Understanding and Preventing HVAC Power Wastage

Mayank Jain
Guided by Prof Krithi Ramamritham

MTech Project Presentation
Department of Computer Science and Engineering
Indian Institute of Technology, Bombay

{mayankjain,krithi}@cse.iitb.ac.in

June 20, 2016

Overview

Introduction

Energy Consumption Pattern of KReSIT

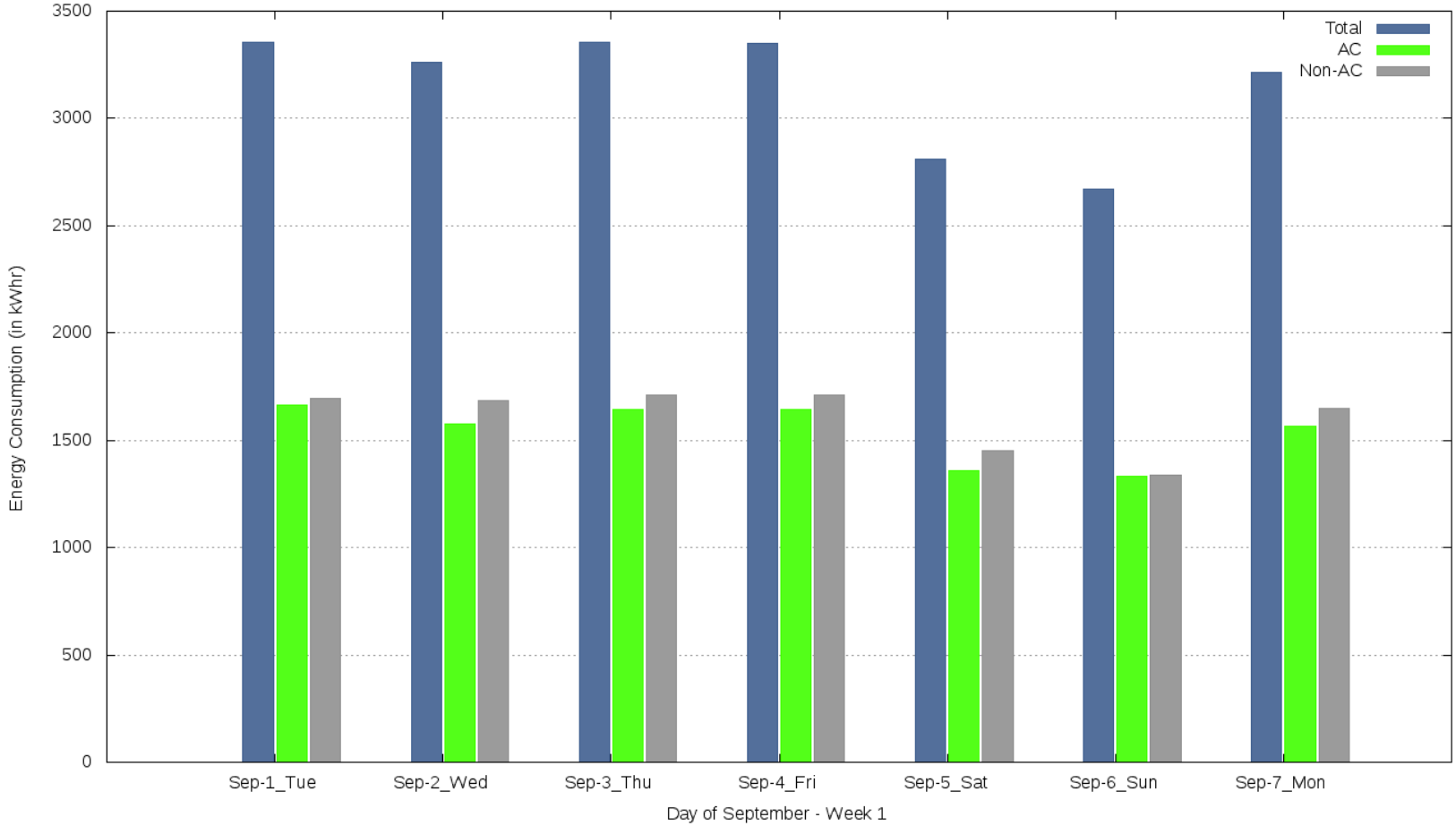

Figure 1 : Energy Consumption of KReSIT in 1st week of September 2015

Focus Areas to Reduce Energy Consumption

Split-up of Energy Consumption

Average Energy Consumption (in kWhr per day)	**Weekdays**	**Weekends**
Total	3307.814	2741.568
AC Load	1618.618	1346.384
Non-AC Load	1689.235	1395.184
AC Load %age	**48.9%**	**49.1%**

Air Conditioning Systems in KReSIT

Overview

- We have over 150 Air Conditioning Systems in KReSIT
- All these systems are different from each other with respect to their working technology

Types of Air Conditioning Systems in KReSIT

- Window AC in Faculty Cabins
- Split ACs in Office, Library, and Server Rooms
- One Chilled Beam System in Circular Hall
- Two Variable Refrigerant Flow (VRF) Air Conditioning System in Classrooms and Laboratories (2nd & 3rd floor)
- One Ducatble Air Conditioning System in F.C. Kohli Auditorium

WHY Focus on Ductable AC of F.C. Kohli Auditorium?

Because...

- Users always feel freezing cold in there
- It doesn't have any centralized system to maintain the thermal comfort level
- Power wastage and User comfort, both are intolerable

Thus...

It is a genuine concern to understand the behaviour of these air conditioning systems, so that we can reduce its energy consumption maintaining user comfort

Understanding Air Conditioning System of F.C. Kohli Auditorium

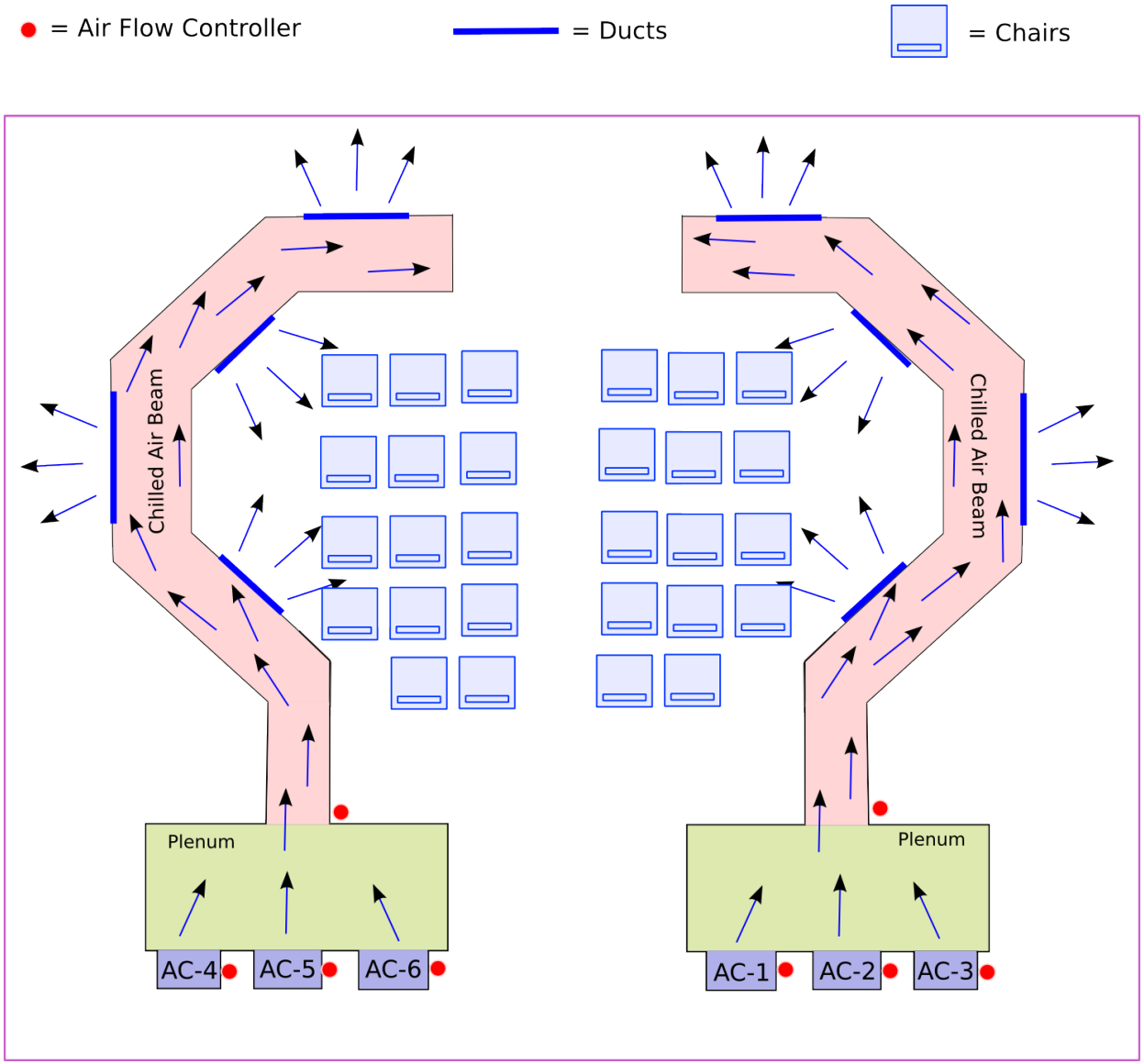

Figure 2 : Schematic of Air Conditioning System in F.C. Kohli Auditorium

Components of Air Conditioning System of FC Kohli Auditorium

- Two Ducted Beams
- Two Air Mixing Plenum Units
- Six Air Conditioning Units

Ducted Beam

- Ducts are used in HVAC system to deliver and remove air
- Duct system is planned (laying out) and optimized with detailed study on finding the pressure losses through it
- Located at the ceiling of the auditorium, on both the halves of the auditorium
- These beams pass the chilled air into the auditorium

Air Mixing Plenum Units

- It is used for mixing air from different ductwork systems
- It has a variable air volume valve which are driven from 0% to 100% opening for balancing the air flow
- It collects chilled air from all air conditioning units and passes it to ducted beam

Air Conditioning Units

- These are 7.5 TR air conditioners manufactured by Voltas
- Their condensing unit uses non-inverter technology based compressor units similar to split-ACs
- They use R22 refrigerant to cool the air in the evaporator
- Their evaporator unit has a fan motor rating of 1.5HP
- They have a air volume control lever attached to it

Air Conditioning Units

- Each air conditioning unit has an individual control panel
- Set point of each air conditioning unit is 23^{o}C
- Studies[2] show that 23^{o}C is the most suitable set point for Air Conditioning systems
- User is comfortable within temperature band of 22^{o}C - 24^{o}C

Current Operation of Auditorium's Air Conditioners

If FC Kohli auditorium is booked for an event of 2 hours, then this is what the HVAC Operator does currently:

- Turn ON four air conditioning units when the event is going to start according to the schedule
- Keep them ON, until the event ends

- We followed this strategy and recorded the power and temperature profile of the auditorium to understand the losses

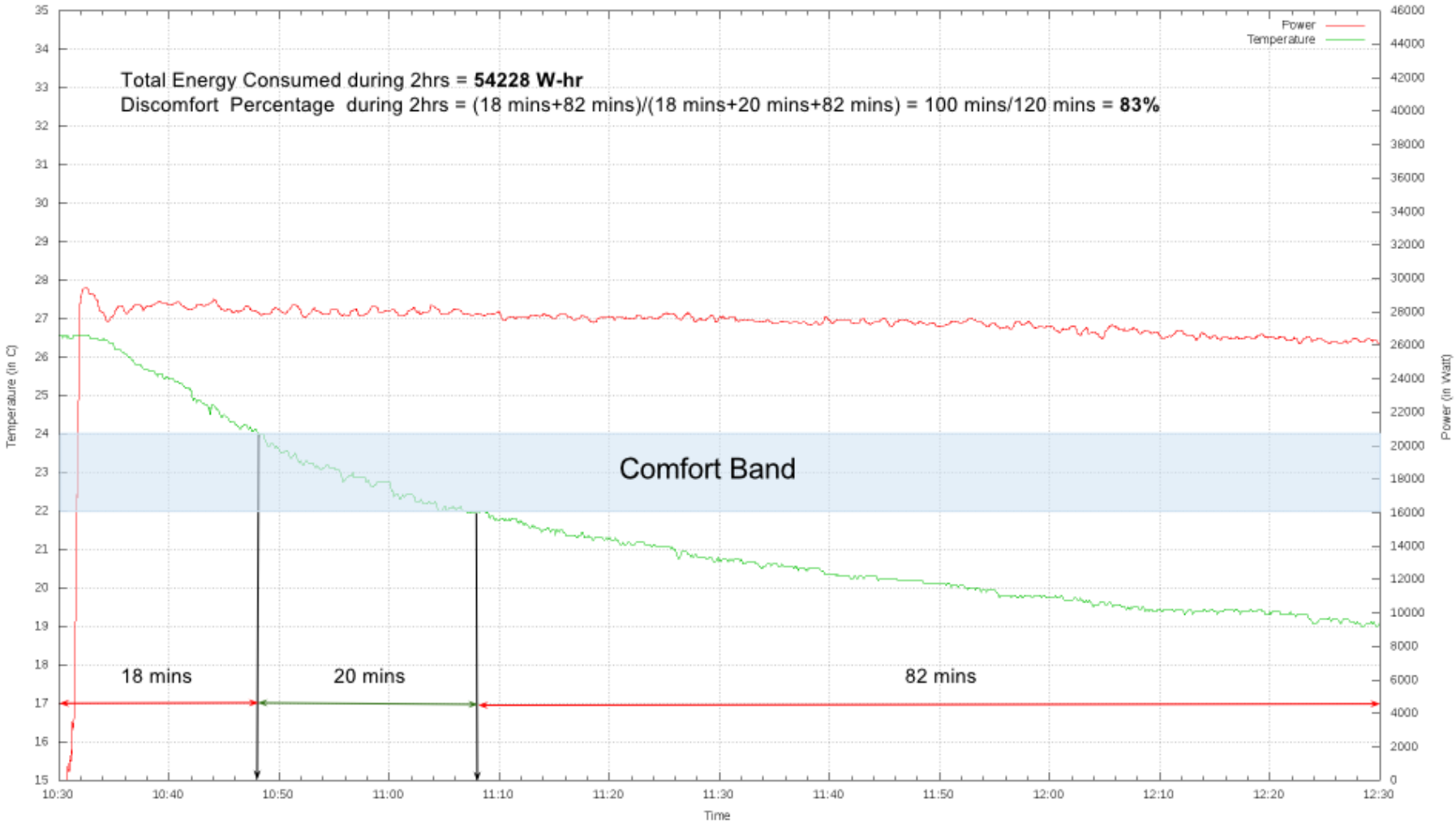

Figure 3 : Current Operation of Auditorium's Air Conditioning System

Observations

- For **initial 18 minutes** user was **uncomfortable** as $T_r > T^U$
- For **last 82 minutes** user was **uncomfortable** as $T_r < T^L$
- User was **comfortable** hardly only for **20 minutes** as $T^L < T_r < T^U$
- Total energy consumption was around **54228 Watt-Hrs**.
- For about **83%** of total event duration users were uncomfortable due to either no cooling or extra cooling.
- Compressor unit didn't turn OFF automatically although the temperature inside the auditorium was far below the set point.

Inferences

- **Pre-cooling** can be applied to get rid of initial discomfort experienced by user
- A thermal comfort **band maintenance** can be done to keep user comfortable throughout
- **Peak shaving** can be done by checking feasibility for minimum number of air conditioning units

Understanding Power Consumption in Non-Inverter Technology

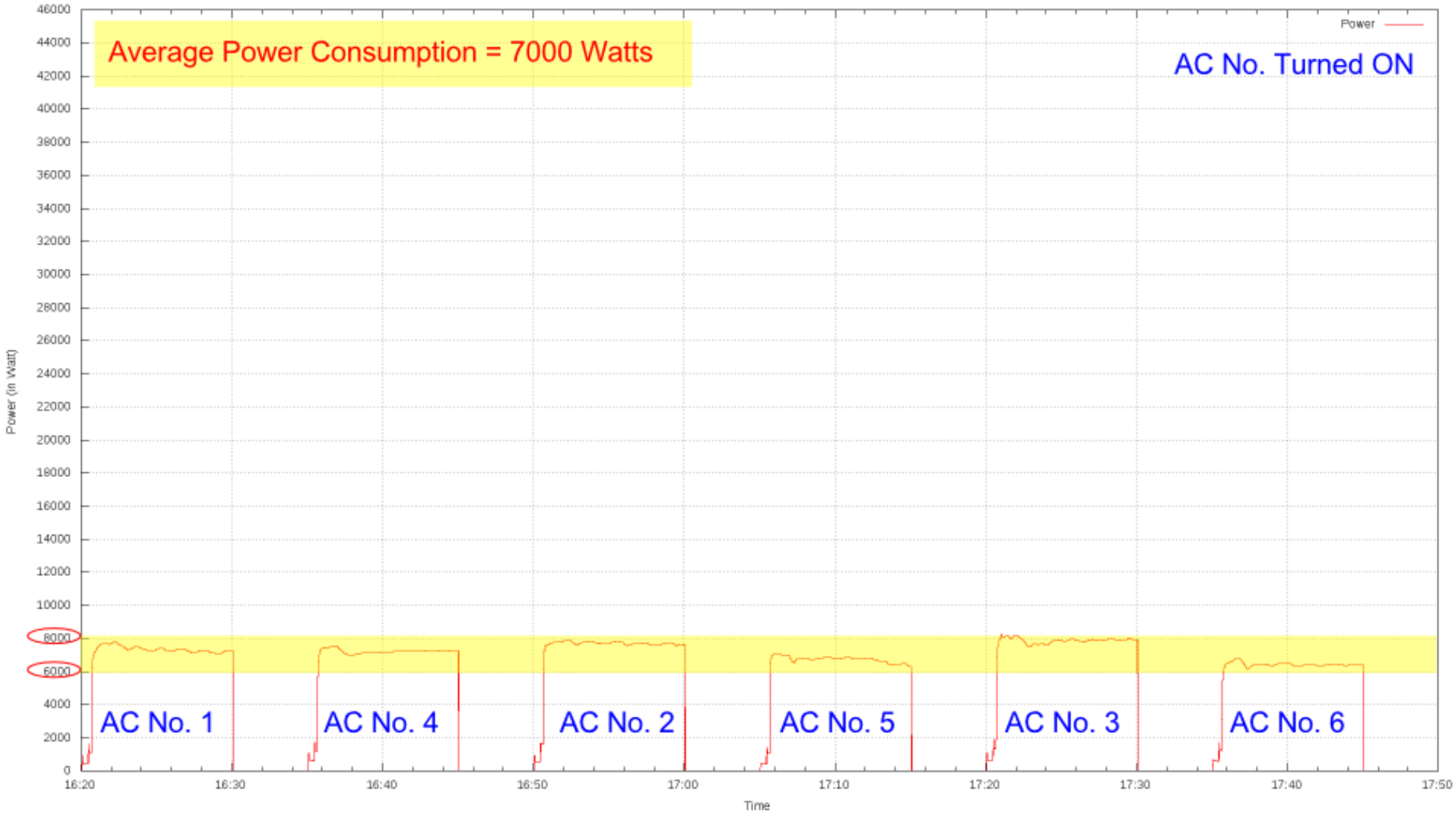

Figure 4 : Power Consumption of individual air conditioning unit

AC ID Turned ON	**Energy Consumed for 10 minutes** (in Watt-Hr)	**Scaled Energy Consumption to 1 hour** (in Watt-Hr)
1	1158	6948
2	906	5436
3	1242	7452
4	1442	8652
5	1064	6384
6	1004	6024

Table 1 : Power Consumption of individual air conditioning unit

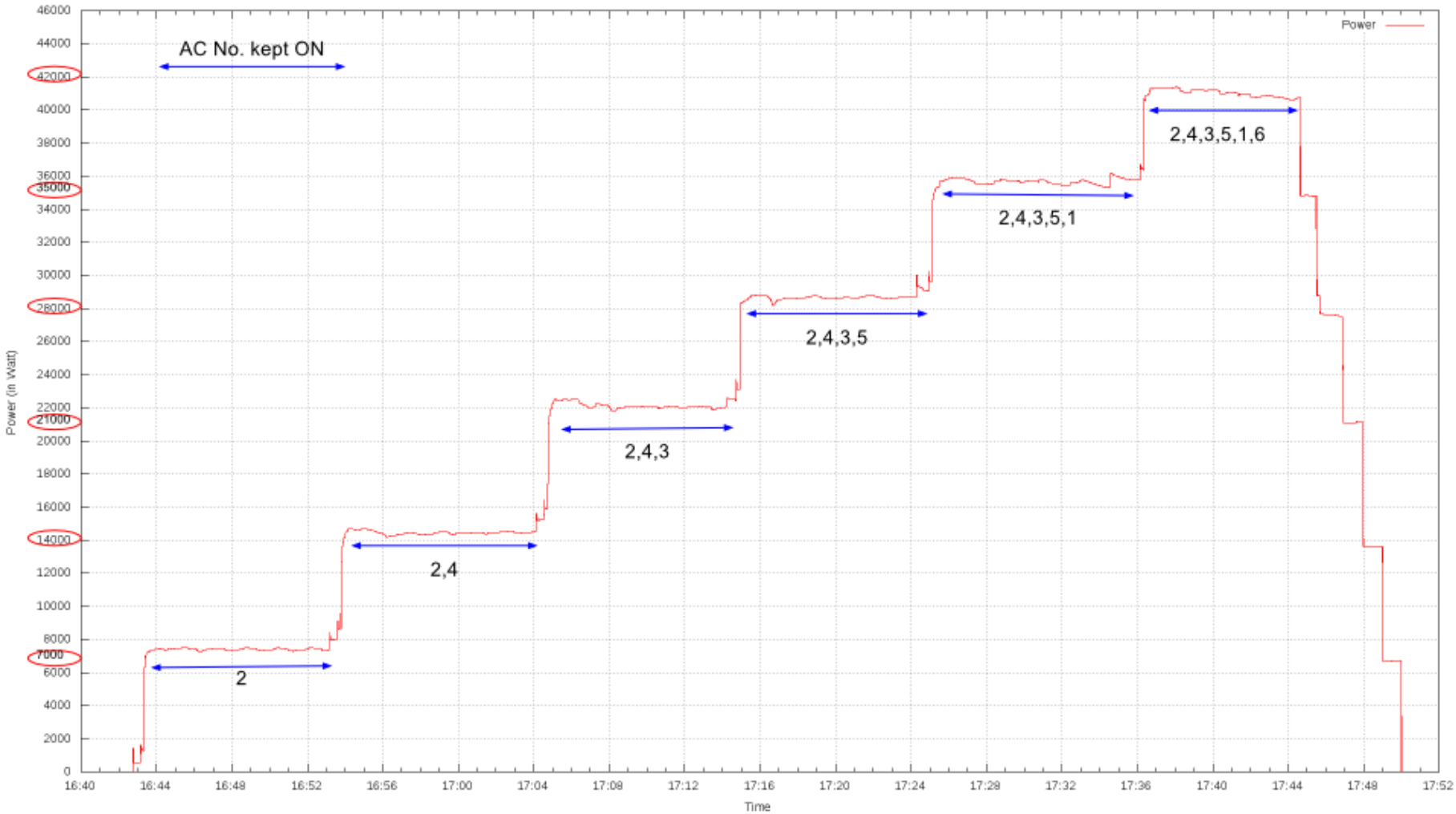

Figure 5 : Cumulative Power Consumption of Air Conditioning Units

Number of ACs Turned ON	**Energy Consumed for 10 minutes** (in Watt-Hr)	**Scaled Energy Consumption to 1 hour** (in Watt-Hr)
1	1160	6960
2	2345	14070
3	3606	21635
4	4694	28164
5	5839	35036
6	6680	40080

Table 2 : Cumulative Power Consumption of air conditioning units

Observations

- Every air conditioning unit consumed about constant power of 6000-8000 Watts throughout
- Power consumption of different number of air conditioning units differs from about 7000 Watts which is big

Inference

- Constant power gap between different number of air conditioning units can be used to determine how many air conditioning units can be turned ON

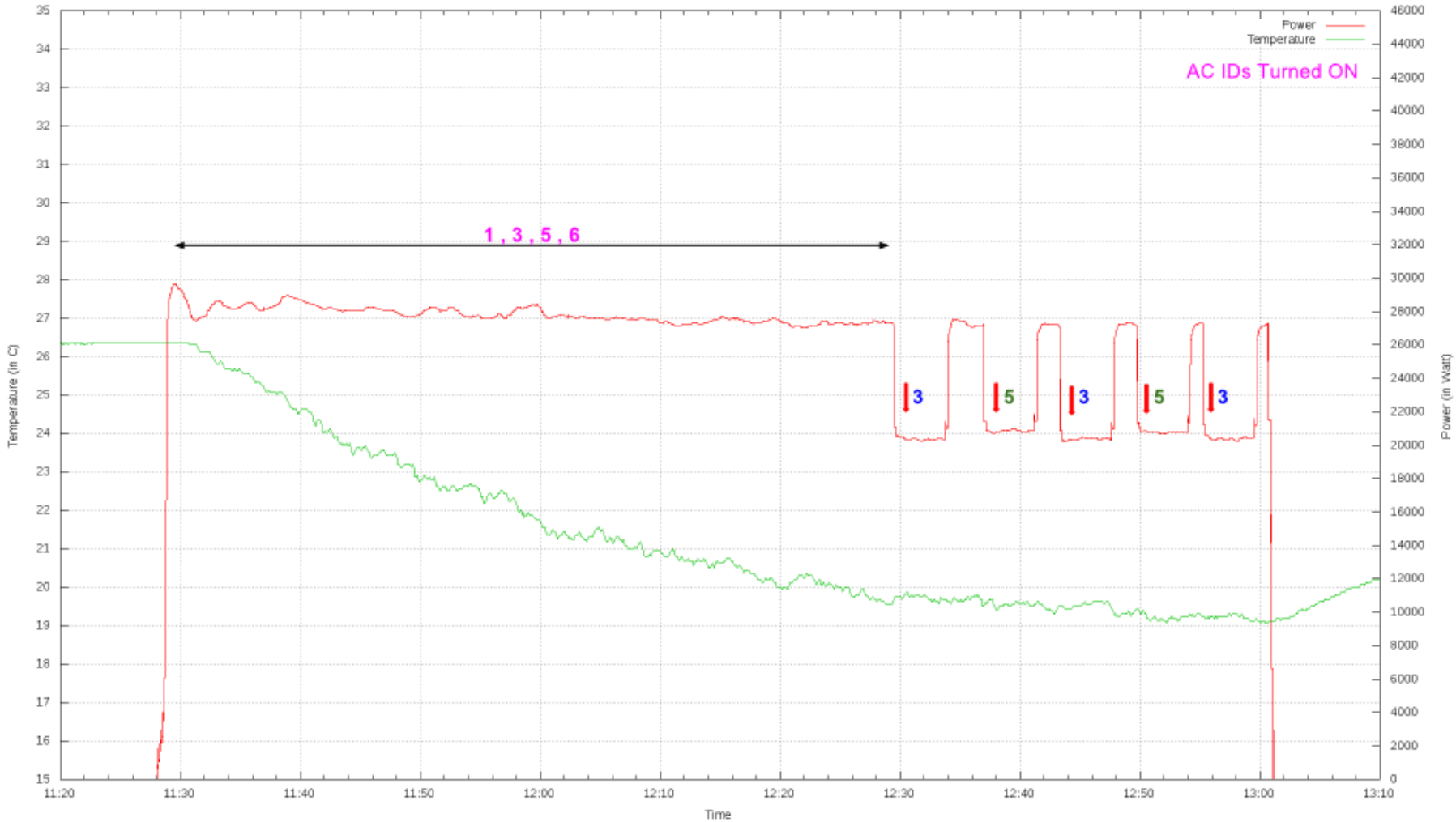

Figure 6 : Automatic Turning ON/OFF of Compressor Unit

Observations

- The temperature of the auditorium was 19.5^{o}C when the set point of 23^{o}C was reached for air conditioning unit
- There is a huge gap of around 4^{o}C between the temperature of the auditorium and the one sensed by the thermostat of the air conditioning unit

Inference

- Feature of automatic turning OFF of the compressor doesn't fulfil its target of maintaining the thermal comfort level and also wastes energy due to extra cooling.

Estimating Maximum Number of Air Conditioning Units under Peak Power Limit

Recalling these observations...

- **Inferred from Figure 5:** Cumulative power consumption of these air conditioning units, show a huge difference of around 7000 watts per air conditioning unit
- **Inferred from Figure 4:** Power consumption of a single air conditioning unit might vary from 8000 watts to 6000 watts at an instant

Equation derived to estimate maximum number of AC

Given Peak Power Limit of P watts, maximum number of air conditioning units m that can be turned ON is given by

$$m = max(\frac{P + 1000}{7000}, \frac{P - 1000}{7000}) \quad (1)$$

Modeling the Cooling of Auditorium

Details of Experiment

- In this experiment, we cooled down the auditorium to its maximum with different number of air conditioning units
- The time duration of the experiments was 3 hours
- Graphs on next slide show the cooling patterns with different number of air conditioning units

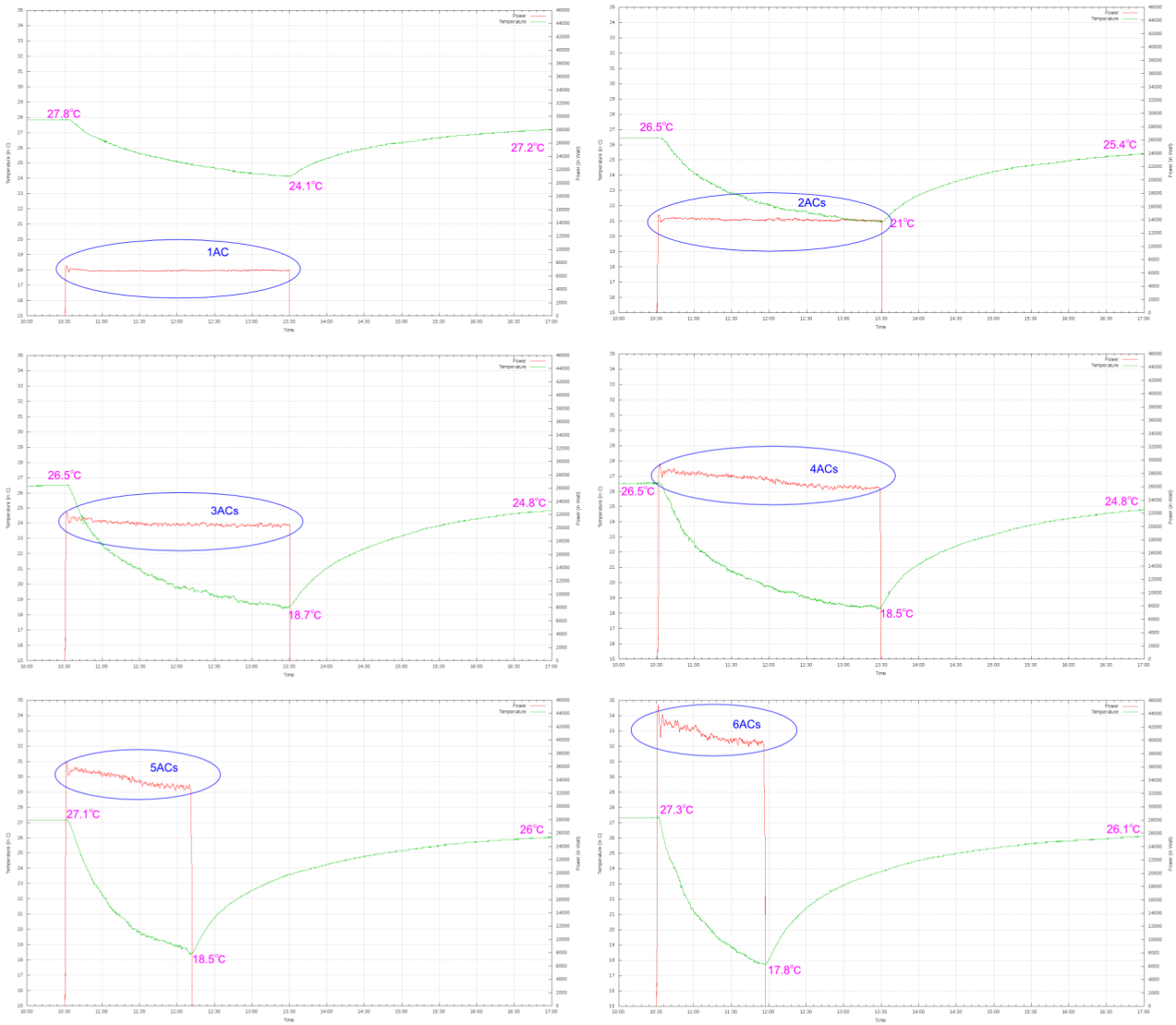

Figure 7 : Cooling by different number of ACs

Number of ACs Turned ON	**Energy Consumed** (in Watt-Hr)	**Time Duration** (in hrs)	**Drop in Temperature** (in ^oC)
1	20408	3	27.8 - 24.1 = **3.7**
2	41950	3	26.4 - 21.0 = **5.3**
3	61764	3	26.4 - 18.8 = **7.6**
4	79832	3	26.5 - 18.5 = **8.0**
5	57428	1.75	27.1 - 18.5 = **8.6**
6	58740	1.5	27.3 - 17.8 = **9.5**

Table 3 : Energy Consumption of Different number of ACs while cooling

Exponential Behaviour of Temperature Change

- Previous studies[1] shows that the change in temperature follows the exponential pattern when the room/auditorium is cooled down or warmed up for a given ambient temperature.
- The exponential pattern of cooling/warming can be given as:

$$T_i(t) = ae^{-bt+c} + d \tag{2}$$

where T_i is the temperature value of the auditorium at a given time instant t

Exponential Behaviour of Temperature Change

- **Figure 7** clearly shows that cooling pattern is different with different number of air conditioning units turned ON
- Hence, the coefficients a,b,c,d for Equation 2 will be different for differnt number of air conditioning units turned ON
- Thus, on fitting the curve upon our experimental data, we get the following values of the coefficients

Number of ACs Turned ON	a	b	c	d
1	14.75	0.00022	-1.279	23.78
2	1.018	0.00022	1.757	20.65
3	0.739	0.00024	2.283	19.19
4	0.742	0.00034	2.372	18.27
5	1.053	0.00052	2.122	18.55
6	7.506	0.00050	0.264	17.02

Table 4 : Cooling coefficients of equation for Different number of ACs

Deriving Equation to Estimate Cooling Time

Equations

- Solving equation 2, we get

$$t = \frac{1}{b}\left(c - ln\frac{T_i - d}{a}\right) \tag{3}$$

- Therefore, the time required for T_i to reach from T^U to T^L can be given as

$$C_i = \frac{1}{b}\left[\left(c - ln\frac{T^U - d}{a}\right) - \left(c - ln\frac{T^L - d}{a}\right)\right] \tag{4}$$

$$C_i = \frac{1}{b} ln\frac{T^L - d}{T^U - d} \tag{5}$$

Number of ACs Turned ON	**26°C-24°C** (in mins)	**24°C-22°C** (in mins)	**22°C-20°C** (in mins)	**20°C-18°C** (in mins)
1	176	-	-	-
2	34	67	-	-
3	24	37	86	-
4	14	20	37	-
5	10	14	27	-
6	8	11	17	37

Table 5 : Cool down time for different bands for different number of ACs

Algorithm for Feasibility Analysis

Algorithm 1 Feasibility Analysis

Given : Thermal Comfort Band $[T^U, T^L]$, Peak Power Limit P, Time Duration T

1: Determine maximum number of air conditioning units m using Equation 1.
2: **For all** AC_i for $i = 1$ to m
3: Determine cooling time C_i, using Equation 5.
4: **If** C_i does not exist then
5: *Infeasible*
6: **Else if** C_i exists and $C_i > T$ then
7: *Infeasible*
8: **Else if** C_i exists and $C_i < T$ then
9: *Feasible*
10: **Endif**
11: **Endfor**

Conclusion

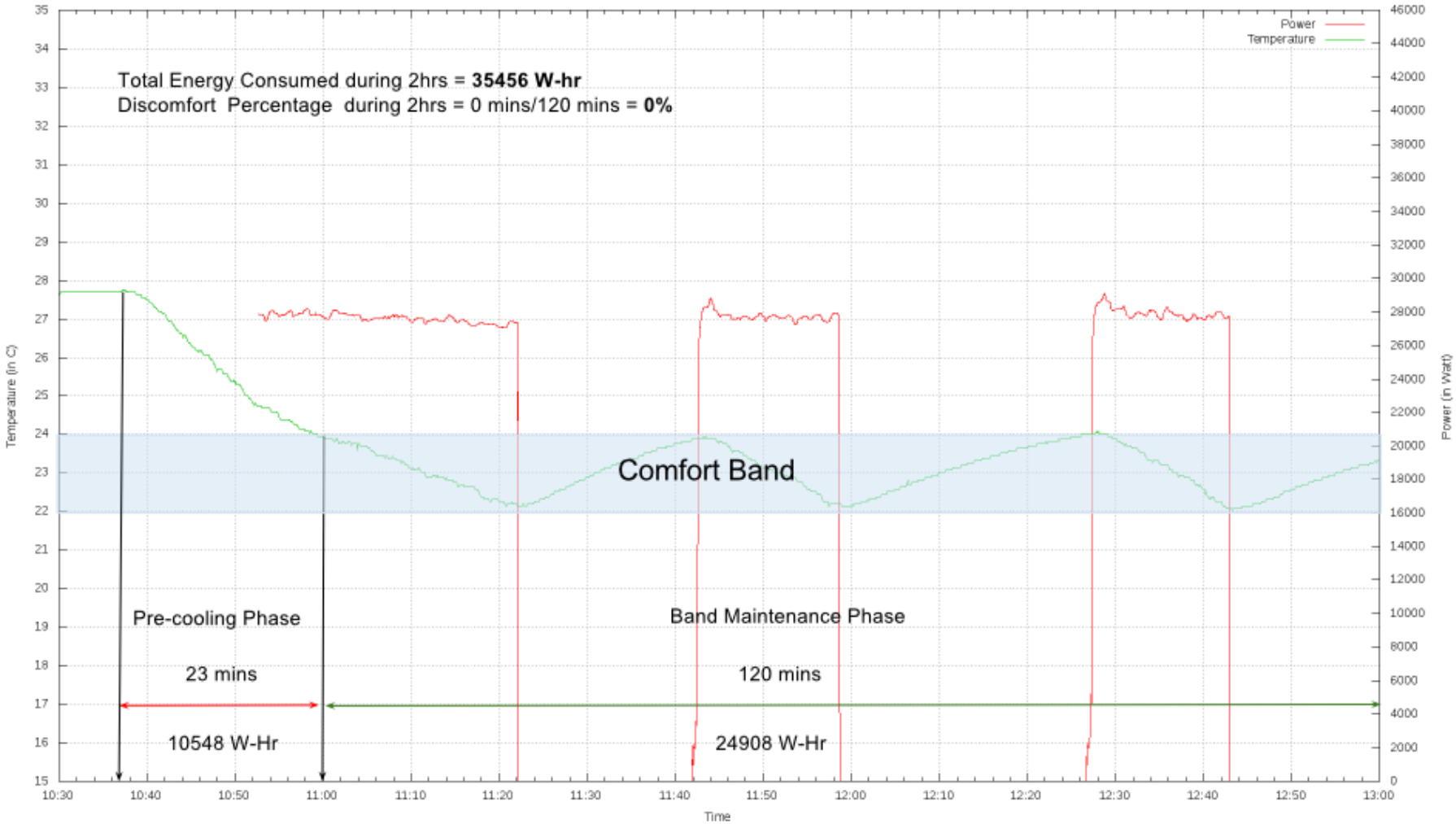

Figure 8 : Optimized Operation of Auditorium's Air Conditioning System

Comparison	**Energy Consumed** (in Watt-Hr)	**Discomfort Level** (in %age)
Current Scheduling	54228	83
Optimized Scheduling	35456	0
Total Savings	18772	-

Table 6 : Results about Energy saving and Comfort Level

Results

Following our approach over the current one can save around **36.4%** of energy achieving **0%** discomfort in the auditorium.

References

G. Karmakar, Gour and Kabra Ashutosh, and Ramamritham Krithi.

Coordinated scheduling of thermostatically controlled real-time systems under peak power constraint

In *Proceedings of Real-Time and Embedded Technology and Applications Symposium (RTAS), IEEE 19th*, pages 33–42, 2013. IEEE.

Jain Mohit, and Chhabra Deepika, and Mankoff Jennifer, and Singh Amarjeet

Energy Usage Attitudes of Urban India.

In *Proceedings of ICT4S*, 2014.

Rongxin Yin and Peng Xu and Mary Ann Piette and Sila Kiliccote

Study on Auto-DR and pre-cooling of commercial buildings with thermal mass in California

`http://www.sciencedirect.com/science/article/pii/S0378778810000150`

Article *volume 42, number 7, pages 967 - 975,* , 2010.

American Society of Heating, Ventilation, Refrigerating and Air-Conditioning Engineers (ASHRAE)

ASHRAE Standard 55-1992: Thermal Environmental Conditions for Human Occupancy

Book published by ASHRAE, Atlanta, GA, 1992.

References


Working of an AC
http://www.airconservices.com.sg/articles/how-does-an-airconwork.htm
2016.


Air Mixing Plenum, wikipedia.
https://en.wikipedia.org/wiki/Air-mixing_plenum.


Ducts in HVAC, wikipedia.
https://en.wikipedia.org/wiki/Duct_(flow).

Thank You