

DISPLACEMENT VENTILATION FOR ROOM AIR MOISTURE CONTROL IN HOT AND HUMID CLIMATE

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Abstract

Displacement ventilation has been used in Northern Europe for three decades. Numerous studies have shown that displacement ventilation is able to improve the indoor air quality in an energy efficient manner. However, displacement ventilation dealing with hot and humid climate are still limited. This paper will illustrate the effect of displacement ventilation on humidity gradient in a factory located in the hot and humid region. The field measurements show that thermal displacement ventilation creates moisture gradient in room spaces. Measurements evince that the humidity gradient is as significant as the temperature gradient.

Introduction

Displacement Ventilation Systems have been used in Northern Europe for more than three decades and proved to be successful especially where energy efficiency and Indoor Air Quality are of primary importance for building inhabitants. However, the success of displacement systems application for hot and humid climates depends strongly on how these systems are able to maintain design air humidity levels in ventilated spaces.

However, studies on hot and humid climate are limited. The basic theories on displacement ventilation have been developed in Scandinavia where climate is totally different. Most of the studies emphasize on temperature and contamination distribution in offices and industrial premises. Humidity control is not playing any role in Northern European countries because dehumidification is not normally needed. The basis of displacement ventilation is quite well studied in European climatic conditions. There is published the design guide that gives valuable insight on the design of displacement ventilation in Europe (Skistad 2001).

There is significant difference between the system's design for the cold and dry climate and hot and humid climate. Displacement

systems in the Northern Europe are designed with 100 % outside air and with heat recovery. Countries in Tropics, systems are designed with a substantial portion of re-circulated air due to energy implication. Hence, the concept and control strategy for displacement ventilation has to be modified in order to be suitable in Tropical conditions (Livchak 2001). This means that some kind of humidity control like bypass is required in AHU to reach target relative humidity in the occupied zone.

It is a common perception, affected by mixing ventilation systems, that humidity is constant throughout the space. Humidity ratio is not uniform in spaces with Thermal Displacement Ventilation, where convective plumes over the heat sources carry impurities and moisture in the upper part of the space. A measurement in the food-factory in Finland showed that the humidity ratio was much higher near the ceiling level than in the occupied zone (Livchak 2001). The CFD simulations indicated the same phenomenon in the classroom where people are the only moisture source (Kosonen 2001).

In this paper, the effect of displacement ventilation on humidity gradient was evaluated using a case-study approach. Field measurements were conducted in a factory, located in the Tropics, served by displacement ventilation. A comparative analysis on the non-dimensional temperature and humidity gradients were carried out. Also, the meaning of the humidity gradient for energy consumption is roughly estimated.

Case-study building

The measurements were performed at Outokumpu factory in Pasir Gudang Johor Malaysia. The dimension of the whole factory is 195 m (L) x 70 m (W) x 10 m (H). There are some areas that are involved in the measurement: the floor area where the measurements were conducted is 10,750 m².

The factory has open-concept layout with two doors for ingress and egress of trucks and the

side doors for freight traffic. The doors are quite often open during the day.

In the factory, the heat gains are not distributed equally over the entire floor area. The factory housed the manufacturing, packaging and storage sections. Some of the production machines are equipped with internal cooling system that makes estimation of the heat load in the factory based on power rating, inaccurate.

A total of 20 air-handling units (AHUs) were installed in the factory but only 13 of them were in operation during the measurements. Some of these units were not in operation because the actual cooling load is smaller than the estimated load during design phase. These AHUs were installed in three rows: along both side the wall and one row in the middle of the factory. The return air is taken in the occupied zone at level of 1.8 m. The extract located at 8 m level. The supply air temperature and humidity ratio of the displacement units is 14 °C and 9.7 g/kg respectively.

The airflow rates of AHUs were determined using velocity/pressure loss measurements in the ductwork. The summarized airflow rates are shown in the table 1. The hall is found to be slightly under-pressurized due to the operations of the 13 AHUs instead of the 20 units.

Table 1. Measured airflow rates

Airflow	m ³ /s
Supply	24.3
Return	17.9
Fresh air	6.4
Exhaust	7.1
Balance	-0.7 (Under Pressure)

Result

In factory hall, the temperature and humidity gradients were measured in four difference zones (Figure 1). Measurements zones 1 and 2 are in the manufacturing area and zones 3 and 4 are in short time storage and loading area respectively. It should be noted that the

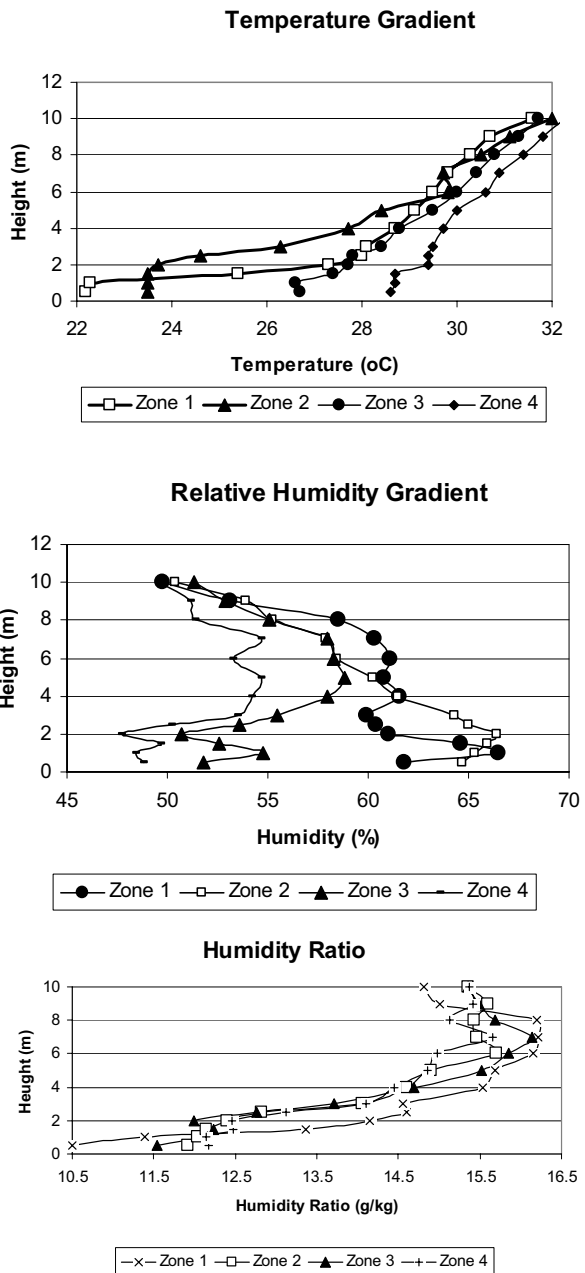


Figure 1. Measured temperature, relative humidity and humidity ratio at different level in the factory hall.

doors, near zones 3 and 4, were open during the operation period.

Temperatures and humidity levels were measured on the lift frame using calibrated hand meter with temperature accuracy of ± 0.3 °C and humidity accuracy of ± 3 %. In this measurement procedure, the temperatures at different levels and different zones were not measured exactly at the same time.

The air temperature difference is about 8 – 10 °C in manufacturing area and 3 – 5 °C in the loading area. The temperature difference in the loading area is smaller because of the influence of the door openings. The humidity ratio is the appropriate factor to study how effective is the moisture control. The humidity ratio difference is about 4 – 5 g/kg in all areas. The maximum humidity ratio occurred at 6- 8 m height. The humidity ratio decreases after the exhaust level (at 8 m). The humidity ratio at the roof level is about 1 g/kg lower than near exhaust level (Fig.1.)

Fig. 2 shows non-dimensional temperature and humidity ratio gradients. The humidity gradient is as significant than the temperature gradient. The measured temperature gradient is quite typical for displacement ventilation. The ratio of the total temperature difference evened out at the floor varied typically with displacement between 0.3 – 0.6. (Mundt 1996).

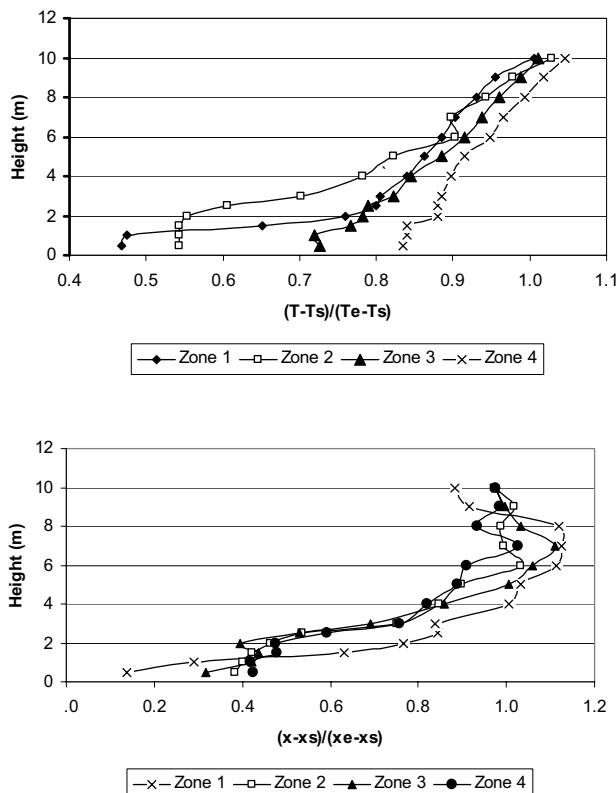


Figure 2. Non-dimensional temperature and humidity ratio gradients in the factory hall.

In this case study, about 0.3 – 0.4 of the humidity ratio difference is evened out at the

floor level. If we were to compare the results with the ideal mixing system, which maintains constant humidity ratio over the space volume, there is the noteworthy difference in the function of the displacement ventilation.

Discussion

Humidity is one of the main comfort factors in the Tropics. To keep the relative humidity at the comfortable level, the supply of dry air is needed. With thermal displacement ventilation, it is possible to reach the same indoor target with relatively higher moisture contents in the supply air. This saves cooling energy compared to rationally mixing ventilation.

The basic level of the humidity ratio in the occupied zone is determined by the humidity of the supply airflow rate. The humidity loads coming into room increases that level. If we consider the different physical mechanisms by which mass is transported into a ventilated space. Three processes, which are used e.g. in CFD simulation, can be identified: (1) transport with a convection flow, (2) turbulent diffusion and (3) molecular diffusion. It should be noted that the difference between the "turbulent diffusion" and the "convection flow" is somewhat subjective. An apparent theoretical approach is the Reynolds averaging, where all unsteadiness is regarded as part of turbulence and turbulence mixing.

The measurements indicated that the convection flow is the most important factor.

Convective plumes from heat sources create the upward going average velocity field which transport humidity away from the occupied zone. Also, into upper zone coming humidity, it is not actively mixed to the occupied zone. That is the reason why with the Thermal Displacement Ventilation system it is possible to create humidity gradient in the room space.

In this case-study, the main humidity load is infiltration via cracks in the building envelope and door openings. The manufacturing process is not a humidity load in the factory hall. The under-pressurization of the factory hall and temperature difference between indoor and outdoor (lower temperature inside) drives that a portion of the infiltration is coming directly into the upper zone.

However, if the factory hall would be over pressurized (or neutral situation) as normally the case in the Tropics, the infiltration would be smaller and probably the gradient becomes

smaller. In this case study, the direct influence of the infiltration, which is created by under-pressure, is not so significant. This infiltration of $0.7 \text{ m}^3/\text{s}$ airflow rate increases the humidity ratio by approximately 0.55 g/kg . Other humidity load, based on the continuity equation, is 79 g/s (284 kg/h).

If we use displacement model where the humidity is assumed to be constant (extract and occupied zone), the humidity ratio difference is computed to be 2.7 g/kg . It means that in the occupied zone the humidity ratio is 12.4 g/kg . This is 0.6 g/kg more than in measurement at the 1.8 m level of return air. In order to reach the same conditions, the supply temperature should in this calculation model should be 0.6 g/kg lower. In cooling capacity, this means of $+6 \%$ over estimation. This higher cooling capacity is based on the calculation that the humidity ratio of the supply airflow should be 9.1 g/kg instead of 9.7 g/kg .

All in all, it seems that the existing calculated models (Mundt 1996 and Skistad 2002), which are not taken account the humidity gradient, are not adequate to estimate the situation in Tropical conditions. This humidity gradient is an extra feature that improves the profitability of thermal displacement system in the hot and humid conditions. This means energy saving and also improve the self-control property of the displacement system to maintain comfortable thermal conditions in the occupied zone.

Thermal Displacement Ventilation Systems is especially efficient in industrial facilities where moisture accompanies thermal plumes above equipment. It is also efficient in applications where the humidity load is coming mainly from infiltration to create significant humidity gradient.

It should be emphasize that at the moment very little measurement information is available on humidity gradient with displacement ventilation in the Tropics. In the future, additional measurement data is required to study displacement ventilation systems with the combinations of different moisture and heat gain. For the humidity gradient it is critical where the humidity loads exist and what is the ratio of the heat gain and humidity load. To estimate this more accurately more measurements and new calculation model to estimate humidity gradient are required.

Conclusion

Based on field study, it is obvious that with Thermal Displacement System it is possible to create humidity gradient. The results indicate that the humidity gradient is as significant as the temperature gradient. This means that this humidity gradient is extra, at the moment not recognized, feature which should be taken into account during the design phase. The combination of the temperature and humidity gradient improves the energy efficiency of displacement system in hot and humid climate. The calculation model where the humidity is assumed to be constant instant of humidity gradient overestimates the cooling capacity 6% .

It should be emphasized that at the moment very little measurement information is available on humidity gradient with displacement ventilation. In the future, additional measurement data is required to study displacement ventilation systems where different moisture and heat gain combinations exist.

Acknowledgments

The study is funded by Technology Agency of Finland (TEKES) and the measurement arrangements are supported by Outokumpu Copper Products Malaysia.

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