Techno-economic assessment of air cooling/ventilating methods for the college convention center

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Abstract. The present building of college convention center posing the problem of improper ventilated and heated atmosphere in most of its parts during large gathering programs. Major part of the building exposed to the sun the roof being heated throughout the day. The additional heat gain is adding up from occupants, light appliances etc. Since there is no provision for the exhaust, it is posing the problem of heated air inside the building. Making the people sweat and suffocate due to lack of fresh or sufficient air circulation. Looking at the climatic zone and the use of convention center for few hours in a day over few days in a year. This paper includes inspection and evaluation of convention center building for establishing balanced thermal atmosphere and improving air quality that satisfies the majority of occupants. Different techniques and methods of building cooling like air cooler and wind turbo rooftop air ventilators are considered. It is proposed to go for low cost natural rooftop ventilation supplemented with additional fans or air coolers at strategic points for improved ventilation and thermal comfort for occupants. Following the concepts of passive cooling techniques or adopting retrofits reduces heat generation and energy consumption.

1. Introduction
Environmental, epidemiological and economic factors will boost the future pressure for better building design, construction and management. For that reason, extra assessment is needed to know about construction behavior, environmental climate and in particular to assess the connection among indoor air quality, comfort ventilation and power usage.

Some of the variables that trigger variation in flow levels are Heating, Ventilation and Air Conditioning (HVAC) layout, assembly, operation, occupant density and air infiltration in construction envelopes. A few of the impacts of ventilation flow levels were acknowledged for a long time. An increment of ventilation level as a rule comes about in better-perceived air quality and a lower concentration of indoor created pollutants. In institutional, business and residential buildings, air-conditioning systems are chiefly for the occupant’s comfort, luxury and health. They are typically referred to as comfort air conditioning systems. In manufacturing buildings and processes, air conditioning systems are accommodated for product, process, or worker’s health and thermal comfort are called processes air-conditioning systems [1-5].

It is consequently imperative to have a decent comprehension of previous and late thermal comfort improvements and the significance for energy use in buildings. This paper introduces a survey of thermal comfort and development work in the building environment and discusses suggestions for energy use. The point is not to perform a thorough study or extensive comparison between distinct models and
studies of thermal comfort, but rather to highlight the problems that are progressively relevant to building energy conservation [6-8].

Objectives of the work are:
- Provide better thermal comfort to the occupants
- Providing fresh air intake
- Reducing the heat gain
- Providing cooling environment with lesser cost of investment
- Lesser cost of operation and maintenance

This paper is structured as follows. Section 2 gives brief introduction to air conditioning systems and climate zones. Human comfort zone and psychrometry are dealt in section 3. Cooling load calculations are given in section 4. Analysis of methods are done in 5. Results and discussion in 6 and finally concluding remarks are presented in section 7.

2. Basic process of air conditioning system and climate zones

Basic processes of air-conditioning systems are mentioned here:

- Sensible cooling
- Sensible heating
- Humidifying
- Dehumidifying
- Air cleaning
- Air change
- Air movement

In sensible cooling and heating process, heat is removed or added in conditioned space to maintain the temperature. Humidification and dehumidification are processes of adding or removing water vapor from the air. Air cleaning is removing dust and other particulates, biological contaminants to maintain air quality. Air change is the process of exchanging air between the outdoor and indoor to maintain oxygen level, air quality and freshness. Air movement is to control air circulation. In view of their size, construction, and working characteristics, air conditioning systems could be categorized as shown in Figure 1.

![Figure 1. Categorization of air-conditioning systems.](image)

Out of these basic processes, the climate decides the required processes which may again differ throughout the year depending on whether the climate is hot and humid or cool and dry. Figure 2 shows the different climate zones of India, the geographic position of Bengaluru being located between 11°40' and 18°27' North latitude. The location of building considered here is at Bengaluru is blessed with an ideal temperature that ranges between 20 to 30 degree C for most of the time with moderate climate zone.

3. Climate zone and human comfort

One of the objectives of a Heating Ventilation and Air Conditioning (HVAC) system is to maintain human comfort conditions in a building, which is achieved by obtaining heat balance between persons and their surrounding environment. It is possible to achieve human comfort at air temperatures between
about 20°C and 26.6°C, and relative humidity between 20% and 70%, at differing air velocities and radiant surface temperatures. Figure 3. Shows the generalized comfort zone for winter and summer climate.

![Generalized comfort zone](image1)

**Figure 2.** Different climate zones of India.

As a function of monthly/seasonal outdoor temperature differences, two adaptive thermal comfort standards ASHRAE Standard 55 and EN15251 are highly helpful in giving a clear picture of occupant comfort conditions.

![Generalized comfort zone](image2)

**Figure 3.** The generalized comfort zone for winter and summer climate. [Source ASHRE Standard 55].

To meet the requirement general audit needs to be done; audit will vary for different end users. In general, it includes inspection and evaluation of air conditioning/ ventilating systems and suggests possible improvements in an existing system or suggests low cost retrofit options. Audit is to see the options for energy savings from different parts of a building to gather the information of the building. Conducting an audit of an existing building is a multiphase task, including data collection, analysis, identifying opportunities, planning and then implementing. With the general audit, identify potential energy saving opportunities from the analysis, e.g., climatic zone of location, general usage of building, adding insulation, window shading, retrofitting lighting system, retrofitting with more efficient STAR rated equipment. Adapting retrofits and maintenance checks to reduce energy consumption etc.

Calculations of heating and cooling loads are needed to assess the appropriate ability of heating and cooling devices, which can sustain the conditions required in the adapted environment. In most cases,
heating and cooling load estimations include methodical, deliberate, step by step methodology that can be used to reach the necessary device potential by considering all of the building energy generation loads [9-11]. In effect, an assortment of strategies running from straightforward dependable guidelines to complex transfer function approaches are utilized practically to get at the building load estimation. ASHRAE recommends various approaches to determine cooling and heating loads on basis of application, such as for homes, for commercial buildings etc [12].

4. Cooling load calculations
The calculation of the cooling load shall take into consideration all loads encountered by the building under a particular set of prescribed conditions. The considerations behind the cooling load design are as per the following:

1. Design outside conditions are drawn from a long-term predictive database. The conditions would not actually represent any particular year, but are illustrative of the location of the building. Design data for outside conditions for different zones of the world have been gathered and are available in tabular form in numerous handbooks.

2. The load on the building because of sunlight based radiation is assessed for steady conditions.

3. The building inhabitancy is expected to be at its maximum capacity.

4. All building appliances and equipment are deemed to be working at its full load rating.

The heat transfers due to conduction comprising of the building walls, rooftops, doors, floor etc. are external loads. These are all sensible heat exchanges. In addition to these the external load also comprises of heat transfer due to infiltration, which consists of both sensible as well as latent components. Heat generated by number of occupants, lighting and other equipment are internal loads. The percentage of external load versus internal load differs with building type, location, climate and building design. The total cooling load on any building comprises of both sensible and latent load components. The sensible load influences dry bulb temperature, while the latent load influences the moisture content of the conditioned space. Cooling load estimation includes assessment of several of the above components from the given information. In the following survey, measurements of the cooling load shall be made on the basis of the CLTD/CLF method proposed by ASHRAE. In this report, many different energy conservation measures (ECM) on ventilating and air conditioning systems for a college convention center building in moderate climate zone, India are evaluated. Fig. 4 shows College Convention center Plan Layout (L*b*h=202.7*173.77*33.1 in ft). E20 heat load calculation sheet is used for estimating the heat load of building.
4.1 Solar heat gain through glass
The heat from the sun is partly dispersed, partly reflected and partly absorbed by the atmosphere. The spread radiation is considered as diffused radiation. Ordinary glass retains a smaller percentage of the solar heat say round 6% and reflects or transmits the remaining. The amount of reflection is dependent on the angle of incidence which is the angle between the perpendicular to the glass surface and the sun rays. Depending on the latitudes, for each month in a year and for different exposures and on different timings there are tables for the solar heat gain. This solar heat gain in Btu/hr/sqft. area is multiplied with the area of the glass and the factor depending on the shade.

| ITEM     | Area (Sq.ft) | Temp. Difference | Factor | BTU/HR |
|----------|--------------|------------------|--------|--------|
| Glass-N  | 246.84       | 16               | 0.56   | 2211.69|
| Glass-S  | 246.84       | 14               | 0.56   | 1935.23|
| Glass-E  | 296.82       | 163              | 0.56   | 27093.73|
| Glass-W  | 296.82       | 163              | 0.56   | 27093.73|

4.2 Solar and transmission heat gain through exposed walls and roof
Heat flows from higher level to the lower whenever there exists a temperature difference. The rate at which the heat flows inside varies with the opposition imposed by that material. The solar heat gain on the exposed wall does not become an instantaneous room load. The heat is absorbed by the external wall and is conducted gradually into the inner layers of the wall and only the convected and radiated heat from its inside surface of building wall is the room load. Because of this unsteady condition of heat flow, it is a general practice to consider an equivalent temperature difference. The equivalent temperature difference is the difference in temperature that occurs in the overall heat transfer into the structure due to varying solar radiation and outdoor temperature.

| ITEM     | Area (Sq.ft) | Temp. Difference | Factor | BTU/HR |
|----------|--------------|------------------|--------|--------|
| Wall-N   | 5509.78      | 18               | 1.2    | 119011.25|
| Wall-S   | 5509.78      | 34               | 1.2    | 224799.02|
| Wall-E   | 6418.22      | 40               | 1.2    | 308074.56|
| Wall-W   | 6418.22      | 44               | 1.2    | 338882.02|
| Roof Sun | 35223.17     | 45               | 0.6    | 951025.59|
4.3 Estimation of loads

**Table 3.** Internal heat gain (occupants, lights and electrical equipment) calculation.

| ITEM            | BTU/HR   |
|-----------------|----------|
| People          | 661500.00|
| Light           | 215565.80|
| Appliances Elec.| 34100.00 |

4.4 Infiltration and ventilation

**Table 4.** Ventilation and infiltration calculation.

| ITEM       | Air Flow (CFM) | Temp. Difference | Factor | BTU/HR    |
|------------|----------------|------------------|--------|-----------|
| Infiltration | 594.20         | 20               | 1.08   | 12834.72  |
| Outside Air | 15613          | 20               | 1.08   | 40469.91  |
| Ventilation |                |                  |        |           |
| CFM/Per     | 13500          |                  |        |           |
| CFM/Sq.ft   | 2113           |                  |        |           |

Infiltration is not a feature for air-conditioning jobs which is so for refrigeration. This is for the simple reason that for air-conditioning, outdoor air is introduced which develops a positive pressure inside the conditioned area and only infiltration does occur. Outdoor air is introduced into the conditioned area so as to dilute the odour given off by the people, smoking and other fumes and contaminations generated inside the room. The quantity of fresh air depends upon the volume of the room or the number of people and the activity. Indoor air quality (IAQ) is now talked loudly by all. Minimum requirement of fresh air for applications having lesser occupancy is one air change per hour. Solar gain through walls, glass, roof and transmission gain through partition walls, ceiling, floors, internal loads such as people, light, equipment and infiltration of fresh air (due to bypass in the cooling coil) constitute Room Sensible Heat (RSH). When the system gain is added to this, this becomes Effective Room Sensible Heat (ERSH). Heat gain through infiltration, people and other sources which adds moisture in the room constitute Room Latent Heat (RLH). When system gain is added it becomes Effective Room Latent Heat (ERLH). The summation of room sensible / effective room sensible and room latent / effective room latent heat is called as Room Total Heat (RTH)/Effective Room Total Heat (ERTH). When outdoor sensible and latent heat is added it becomes Grand Total Heat (GTH) based on which the air-conditioning system is designed. The effective room sensible heat over the effective room total heat is called as effective room sensible heat factor. With this factor and the inside design conditions, Apparatus Dew Point (ADP) is calculated.

5. Analysis of methods
Considering the objective of providing thermal comfort and fresh air to occupants along with the consideration of climate zone, occasional usage of building, three methods are considered, which are (i) Evaporative cooling (ii) Wind turbo rooftop natural Eco air ventilators and (iii) Passive cooling. Out of these, Evaporative cooling and wind turbo rooftop natural eco air ventilators methods are discussed in detail and compared in terms of efficiency in reducing cooling load and cost effectiveness. Additionally, the passive cooling methods which can be considered to improve the thermal comfort and cooling effect are also discussed.
5.1 Evaporative cooling
Evaporative cooling is a typical type of cooling buildings for thermal comfort since it is comparatively low priced and requires less energy than other types of cooling. Evaporative cooling is best when the relative humidity is on the low side, limiting its acceptance to dry climates. The substantial climate considerations are dry-bulb temperature, wet-bulb temperature, and wet bulb depression during the summer.

Evaporative cooling air conditioning systems use the cooling of the evaporation of liquid water to cool an airstream directly or indirectly. An evaporative cooling system comprises of an intake chamber, filter(s), supply fan, direct-contact or indirect contact heat exchanger, exhaust fan, water sprays, reticulating water pump and water sump.

Filtered and cooled by an evaporative air cooler, the outdoor fresh air is ceaselessly sent into the indoor space through the air duct and appropriated outlets. With the constant supply of fresh air, the indoor space is in a positive pressure condition, in this manner the original hot air containing odour and dust will be wiped out of the building, bringing about a cool, ventilated, clean and comfortable condition.

Advantages:
- The average cost of establishment is around half or less the cost of central refrigerated air conditioning, due to absence of a compressor.
- The approximate operating cost is 1/8 that of refrigerated air conditioning.
- Power consumption is confined to water pump and fan.
- The working fluid is water, which is cheaper and easily available.

Disadvantages:
- Evaporative coolers necessitate a steady supply of water to moisten the pads.
- Water having considerable mineral content (hard water) leaves mineral deposits on the pads and inside of the cooler.
- An evaporative cooler becomes a natural breeding ground for mosquitoes. An improperly managed cooler is a threat to public health.
- No dehumidification.
- Higher initial cost and running costs are associated.
- Requires frequent maintenance.

5.2 Wind turbo rooftop natural eco air ventilators
This method is the natural way of providing ventilation for hot air from the building. Figure 5a & 5b. shows the working of Wind turbo rooftop natural ventilation. Natural ambient wind blowing through the rooftop turbine making it spin, producing a suction within the building that pulls up the condensed hot, humid and polluted air from within the building and disperses it through the rooftop turbine. This pulled out air is supplemented by new air from windows and doors. Which does not require electricity for its operation and least maintenance. As the hot air rises up cool or fresh air will be thrown inside auditorium through open windows. Thus, providing the fresh comfortable air inside the auditorium.

![Figure 5](image-url)

**Figure 5.** (a), (b) Working of wind turbo rooftop natural ventilation.
Natural ventilation acts as a factor in lowering the spread of airborne illness like tuberculosis, the common cold, influenza and meningitis. Natural ventilation needs lesser maintenance and is not high priced.

Benefits of renovating or revamping with Wind turbo rooftop natural Eco air ventilators the Auditorium building:

- Improved fresh and purer air quality.
- Removes heat, humidity dust and pollution from the building.
- Better comforts to the occupants.
- Avoidance of sweat and suffocation.
- Reduction in energy consumption—thus saving the nation’s power resources and ecology.
- Improved fresh and productive environment.
- Non-existent running and maintenance costs.

5.3 Passive cooling methods

To reduce heat gain through building envelops some simple and effective methods are recommended based on the survey and climate zone condition which can be followed. The recommendations are:

Heat generated by equipment can be reduced by using energy-efficient appliances which generates less heat and use less energy. Heat generated by lighting electrical appliances can be considerably reduced by making use of day light, sky lighting systems. Use of energy efficient lights and equipment also considerably reduces heat load and considerable savings in electricity consumption. Minor adaptation of the lighting system in the building could result in a reduction of the cooling load. This is a very practical means of reducing the cooling load also it is easy to execute and economical method. Solar heat gain from glass can be reduced by using reflective window coating and spectrally selective glazing for more day light, less heat gain.

Solar heat generation by walls can be reduced by careful plantation of trees, shrubs outside the building to shade the east and west walls. Use of light color on walls, use of shading devices like light colored awnings, louvers and solar screens can block direct sunlight and reduce considerable heat gain. Solar heat generation by Roof can be reduced by using naturally or mechanically ventilated roofs. White-washed external roof surfaces to reduce solar absorptivity, usage of high thermal capacity materials, coat roof with bright white or shiny material, roofs covered with vegetation. Additionally, use of water fountains, reflecting pools, water falls in and around the building also serve the purpose of passive cooling.

6. Results and discussion

By the study conducted the following points are worth noting:

Conduction, convection and radiation are the three modes by which heat is transferred from high temperature atmospheric air to the building envelop. Heat gain by a building by different sources are calculated and found that, the highest amount of heat is poured through roof heat gain (33%) followed by glazed walls (32%), internal heat gain (26%) and lights load (6%) are shown in building heat gain factors chart.

From the survey and audit of the building, the heat load calculated is 320 TR considering the diversity factor of 0.8. The approximate cost of Conventional Air conditioning may vary between INR 35,000/TR to INR 50,000/TR based on different method, equipment, brand and technologies used. With evaporative cooling method approximately INR 35 lacks to INR 40 lacks rupees plus additional running charges of electricity consumption and maintenance charges.
Figure 6. Building heat gain factors chart.

With natural rooftop ventilation method, required ventilation rate \( Q(\text{cfm}) = \frac{\text{Volume} \times \text{Air change rate}}{60} \). Ventilation rate \( Q(\text{cfm}) = (1165887 \times 12/60) = 233177.4 \text{ cfm} \), Air change rate selected = 12 times per hour. Under wind velocity of 3mph, temperature difference of 5 degrees, stack height=30 ft. Selecting the air turbine ventilator of Exhaust capacity = 1550 cfm, Air turbine ventilators required quantity = \( \frac{233177.4}{1550} \) = 150 Numbers. Approximate cost of rooftop ventilation system would be INR 3 lacks to INR 4 Lacks (is a rough estimation cost).

Evaporative cooling provides a better cooling effect, clean and comfortable environment. A natural eco air ventilator provides the fresh comfortable air inside the auditorium. Initial cost of evaporative cooling is approximately 6 to 10 times more than the natural eco ventilators cost. Also, the running cost and maintenance costs add up to evaporative cooling which are not in natural eco ventilators cooling. In keeping thermal comfort exclusively by means of natural ventilation might not be conceivable. Air conditioning systems can be utilized as either backups or supplements. Table/floor fans can be used to circulate more air within a building for the function of reducing the perceived temperature by increasing evaporation of perspiration on the skin of the occupants. Fans and evaporative coolers will complement cooling techniques and cost less to install and run than air conditioners.

7. Conclusions
This paper assesses natural rooftop cooling and evaporative cooling methods to be implemented on a college convention center building in moderate climate zone, India. The following conclusions can be drawn:

The factors which are mainly responsible for heated atmosphere and lack of fresh air can be pointed out as conduction through glazed walls, internal heat gain, roof conduction, wall conduction. Looking at the climatic zone as moderate and also the use of convention center for few hours in a day over few days in a year.

With the urgent need to reduce the economic costs of energy consumption and environmental impacts, it is sensible to go for low-cost natural rooftop ventilation instead of costlier air conditioning. Natural rooftop ventilation supplemented with additional fans and air coolers at strategic points and also considering the recommended passive cooling techniques, the problem of improper ventilation and heated atmosphere of building can be reduced and better human comfort conditions can be achieved.

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