Portable+ Thermostats
Towards Comfortable-Energy Savings

Milan Jain
26-Sep-2017
Introduction

Energy Window
South Lakes Windows Ltd
PVC U Window System
System 10 A Rated

<table>
<thead>
<tr>
<th>Energy Index (kWh/m²/year)</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Index certified by BFRC and based on UK Standard window. The actual energy consumption for a specific application will depend on the building, the local climate and the indoor temperatures.</td>
<td></td>
</tr>
<tr>
<td>The climate zone is:</td>
<td></td>
</tr>
<tr>
<td>Thermal Transmittance (U_window)</td>
<td>1.4 W/m².K</td>
</tr>
<tr>
<td>Solar Factor (g_thermal)</td>
<td>0.47</td>
</tr>
<tr>
<td>Effective Air Leakage (L_{ef})</td>
<td>0.00 W/m².K</td>
</tr>
</tbody>
</table>

Reg. No.: 2983/1 AR818
www.bfrc.org

This label is not a statutory requirement. It is a voluntary label provided as a customer service to allow consumers to make informed decisions on the energy performance of competing products.

Energy Guide

Estimated Yearly Operating Cost
$67

Cost Range of Similar Models

630 kWh
Estimated Yearly Electricity Use

Your cost will depend on your utility rates and use.

- Energy Efficiency Ratio = Cooling Capacity (W)/ Power consumption (W)
- Total number of stars is limited to 5 for all ACs.
- No. of stars in red background indicates the rating granted to that particular model.
- e.g. This one is a 4 star rated model
- Brand-specific details
- Logo of Bureau of Energy Efficiency

The more stars the more energy efficient

Energy Rating

Annual Energy Cost $XX
Annual Energy Consumption XXX kWh

Compare models at www.energysaving.gov.au

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Introduction

Sector-Wise Electricity Consumption

- Residential: 26%
- Commercial: 21%
- Industry: 24%
- Transportation: 29%
Introduction

India - 3rd largest consumer of Electricity!
Government to sell energy-efficient ACs, fan at lower price: Piyush Goyal

NEW DELHI: After the LED bulb distribution scheme, the government is mulling a similar programme under which it will sell on EMI energy-efficient fans and air conditioners at prices much lower than market rates.

"We will soon come out with highly energy-efficient air conditioners on payment plans, so that you can pay for the air conditioner as you save money," Power Minister Piyush Goyal said addressing a press conference here.
Appliance-Wise Power Consumption

- **Kitchen**: 18%
- **Lighting**: 26%
- **Entertainment**: 16%
- **Heating/Cooling**: 40%
Introduction

Power Consumption (TWh)

# of ACs

AC Power Requirements

Power Consumption (TWh)

- 2006: 50
- 2011: 75
- 2016: 110
- 2021: 164
- 2026: 220
- 2031: 280
Replacement will incur huge capital expenditure - practically infeasible
Introduction

Replacement will incur huge capital expenditure - practically infeasible

The problem of energy-efficient usage of appliance remains unsolved!
Introduction

Make them energy-efficient and SMART!
Introduction

Minimal Instrumentation
Introduction

Minimal Instrumentation

Low-Cost Solution
Introduction

- Minimal Instrumentation
- Low-Cost Solution
- Prioritise User Preference
AC101 - How AC Works?
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AC101 - How AC Works?
AC101 - Intuition

Thermostat Temperature

16 17 18 19 20 21 22 23 24 25 26 27 28
AC101 - Intuition

Thermostat Temperature

![Graph showing thermostat temperature range](image-url)
AC101 - Intuition

![Graph showing thermostat temperature range]

Thermostat Temperature

16 17 18 19 20 21 22 23 24 25 26 27 28
AC101 - Intuition

Thermostat Temperature

16 17 18 19 20 21 22 23 24 25 26 27 28
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Towards Peak Comfort
AC101 - Intuition

Towards Peak Comfort

Thermostat Temperature
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AC Energy Consumption

Thermostat Temperature

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AC Energy Consumption

Thermostat Temperature

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AC Energy Consumption

Scope for Energy Savings

Thermostat Temperature
**AC101 - Intuition**

Towards Peak Comfort

Scope for Energy Savings

**AC Energy Consumption**

Thermostat Temperature
Can we dynamically vary the thermostat temperature (as climate changes) to achieve the desired comfort-energy tradeoff (for the user) while leveraging existing infrastructure?
Approach
Approach
Approach

Along with Thermostat Temperature
Approach

Along with Thermostat Temperature

Comfort-Energy Tradeoff
Approach
Approach

Tuner
Approach

Tuner
Approach

Tuner
Approach

Tuner
Approach

Tuner
Approach

Tuner

Optimiser
Approach

- Tuner
- Optimiser

Temperature:
- 9 PM: 21°C
- 10 PM: 24°C
- 11 PM: 24°C
Approach

Tuner

Optimiser
Approach

9 PM
21°C

10 PM
24°C

11 PM

Tuner

Optimiser
Approach
Approach
Approach
Approach
Approach
Evaluation

Controlled Experiment

#Days = 14
#Rooms = 2
Evaluation

Controlled Experiment

#Days = 14
#Rooms = 2

In-Situ Deployment

#Days = 180
#Rooms = 5
Evaluation Metric - Savings

\[ E_{act/pot^+} = \frac{\tau}{3600} \times \sum_{t=t_{on}}^{t_{off}} S_{AC}^{(t)} \times P_r \]
Evaluation Metric - Savings

\[ E_{act/pot} = \frac{\tau}{3600} \times \sum_{t=t_{on}}^{t_{off}} S^{(t)}_{AC} \times P_r \]

Sampling Rate = 30s
Evaluation Metric - Savings

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Evaluation Metric - Savings

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Compressor On Duration
Evaluation Metric - Savings

\[ E_{act/pot+} = \frac{\tau}{3600} \times \sum_{t=t_{on}}^{t_{off}} S^{(t)}_{AC} \times P_r \]

Sampling Rate = 30s

Compressor On Duration

Rated Power of AC
Evaluation Metric - Savings

\[ E_{act/pot^+} = \frac{\tau}{3600} \times \sum_{t=t_{on}}^{t_{off}} S_{AC}(t) \times P_r \]

Sampling Rate = 30s

Compressor On Duration

\[ savings_{\%} = \frac{E_{act} - E_{pot^+}}{E_{act}} \times 100 \]
Evaluation Metric - Discomfort

PMV Scale

Very Cold  Cold  Cool  Neutral  Warm  Hot  Very Hot
# Evaluation Metric - Discomfort

## PMV Scale

<table>
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<tr>
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<th>Cold</th>
<th>Cool</th>
<th>Neutral</th>
<th>Warm</th>
<th>Hot</th>
<th>Very Hot</th>
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</thead>
</table>

\[
dc_{act/pot+} = \left| pmv_{act/pot+} - pmv_{ref} \right|
\]
Evaluation Metric - Discomfort

PMV Scale

Very Cold  Cold  Cool  Neutral  Warm  Hot  Very Hot

\[ dc_{act/pot+} = \left| pmv_{act/pot+} - pmv_{ref} \right| \]

\[ \Delta_{dc} = \frac{dc_{act} - dc_{pot+}}{dc_{act}} \]
Analysis

Maximising Savings
Mean Energy Savings : 26%

Controlled Experiment: R1-R2
In-Situ Deployment: R3-R7

Energy Savings (%)
Analysis

Maximising Savings
Min. Savings: 17%  |  Max. Savings: 52%

Controlled Experiment: R1-R2
In-Situ Deployment: R3-R7
Maximising Comfort
Mean Energy Savings : 11%

Controlled Experiment: R1-R2
In-Situ Deployment: R3-R7
Maximising Comfort
Min. Savings: 6% | Max. Savings: 25%

Energy Savings (%)

Controlled Experiment: R1-R2
In-Situ Deployment: R3-R7
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Towards Peak Comfort

Scope for Energy Savings

AC Energy Consumption

Thermostat Temperature
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Towards Peak Comfort

Scope for Energy Savings

AC Energy Consumption

Inefficient Region

Thermostat Temperature

16 17 18 19 20 21 22 23 24 25 26 27 28
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Towards Peak Comfort
Scope for Energy Savings

AC Energy Consumption

Thermostat Temperature

Inefficient Region
Efficient Region
Maximising Savings
Mean Improvement in User Comfort: -11%
Maximising Savings
Min. Improvement: -30% | Max. Improvement: 1%

Increase in Comfort (%)
Maximising Comfort
Mean Improvement in User Comfort: 23%
Maximising Comfort
Min. Improvement: 10% | Max. Improvement: 47%
Conclusion

1. Currently, India has 10 million ACs consuming around \(\sim 110\) TWh energy
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2. Portable+ thermostat - a service over existing infrastructure
Conclusion

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   - Can save in between 20-30%
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1. Currently, India has 10 million ACs consuming around ~110 TWh energy

2. Portable+ thermostat - a service over existing infrastructure
   - Can save in between 20-30%
   - And also enhance the user experience by 20-30%
Conclusion

1. Currently, India has 10 million ACs consuming around ~110 TWh energy

2. Portable+ thermostat - a service over existing infrastructure
   - Can save in between 20-30%
   - And also enhance the user experience by 20-30%

3. Can be extended to Roof-Top Units (RTUs) prevalent in the USA.
Thank You