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# Indoor Air Quality in Triage Area: A Case Study of Bir Hospital, Kathmandu, Nepal

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**Abstract**

When it comes to people's health, indoor air quality is just as crucial as outdoor air quality, if not more so. In the Kathmandu Valley, where the yearly average concentration of PM 2.5 is around five times greater than WHO recommendations, air pollution poses a serious threat to human health. Hospital is one building type in which maintaining Indoor Air Quality (IAQ) is of utmost importance for the health and wellbeing of healthcare practitioners, staffs and patients. This paper highlights the existing physical parameters of Indoor Air Quality of triage area of Bir Hospital, a hospital located in Kathmandu, Nepal. By employing LaserEgg2+ technology for data gathering along with questionnaire survey with health practitioners working inside the department, this inquiry compares the current IAQ to both the WHO standard and the ASHRAE Standard for Healthcare facilities. This study takes into account the perception of Health practitioners towards Indoor Air Quality of emergency department. Hospital and standalone emergency rooms treat a range of medical ailments, including those involving severe trauma, infectious infections, lacerations, and broken bones so high risk of infection is always present. This paper recommends the intervention measures from simulation research method in Autodesk Ecotect Software to ensure thermal comfort and ASHRAE guided environmental conditions for the occupants accessing the emergency department.

**Keywords**

Indoor air pollution, hospital indoor air, indoor air quality, Ventilation, ASHRAE Standards, Thermal comfort, occupational health and safety

## 1. Introduction

Indoor air quality (IAQ) is a term which refers to the air quality within and around buildings and structures, especially as it relates to the health and comfort of building occupants [1]. In terms of people's health, indoor air quality is just as critical as outside air quality, if not more so. Numerous studies have demonstrated that, even in some of the most polluted locations, such city centers, indoor air quality is typically worse than outside air quality. In actuality, interior air pollution in our homes, workplaces, schools, hospitals, and industries can be two or even five times worse than outside air pollution. It is possible to characterize indoor air quality using physical, chemical, and sensory factors [2].

IAQ is determined by obtaining air samples, analyzing how much pollution people are exposed to, collecting samples from building surfaces, and simulating indoor air flow using a computer. Indoor air quality (IAQ) is a component of indoor environmental quality (IEQ), which also incorporates other factors of living inside, such as lighting, visual quality, acoustics, and thermal comfort [3].

### 1.1 Hospital and IAQ

A hospital is a healthcare facility where indoor air quality is of utmost importance. It is an institution that gives specialized therapeutic and nursing care as well as restorative supplies to patients. The foremost well-known form of the hospital is the common clinic, which as a rule carries a crisis division to handle critical wellbeing issues such as fire and mishap casualties, as well as therapeutic crises [4]. Research has shown that employee exposure to several gaseous chemicals is nevertheless widespread throughout modern healthcare facilities, despite mechanical ventilation and active filtration systems. Safety professionals can significantly enhance patient and working staff safety in these facilities by integrating adequate ventilation, waste gas scavenging, and ongoing air monitoring and sampling [5].

### 1.2 Air Pollution and Kathmandu Valley

Air pollution is the leading risk factor for deaths in Nepal; more than 42 thousand in 2019 deaths were linked to air pollution [6]. There are 222 deaths per 100,000 people due to air pollution in Nepal which is higher than the global average (86 deaths per 100,000), adjusted for differences in age. 19% of total air-pollution-attributable deaths in Nepal are in children under 5, and 27% are in adults over 70. Air pollution reduced life expectancy in Nepal by 3 years. [7] Since air pollution has been a major public health risk in the valley, in response, the Ministry of Health and Population and the World Health Organization (WHO) are implementing the Urban Health Initiative (UHI) in the Kathmandu Valley to increase the capacity of the health sector, build evidence on the health effects of air pollution, and raise awareness of this problem. This policy brief addresses the relationship between health and air pollution in the Kathmandu Valley and covers a variety of air pollution sources [8].

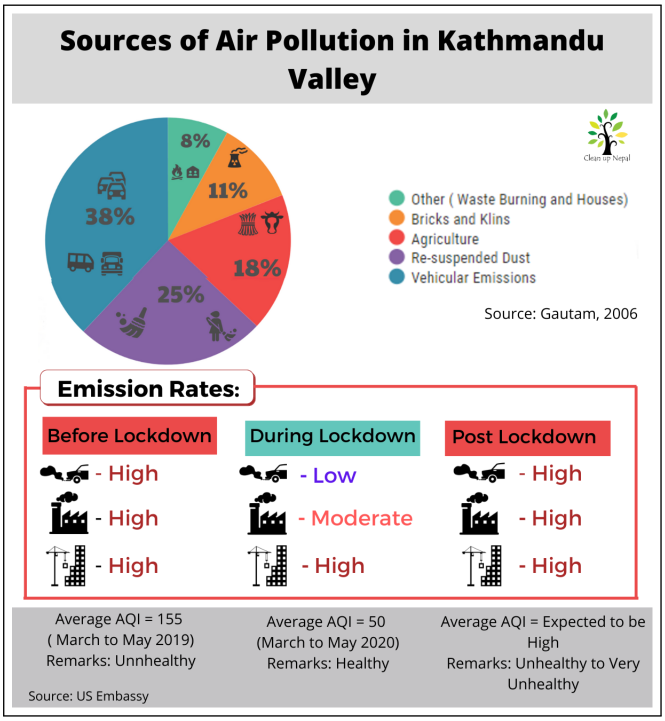



**Figure 1:** Sources of air pollution in kathmandu valley (Source: US Embassy)

## 2. Methodology

**Quantitative Analysis:** IAQ of different zones of Bir Hospital Emergency Department were measured in terms of Temperature, Overall AQI, Humidity, PM 2.5 and TVOC levels with the help of Laser Egg2+ device provided by Centre for Energy Studies (CES), IOE, Pulchowk campus. The limitation to quantitative analysis was that the data could be measured for a short period of 10 days from 2nd August, 2023 to 12th August, 2023 to produce result from the obtained data. However, most of the data were taken during the time of the day that occupants felt most dissatisfied with the IAQ.

**Qualitative Analysis:** Pilot survey questionnaire was conducted among health practitioners to know the time of the day they felt most uncomfortable. The survey was conducted around 12 in the morning among thirty seven participants. Participants answered that they felt uncomfortable most during daytime than other part of their shift. The survey began from 2nd August, 2023 to 7th August, 2023.

**Simulation Analysis:** Base case scenario was created in Autodesk Ecotect analysis software to figure out the thermal comfort conditions of occupants inside the emergy department of Bir Hospital.Recommended thermal and occupant comfort conditions was simulated and optimized condition was figured from simulation analysis using Natural, Mixed mode and Mechanical ventilation.

## 3. Literature Review

The healthcare facility is a complex building. Hospitals have special needs in their mission to save lives. It can be hard to make a healthcare facility run smoothly, especially because this industry uses a lot of energy. There are many things that make it difficult to have efficient energy use and maintaining indoor thermal comfort for the occupants in a hospital.

**Thermal Comfort:** For our bodies to work and function properly, we need to have a body temperature of around 37°C and a skin temperature of between 32 and 33°C. However, people have different ideas about what temperature is perfect for them. So, it's helpful to be able to adjust the temperature of a room to meet someone's specific needs. There is always a risk of contamination of dangerous infectious diseases like tuberculosis, COVID-19 in the hospital emergency department. So, a thermal environment that pose a less risk of infection must be maintained considering thermal comfort for the occupants.

**Indoor Air Quality:** The phrase "indoor air quality" (IAQ) describes the quality of air within and around buildings and structures, with an emphasis on the ways the air quality impacts building occupants' comfort and health. There are two main factors that help decide if the air indoors is good. These factors are comfort and health. General pollutant types that affect air quality include:

- **Biological**—bacteria, fungi, viruses, molds, pollen, animal hair, dander and excrement are examples of common biological pollutants that can impact air quality.
- **Chemical**—Common examples of airborne chemicals are fuels, adhesives, cleanser, solvents, and different combustion byproducts, as well as emissions from furniture and wall and floor coverings.
- **Particles and Aerosols**—are substances that can be suspended in the air, either solids or liquids. The three basic types of particles are coarse, fine, and ultrafine. Particles originate from several sources such as dust, materials for construction, printing, photocopying, industrial procedures, burning, and some chemical reactions where vapors condense to produce particles. These come under the following categories: condensates, smoke, mist, fume, and dust.[9]

| SPACE GUIDELINES FOR HEALTHCARE FACILITY COMPARISON | | |
|---|---|---|
| **Space** | **AREA IN Sq. m. (International)** | **Area in Sq. m. (Case)** |
| Waiting Area | 0.65/ Person | 0.65/ Person (Circulation Inc.) |
| Nurse Station | 5.02/ Staff | 2.78 |
| Examination and Treatment Area with Lavatory | 7.43/ Bed | 4.39/ Bed |
| Equipment and Supply Storage Area | 4.65 | Not Given |
| Wheeled Stretcher Area | 1.08/ Stretcher | 1.58/ Stretcher (Outside) |

**Figure 2:** Areas allocated for different Spaces [10]

## 4. Site Context

The site taken for the base case is Bir Hospital Emergency department located in Kantipath, Kathmandu, Nepal. It was established in 1947 B.S., and it is one of the oldest and the busiest hospitals of Nepal. The hospital every day, serves around 3,000 patients seek outpatient services at the Bir Hospital.[11] The department is divided into four zones namely Green zone, Yellow Zone, Red zone and Black zone. However, because black zone is the area where only dead bodies are places, other three zones are taken into study. The case area is around 2646.75 Sq. ft. After the measurement, space was compared with standard area in sq. m. provided by international standard. The table presented above shows the comparison between different facilities inside the hospital emergency department.

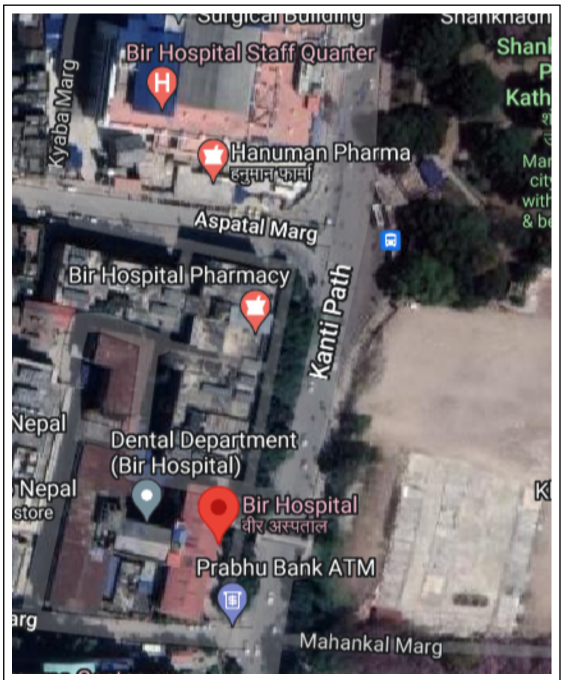



**Figure 3:** Location of Bir Hospital (Source: Google Map)

## 5. Energy Modelling and Simulation

A total of 52 questions were prepared for the questionnaire and 37 health practitioners were surveyed to determine the level of comfort experienced by them. Out of 37 people surveyed, around 55% were adults of age group 21-30. 31-50 aged people contributed around 40% of the total survey.

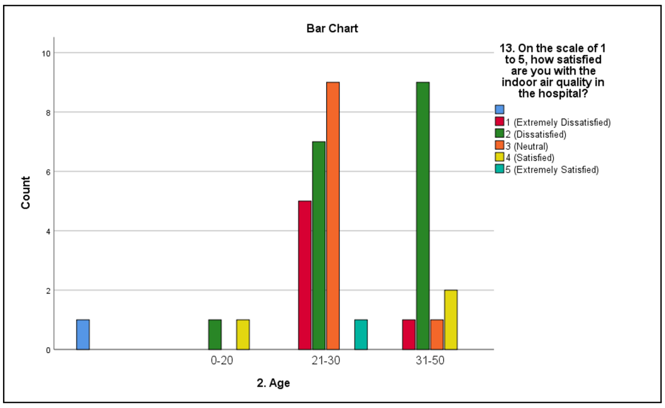
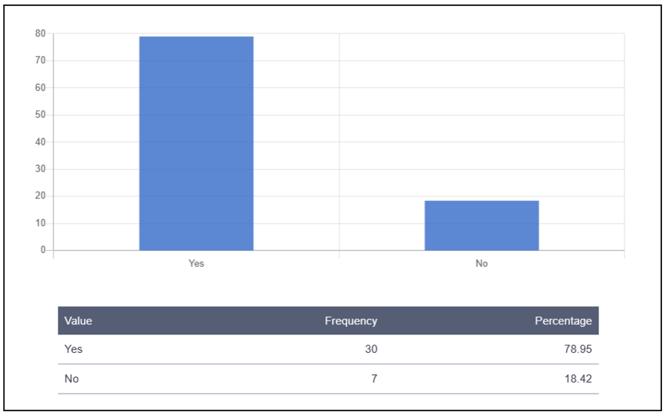



**Figure 4:** Participants age and dissatisfaction level

Out of the total participants, majority of them felt Dissatisfied, Neutral or Extremely dissatisfied with the Indoor Air quality in the emergency department premises.

Thirty persons out of thirty seven participants felt dissatisfaction with the Indoor Air Quality. Almost 80% of the participants felt discomfort with the Bad IAQ of the hospital.



| Value | Frequency | Percentage |
|---|---|---|
| Yes | 30 | 78.95 |
| No | 7 | 18.42 |

**Figure 5:** Participants and discomfort with IAQ

There are some common symptoms that is caused due to Bad IAQ in one questions of the survey. Some of the symptoms are general, but when exposed to bad indoor air quality for a longer period of time can amplify the symptoms to some chronic health related problems. These symptoms, in a hospitl can be caused by outdoor air contamination, disinfectants, waste anesthetic gases, etc. Following were the symptoms that were asked in the questionnaire:

- Runny Nose
- Stuffy Eyes
- Muscle Aches
- Sneezing and Coughing

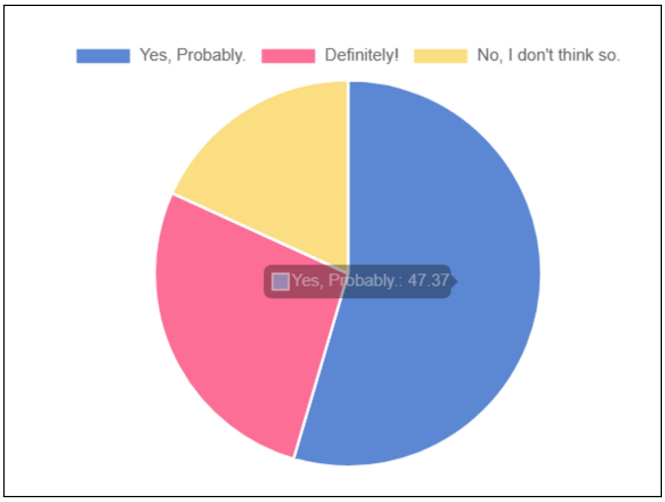



**Figure 6:** Participants when asked if Bad IAQ contributed to health symptoms

| FIELD AIR QUALITY INDEX DATA COLLECTION | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PARAMETERS | OVERALL AQI US | | | AQI US | | | PM 2.5 | | | TVOC PPM | | | TEMPERATURE (°C) | | | RELATIVE HUMIDITY(%) | | |
| ZONES | GZ | YZ | RZ | GZ | YZ | RZ | GZ | YZ | RZ | GZ | YZ | RZ | GZ | YZ | RZ | GZ | YZ | RZ |
| DAY 1 (10am -12 pm) | 50 | 42 | 50 | 50 | 42 | 46 | 12 | 10 | 11 | 0.14 | 0.12 | 0.12 | 29 | 29 | 31 | 69 | 69 | 67 |
| DAY 4 (8-10 pm) | 72 | 68 | 72 | 72 | 68 | 72 | 23 | 20 | 22 | 0.12 | 0.15 | 0.12 | 25 | 26 | 26 | 79 | 83 | 77 |
| DAY 2 (3-5 pm) | 78 | 59 | 63 | 78 | 59 | 66 | 25 | 16 | 17 | 0.16 | 0.12 | 0.23 | 29 | 29 | 29 | 71 | 71 | 73 |
| DAY 3 (3-5 pm) | 59 | 50 | 33 | 57 | 53 | 33 | 15 | 13 | 8 | 0.22 | 0.12 | 0.12 | 29 | 29 | 30 | 70 | 69 | 64 |
| DAY 5 (3-5 pm) | 102 | 87 | 96 | 99 | 87 | 91 | 35 | 30 | 30 | 0.12 | 0.12 | 0.29 | 26 | 28 | 27 | 77 | 72 | 78 |
| DAY 6 (3-5 pm) | 70 | 78 | 82 | 70 | 78 | 82 | 21 | 25 | 30 | 0.19 | 0.23 | 0.15 | 27 | 27 | 27 | 75 | 78 | 76 |
| DAY 7 (3-5 pm) | 102 | 97 | 93 | 99 | 97 | 93 | 35 | 34 | 32 | 0.13 | 0.16 | 0.14 | 27 | 27 | 27 | 83 | 83 | 82 |
| DAY 8 (3-5 pm) | 78 | 70 | 63 | 78 | 70 | 63 | 32 | 26 | 21 | 0.14 | 0.44 | 0.34 | 27 | 30 | 29 | 82 | 67 | 69 |
| DAY 9 (12- 2 pm) | 119 | 134 | 149 | 119 | 130 | 152 | 43 | 46 | 58 | 0.12 | 0.12 | 0.12 | 29 | 29 | 28 | 69 | 70 | 70 |
| DAY 10 (12- 2 pm) | 157 | 153 | 110 | 157 | 153 | 110 | 66 | 59 | 39 | 0.51 | 0.45 | 0.16 | 25 | 25 | 24 | 72 | 74 | 74 |
| 10 Days Zone Averages | 88.7 | 83.8 | 81.1 | 87.9 | 83.7 | 80.8 | 30.7 | 27.9 | 26.8 | 0.185 | 0.203 | 0.179 | 27.3 | 27.9 | 27.8 | 74.7 | 73.6 | 73 |

**Figure 7:** Field Data Collection from Equipment

**Findings from Quantitative Analysis:** Data were taken in different times of the day for three separate days and time of day when IAQ was bad was analysed. From questionnaire, most uncomfortable part of the day was asked among participants. Field data was measured in the afternoon time as participants felt most uncomfortable then. Since, black zone was for dead bodies, different data were recorded for each of Green zone, Yellow Zone and Red Zone. Based on this, following table shows the findings of the primary data collected from LaserEgg2+. The limitation to this data collection is that it was carried out for 10 days.

| Design Parameters Standard VS Site Context | | | |
|---|---|---|---|
| Parameters | ASHRAE Standards | INDIAN Standards | SITE Context |
| Pressure Relationship to adjacent areas | Negative | Negative | N/R |
| Minimum ACH | 12 | 12 | 2-3 ACH |
| Room air exhaust to outdoor | Yes | Follows ASHRAE | NO |
| Air Recirculation | Not Required | Follows ASHRAE | All air recirculated |
| Relative Humidity, RH % | Max 65 | 45 to 55 | 63-83 |
| Temperature | 21-24 °C | 24-26 °C | 24-31 °C |

**Figure 8:** Standard [12] Vs Site environmental design [13]

In any part of the day, the number of people inside emergency department exceeded the capacity of the department and lack of ventilation was fairly evident in the data collection area. The following shortcomings regarding physical parameters of Indoor Air Quality were found after comparing the measurements taken from the emergency department with the environmental standards set by ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers):

- Temperatures at any time of day exceeded the standards i.e. 21 to 24 degrees
- Humidity exceeded the standard set Humidity levels i.e. 65%
- Overall AQI at certain parts of the day was more than standards (Below 100)
- Overall PM 2.5 levels at certain parts of the day was more than standards (Below 50)[14]

From the above findings, it is evident that the environmental standards were not met in the emergency department of Bir Hospital. Considering the spaces and the temperature, humidity levels recorded, a base case scenario was developed in Autodesk Ecotect software. Possible interventions to the case study area was proposed. First, Fully mechanical system was simulated and for the second intervention, mixed mode system was selected and windows was replaced with double glazed window. Results are discussed in the next section.

## 6. Results and Analysis

The required thermal and occupant comfort conditions was simulated and optimized condition was figured out from simulation analysis using Natural, Mixed mode and Mechanical ventilation. Firstly, base case scenario was developed. Then other two optimal conditions were simulated to find best solution for the department. The findings are calculated and compared in terms of Temperature, humidity, etc. Table below shows the end results from the simulation.

| COMPARISON CHART | | | |
|---|---|---|---|
| PARAMETERS | BASE CASE | IMPROVED CASE | RECOMMENDED CASE |
| Air Exchange System | Natural Ventilation | Full Mechanical System | Mixed Mode (HVAC + Natural) |
| Electric Consumption | 42918.5 Kwh | 42763.8 Kwh | 43946.02 Kwh |
| Heating Load | 0 Kwh | 5301.39 Kwh | 1198.01 Kwh |
| Cooling Load | 0 Kwh | 82549.27 Kwh | 51012.95 Kwh |
| | | | |
| GAINS BREAKDOWN | In percentage | In Percentage | In Percentage |
| Fabric | 33.9 (Loss) | 33.9 (Loss) | 29.8 (Loss) |
| Ventilation | 55.5 (Loss) | 55.5 (Loss) | 59.9 (Loss) |
| Internal | 97.8 (Gain) | 97.8 (Gain) | 88.5 (Gain) |
| Inter - Zonal | 10.6 (Loss) | 10.6 (Loss) | 10.3 (Loss) |
| | | | |
| DISCOMFORT HOURS | In a Year (8760 hrs) | In a Year | In a Year |
| Total Hours | 8005.7 | 0 | 0 |

**Figure 9:** Comparison chart of Base case and Interventions

## 7. Conclusion

The hospital is a healthcare facility where indoor air quality is of utmost importance as it can effect the health of staffs, visitors and patients. Occupant behavior and the number of people per unit area must be considered during the design and operation of the department. The major issues in this hospital causing discomfort was found to be internal gains which occurred due to large number of people in the same space. The simulation analysis was conducted and the existing base case scenario was developed from the process of data collection and field measurements. Emergency department resides on the ground floor of four storied tall building and is more than 25 years old, so alterations to walls and other parts for improving thermal comfort could damage the structural strength of the hospital. So, only interventions that were proposed were to reduce the number of occupants inside the emergency department, changing the single glazed window to double glazed and introducing new HVAC for mixed mode ventilation (i.e. using both natural ventilation and mechanical ventilation) to meet the required environmental conditions for safer health of occupants.These interventions from the analysis, have improved thermal comfort whereas increase the thermal load in the building due to the addition of HVAC. The discoveries from this research can give a reference for decision-makers and originators to move to realize economical improvement with regard to vitality, the economy, and the environment.

## 8. Recommendation

The results from the field analysis showed that there is an uncomfortable Indoor Air Quality in terms of physical parameters in the Emergency Department. There was higher temperature, humidity, AQI levels and PM 2.5 concentration than that was recommended by WHO and ASHRAE Standards. [14] Simulation was conducted to find different alternatives to better the existing situation.

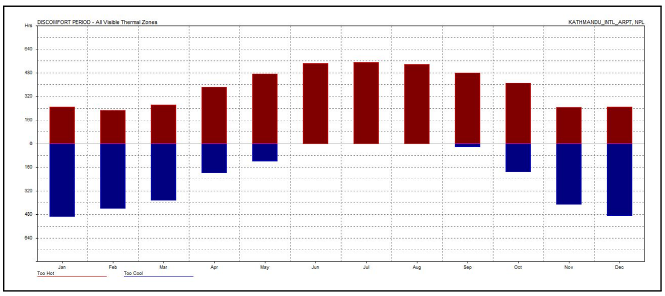


**Figure 10:** Discomfort hours in Base Case Scenario

The proposed recommended intervention was Double glazed panel on windows and installation of Mechanical HVAC devices. The main criteria to focus on environment of emergency department are to cater faster recovery of patients, prevent contamination and to maintain highly comfortable air quality for the occupants of the emergency department. The addition of HVAC only translated to better Indoor Air Quality and acceptable temperature and humidity levels.

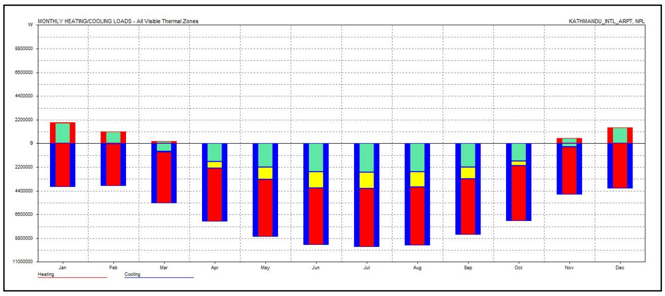


**Figure 11:** Addition of Heating/Cooling Loads in different zones after addition of Mixed mode system

However, the consumption of heating and cooling loads increased significantly when only HVAC was used. Hence the intervention was proposed for a system with HVAC as well as Natural ventilation, this led to lesser heating and cooling loads when compared to the use of HVAC only. Since major passive load was due to higher internal gains, one visitor per bed would help to solve the problem. Thes recommendations showed that addition of Mixed mode system (HVAC + Natural ventilation) can improve the Indoor Air Quality with just slight increment in heating and cooling loads than existing system.

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