A review of occupant responses to localized air distribution systems

K.E. Charles*

Institute for Research in Construction, National Research Council of Canada, Ottawa, Canada

ABSTRACT
This paper is a review of occupant responses to localized (floor and desk mounted) air distribution systems. These systems offer personal control, and can produce good ambient conditions, but few studies have examined their effects on actual occupants. A review of eleven studies suggested these systems can lead to favourable occupant responses, which in some cases exceed those encountered using traditional mixing systems. However, most of the studies included methodological limitations, which reduce the strength of conclusions that can be drawn. It was unclear whether improvements occurred because occupants adjusted their personal controls to achieve better physical conditions, or whether perceived control affected responses, irrespective of whether it was exercised. Alternatively, it could simply be the case that air delivered at the floor or desk was the most appropriate design for the office spaces tested. Further research is needed on these issues, to guide the design of appropriate air distribution systems.

INDEX TERMS
Air distribution; Local ventilation; Human response; Office building; Review

INTRODUCTION
Localized air distribution systems are designed to deliver air to specific locations within an office space. Compared to other methods of air distribution (e.g. mixing, displacement), localized systems use a larger number of diffuser outlets that deliver air directly to each occupant. Air is distributed through grills mounted in the floor (underfloor, UF, system), or through outlets mounted on the desk (task/ambient conditioning, TAC, system). An important feature of localized air distribution systems is the personal control provided to adjust parameters such as air speed, air direction, and supply air temperature.[1]

Localized air distribution systems are argued to benefit office occupants, by producing superior indoor air quality (IAQ) and thermal conditions. Experimental studies have suggested they can achieve '…a significant, but generally modest, enhancement of ventilation…' (Fisk *et al*., 1991) in the occupied zone, as compared to traditional, ceiling-mounted mixing systems. However, the largest improvements in IAQ tend to occur when air is directed towards the occupant's location, which could cause local discomfort from draught (Fisk *et al*., 1991; Faulkner *et al*., 1999). The majority of work on localized air distribution systems has been conducted in laboratory settings, and has focused on the physical characteristics of these systems. However, 'potentially the most significant performance characteristic of LV [local ventilation] systems is their controllability by individual office workers' (Arens *et al.,* 1991). It is, therefore, vitally important to understand how actual occupants respond to these systems. This paper reports on a literature review that was conducted to examine occupants' responses to localized air distribution systems.

---

*E-mail: kate.charles@nrc-cnrc.gc.ca

[1]Some localized systems also incorporate other ambient controls, such as task lighting and sound masking devices. In this review, only aspects relating to IAQ and thermal conditions are considered.

METHODS

Studies included in this review were selected from extensive searches of electronic databases, such as *EI Compendex*, *Current Contents*, *Ergonomic Abstracts*, and *PsychInfo*. A wide range of journals and conference proceedings were searched, including *Indoor Air*, *ASHRAE Transactions*, *Energy and Buildings*, *Journal of Environmental Psychology*, *IAQ*, *CLIMA 2000*, and *ROOMVENT*. Studies were included if they examined UF or TAC localized air distribution systems, and also measured occupant responses. Studies that focused primarily on local air filtering (e.g. portable air cleaners), rather than local air distribution, were not included. The search was restricted to studies in office settings (either field studies or laboratory office mock-ups), and those published from 1990 onwards. The literature search revealed that eligible studies were sparse, and only eleven relevant studies were found.

RESULTS

Five of the studies described occupants' responses to localized air distribution systems in isolation, either in laboratory office mock-ups, or in post-occupancy evaluations. The remaining six studies compared responses between localized and traditional, ceiling-mounted mixing systems, either in pre–post installation comparisons, or in cross-sectional comparisons of the two air distribution systems.

The two laboratory studies, both using UF systems, showed that occupants, wearing standardized clothing, were able to achieve neutral temperature sensations and comfortable conditions (Nakamura *et al.*, 1999), and generally did not perceive air movement to be uncomfortably draughty (Hanzawa and Nagasawa, 1990). However, little information was provided on the research design or sample populations in these studies, so the possibility of extraneous variables influencing the findings cannot be determined. These studies also used relatively few participants, exposed for relatively short time periods.

Two of the post-occupancy evaluations suggested that the installation of UF systems was associated with a reduction in occupant complaints (Spoormaker, 1990), favourable responses to dustiness and to the system in general, and few draught complaints (Matsunawa *et al.,* 1995). Again, however, these studies provided little information on research design, survey methods, office setting, or study population. The third post-occupancy evaluation (Hedge *et al.* 1993) was more comprehensive. This survey of 151 office occupants and six facilities managers examined responses to UF systems that had been in place for more than 6 months. Occupants were satisfied with heating, ventilation, and IAQ resulting from the systems. Retrospective comparisons to experiences of other types of air distribution suggested that managers felt that complaints were fewer, and occupants felt that localized air distribution produced better temperatures and IAQ, and favourably affected their health and productivity. The increased availability of control was also seen as beneficial. However, draughts were found to be an issue.

Taken together, these studies suggest that localized air distribution is positively evaluated by occupants. However, because these studies did not include pre–post installation comparisons, or comparisons to a control group, it is not possible to determine whether these reactions were better than those obtained from alternative air distribution systems. Although Hedge *et al.*'s (1993) study included retrospective comparisons, pre–post installation data is more reliable because it is less prone to bias. In addition, although some physical measurements were conducted, they were not systematically analysed in relation to occupant responses.

The remaining six studies provided stronger evidence, because they compared localized air distribution to traditional, ceiling-mounted mixing systems. Two studies, using office mock-ups, compared workstations with and without TAC air distribution. These studies suggested that occupants with TAC units experienced more neutral thermal sensations and were more comfortable (Bauman *et al*., 1993), were less dissatisfied with IAQ and air freshness, and reported better symptoms of wellness (Kaczmarczyk *et al*., 2002), as compared to occupants without TAC units.

Two studies compared office occupants working in areas ventilated with localized air distribution with those in areas with traditional ceiling-mounted mixing systems. One study (Fukao *et al*., 1996) found slight benefits to perceptions of air pollution and comfort with a UF system. However, responses to thermal sensation, comfort and acceptability did not differ between the two groups, and occupant responses were largely favourable under both methods of air distribution. Another study (O'Neill, 1992) suggested that occupants using UF systems perceived seasonal variations in temperature to be better than those using traditional mixing systems. However, perceptions of air freshness and temperature did not significantly differ. In these two studies, extraneous differences between areas or buildings were not reported, and could have confounded these findings. In addition, O'Neill's (1992) comparison was conducted on uneven groups (20 versus 180), which undermines its statistical reliability.

A study by Kroner and Stark-Martin (1994) compared occupants before and after they moved to a new building equipped with TAC air distribution. Results indicated that satisfaction and task performance improved following the move. Task performance also deteriorated during tests in which the TAC controls were deactivated. However, the change to localized air distribution occurred in parallel with a building move, and differences between the two buildings could have confounded these results. In addition, when the TAC controls were turned off, it is not clear whether detrimental responses resulted from a deterioration of physical conditions, or because of annoyance from losing personal control and a previously available amenity.

Finally, Bauman *et al.* (1998) conducted a field study using a pre–post intervention with control group methodology. In this study, physical measures and occupant surveys were conducted both before and 3 months after the installation of TAC units for 28 occupants (test group). Comparisons were also made against 25 occupants, who had a ceiling-mounted air distribution system throughout the study (control group). Pre–post improvements were found for the test group, in relation to satisfaction with air quality and thermal quality. By comparison, pre–post responses for the control group were largely similar. Post-installation, there was a shift in the test group towards cooler thermal sensations, increased thermal acceptability, and reduced desire for temperature changes. The percentage of control group occupants reporting acceptable temperatures did not change. However, average air temperatures did not significantly change for either group, suggesting that some factor other than objective temperature had affected the test group's temperature perceptions. Air velocity for the test group increased from 0.08 to 0.11 m/s following installation of TAC units. This change was accompanied by increased acceptability of air movement, and a large increase in test occupants wanting no change in air movement, suggesting that the test group had used their TAC controls to modify air velocity to suit their preferences. This increased air velocity might also have been the cause of improvements in temperature perceptions.

Taken together, these studies provide some evidence that occupant satisfaction is improved with the use of localized air distribution systems, as compared to ceiling-mounted mixing systems. However, in most cases there were a number of methodological limitations that undermine the reliability of these results. For example, the pre–post installation studies did not incorporate a control group, leading to the possibility that factors other than the change in air distribution system influenced occupant responses. Similarly, those studies which compared air distribution systems operating in different buildings or areas did not adequately control for building, indoor environment or occupant differences, which might have confounded the results. Furthermore, although some studies did measure IAQ and thermal conditions, these variables were not consistently analysed in combination with occupant responses. Table 1 shows sample physical measurements from the studies, along with the main occupant response findings. A range of physical conditions were associated with positive occupant responses, suggesting either that occupants vary in their preferences, or that the availability of personal control influenced responses, irrespective of the objective physical conditions. Future studies that systematically compare physical conditions and occupant responses would help to clarify the mechanisms behind these relationships.

Table 1 Sample physical conditions and occupant responses

Author, date	Study	Air temperature, °C	Air speed, m/s	Main findings
Nakamura *et al.* (1999)	Lab, UF	28.5	2.6–23.2	+ve
Hanzawa and Nagasawa (1990)	Lab, UF	26	0.05–0.1	+ve
Spoormaker (1990)	Field, UF	23–24		+ve
Matsunawa *et al.* (1995)	Field, UF	~24–29	<0.2	+ve
Hedge *et al.* (1993)	Field, UF	—	—	+ve
Bauman *et al.* (1993)	Lab, TAC versus no TAC	22.2–23.6	0.06–0.18 (TAC) 0.07–0.10 (no TAC)	↑
Kaczmarczyk *et al.* (2002)	Lab, TAC versus no TAC	23		↑
Fukao *et al.* (1996)	Field, UF versus mixing	24.5 (UF) 25.2 (mixing)	0.12 (UF) 0.19 (mixing)	↔/↑
O'Neill (1992)	Field, UF versus mixing	—	—	↔/↑
Kroner and Stark-Martin (1994)	Field, pre–post TAC	—	—	↑
Bauman *et al.* (1998)	Field, pre–post TAC, TAC versus no TAC	22.9 (TAC pre) 22.7 (TAC post) 22.6 (control pre) 22.9 (control post)	0.08 (TAC pre) 0.11 (TAC post) 0.08 (control pre) 0.09 (control post)	↑

+ve = favourable responses to localized air distribution.
↑ = improved responses with localized air distribution.
↔ = no difference in responses between conditions.

DISCUSSION

Overall, the studies reviewed suggested that localized air distribution systems can lead to favourable occupant responses, which in some cases might exceed those encountered using traditional ceiling-mounted mixing systems. However, most of these studies included methodological limitations, limiting the strength of conclusions that can be drawn.

The relationship between all air distribution systems (mixing, displacement and localized) and occupant responses is complex, as is illustrated by Figure 1. Air distribution systems affect airflow patterns and the extent of air mixing, which in turn affect the physical IAQ and thermal conditions in the space. These physical conditions in turn affect occupant responses.

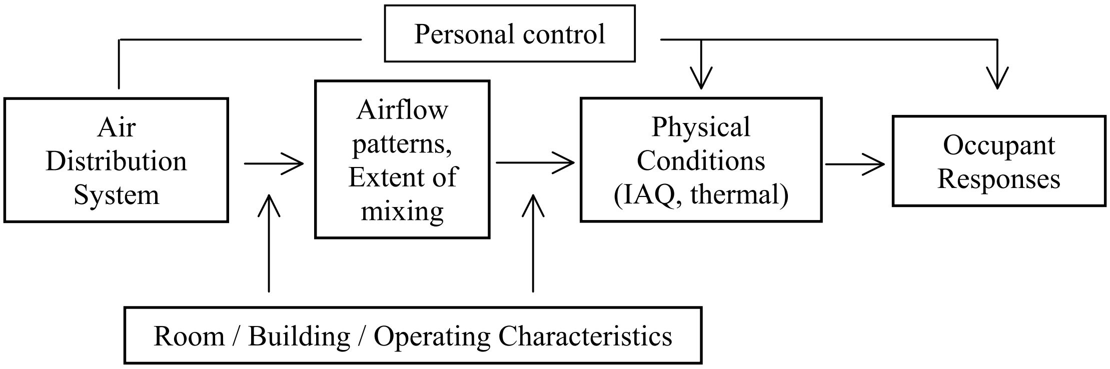

Figure 1 Relationships between air distribution systems and occupant responses.

Two additional mechanisms influence whether a given air distribution system will positively influence occupant responses. First, numerous extraneous factors, such as room geometry, pollutant sources, heat load, return location, air velocity and supply air temperature, have been argued to affect the performance of air distribution systems and the physical conditions they create. Therefore, it is likely that the 'best' air distribution system will vary, depending on the particular context in which it is used. Positive reactions to localized systems, therefore, could simply be because air supplied from the floor or desk was the most appropriate design for the given context.

Second, localized air distribution systems offer personal control to occupants. Occupant responses could be improved simply by having this option for control, irrespective of whether occupants use it. Alternatively, occupants' use of their controls could change the physical conditions, and thus responses. None of the studies adequately separated the effects of the physical environment and personal control. Although Bauman *et al.*'s (1998) study provided some evidence that improvements occurred because occupants were able to control the physical environment to suit their preferences, the nature of these relationships remain somewhat unclear.

CONCLUSIONS

This literature review provides some support for the beneficial effects of localized air distribution systems. However, the mechanisms described above suggest that comparisons between different types of air distribution systems might not lead us to meaningful conclusions. An improvement in occupant responses, for example, might simply reflect the suitability of one system over another for a given context, rather than the superiority of that system in general. A more fruitful research direction might be to focus attention on the relationships between physical conditions and occupant responses. Once these relationships are more clearly understood, they can be translated into the design of air distribution systems capable of achieving appropriate indoor environments that are most beneficial to occupants.

ACKNOWLEDGEMENTS

This work forms part of the NRC/IRC Cost-Effective Open-Plan Environments (COPE) project, supported by Public Works and Government Services Canada, Natural Resources Canada, Building Technology Forum, Ontario Realty Corp, British Columbia Buildings Corp, USG Corp, and Steelcase Inc. The author is grateful to Jennifer Veitch, Guy Newsham and John Shaw for their contributions to this review.

REFERENCES

Arens, E.A., Bauman, F.S., Johnston, L.P. *et al*. (1991). Testing of localized ventilation systems in a new controlled environment chamber. *Indoor Air* **3**, 263–281.

Bauman, F.S., Carter, T.G., Baughman, A.V. *et al*. (1998). Field study of the impact of a desktop task/ambient conditioning system in office buildings. *ASHRAE Transactions* **104**(1B), 1153–1171.

Bauman, F.S., Zhang, H., Arens, E.A. *et al*. (1993). Localized comfort control with a desktop task conditioning system: laboratory and field measurements. *ASHRAE Transactions* **99**, 733–749.

Faulkner, D., Fisk, W.J., Sullivan, D.P. *et al*. (1999). Ventilation efficiencies of desk-mounted task/ambient conditioning systems. *Indoor Air* **9**, 273–281.

Fisk, W.J., Faulkner, D., Pih, D. *et al*. (1991). Indoor air flow and pollutant removal in a room with task ventilation. *Indoor Air* **3**, 247–262.

Fukao, H., Oguro, M., Hiwatashi, K. *et al*. (1996). Environment evaluation in an office with floor-based air-conditioning in an office building: Thermal environment and IAQ in comparison with ceiling-based air-conditioning system. *Proceedings of ROOMVENT '96: The 5th International Conference on Air Distribution in Rooms,* pp. 315–322.

Hanzawa, H. and Nagasawa, Y. (1990). Thermal comfort with underfloor air-conditioning systems. *ASHRAE Transactions* **96** (2), 696–698.

Hedge, A., Michael, A.T. and Parmelee, S.L. (1993). Reactions of office workers and facilities managers to underfloor task ventilation in offices. *Journal of Architectural and Planning Research* **10** (3), 203–218.

Kaczmarczyk, J., Zeng, Q., Melikov, A. *et al*. (2002). The effect of a personalized ventilation system on perceived air quality and SBS symptoms. *Proceedings of Indoor Air 2002: The 9th International Conference on Indoor Air Quality and Climate*, vol. 4, pp. 1042–1047. Santa Cruz, CA: Indoor Air 2002.

Kroner, W.M. and Stark-Martin, J.A. (1994). Environmentally responsive workstations and office-worker productivity. *ASHRAE Transactions* **100** (2), 750–755.

Matsunawa, K., Iizuka, H. and Tanabe S. (1995). Development and application of an underfloor air-conditioning system with improved outlets for a ‘smart’ building in Tokyo. *ASHRAE Transactions* **101** (2), 887–901.

Nakamura, Y., Mizuno, M., Ueno, O. *et al*. (1999). Study on thermal comfort of task-ambient air conditioning system. *Proceedings of ROOMVENT '99: The 6th International Conference on Air Distribution in Rooms,* pp. 257–264.

O'Neill, M.J. (1992). Effects of workspace design and environmental control on office workers' perceptions of air quality. *Proceedings of Human Factors Society 36th Annual Meeting,* part 2, pp. 890–894. Santa Monica, CA: The Human Factors Society.

Spoormaker, H.J. (1990). Low-pressure underfloor HVAC system. *ASHRAE Transactions* **96** (2), 670–677.