 59000 $\times 440$ KWHr = 25960 MWHr

The saving in consumption of electricity = 34920 – 25960 = 8960 MWHr
Consequent saving in emission of CO\(_2\) = 8960 \times 1261 \times 1.25 \times \frac{1}{2204.6} = 1281

Metric ton.

Considering only the refrigerators of Guwahati city, the savings are substantial.

Finally it is observed that use of Energy Star in Domestic Refrigerators and Room Air-conditioners contribute in saving Electric Energy and Environment and also is beneficial to the customer as he/she saves money from reduced electricity bills.

**Calculations for Analysis of Airconditioners:**

From the graph 8.3 for 8 months (240 days) running @ 8hrs per day,

The power consumption with R-22 refrigerant standard (590 gm)

= \(241350\) Watt.minutes

= \(241350 \times \frac{8}{6} \times 240 \times \frac{1}{60000}\)

= 1287 kWh

The power consumption with R600a = 159604 watt.minutes (for 6 hours)

= \(159604 \times \frac{8}{6} \times 240 \times \frac{1}{60000}\)

= 851 kWh per annum

If only R600a refrigerant is considered at different amount of refrigerant inside the system, then the consumptions are as follows

For 236gm of R-600a energy consumption

= 159604 watt meter per 6hours

For 8 hours a day for 240 days a year consumption

= \((159604 \times 8/6 \times 210)/60000\)

= 851 kWh

For 227gm of R-600a i.e. 4\% less (which is equivalent to 10\% less in case of R-22) the energy consumption

= 158354.25 watt.minutes per 6 hours
For 8 hours a day for 210 days a year consumption

\[= \frac{(158454.25 \times 8/6 \times 210)}{60000}\]

\[= 845 \text{kWH}\]

For 227gm of R-600a i.e. 8% less (which is equivalent to 20% less in case of R-22) the energy consumption

\[= \frac{157554.25 \text{ watt minutes per 6 hours}}{60000}\]

For 8 hours a day for 210 days a year consumption

\[= \frac{(157554.25 \times 8/6 \times 210)}{60000}\]

\[= 840 \text{kWH}\]

From equation (6.1)

\[LCC = IC + \sum_{t=1}^{N} \frac{OC_t}{(1 + r)^t}\]

\[= 15200 + \frac{2430}{(1+0.06)^1} + \frac{2430}{(1+0.06)^2} + \frac{2430}{(1+0.06)^3} + \frac{2930}{(1+0.06)^4} + \frac{3030}{(1+0.06)^5} + \frac{3030}{(1+0.06)^6} + \frac{3030}{(1+0.06)^7} + \frac{3030}{(1+0.06)^8} + \frac{3030}{(1+0.06)^9} + \frac{3030}{(1+0.06)^10} + \frac{3030}{(1+0.06)^11} + \frac{3030}{(1+0.06)^12} + \frac{3030}{(1+0.06)^13} + \frac{3030}{(1+0.06)^14} + \frac{3030}{(1+0.06)^15}\]

\[= \text{Rs. 15200} + 2292 + 2163 + 2040 + 2321 + 2264 + 2136 + 2015 + 1901 + 1794 + 1692 + 1596 + 1507 + 1422 + 1341 + 1268 = \text{Rs. 42952}\]

Hence the Life time cost of the 5 star refrigerator = Rs.42952/-

If we consider the LCC of a no-star refrigerator, then

From equation (6.3)

\[OC_f = EC + RC + MC\]

\[OC_i = \text{Rs.5.64 X 1347 + 0 +0 = Rs.7597}\]
OC_2 = Rs. 5.64 \times 1347 + 0 + 0 = Rs. 7597 \\
OC_3 = Rs. 5.64 \times 1347 + 0 + 0 = Rs. 7597 \\
OC_4 = Rs. 5.64 \times 1347 + 233 + 0 = Rs. 7830 \\
OC_5 = Rs. 5.64 \times 1347 + 233 + 100 = Rs. 7930 \\
OC_6 = OC_7 = OC_8 = OC_9 = OC_{10} = OC_{11} = OC_{12} = OC_{13} = OC_{14} = OC_{15}

From equation (6.1), taking price of no-star refrigerator as Rs. 7000/-

\[ \text{LCC} = IC + \sum_{t=1}^{N} \frac{OC_t}{(1 + r)^t} \]

\[ = (\text{Rs. 7000/-} + 200/-) + 7597/ (1+0.06)^1 + 7597/ (1+0.06)^2 + 7597/ (1+0.06)^3 \\
+ 7830/ (1+0.06)^4 + 7930/ (1+0.06)^5 + 7930/ (1+0.06)^6 + 7930/ (1+0.06)^7 \\
+ 7930/ (1+0.06)^8 + 7930/ (1+0.06)^9 + 7930/ (1+0.06)^10 + 7930/ (1+0.06)^11 \\
+ 7930/ (1+0.06)^12 + 7930/ (1+0.06)^13 + 7930/ (1+0.06)^14 + 7930/ (1+0.06)^15 \\
= \text{Rs. 7200} + \text{Rs. 7167} + \text{Rs. 6761} + \text{Rs. 6379} + \text{Rs. 6214} + \text{Rs. 5926} + \text{Rs. 5592} + \text{Rs. 5287} + \text{Rs. 4987} \\
+ \text{Rs. 4695} + \text{Rs. 4430} + \text{Rs. 4178} + \text{Rs. 3945} + \text{Rs. 3723} + \text{Rs. 3509} + \text{Rs. 3318} \\
= \text{Rs. 85311/-} \]

\text{Life time cost of the No star refrigerator} = \text{Rs. 85311/-} \]

The same lcc analysis for a 4 star refrigerator is as follows

From equation (6.3), considering the price of 4 star refrigerator as Rs. 13500/-

\[ OC_t = EC + RC + MC \]

\begin{align*}
OC_1 &= \text{Rs. 5.64} \times 467 + 0 + 0 = 2634 \\
OC_2 &= \text{Rs. 5.64} \times 467 + 0 + 0 = 2634 \\
OC_3 &= \text{Rs. 5.64} \times 467 + 0 + 0 = 2634 \\
OC_4 &= \text{Rs. 5.64} \times 467 + 450 + 0 = 3084 \\
OC_5 &= \text{Rs. 5.64} \times 467 + 450 + 100 = 3184 \\
OC_6 &= OC_7 = OC_8 = OC_9 = OC_{10} = OC_{11} = OC_{12} = OC_{13} = OC_{14} = OC_{15}
\end{align*}

132
Now, again from equation (6.1)

\[ \text{LCC} = \text{IC} + \sum_{t=1}^{N} \frac{\text{OC}_t}{(1+r)^t} \]

\[ = (\text{Rs.13500} + 200) + \frac{2634}{(1+0.06)^1} + \frac{2634}{(1+0.06)^2} + \frac{2634}{(1+0.06)^3} \]
\[ + \frac{2634}{(1+0.06)^4} + \frac{2634}{(1+0.06)^5} + \frac{2634}{(1+0.06)^6} + \frac{2634}{(1+0.06)^7} \]
\[ + \frac{2634}{(1+0.06)^8} + \frac{2634}{(1+0.06)^9} + \frac{2634}{(1+0.06)^{10}} + \frac{2634}{(1+0.06)^{11}} \]
\[ + \frac{2634}{(1+0.06)^{12}} + \frac{2634}{(1+0.06)^{13}} + \frac{2634}{(1+0.06)^{14}} + \frac{2634}{(1+0.06)^{15}} \]
\[ = \text{Rs.13700} + 2485 + 2346 + 2213 + 2444 + 2380 + 2245 + 2123 + 1999 \]
\[ + 1885 + 1779 + 1676 + 1584 + 1495 + 1409 + 1329 \]
\[ = \text{Rs. 43092/-} \]

**Life time cost of the 4 star refrigerator = Rs.43092/-**

The observed difference in life cycle cost is shown in Figure D-1.
From equation (6.3)

OC\(_j\) is calculated as follows

\[
OC_1 = Rs 5.64 \times 431 \text{KWH/yr} + 0 + 0 \text{ (first year)} = Rs.2430/-
\]

\[
OC_2 = Rs 5.64 \times 431 \text{KWH/yr} + 0 + 0 \text{ (2nd year)} = Rs.2430/-
\]

\[
OC_3 = Rs 5.64 \times 431 \text{KWH/yr} + 0 + 0 \text{ (3rd year)} = Rs.2430/-
\]

\[
OC_4 = Rs 5.64 \times 431 \text{KWH/yr} + 500 + 0 \text{ (4th year)} = Rs.2930/-
\]

\[
OC_5 = Rs 5.64 \times 431 \text{KWH/yr} + 500 + 100 \text{ (5th year)} = Rs.3030/-
\]

\[
OC_6 = Rs 5.64 \times 431 \text{KWH/yr} + 500 + 100 \text{ (5th year)} = Rs.3030/-
\]

\[
OC_7 = OC_8 = OC_9 = OC_{10} = OC_{11} = OC_{12} = OC_{13} = OC_{14} = OC_{15}
\]

Now, from equation (6.3)

\[
OC_t = \text{EQ} + \text{RC} + \text{MC}
\]

\[
OC_1 = Rs 5.64 \times 1287 \text{KWH/yr} + 0 + 0 \text{ (first year)} = Rs.7259/-
\]

\[
OC_2 = Rs 5.64 \times 1287 \text{KWH/yr} + 0 + 0 \text{ (2nd year)} = Rs.7259/-
\]

\[
OC_3 = Rs 5.64 \times 1287 \text{KWH/yr} + 933 + 467 \text{ (3rd year)} = Rs.8659/-
\]

\[
OC_4 = Rs 5.64 \times 1287 \text{KWH/yr} + 933 + 467 \text{ (4th year)} = Rs.8659/-
\]

\[
OC_5 = Rs 5.64 \times 1287 \text{KWH/yr} + 933 + 467 \text{ (5th year)} = Rs.8659/-
\]

\[
OC_6 = Rs 5.64 \times 1287 \text{KWH/yr} + 933 + 467 \text{ (6th year)} = Rs.8659/-
\]

\[
OC_7 = OC_8 = OC_9 = OC_{10} = OC_{11} = OC_{12} = OC_{13} = OC_{14} = OC_{15}
\]
From equation (6.1) again,

\[ \text{LCC} = \text{IC} + \sum_{t=1}^{N} \frac{\text{OC}_t}{(1+r)^t} \]

taking \( r = 6\% \) as recommended for split AC and lifetime = 15 years (ASHRAE)

\[ = 30000 + \frac{7259}{(1+0.06)} + \frac{7259}{(1+0.06)^2} + \frac{8659}{(1+0.06)^3} + \frac{8659}{(1+0.06)^4} + \frac{8659}{(1+0.06)^5} + \frac{8659}{(1+0.06)^6} + \frac{8659}{(1+0.06)^7} + \frac{8659}{(1+0.06)^8} + \frac{8659}{(1+0.06)^9} + \frac{8659}{(1+0.06)^10} + \frac{8659}{(1+0.06)^11} + \frac{8659}{(1+0.06)^12} + \frac{8659}{(1+0.06)^13} + \frac{8659}{(1+0.06)^14} + \frac{8659}{(1+0.06)^15} \]

\[ = \text{Rs. 30000} + 6848 + 6460 + 7270 + 6861 + 6472 + 6106 + 5773 + 5446 + 5127 + 4837 + 4562 + 4308 + 4061 + 3831 + 3614 \]

\[ = \text{Rs. 111576} \]

7.4.1 LCC with 10% less refrigerant in the 4th year (say)

From equation (6.3)

\[ \text{OC}_t = \text{EC}_t + \text{RC}_t + \text{MC}_t \]

\[ \text{OC}_1 = \text{Rs}5.64 \times 1287 \text{ KWH/yr} + 0 + 0 \text{ (first year)} \]
\[ = \text{Rs. 7259/-} \]

\[ \text{OC}_2 = \text{Rs}5.64 \times 1287 \text{ KWH/yr} + 0 + 0 \text{ (2nd year)} \]
\[ = \text{Rs. 7259/-} \]

\[ \text{OC}_3 = \text{Rs}5.64 \times 1287 \text{ KWH/yr} + 933 + 467 \text{ (3rd year)} \]
\[ = \text{Rs. 8659/-} \]

\[ \text{OC}_4 = \text{Rs}5.64 \times 1587 \text{ KWH/yr} + 933 + 467 \text{ (4th year)} \]
\[ = \text{Rs. 10351/-} \]

\[ \text{OC}_5 = \text{Rs}5.64 \times 1587 \text{ KWH/yr} + 933 + 467 \text{ (5th year)} \]
\[ = \text{Rs. 10351/-} \]
OC\(_6\) = Rs5.64 \times 1287\text{KWH/yr} + 933 + 467 (6^{\text{th}} \text{ year})
= Rs.10351/-

OC\(_7\) = OC\(_8\) = OC\(_9\) = OC\(_{10}\) = OC\(_{11}\) = OC\(_{12}\) = OC\(_{13}\) = OC\(_{14}\) = OC\(_{15}\)

From equation (6.1) again,
\[
\text{LCC} = IC + \sum_{t=1}^{N} \frac{OC_t}{(1 + r)^t}
\]
\[
= 30000 + \frac{7259}{(1+0.06)^1} + \frac{7259}{(1+0.06)^2} + \frac{8659}{(1+0.06)^3} + \frac{10351}{(1+0.06)^4} + \frac{10351}{(1+0.06)^5} + \frac{10351}{(1+0.06)^6}
+ \frac{10351}{(1+0.06)^7} + \frac{10351}{(1+0.06)^8} + \frac{10351}{(1+0.06)^9}
+ \frac{10351}{(1+0.06)^10} + \frac{10351}{(1+0.06)^11} + \frac{10351}{(1+0.06)^12}
+ \frac{10351}{(1+0.06)^13} + \frac{10351}{(1+0.06)^14} + \frac{10351}{(1+0.06)^15}
\]
= Rs. 30000 + 6848 + 6460 + 7270 + 8202 + 7341 + 6901 + 6510 + 6128 + 5783 + 5454 + 5150 + 4855 + 4580 + 4320 = Rs. 123536

7.4.2 LCC with 20% less refrigerant in the 4th year (say)

from equation (6.3)
\[
OC_t = EC_t + RC_t + MC_t
\]

OC\(_1\) = Rs5.64 \times 1287\text{KWH/yr} + 0 + 0 (\text{first year})
= Rs.7259/-

OC\(_2\) = Rs5.64 \times 1287\text{KWH/yr} + 0 + 0 (\text{2nd year})
= Rs.7259/-

OC\(_3\) = Rs5.64 \times 1287\text{KWH/yr} + 933 + 467 (\text{3rd year})
= Rs.8659/-
From equation (6.1) again,

\[ \text{LCC} = \text{IC} + \sum_{t=1}^{N} \frac{OC_t}{(1+r)^t} \]

\[ = 30000 + \frac{7259}{(1+0.06)^1} + \frac{7259}{(1+0.06)^2} + \frac{8659}{(1+0.06)^3} + \frac{10819}{(1+0.06)^4} + \frac{10819}{(1+0.06)^5} + \frac{10819}{(1+0.06)^6} + \frac{10819}{(1+0.06)^7} + \frac{10819}{(1+0.06)^8} + \frac{10819}{(1+0.06)^9} + \frac{10819}{(1+0.06)^{10}} + \frac{10819}{(1+0.06)^{11}} + \frac{10819}{(1+0.06)^{12}} + \frac{10819}{(1+0.06)^{13}} + \frac{10819}{(1+0.06)^{14}} + \frac{10819}{(1+0.06)^{15}} \]

\[ = \text{Rs. 30000} + 6848 + 6460 + 7270 + 8573 + 8086 + 7673 + 7213 + 6804 + 6406 + 6044 + 5700 + 5377 + 5075 + 4787 + 4527 = \text{Rs. 126841} \]

Present consumption = 560 kWh for each 4-Star marked refrigerator per annum (actual average)
And 600 kWh for each 3-Star marked refrigerator per annum (actual average)
And 800 kWh for each No-Star marked refrigerator per annum (actual average)
Total consumption = 34,360 X 560 + 16,870 X 600 + 16,250 X 800 kWh = 20720 + 10200 + 4000 = 34920 MWh per annum
On the other hand replacing these 59000 by 5-Star (new) refrigerator will lead to consumption = 59000 X 440 kWh = 25960 MWH
Calculation of release of CO$_2$ equivalent from leakage/ bad servicing practice

(i) As such, 836907 unit X 150 gm X 0.8 /1000 = 100429 Kg of refrigerant is emitted in 10 years or 10043 Kg per year.

Now its GWP = 10043 X 1300 (GWP of R134a) =13055900 i.e it is equivalent to release of about 13056 ton of CO$_2$ into atmosphere per annum.

This amount is without considering already existing refrigerators before 2008.

(ii) Secondly consumption of electricity of each refrigerator is about 466 KWH per annum (considering 431 KWH to 500 KWH from 5 star to 3 star respectively in 2008-2011) i.e. for 836907 number of refrigerators the total consumption of electricity for 1 year will be 836907 X 466 = 389998662 kWH = 390 X 10$^3$MWH (approx)

(iii) The consequent release of CO$_2$ into the atmosphere will be 390 X 10$^3$X1,216 lbs CO$_2$ per megawatt-hour generated $\times$ 1.25 MWh delivered/MWh generated $\times$ 1 metric ton/2,204.6 lb = 268892 Metric Ton of CO$_2$.(considering all the power is generated from fossil fuel).

However from table 6.4, it is found that out of total 1159 MW of power allotted to Assam a total of 164+38+162+157+120 = 641 MW is from thermal/gas based power stations and the rest from Hydro Electric Power station i.e. 55.3% is from fossil fuel.

So, the amount of release of CO$_2$ = 268892 X 0.553 = 148697 metric ton.

Now, if all the refrigerators of Assam are replaced by new 5 Star (of 2014) refrigerators, the savings will be tremendous. Even if only the comparatively new refrigerators (from 2008-2013) sold in Assam by different manufacturers (Table 6.5) it are considered and replaced by new refrigerators (5Star) of latest model (2014), then the total savings will be as follows:

Total No of refrigerators = 836907 (excluding Godrej refrigerators).

Consumption of electricity per refrigerator = 440 kWh (average)

Total consumption per annum = 836907 X 440 /1000 = 368239 MWH

Total production of CO$_2$ = 253888 ton per annum

Saving in Power = 468667 - 368239 =100428 MWH
The above calculation is valid only when one considers the comparatively new refrigerators of 3, 4 and 5 star refrigerators are replaced by new 5 star refrigerators.

To be more pragmatic, the survey undertaken within this research activity may be explored as given below:

165-225 litres are the preferred capacities, with a 91% grip on the market in the direct cool segment. Out of this, 165 to 184 litres category has 45% share and 185-225 litres category has 46% share. (Refrigerators, 2011, internet)

In both refrigerators and air conditioners the sale pattern is about 30:40:40 among 3 star, 4 star and 5 star marked products. No 1 star and 2 star are available in the market.