Design Engineering Review of Two Canadian Displacement Ventilation Approaches with in-situ Performance Measurement of the Buildings

M. Tardif
Centre of Energy technology of CANMET, Canada

B. Ouazia
National Research Council, Canada

M. Bérubé Dufour, R.Zmeureanu, D. Derome*
Concordia University, Canada; EMPA, Switzerland*

S. Celis-Mercier, A.Potvin
Université Laval, Canada

ABSTRACT

Displacement Ventilation approach is becoming an interesting alternative to mixing ventilation among Canadian consulting engineers. This paper presents two recent Displacement Ventilation projects designed by two major Canadian engineering firms. The design approach chosen by the mechanical engineers is reviewed and compared to European and American existing Displacement Ventilation design guidelines. The paper shows that some traditional mixing ventilation assumptions are still prevailing which alter the expected benefits of the Displacement Ventilation approach. *In situ* performance measurements from two buildings during the winter of 2008 are presented. Thermal comfort and air quality indicators are assessed and compared to the expected performance of the designed Displacement Ventilation system. Major discrepancies are highlighted and preliminary explanations are given in the light of the most recent considerations about this ventilation strategy.

1- INTRODUCTION

Until recently, the vast majority of indoor air distribution systems in Canadian commercial buildings were of overhead mixing type. Displacement Ventilation breakout occurred on a low-key basis since the years 2000. The introduction of a new technology among design engineers is always challenging, and the success or failure of the outcome greatly depends on the approach taken. Displacement Ventilation is proven to provide better indoor air quality without altering thermal comfort. It is also known for its energy savings benefits, which are mostly associated with reduced cooling needs. This paper is reviewing and assessing the performance of two recent Displacement Ventilation field settings located in eastern Canada, province of Québec. It also investigates about the calculation methods selected by the design engineers with highlights on the major differences between field key design factors and available guidelines. Field assessment, in compliance with ASHRAE standard 113-2005, has been achieved for the winter condition along with comfort surveys in both buildings. Spring and summer tests have been scheduled and the results will be presented in a future paper.

2- CASE STUDIES

2.1 Multimédia room, Québec

This 97 seats multimedia room is located in a hotel building. Walls, ceiling and floor are completely encapsulated.

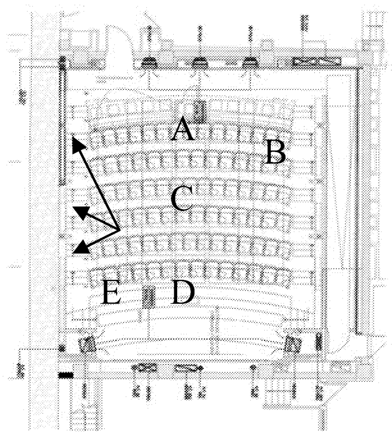

Figure 1: Ground floor plan of the multimedia room, with the stage of the bottom of the plan and diffusers distributed along the three others sides of the room.

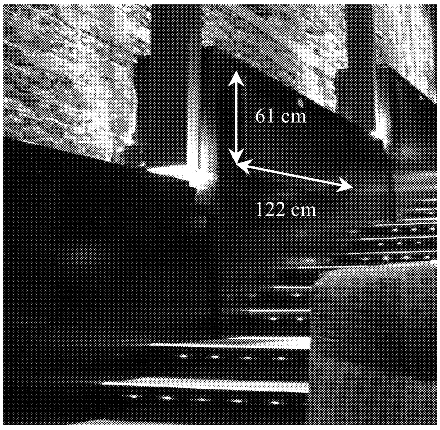

Figure 2 View of the supply ducts at the side of the multimedia room, with indications of the dimensions of the diffuser grills.

Figure 1 illustrates the location of sidewall displacement diffusers (indicated by arrows on the left wall), and the five measurement locations (A to E). Figure 2 shows face area dimensions (height and width) of one diffuser. There are nine sidewall diffusers distributed evenly on the side and back walls. Table 1 shows the input data for the design. Given that the envelope has no windows and no exterior walls, heat transfer through the room envelope is small compared to internal load from occupants and lighting, and thus negligible for this case. The supply air temperature of 16.4^{0}C is at peak cooling load. The low velocity sidewall diffusers are of displacement type with a nominal flow rate of 140 l/s per diffuser.

Table 1: Technical information multimedia room

Input data	Value
General details	
Floor area	141 m^2
Average ceiling height	4.9 m
Max height	6.1 m
Ventilation	
Air system	Single zone constant volume
Outside air	686 l/s
Total supply air	1415 l/s
Supply air temperature	16.4 ^{0}C
Outdoor air CO_2	400 ppm
Zone loads	
People	12.8 kW
lighting	5.6 kW

2.2 Public library, Montréal

The Montréal public library is a large four stories building. The design review and performance assessment has been achieved in five different locations. However, for the purpose of this paper, we will discuss the results of one location, namely the Newspapers & Magazines area.

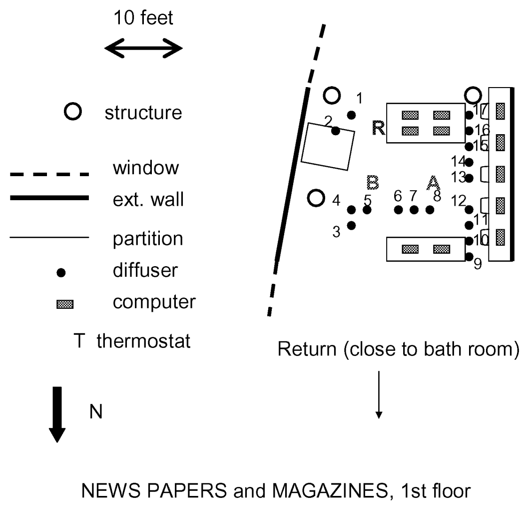

Figure 3: Schematic floor plan Public Library

Figure 4: Typical floor layout, Public library

Figure 3 is a schematic plan of the area for Newspapers & Magazines where measurements have been carried out. This location, oriented south east, has external heat gains. The floor area of this location is a fraction of the total floor area of the public library and therefore the internal loads have been prorated accordingly. Measurements were performed at two locations within this area, identified with letters A&B on the schematic plan. The floor diffusers of swirl type are represented by the dots. The diffusers come with a damper (open or closed) and are operated in sequence by a wall-mounted thermostat. The cool fresh air is mixed with the return air supplied through a pressurized plenum. The low velocity floor diffusers can be seen in Figure 4.

Table 2: Technical information Public library

Input data News paper & Magazine	Value
General details Floor area Ceiling height	 53 m^2 3.4m
Zone Ventilation Air system Outside air Supply air Supply air temperature Outdoor air CO_2	 Multizone variable volume 202 l/s 1029 l/s 16.3 ^{0}C 400 ppm
Zone loads People Lighting Computer Solar	 2.1 kW 0.2 kW 4.6 kW 2.1 kW

Table 2 shows the input values for ventilation and loads. Computer load is relatively high for this area since most of the occupants have computer access in this area.

3- DESIGN REVIEW

3.1 Multimedia room, Québec

Asked the motivations of selecting Displacement Ventilation, the design engineers quoted acoustic level as the most significant design factor followed by thermal comfort and controls. Considering the noise criteria required for a multimedia room (NC25,) the low velocity diffusers were the appropriate choice for meeting this prerequisite. IAQ and energy savings were quoted less significant. To perform the design review, we have looked at some key design factors calculated by engineers to achieve a good performance of the ventilation system.

Table 3: Comparison of design and measured thermal values for the Multimedia room

Key parameter	Design	Rehva	Ashrae	Winter test
Ceiling height (m)	4.9	> 2.3	> 2.4	
Max cooling load (W/m^2)	131	131	<120	
Load Heat surplus (kW)	18.5	12.9	18.5	
(θe-θs) mean value (^{0}C)	10.6	7.4	8.0	*3.0*
T supply at diffuser (^{0}C)	16.4	17.6	18.1	*21.7*
Required air flow rate (l/s)	1415	1455	1873	

Tables 3 and 4 summarize the design values in comparison with guidelines and field measured values. Design guidelines values are used to verify the applicability of Displacement Ventilation. The multimedia room complies with the minimum height for design conditions

(Table 3) and is in the high range for maximum cooling load. It must be said that the engineers estimated that almost half of the lighting loads would be exhausted above the suspended ceiling, reducing the maximum load to about 110W/m^2. However, the most surprising features for the multimedia room are the measured temperature difference between supply and return [θe- θs] temperature, of only 3ºC, and the high supply temperature at the diffusers, of 21.7ºC.

Table 4: Comparison of design and measured air quality values for the Multimedia room

Key parameter	Design	Rehva	Ashrae	Winter test
Stratification height (m)	n/a	Above breathing zone	Above breathing zone	~ 1.7
Supply air flow rate (l/s)	1415	970 - 1940	1873	
Required fresh air flow rate (l/s.p)	7.08	7.08 l	1.09 (2004)	
CRE at (~ 1.1m)	1	1.6	2.48	2.3
CO_2 bz (~ 1.1m) (ppm)	<1000	<1000	<1000	1354

During the measurement in February 2008, the room was almost fully occupied (96%). Temperature difference between supply and return was expected to be in the range of 7 to 10 degrees Celsius as predicted by the guidelines and/or calculated by the engineers. The average temperature difference measured during the test session was of 3^{0}C only. Furthermore, despite an average supply temperature of 21.7^{0}C, the thermal conditions were found to satisfy up to 95% of the occupants. Based on the simple steady-state heat balance equation, the maximum sensible heat load that can be removed with a temperature difference of 3^{0}C is approximately one-fourth (27.7%) of the total heat surplus calculated by the design engineers (18.5 kW). It appears that the surrounding walls, with cooler surface temperature, have absorbed a significant amount of that heat. Concerning air quality, we have measured a stratification height (CO_2 level) of 1.7 meter. We have also calculated a contaminant removal efficiency of 2.3 at breathing zone height, which is consistent with ASHRAE guidelines results.

3.2 Public library, Montréal

The qualitative assessment indicates that Displacement Ventilation was selected firstly for architectural considerations. Engineers reported that they did not object to this concept. Acoustic and indoor air qualities were also significant factors.

Table 5: Comparison of design and measured thermal values for the Public library

Key Parameter	Design	Rehva	Ashrae	Winter test
Ceiling height (m)	3.4	> 2.3	> 2.4	
Max cooling load (W/m^2)	181	140	<120	
Load Heat surplus (kW)	9	6.7	9	
(θe-θs) mean value (^{0}C)	7.7	6.8	7.5	*4.5*
T supply at diffuser (^{0}C)	16.4	17.6	18.4	*19.1*
Required air flow rate (l/s)	1029	816	1076	

Table 5 shows the differences between key design parameters for thermal comfort. The design cooling load is particularly high at 181Watts/m^2. While the design team made use of adjusting factors for the heat transmitted to the floor by fenestration (65%), the actual computers loads and the occupant density were higher than the design average at this location. The design team also assumed that 100% of equipment and occupant load had to be handled in the occupied zone. The airflow rate measured was also unusual (0,4 l/s.m^2) (this value is not presented in Table 5). This is based on the fact that only one diffuser out of 18 was opened during the measurement. Post measurement investigation determined that there was a mechanical problem with the dampers. A pre-monitoring session showed that in normal mode, the average flow rate for this location is about 7 $l/s.m^2$. This value is still much less than the design value. Once again the temperature difference between supply and return [θe -θs] differed significantly from design and proposed design guidelines values.

Table 6: Comparison of design and measured air quality values for the Public library

Key parameter	design	Rehva	Ashrae	Winter test
Stratification height (m)	n/a	Above breathin g zone	Above breathing zone	~ 1.7
supply air flow rate (l/s)	1029	286-572	1076	
required fresh air flow rate (l/s.p)	8	7.08	1.09 (2004)	
CRE at (~ 1.1m)	1	1.7	2.97	1.03
CO_2 bz (~ 1.1m) (ppm)	<1000	<1000	<1000	760

The air quality table (Table 6) shows a poor contaminant removal efficiency (1.03), but since there was virtually no airflow during the measurement, only the buoyancy forces could transport contaminants to the ceiling exhaust. We have counted 6 occupants during the testing session while the design was based on 28 occupants.

4-- WINTER PERFORMANCE RESULTS

4.1 Multimedia room, Québec

Following the design review, it was planned to do a measurement session to assess the performance of the ventilation system. A first measurement session was carried out in February 2008. ASHRAE standard 113-2005 was rigorously followed. Air Velocity, temperature and CO_2 were measured at five different locations as shown in Figure 1. In addition to this measurement, a comfort survey was achieved. Table 7 shows that thermal comfort and air quality indicators were inside the acceptable range. The comfort survey revealed an overall satisfaction of 95% related to thermal comfort, air movement and air quality.

Table 7: Comfort & air quality indicators multimedia room

Indicator	*Average Value*	*Acceptable range*
Vertical air temperature difference (VATD)	1.0 ^{0}C	< 3^{0}C
Draft ratio (DR)	6.6%	<20%
Contaminant removal efficiency (CRE)	1.82	> 1.0

Acoustic level was also rated very satisfying by 93% of the people. While this last result is in line with the most significant key factor as reported by the design engineers, the overall unexpected good performance of Displacement Ventilation system raised a certain number of questions in regard of the design approach. Design calculation was done for mixing ventilation leading to overestimate the required air flow rate, and to incorrect determine a too low cooling supply temperature. The immediate impact of this design approach is that the full benefits of Displacement Ventilation are not taken into account. Energy savings could be enhanced with the improved ventilation effectiveness by reducing fresh air flow rate and first cost reduced with a better sizing of supply fan flow rate and cooling coils.

4.2 Public library Montréal

Table 8: Comfort & air quality indicators Public library

Indicator	*Average Value*	*Acceptable range*
Vertical air temperature difference (VATD)	1.7 ^{0}C	< 3^{0}C
Draft ratio (DR)	7,5%	<20%
Contaminant removal efficiency (CRE)	1.03	> 1.0

Table 8 illustrates the result of News Paper & Magazine location (Figure 3) during the February measurements at the Montreal public library. With the exception of CRE, Comfort indicators are very good. Due to a too small sample set, we have not included results of the comfort survey. The temperature profile for this location and the four others that were achieved in February are typical of Displacement Ventilation. The smaller temperature difference and the supply temperature at the diffuser strengthen once again the assumption that full benefits of Displacement Ventilation are not achieved.

5- CONCLUSION

Displacement Ventilation can provide thermal comfort, air quality and low acoustic level as expected by the design engineers and confirmed by the performance assessment results. Unexpectedly, the design approach taken by both design teams was to calculate loads, required airflow rates, air change and supply temperatures as for mixing type ventilation. Temperature difference between supply and return were designed at 10,6 ^{o}C for multimedia room and 7,8 ^{o}C for the public library. Field results showed a 3,0 ^{o}C difference for the multimedia room and 4,5 ^{o}C for the public library. Surprisingly, with the exception of required fresh air (ASHRAE 2004) and ventilation effectiveness, the measured values were not so different from design values. The overall performance of both ventilation systems were beyond expectations. To reconcile the measurements results with design values, it is imperative that we improve existing guidelines and provide design engineers with tools that will drive their approach in order to get the full benefits of Displacement Ventilation

REFERENCES

REHVA. 2002. Displacement Ventilation in Non-Industrial Premises, ed. Skistad,H.et al.

ASHRAE. 2005. ANSI/ASHRAE Standard 113-2005 Method of Testing for Room Air Diffusion. Atlanta; American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE. 2004. ANSI/ASHRAE Standard 55-2005 Thermal Environmental Conditions for Human Occupancy. Atlanta; American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE. 2004. ANSI/ASHRAE Standard 62-2004 Ventilation for Acceptable Indoor Air Quality. Atlanta; American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Fisk, W.J., Faulkner, D., Sullivan, D.P., Chao, C., Wan, M.P., Zagreus, L., Webster, T. (2006) Performance of Underfloor Air Distribution in a Field Setting; International Journal of Ventilation Volume 5 No3 pp 291-300

Cermak, R., Melikov, AK. (2006) Air Quality and Thermal Comfort in an Office with Underfloor, Mixing and Displacement Ventilation ;International Journal of Ventilation Volume 5 No3 pp 323-332

Huizenga, C., Abbaszadeh, S., Zagreus, L., Arens,E. (2006) Air Quality and Thermal Comfort in Office Buildings: Results of a Large Indoor Environmental Quality Survey, Proceedings of Healthy Buildings pp 393-397.