WORKSTATEMENT

Title:

The Design of Displacement Ventilation Systems Within Industrial Facilities

TC/TG & Contact:

TC 5.08 - Duncan Phillips,

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Research Category:

Research Classification:

TC/TG Priority:

1st

Estimated Cost & Duration:

$200,000 & 24 months.

Other Interested TC/TGs:

Search for other TC/TGs in progress, TC 4.10?

Possible Co-funding Organizations:

None currently identified

Handbook Chapters to be Affected By Results of this Project:

Chapters 28 & 29

State-of-the-Art (Background):

The merits of displacement ventilation for industrial premises are well understood. By arranging the ventilation flow paths to be unidirectional, usually upwards, contaminants are efficiently flushed from the occupied space. This increased efficiency leads to a combination of better air quality at a lower cost. The relative improvements of these factors depends on the configuration of the system installed.

As it stands now, most of the research that is been published on displacement ventilation deals with the steady behaviour of a controllable occupied space. The heat loads and air flows are constant. The majority of the work available has been for office or commercial spaces. For instance, one of the results from ASHRAE Research Project (RP 949) was a design methodology for ventilation professionals to use when designing ventilation systems for occupied spaces (Yuan et al., 1999a).

Displacement ventilation has become a popular means for contaminant control in European industrial facilities. Both horizontal (Skistad, 1994) and vertical systems (Akimoto, 1999) are used. Their advantage is that they can maintain an appropriately high level of air quality in the occupied zone while reducing the ventilation costs of more traditional mixing ventilation systems. Despite this, detailed design literature on industrial displacement ventilation systems is scarce.

With few exceptions, the spaces modelled, measured and analyzed in the literature have had static conditions and more or less ideal flow systems. That said, the use of current design guides that assumes static conditions may not provide for a sufficient margin of safety should "off-design" conditions occur. Furthermore, the design guides do not provide any information regarding the ability of a displacement ventilation flow pattern to re-establish itself after being upset.

The studies that have reviewed the transient nature of displacement ventilation and disturbances have identifed some of the issues but not necessarily solutions. For example, in a study of a displacement system in an industrial facility, Niemelä & Koskela (1996) discovered that the establishment of a vertical displacement air patterns in an industrial hall was problematic first thing in the morning when the air temperatures were not favourable to the flow system. In this case, the supply was at the floor and the exhaust at the roof. In addition, the results varied depending on the contaminant. A gaseous contaminant was effectively drawn out of the breathing zone while larger particles were not. Mundt (1994) presents the results of a study of displacement ventilation in a room. The work shows the effect of a disturbance on the breakdown of the displacement pattern and the delay before it re-establishes itself. While the disturbance might not be typical of that in an office, large changes to the flow patterns are observed in industrial facilities from processes and operations within the ventilated environment. Mattson & Sandberg (1994) show that movement within a room, similar to that of a human walking, can have a strong influence on the ventilation flows, and thus effectiveness, within a displacement ventilated room. In a review of natural ventilation, Linden (1999) includes a discussion on the requirements of a wind driven flow that would be able to break down a stably stratified flow - e.g. displacement ventilation. While he suggests that the level of wind flow is too high to be permitted in a building designed for comfort, it may not necessarily be true for an industrial facility that has large openings.

Thus the state of the art at the moment can be summarized as follows:

1) We understand how displacement ventilation can contribute to energy savings and indoor air quality improvements.

2) There is a far amount of literature on office and commercial spaces, but a lack of specifics on industrial facilities.

3) The studies conducted usually concentrated on the static, or well developed, flow conditions as well as an environment that did not change - e.g. heat loads were constant, no upsetting forces due to process or people movement.

4) The design documents that exist do not provide a means to establish how robust the flow pattern is (e.g. can it be upset by a temporary change in the environment) nor does it provide for factors of safety should "off-design" environmental conditions exist.

Advancement to the State-of-the-Art:

The purpose of this research project will be to focus on the industrial ventilation environment and provide clear direction on that listed below. While it is anticipated that one of the deliverables is a design guide, there is significant work that needs to be done to fill in the missing information. The research project should:

1) Provide a means to identify when displacement ventilation systems will work and when they will not: identify the limitations.

2) Identify the permissible range of operating variability that will permit the system to continue to operate efficiently.

3) Evaluate the ability of the system to recover from a driving force (e.g. conveyor movement, opening of doors, process changes) that causes an adverse disturbance to the flow field.

4) Evaluate the critical system factors to ensure that the occupied zone remains clear of heat and contaminants. These shall include heat loads, contaminant generation rates and building envelope types as a minimum.

Justification and Value to ASHRAE:

As it stands now, there are tens of thousands of industrial facilities in North America. This research could impact a significant proportion of these facilities. The ASHRAE membership will benefit from the availability of design proceedures that address both variability and margins of error. In terms of the impact on general society, if a refined ventilation system can address both indoor air quality and energy efficiency at the same time, then there is a clear advantage to the design. However, the research project will also identify conditions underwhich displacement ventilation will not be appropriate.

Objective:

The research project deliverables will provide the following:

1) A design guide for displacement ventilation
2) Enhancements in the form of details to Chapters 28 & 29.

Scope:

Given the nature of the problem, it has been determined that assessing transient phenomena in different types of facilities, multiple times would make the project too costly. In order to reduce the costs of the experimental stage, this proposal lays out a framwork in which a literature review is conducted, detailed data from one facility is taken, the experimental facility is simulated and the simulation methodology shown to be representative of the flows in the facility and finally, the simulation methodology extended to multiple facilities to generate a parametric database of displacement ventilation environments. The simulations can be numerical or physical.

The buildings that are of interest are industrial facilities with heights ranging from 12 ft to 50 ft. North American weather conditions are of immediate interest, although bidders are free to add other conditions as they see fit.

The scope of work for this project can be divided into two parts with a total of five phases.

Part 1) Background Literature Review and Experimental Program
Phase 1)
In this part of the work, the relevant literature will be reviewed and evaluated in order to assess existing design criteria, theory and methodology and to also define criteria through which displacement ventilation systems will be deemed to be operating and what constitudes a breakdown of the flow patterns when a disturbance occurs. This review should include the ventilation literature as well as other disciplines that deal with contained stratified flows. Where possible, methods to quantify or describe disturbances, stratification strength, recovery times and other displacement ventilation parameters are desired.

The experimental program that Bidders outline in the proposal should be flexible to encompass any new information generated through the literature review. The PMS and PI will discuss the literature review and reach a consensus on the experimental plan.

Phase 2)
This component of the work is intended to generate a data set of full-scale flow and environmental conditions inside a controlled or documentable industrial environment. This phase is a detailed experimental study of an experimental or well defined/controlled facility. Data on temperature & velocity distributions, concentrations of tracer gas or contaminants during steady operating conditions will be taken.

Following the collection of data during normal conditions a series of three, well defined distubances will be imposed on the flows inside the facility and the flow variables continuously monitored until the facility returns to the steady state measured earlier. The three distubances are: i) a door in the facility envelope being opened and flow entering/exiting from outside the flow domain; ii) a large object being moved from one side of the facility to the other; and, iii) a large internal distubance caused by a "process" change - for example a large fan could be turned on for several minutes to simulate the charging of a furnace). This data will be used to assess the effects of disturbances on flow patterns inside the test facility.

The data collected during Phase 2) will be used to benchmark the simulation methodology in Part 2) of the work.

Part 2) Physical or CFD Simulations
Phase 3)
The objective of phase 3 is to use the data collected above to to validate the simulation/modeling methods. All aspects of the experimental phase will be simulated and the techniques assessed.

Phase 4)
The objective of this last phase is to repeat the simulation methodology on a suite of other design

facilities in order to build up a large enough data set for a "parametric" evaluation of displacement ventilation. It is expected that there will be 3 different types of facilities (dimensions/process type) and at least five different process and/or environmental conditions run within each of these facilities for both the steady flow condition as well as the three disturbances. This suggests:

3 facilities x 5 boundary condition sets x 4 simulations per configuration = 60 simulations.

Where possible, the PI is encouraged to use non-dimensional analysis to extend the range of simulations beyond those that are performed. The actual parameters of most importance and thus of interest to vary and simuilate will come from the literature review in Phase 1.

Phase 5)
Phase 5 will be used to distill the data and simulations into a useable form for the ventilation design community. This should include but is not limited to:

- proper design calculation techniques
- tests for engineers to use to ensure a displacement ventilation system is feasible
- identify means to quantify robustness or the ability to resist upset
- identify means to evaluate time from upset to reestablishment of stratification
- identify the means through which to calculate the consequence of a transition to a mixed zone and back again (e.g. if the stratification layer is hot, contaminant laden, etc., what effect on the workers is possible.)
- redefinition of "robustness" and other parameters as appropriate

<u>Deliverables:</u>

· Progress and Financial Reports shall be made to the to the Society through its Manager of Research at quarterly intervals; specifically on or before each January 1, April 1, June 10 and October 1 of the contract period.

· The Principal Investigator shall report in person to the TC at the annual and winter meetings, and answer such questions regarding the research as may arise.

· The Principal Investigator shall communicate with the PMS on a regular basis as to the progress of the project and any problems or questions that may arise. The Principal Investigator shall meet with the PMS at the annual and winter meetings to discuss the project progress in detail.

· A Preliminary Report is to be prepared, submitted to, and approved by the PMS at the completion of the first phase before the Final Report is written.

· A Final Report shall be prepared and submitted to the Manager of Research by the end of the contract period covering complete details of all research carried out on the project. Unless otherwise specified, six draft copies of the final report shall be furnished for review by the PMS.

· Write a section(s) on displacement ventilation suitable for inclusion in the ASHRAE Handbook.

Following approval by the PMS and the TC, final copies of the Final Report shall be furnished as follows:

- An Executive Summary suitable for wide distribution to the industry and to the public.
- Six bound copies.
- One unbound copy, printed on one side only, suitable for reproduction.
- Two copies on 3.5" diskette(s), one in ASCII format and one in Microsoft Word 6.0.

At least two Technical or Symposium papers on this research shall be prepared in a form suitable for presentation at a Society meeting. The Paper(s) shall conform to the Society's "Submitting Manuscripts for ASHRAE Transactions" which may be obtained from the Special Publications Section. (On the ASHRAE Home Page, these Guidelines are titled "Meeting Paper Preparation" and can be found under "How to Participate.")

All papers or articles submitted for inclusion in any ASHRAE publication shall be made through the Manager of Research and not to the publication's editor.

A Technical Article suitable for publication in the ASHRAE Journal will be required by the Society. While normally a voluntary submission the level of funding on the project requires that the ASHRAE membership be well informed.

Level of Effort:
The estimated level of effort for the project is approximately 4 months of PI time and 16 months of research assistant time over the course of 30 months. At some times, e.g. during the experimental phase, it is conceivable that there will be multiple technicians working on the project.

Other Information for Bidders:
It is anticipated that the bidder(s) will have had a range of experience in a variety of industrial facilities (e.g. heavy manufacturing, steel, assembly, electronics, pharmaceutical, and farming). This experience should include design, construction and/or analyses of industrial ventilation systems in various scenarios. Bidders are advised to highlight these qualifications in their proposal.

Sufficient flexibility has been provided for the proposals to allow for either numerical or physical simulations of the ventilated environments. Numerical simulations might be carried out by computational fluid dynamics (CFD) while physical simulations might be carried out using water/salt modeling. The bidder(s) should outline their experience with these sorts of simulations and stratified flows where appropriate.

Due to the staged approach to the project - review, experiments and numerical simulations, bidders are advised to build some consultation time with the PMS into their schedules. Specifically, consultations should occur:
1) following the literature review and prior to the start of experiments. The PI is advised to discuss the results of the review and experimental plan with the PMS and be prepared to make adjustments to the initial experimental plan outlined in the proposal.

2) following the successful simulation (CFD or physical) of the experimental domain and prior to the execution of the numerical experiments the PI should discuss the nature of the successful simulation of the experimental domain and basis on which the evaluation of success was done.

References:

Linden, P.F., (1999),
The Fluid Mechanics of Natural Ventilation, *Annual Review of Fluid Mechanics*, Vol. 31, pages 201 - 238.

Mattsson, M. & Sandberg, M., (1994)
Displacement Ventilation - Influence of Physical Activity, *ROOMVENT '94: Proceedings of the 4th International Conference on Air Distribution in Rooms*, Krakow: Vol. 2, pages 77 - 92.

Mundt, Elisabeth, (1994),
Contaminant Distribution in Displacement Ventilation - Influence of Disturbances, *Building and Environment*, Vol. 29, No. 3, pages 311-317.

Niemelä, Raimo & Koskela, Hannu (1996),
Air Flow Patterns in a Large Industrial Hall with Displacement Ventilation, *ROOMVENT '96: Proceedings of the 5th International Conference on Air Distribution in Rooms*, Tokyo: July 17th - 19th, 1996, pages 363 - 370.

Yuan, Xiaoxiong, Chen, Qingyan, & Glicksman, Lean R., (1999a),
Performance Evaluation and Design Guidelines for Displacement Ventilation, *ASHRAE Transactions*, Vol. 105, Part 1.

Authors:
There has been one primary author - Duncan Phillips of RWDI, Guelph, Ontario. Other have contributed comments and requests.

Proposal Evaluation Criteria:
Research proposals from bidders of this project will be evaluated based on the following criteria:

1) Contractors understanding of Work Statement as revealed in the proposal (20 points)
   a) Logistical problems associated
   b) Technical problems associated
   How do we measure this and how to apply the findings

2) Quality of methodology proposed for conducting research (25 points)
   a) Organization of project
   b) Management Plan

3) Contractor's capability in terms of facilities (15 points)
   a) Data collection equipment
   b) Technical expertise

c) Industrial facilities proposed for Part 2
d) Managerial support
types of instruments

4) Qualification of personnel for this project (25 points)
a) Project team 'well rounded' in terms of qualification and experience in related work
b) Project manager person directly responsible: experience and corporate position
c) Team members' qualifications and experience
d) Time commitment of Principal Investigator

5) Student involvement (0 points)
While student involvement on ASHRAE research projects is desirable, the level of detail and sophistication of the project suggest that student involvement, per se, may not be to the contractor's advantage.

6) Probability of contractor's research plan meeting the objectives of the Work Statement (10 points)
a) Detailed and logical work plan with major tasks and key milestones
b) All technical and logistic factors considered
c) Reasonableness of project schedule

7) Performance of contractor on prior ASHRAE projects (no penalty for new contractors) (5 points)

Prospective Bidders:
There are couple of organizations that are in the position to bid on this project:
1) Rowan Williams Davies & Irwin Inc., Ontario
2) Massachussets Institute of Technology, MA
3) Aalborg University, DK
