# Thermal environmental case study of an existing underfloor air distribution (UFAD) system in a high-rise building in the tropics

Y H Ya[1] and K S Poh[2]
[1]Associate Professor, Department of Mechanical Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia
[2]Postgraduate Student, Department of Mechanical Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia

Email: yhyau@um.edu.my

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**Abstract.** The performance of an existing underfloor air distribution (UFAD) system in a renowned high-rise office tower in Malaysia was studied to identify the root cause issues behind the poor indoor air quality. Occupants are the best thermal sensor. The building was detected with the sick building syndrome (SBS) that causes runny noses, flu-like symptoms, irritated skin, and etc. Long period of exposure to indoor air pollutants may increase the occupant's health risk. The parameters such as the space temperature, relative humidity, air movement, air change, fresh air flow rate, chilled water supply and return are evaluated at three stories that consist of five open offices. A full traverse study was carried out at one of the fresh air duct. A simplified duct flow measurement method using pitot-tubes was developed. The results showed that the diffusers were not effective in creating the swirl effect to the space. Internal heat gain from human and office electrical equipment were not drawn out effectively. Besides, relative humidity has exceeded the recommended level. These issues were caused by the poor maintenance of the building. The energy efficiency strategy of the UFAD system comes from the higher supply air temperature. It may leads to insufficient cooling load for the latent heat gained under improper system performance. Special care and considerations in design, construction and maintenance are needed to ensure the indoor air quality to be maintained. Several improvements were recommended to tackle the existing indoor air quality issues. Solar system was studied as one of the innovative method for retrofitting.

[1] To whom any correspondence should be addressed.

## 1. Introduction

Indoor air quality problems can be non-obvious and do not always generate straightforwardly recognized impacts on health, well-being or the physical plant. Symptoms such as headache, fatigue, shortness of breath, sinus congestion, coughing, sneezing, dizziness, nausea, and irritation of the eye, nose, throat and skin, are not really due to the air quality deficiencies, but can also be caused by other factors such as the poor lighting, stress, noise, and others [1].

A complete indoor environmental quality (IEQ) assessment is necessary to find out the alarming factors that influence the poor IEQ. Unfortunately, occupants moved out from the site and the demolishment work started. Hence, a complete IEQ assessment could not be performed under the current site situation. For this reason, alternative assessment procedures focusing on indoor air quality (IAQ) has been taken in place to identify the possible causes to the poor IEQ.

The assessments were conducted with the objectives of identifying the design and the performance of the existing underfloor air distribution (UFAD) system, and to obtain the systems' data and thermal environment data prior to the refurbishment as a baseline to verify the future enhancement to be made. Figure 1 shows the schematic diagram of the underfloor air distribution system (UFAD).

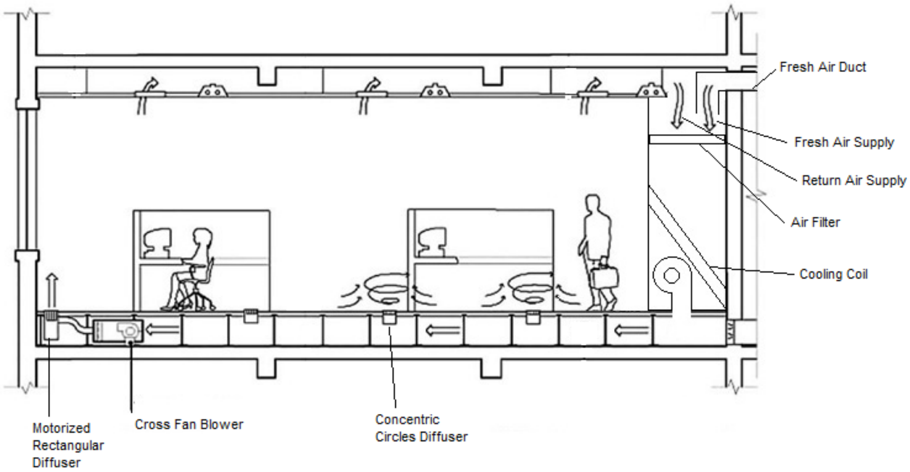


**Figure 1.** Schematic Diagram of Underfloor Air Distribution System (UFAD) [2].

## 2. Methodology

The assessment methodology was modified from conventional IAQ assessments methodology [3]. The procedures are divided into 4 stages: preliminary, sampling, evaluation and recommendation.

### *2.1 Preliminary Stage*

A walkthrough process is necessary to identify the possible areas where the problem mostly occurs. Occupants are the best thermal sensor. Feedbacks from the occupants are essential during the walkthrough process as their long hours of exposure in the environment. It was evident that the occupants were feeling sneezing, dizziness, irritation of the eye and skin in a long period of time.

### *2.2 Sampling Stage*

The sampling data was emphasized on the understanding of the room air physical parameters and the performance of the HVAC system. The assessed parameters were the space temperature, relative humidity, air movement, air change, fresh air flow rate, chilled water supply and return flow rate and temperature. The sampling locations were Levels 33N, 33S, 34N, 34S and 35S. Each location is divided into five thermal zones. Physical parameters were measured at each individual thermal zone to identify the overall indoor air quality.

Fresh air is drawn from outdoor and precooled using a Precool Air Unit (PAU) before it is supplied to each Underfloor Supply Unit (USU) located at each thermal zone. The fresh air flow rate was measured using a pitot tube Traverse Method (Log-Tchebycheff Method). In order to minimize the damage impact on the existing duct, a simplified traverse method was developed and compared with data collected from the full Traverse Method.

Figures 2 and 3 show the Traverse Method in the fresh air flow rate measuring in the ducting.

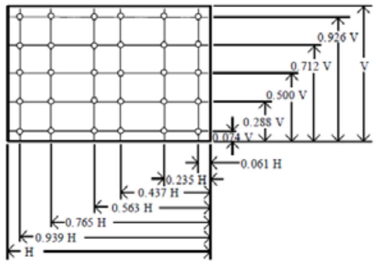


**Figure 32: Location of Measuring Points for Traversing a Rectangular Duct using Log-Tchebycheff Method**

For this duct, a 30-36" horizontal dimension requires 6 points (or 6 traverse lines). For this duct, a vertical dimension less than 30" requires 5 points (or 5 traverse lines).

| # of Points or Traverse Lines per Side | Position Relative to Inner Wall |
|---|---|
| 5 | 0.074, 0.288, 0.500, 0.712, 0.926 |
| 6 | 0.061, 0.235, 0.437, 0.563, 0.765, 0.939 |
| 7 | 0.053, 0.203, 0.366, 0.500, 0.634, 0.797, 0.947 |

**Figure 2**. Traverse Methodology [4].

**Figure 3.** Measuring fresh air flow rate inside the ducting.

### *2.3 Evaluation Stage*
Based on the parameters measured, data were compared to the local and international standard and regulation. The local and international standard and regulation used in the present study are Industry Code of Practise on IAQ 2010 [5], Malaysian Standard MS 1525 [6] and ASHRAE Standard 62.1 [7].

### *2.4 Recommendation Stage*
Due to the site was under renovation, recommendations have to be realistic, and it was crucial to have the rectifications implemented on time to eliminate the future repeating IAQ problems.

## 3. Results and Discussion

### *3.1 Indoor Air Temperature, Relative Humidity (RH) and Air Velocity*

The results as shown in Figure 4 indicate that the air temperatures are in the average of 21-23°C. As compared to 23-26°C recommended, the low average temperatures throughout all spaces are due to without occupancy conditions. The heat load from humans and electronics are not available. The temperatures are expected to rise within the recommended range during full occupancy conditions based on the current data obtained.

Relative humidity has exceeded the 70% threshold limit recommended. The relative humidity at the just mentioned level will encourage the growth of mold. During the walkthrough stage, mold was seen growing seriously especially at the return air grill. The data shown have proven the real condition of mold growth due to the high humidity.

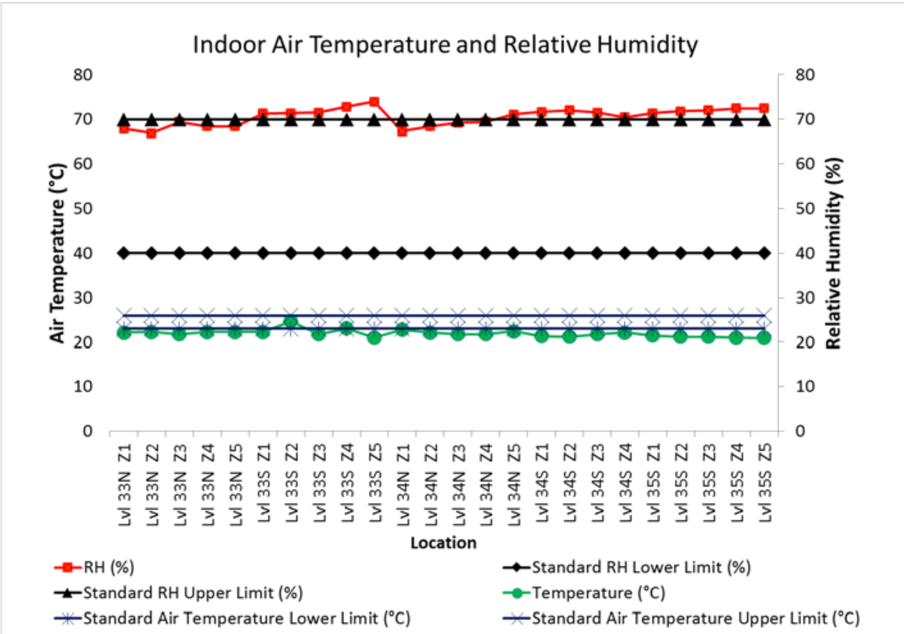


**Figure 4.** Indoor air temperature and relative humidity compared to recommended threshold limit based on Malaysian Standard MS 1525.

### *3.2 Fresh Air Intake*

The fresh air flow rate was measured using a full Traverse Method at Level 35S. The full data at Level 35S is shown in Table 1.

**Table 1**: Traverse Measurements in CFM at the Fresh Air Duct at Level 35S.

| | | | | | | |
|---|---|---|---|---|---|---|
| 2839 | 2840 | 2758 | 3413 | 4308 | 4632 | 4480 |
| 3037 | 2954 | 2924 | 3550 | 4183 | 4488 | 4265 |
| 3024 | 2721 | 3033 | 3352 | 4034 | 4129 | 3907 |
| 3048 | 2834 | 2968 | 3338 | 3541 | 3661 | 3585 |
| 2440 | 2521 | 2861 | 2909 | 2939 | 3156 | 3220 |

A simplified method was developed using a correction factor on the flow rate measurements at the center point of the ducting. The following measurements at Levels 33N, 33S, 34N and 34S were measured using the simplified method. The data and calculation are shown in Tables 2 and 3.

**Table 2.** Fresh Air Data for Level 35S.

| | |
|---|---|
| Air Temperature (°C) | 19.30 |
| Relative Humidity (%) | 89.50 |
| Average Volumetric Flow Rate (cfm) | 3368.34 |
| Correction Factor with Centre Point | 1.0049 |
| Area of L35S (ft$^2$) | 8676.00 |
| Floor height (ft) | 10.00 |

**Table 3.** Fresh Air Data for Levels 33N, 33S, 34N and 34S.

| Level | 33N | 33S | 34N | 34S |
|---|---|---|---|---|
| Air Temperature (°C) | 18.80 | 15.60 | 16.50 | 19.20 |
| Relative Humidity (%) | 89.60 | 92.10 | 88.90 | 89.30 |
| Volumetric Flow Rate at Centre-Point (CFM) | 4059.00 | 2735.00 | 1951.00 | 2167.00 |
| Corrected Volumetric Flow Rate (CFM) | 4078.79 | 2748.33 | 1960.51 | 2177.57 |
| Floor Area (ft$^2$) | 9310.50 | 9310.50 | 9171.00 | 9171.00 |
| Floor height (ft) | 10.00 | 10.00 | 10.00 | 10.00 |

A comparison with the ASHRAE Standard 62.1 is shown in Figure 5. The results show that the fresh air intake at Levels 33N, 33S and 35S are higher than the minimum fresh air rate required by the ASHRAE Standard 62.1. The outdoor fresh air is normally high in temperature and humidity. High latent heat load from the outdoor fresh air may cause the indoor relative humidity to exceed the threshold limit because the USUs are not tasked to accomplish such a load. Hence, the optimum fresh air intake closes to the minimum fresh air intake is needed.

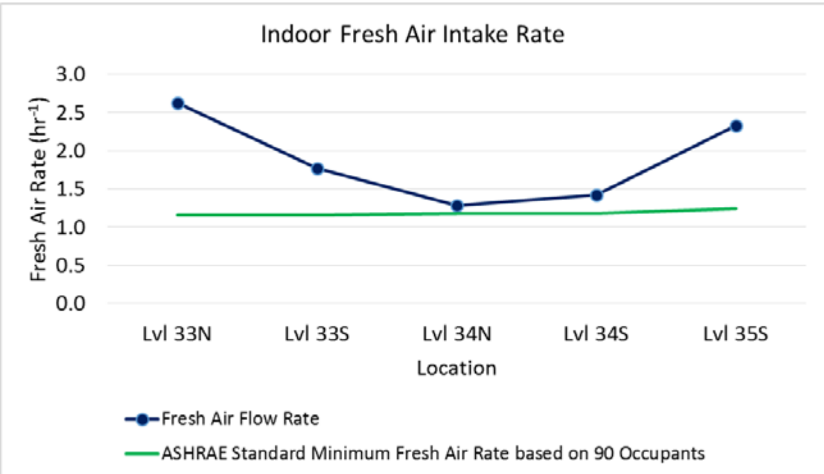


**Figure 5.** Indoor fresh air intake rate.

*3.3 Walkthrough Inspection*

There were some findings during the walkthrough stage. First, the valve actuator was not functioning, and hence, the chilled water was running at the full load at all time. Second, the underfloor diffusers were not properly maintained. Most diffusers were broken or parts were missing. These issues must be rectified to ensure that the air-side and water-side HVAC systems function properly.

**Figure 6.** Walkthrough inspection shows improper underfloor diffusers and malfunctioning valve actuator.

## 4. Recommendations and Conclusions

The recommendations to rectify the poor indoor air quality are as follows:

1. It is suggested that all broken underfloor diffusers to be replaced to ensure a proper air flow. So that the air stagnancy can be eliminated.
2. It is recommended that the malfunctioning valve actuators to be replaced to ensure a proper control of the chilled water flow rate.
3. The CO2 sensors are recommended to be installed to control the optimum fresh air supply flow rate.

The current study reveals that the maintenance team has a crucial role to ensure the indoor air quality to be maintained up to the standard. A scheduled checking and maintenance work must be taken in place. So that HVAC&R systems can function based on the intended design. Solar energy is studied as one of the possible methods to enhance the humidity control. It is noted that the façade of the high-rise building has a huge surface area and can be installed with solar panels to harvest solar energy for the use of air heating in the USUs. This will improve the relative humidity of the air before it is delivered to the space.

## 5. Acknowledgements

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