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TO: Josiah Wiley, Chair TC 5.6, jwiley@ruskin.com
Paul Turnbull, Research Subcommittee Chair TC 5.6, paul.turnbull@siemens.com
Paul Turnbull, John Klote, Peter McDonnell, Work Statement Author(s), paul.turnbull@siemens.com; johnhklote@gmail.com;

FROM: Michael R. Vaughn, Manager of Research and Technical Services (MORTS)

CC: Dennis Loveday, Research Liaison 5.0, d.l.loveday@lboro.ac.uk

DATE: July 9, 2018

SUBJECT: Work Statement (1644-WS), "Smoke Control in Long Atria"

During their recent annual meeting, the Research Administration Committee (RAC) reviewed the subject Work Statement (WS) and voted 13-0-0 to conditionally accept it for bid provided that the RAC approval conditions below are addressed to the satisfaction of your Research Liaison in either written responses or revisions to the work statement.

See the approval conditions below.

1. Clearly explain why the project is important, in energy and air-flow perspectives.
2. Need better breakdown of tasks. For example, perhaps perform and submit the first 3 or 4 simulation for review and then fine tune the model before completing the balance of the simulations.
3. Better define the deliverables.
4. The budget appears too high to validate a tool.

The WS review summary also contains comments from individual members of RAC that the TC may or may not choose to also consider when revising the WS; some of these comments may indicate areas of the WS where readers require additional information or rewording for clarification.

Lastly, please provide ASHRAE staff with the final names and contact information for the Proposal Evaluation Subcommittee (PES) roster, and the Technical Contact that will respond to questions from prospective bidders during the bid posting period (typically this is a WS author or PES member). The technical contact and all members of the PES must also agree to not bid on this project directly or through their employer as the primary contractor or a subcontractor.

Please coordinate changes to this Work Statement with your Research Liaison, Dennis Loveday, RL5@ashrae.net or d.l.loveday@lboro.ac.uk. Once he is satisfied that the approval conditions have been met, the project will be ready to bid.

The first opportunity that you will have for this project to possibly bid is fall 2018. To be eligible for this bid cycle, a revised work statement that has been approved for bid by your research liaison should be sent (electronically) to Michael Vaughn, Manager of Research and Technical Services, mvaughn@ashrae.org or morts@ashrae.net, by **September 1, 2018**. The next opportunity for bid after that will be spring 2019.

Project ID	**1644**	
Project Title	**SMOKE CONTROL IN LONG ATRIA**	
Sponsoring TC	TC 5.6, (Control of Fire and Smoke)	
Cost / Duration	$75,000 / 12-15 Months	
Submission History	**1st WS Submission, RTAR Accepted w/Comments January 2016**	
Classification: Research or Technology Transfer	Basic/Applied Research	
RAC 2018 Annual Meeting Review	**RTAR STAGE FOLLOWED**	
Check List Criteria	**Voted NO**	**Comments & Suggestions**
State of the Art (Background): The WS should include some level of literature review that documents the importance/magnitude of a problem. If not, then the WS should be returned for revision. **RTAR Review Criterion**		
Advancement to the State-of-the-Art Is there enough justification for the need of the proposed research. Will this research significantly contribute to the advancement of the State-of-the-Art. **RTAR Review Criterion**		
Relevance and Benefits to ASHRAE: Evaluate whether relevance and benefits are clearly explained in terms of: a. Leading to innovations in the field of HVAC & Refrigeration b. Valuable addition to the missing information which will lead to new design guidelines and valuable modifications to handbooks and standards. Is this research topic appropriate for ASHRAE funding? If not, Reject. **RTAR Review Criterion**		
IF THE THREE CRITERIA ABOVE ARE NOT ALL SATISFIED - MARK "REJECT" BELOW BUT ADDRESS THE FOLLOWING CRITERIA AS APPROPRIATE		
Detailed Bidders List Provided? The contact information in the bidder list should be complete so that each potential bidder can be contacted without difficulty.		**#7** - no bidders provided **##11**- 5 identified.
Proposed Project Description Correct? Are there technical errors and/or technical omissions that the WS has that prevents it from correctly describing the project? If there are, than the WS needs major revision.		**#7** - Is there any provisions to validate the equations and models developed against a real word test? Is that not necessary? **#11** - I am not familiar with the NIST FDS CFD code referred to in the WS and I don't know its capabilities, but use of such terms as heat transfer values of building materials in a CFD simulation is odd, unless the authors mean wall thermal resistance to compute heat transfer to adjacent spaces or the outdoors or surface radiation properties. There is no specification as to what height the plume has to sink to to consider it to have "desceded". Is this typical human height? What are the criteria for the arrival of the plume at a given location: a temperature? a concentration? Perhaps the authors should coordinate this with TC4.10, which has a goodly number of CFD experts
Task Breakdown Reasonable? Is the project divided into tasks that make technical and practical sense? Are the results of each task such that the results of the former naturally flow into the latter? If not, then major revisions are needed to the WS that would include: adding tasks, removing tasks, and re-structuring tasks among others.		**##5** - Very good WS identifying the required tasks. **MP** - Milestone 3 should have more details of the simulations criteria that would require new runs. **#12** - very well written with clear tasks and workbreakdown. **#11** - There is a long narrative and detailed specification of the cases to be run but no task breakdown. However, there is a list of milestones at the end that includes a list of 19 briefly defined Tasks. These should be moved to the "Approach" section of the WS.
Adequate Intermediate Deliverables? The project should include the review of intermediate results by the PMS at logical milestone points during the project. Before project work continues, the PMS must approve the intermediate results.		**#12** - the proposed schedule and task description allow for a stage-gate process to ensure proper research management. #11 - 6 milestones and associated tasks are provided in a table at the end of the WS. This should be moved to the approach section.
Proposed Project Doable? Can the project as described in the WS be accomplished? If difficulties exist in the project's WS that prevent a successful conclusion of the project, then the project is not doable. In this situation, major revision of the WS is needed to resolve the issues that cause the difficulty.		**#11 -** Not sure because of my lack of familiarity with the capabilities of the NIST FDS code.
Time and Cost Estimate Reasonable? The time duration and total cost of the project should be reasonable so that the project can be as it is described in the WS.		**#12** - I think the cost is too low to finish this project adequately; the task to set up the initial 3 major CFD simulations will take long to make it right, then there will be 22 additional cases! I would expect that the 75k would be spent on setting up the problem alone! **#11** - Unable to judge, but it looks like it is on the light side. Again, it looks like this is just executing the NIST FDS program for all the cases listed. Not being familiar withat program, I cannot judge this.
Proposed Project Biddable? Examining the WS as a whole, is the project described in the WS of sufficient clarity and detail such a potential bidder can actually understand and develop a proposal for the project? This criterion combines the previous three criteria into an overall question concerning the usefulness of the WS. If the WS is considered to not be biddable, then either major revisions are in order or the WS should be rejected.		**#7** - Would like to see greater clairification on Milestone 3 simulations. **#11**- I defer to others familiar with the fire and smoke CFD codes such as the NIST FDS code.
Decision Options	**Initial Decision**	**Final Approval Conditions**
ACCEPT		**##5** -Well written WS with very good tasks identified. I would suggest adding PMS review between each milestone. **#13** - Need better breakdown of tasks. For example, perhaps perform and submit the first 3 or 4 simulation for review and then fine tune the model before completing the balance of the simulations. MP- see comments on milestone 3. **#12** - Need to increase the budget to at lease $125k. **#11** - I could also vote "RETURN" but I defer to others more familiar with the topic. This project should be coordinated with TC4.10, which has broad experience in CFD. IS the fire plume treated as a gas or a cloud of fine particles or both? I suppose these are considered in the NIST code, along with turbulent entrainment and both convective and radiative heat transfer.
COND. ACCEPT		
RETURN		
REJECT		

ACCEPT Vote - Work statement(WS) ready to bid as-is
CONDITIONAL ACCEPT Vote - Minor Revision Required - RL can approve WS for bid without going back to RAC once TC satisfies RAC's approval condition(s) to his/her satisfaction
RETURN Vote - WS requires major revision before it can bid
REJECT Vote - Topic is no longer considered acceptable for the ASHRAE Research Program due to duplication of work by another project or because the work statement has a fatal flaw(s) that makes it unbiddable

WORK STATEMENT COVER SHEET

Date: May 7, 2018

(Please Check to Insure the Following Information is in the Work Statement)

A. Title	✓
B Executive Summary	✓
C. Applicability to ASHRAE Research Strategic Plan	✓
D. Application of the Results	✓
E. State-of-the-Art (background)	✓
F. Advancement to State-of-the-Art	✓
G. Justification and Value to ASHRAE	✓
H. Objective	✓
I. Scope	✓
J. Deliverables/Where Results will be Published	✓
K. Level of Effort	
Project Duration in Months	✓
Professional-Months: Principal Investigator	
Professional-Months: Total	
Estimated $ Value	✓
L Proposal Evaluation Criteria & Weighting Factors	✓
M. References	✓
N. Other Information to Bidders (Optional)	✓

Title: Smoke Control in Long Atria

WS# 1644
(To be assigned by MORTS - Same as RTAR #)

Results of this Project will affect the following Handbook Chapters, Special Publications, etc.:

HVAC Applications - Chapter 53, and
ASHRAE special publication "Handbook of Smoke Control"

Responsible TC/TG: TC 5.6 Fire and Smoke Control

Date of Vote: Letter Ballot sent March 22, 2018, with three follow-ups

For		8
Against	*	0
Abstaining	*	0
Absent or not returning Ballot	*	4
Total Voting Members		12

This W/S has been coordinated with TC/TG/SSPC (give vote and date):
None

Has RTAR been submitted? Yes - approved January 2016

Strategic Plan Theme/Goals:
2010-2018 Strategic Plan:
Goal 7 (development of tools, procedures)
Goal 9 (improved system safety)

Work Statement Authors: **
Paul Turnbull

Proposal Evaluation Subcommittee:
Chair: Paul Turnbull
Members: John Klote
Peter McDonnell

Project Monitoring Subcommittee:
(If different from Proposal Evaluation Subcommittee)
Same as PES

Recommended Bidders (name, address, e-mail, tel. number): **

Michael J. Ferreira, Hughes Associates, Inc., 3610 Commerce Dr.,
Suite 817, Baltimore, MD 21227-1652. ph. 410-737-8677

Ahmed Kashef, National Research Council Canada, 1200 Montreal Road,
Building M-59, Ottawa, ON, Canada K1A 0R6. ph. 613-990-0646

Jeffrey S. Tubbs, Arup, 955 Massachusetts Ave, 4th Floor,
Cambridge, MA 02139. ph. 617-864-2987

James A. Milke, University of Maryland, 3104 JM Patterson Building,
College Park, MD 20742. ph. 301-405-3995

George Hadjisophocleous, Carleton University, 1125 Colonel By Dr.,
Ottawa, ON, Canada K1S 5B6. ph. 613-520-2600

(Three qualified bidders must be recommended, not including WS authors.)

Potential Co-funders (organization, contact person information):
None we are aware of.

	Yes	No	How Long (weeks)
Is an extended bidding period needed?		✓	
Has an electronic copy been furnished to the MORTS?	✓		
Will this project result in a special publication?	update		
Has the Research Liaison reviewed work statement?	✓		

* Reasons for negative vote(s) and abstentions

No negative votes or abstentions.
Four ballots were not returned.
One person is known to have left their company and stopped participating in TC5.6.
Three others did not return a ballot after three requests over a span of 4 weeks.

** Denotes WS author is affiliated with this recommended bidder
Use additional sheet if needed.

WORK STATEMENT# 1644

Title:

Smoke Control in Long Atria

Sponsoring TC/TG/MTG/SSPC:

TC 5.6 Fire and Smoke Control

Co-Sponsoring TC/TG/MTG/SSPCs (List only TC/TG/MTG/SSPCs that have voted formal support)

None

Executive Summary:

This project will use CFD simulations to develop limits and guidelines for use in designing smoke control systems for long atria such as malls, airport terminals, and concourses in stadiums and arenas. The few guidelines that currently exist were based on committee beliefs about what might be appropriate, but were not determined from experimental data. Current design tools do not address cooling of smoke due to heat transfer from the smoke to the surrounding walls, ceiling, or other building structures and the resulting descent of the smoke into occupied space. This project will establish the maximum design distance for horizontal smoke travel before the smoke layer is expected to start descending toward the floor. This will provide designers with guidance on when a smoke zone should be subdivided, or when additional exhaust fans are needed. Without this knowledge, systems may be under-designed resulting in a life safety hazard and a liability for the designer, or over-designed leading to additional cost and excess energy usage.

Applicability to the ASHRAE Research Strategic Plan:

This project targets Goals 7 and 9 of the 2010-2018 Strategic Plan.

The purpose of this project is to develop design guidance regarding the maximum sizes of smoke zones or maximum horizontal distances for smoke flow before detailed evaluation including heat transfer is required. It is expected that the research will provide experimental evidence to justify larger distances than are currently allowed.

This project supports Goal 7 (support development of tools, procedures and methods suitable for designing low-energy buildings) by providing design guidance to help with "right sizing" the quantity of air moving equipment to ensure that excess energy is not used if not needed. At the same time, this project strongly supports Goal 9 ("improved system efficiency…and safety", specifically research examples 14 & 15) by ensuring that any reductions in equipment do not cause a negative impact on the life safety within the building. If, instead of the expected increase in smoke zone size or smoke travel distance, the results were to indicate a smaller size is justified, this would increase the level of life safety in the building. In either case, design engineers would have the information to guide them toward a more detailed evaluation to achieve the needed life safety goals, when needed.

Application of Results:

The knowledge and associated guidance obtained from this project will be used to update Chapter 53 (Fire and Smoke Control) of the HVAC Applications Handbook, and ASHRAE special publication *Handbook of Smoke Control Engineering.*

State-of-the-Art (Background):

Interior building spaces with ceiling heights ranging from 7 – 15 m and large horizontal dimensions in one direction (e.g. malls, airport terminals, and concourses in stadiums and arenas) can be classified as long atria. These spaces are very different from the spaces used in the research that formed the basis for the guidelines provided in Chapter 53 of the ASHRAE HVAC Applications Handbook and the requirements in NFPA 92 [1], which focus on high spaces. For high atria, smoke is expected to rise to the ceiling, where it is exhausted, so the focus has been on developing engineering correlations to determine the smoke production rate in the plume rising above the fire.

Low and long atria present a different challenge for the design of smoke control systems because much of the smoke movement will be flowing horizontally below the ceiling rather than as a vertical plume. With large horizontal travel distances, the smoke will cool when it contacts the ceiling and walls, lose its buoyancy, and descend toward the floor, affecting the ability of occupants to safely evacuate. This was demonstrated in tests conducted in a 600 m long tunnel in Glasgow [2, 3]. The tests showed that as the smoke propagated along the tunnel, thinner smoke formed under the smoke layer, which could lead to smoke filling the full height and width of the space.

There are no requirements in North American codes and standards that limit the length or area of a smoke zone. UK guidelines for smoke control in shopping centers [4, 5] recommend a maximum area of 2000 sq. m for natural ventilation and 2600 sq. m for mechanical exhaust where the objective is to protect egress routes, or a maximum area of 3000 sq. m where the objective is to protect property and there is no significant life safety objective. The maximum recommended length of a smoke reservoir is 60 m [5].

No experimental test data have been identified to substantiate the 2000 - 3000 sq. m area limitation on smoke reservoirs, or to indicate that a hazard exists beyond this size. CIBSE Guide E [4] calls these values "historical" and an "arbitrary limitation". It is noted in [4, 6] that the maximum area of the reservoir could be increased once there is sufficient confidence in the ability of numerical models to calculate the heat transfer processes from the smoke layer to the surrounding structure.

According to [6], the origin of the 60 m limit on length has never been formally published, but anecdotally first appeared in 1972 [7] based on UK committee belief that people escaping below a buoyant smoke layer should be able to move out from below that layer in less than 30 m from any point. Earlier guidelines for fire venting [8] appeared in 1965, stating that, where possible, building subdivisions should not exceed 200 ft (~ 60 m) in length. This guideline based its recommendation on a technical paper describing roof venting systems [9] and the results of physical scale modeling of the flow of hot gases during roof venting [10].

In summary, even though the 200 ft (60 m) guideline for maximum length of a smoke zone has existed for over 50 years, no experimental data related to smoke and its behavior in long atria have ever been developed. This leaves designers with no data to guide them in selecting an appropriate maximum horizontal distance that smoke should be expected to flow before measures must be taken to prevent the smoke from cooling and descending to the floor.

Advancement to the State-of-the-Art:

This research will significantly advance the body of knowledge regarding smoke movement in long and low atrium spaces by developing guidelines for maximum area or length that are based on data. Designers will then understand when current design practices are appropriate, and when it becomes necessary to subdivide the atrium into smaller spaces or use more advanced design tools that include heat transfer analysis to evaluate their designs.

This research will also satisfy the conditions set forth in CIBSE Guide E [4] and BR 368 [6] that would allow the maximum area of the smoke reservoir to be increased beyond the currently stated limits once there is sufficient confidence in the ability of numerical models to calculate the heat transfer processes from the smoke layer to the surrounding structure.

Justification and Value to ASHRAE:

An increasing number of large building complexes are being constructed to include long atrium spaces. Airport terminals, shopping malls, conference centers, hotels, and sports arenas are examples of facilities with long atria, and all of these facilities have high population concentrations. With the present level of knowledge, it is impossible to provide fact-based guidelines for the maximum size of smoke reservoirs for such buildings before dangerous conditions occur that are not predicted by current tools. It is also impossible to provide guidance for the design of cost-effective and energy efficient smoke control systems for such spaces. Without better information, building designs that include long atria may unknowingly expose the public to hazardous conditions during a fire, which will result in liability issues for the designers of the HVAC and Life Safety systems.

There are very few guidelines, worldwide, for maximum area or length of low atria, and those guidelines that do exist are not based on any experimental data involving smoke movement, but instead represent committee beliefs of what might be appropriate. This research will significantly advance the body of knowledge regarding smoke movement in long and low atrium spaces by developing guidelines for maximum area or length that are based on data. Designers will then understand when current design practices are appropriate, and when it becomes necessary to subdivide the atrium into smaller spaces or use more advanced design tools that include heat transfer analysis to evaluate their designs.

The guidelines resulting from this research will be added to the ASHRAE Handbook (HVAC Applications-Chapter 53) and special publication Handbook of Smoke Control Engineering. This information will allow HVAC and Life Safety system designers to have confidence that their designs will result in the intended level of life safety for building occupants.

Objectives:

The main objectives of this project are:

1) Use CFD simulations which include heat transfer evaluations to determine the horizontal distance from a fire at which the smoke begins to lose its buoyancy in long atria of different aspect ratios.

2) Develop guidelines for the maximum sizes of smoke zones or maximum horizontal distances for smoke flow before detailed evaluation including heat transfer is required.

The specific deliverables of the project are:

1) Descriptions of the CFD simulations used in the investigation.

2) Horizontal distance smoke travelled before beginning to descend, for each CFD simulation.

3) Concise recommendations for the maximum length of a long atrium, which could be used as prescriptive guidelines for atrium design that does not include heat transfer analysis.

Note: Unless a one-size-fits-all recommendation is justified, these guidelines should be stated in the form of an equation that is dependent on the variables under study. The guideline should be accompanied by a statement to the effect that the resulting length is not necessarily a maximum horizontal travel distance, but simply represents a horizontal travel distance that does not require more detailed study. Long atria exceeding the recommended length could still be constructed if they were subdivided into smaller spaces, or if an engineering analysis which includes analysis of heat transfer characteristics was performed to justify greater distances.

Scope/Technical Approach:

General:
In recent years, there has been a rapid increase in the use of CFD models to simulate smoke movement in buildings. CFD is typically used to model smoke plumes and smoke movement in the vicinity of the smoke plume. Heat transfer is not an important parameter for this application, so it is generally not considered by most designers. For the long atria application, smoke will cool and lose its buoyancy as it contacts the walls and ceiling during its horizontal travel, and will eventually descend toward the floor and building occupants, thereby creating a hazard in the egress route. In order to predict the point at which smoke will lose its buoyancy and become a hazard, it is necessary to accurately model the heat transfer processes between the smoke layer and the surroundings in the far field.

In the hands of an experienced modeler, CFD simulations which include heat transfer evaluations can be developed, but this type of simulation is not normally performed, due at least in part to the complexity and additional computing time required. Currently, there is no data to help designers know when this additional investigation is necessary.

The proposed project will use CFD simulations which include heat transfer evaluations to determine the horizontal distance from a fire at which the smoke begins to lose its buoyancy in long atria of different aspect ratios and different heat transfer characteristics. From these data, guidelines will be developed regarding the maximum sizes of smoke zones or maximum horizontal distances for smoke flow which are appropriate to design without factoring in changes to the buoyancy of the smoke due to heat transfer. System designs that would exceed these guidelines would indicate to the designer that the smoke zones should be divided into smaller spaces or would indicate the need for more detailed CFD simulations including heat transfer evaluation.

Technical Approach / Method
In the proposed project, CFD simulations will investigate horizontal smoke movement through long and low atria. The CFD model must include heat transfer between the smoke layer and the ceiling and wall materials, and between interior air and the smoke plume. Heat transfer values used in the model should be selected to be consistent with properties of materials found in long atria of typical buildings. (No survey of materials in buildings is required.) The results of the CFD simulations are to be analyzed to determine the horizontal distance from the fire where the smoke layer begins to descend. This analysis may be by direct observation of smoke layer height, by determination of divergence from results of an identical CFD model without heat transfer properties, or by other means to be explained in the bid.

Since Fire Dynamics Simulator (FDS), which is available at no charge from NIST, is the most commonly used CFD program for smoke control system design, it is anticipated that FDS will be used for the CFD analysis portion of this project. The smoke production and fire modeling capabilities of FDS have been validated against many fire scenarios, so validation of the FDS program is not required. However, a "reality check" of the constructed model should be run to determine appropriate cell sizes and to confirm that the heat transfer portion of the model is functioning properly. If a CFD program other than FDS will be used, the program to be used shall be identified in the bid and data validating the proposed CFD program against real fire data or against FDS shall be included in the preliminary investigation stage of the project.

Multiple simulations are to be conducted to investigate individual factors that affect the buoyancy of the smoke layer, including fire sizes from 1-5 MW, ceiling heights from 7-15 m, atrium widths from 10-60 m, makeup air provided evenly or at one end, makeup air temperature (unconditioned winter temperature or conditioned to interior temperature), and different thermal transfer rates of wall and ceiling materials. It is understood that many variables affect the cooling of the smoke layer, including building location, weather, exterior and interior temperatures, ceiling and wall construction, insulation, etc., but the simulations should take these in aggregate, rather than individually, by investigating different Thermal Transfer Rates from the smoke layer to the wall and ceiling. Users of the research results will be expected to calculate the thermal transfer rate for the specific building materials, configuration, and conditions in their design. Up to 25 configurations are anticipated to allow investigation of the effects of individual factors. The exact number and configurations will be determined jointly by the contractor and the PMS after the baseline simulations are completed. Thermal Transfer Rates used in simulations should be justified by describing the materials, construction, and temperatures assumed. Bidders should include a tentative list of configurations to be tested in their bid.

Table 1 indicates the baseline simulations to be included as part of this project. The baseline simulations are intended to define the minimum and maximum travel distances for the simulations in this study, which will define the length of the atrium to be used in subsequent simulations. The baseline simulations will also determine the make-up air location to be used for the bulk of the simulations.

The remaining entries in Table 1 are examples of configurations that may be included. The basic investigation should be performed using unconditioned make-up air at winter temperature, with the make-up air provided at the location determined from the baseline simulations to be the worst case. It is intended that only a single parameter should be changed between simulations, in order to allow isolation and investigation of the effect of each parameter under study on the horizontal travel distance. It is expected that the parameter values within the ranges defined for this project that result in the worst case (shortest horizontal travel distance) will be thoroughly investigated. Other parameter values within the ranges defined for the project should be included in order to develop an equation explaining each parameter's contribution to the horizontal travel distance.

Bidders are encouraged to include additional simulations to more fully investigate each parameter or combinations of parameters, as suggested by bidder's experience or as indicated by preliminary results.

As noted above, the basic investigation should be performed using unconditioned make-up air at winter temperature, with the make-up air provided at the location determined to be the worst case. If sufficient data can be obtained within the anticipated 25 simulations, it is highly desirable for the investigation to include the effect of make-up air supplied at interior temperature and/or the alternate location (end vs. distributed). This enhancement to the equation would give the designer the option of using one or both of these options to extend the size of the smoke zone.

Bidders should anticipate that additional simulations beyond those specifically listed in the bid may be required to have enough data to complete this project. However, the number of configurations is not expected to exceed 25, unless a greater number is indicated in the bid.

The following conditions apply to all simulations:

- The ends of the atrium should be closed so that the entire atrium has interior conditions.
- The atrium should be long enough so that smoke descent will occur before reaching the end. Since the horizontal travel distance is currently unknown, the baseline simulations should be run with an atrium length in excess of 1300 ft (400 m). Atrium length for non-baseline simulations should be adjusted to not less than 150% of the horizontal smoke travel distance determined in the baseline simulations.
- The fire should be positioned approximately 25% from the end of the atrium, in order to achieve an axisymmetric plume and reduce interactions with the far wall.
- Atrium exhaust shall be provided. The exhaust shall be sized to maintain steady conditions for the fire size being evaluated (exhaust volume matches smoke production). Since the goal of the project is to investigate the horizontal smoke travel distance in the presence of cooling from contact with the walls and ceiling, and mixing with make-up air, the atrium exhaust intake should be located where it does not help or hinder smoke flow along the ceiling. (This may require positioning the exhaust intake at a location that would not be used in a real building. In these simulations, the goal of the exhaust intake is to provide a relief for the make-up air, not to remove the smoke.)
- Total make-up air volume should be approximately 95% of the exhaust volume.
- When make-up air is distributed, the make-up air velocity should be set at 200 ft/min (1 m/s) at each inlet to mimic designs that comply with current codes. A sufficient number of inlets to satisfy the exhaust shall be provided.
- When make-up air is provided at the end of the atrium, make-up air velocity should not exceed 200 ft/min (1 m/s). If additional make-up air is needed to satisfy the exhaust, the additional make-up air should be distributed evenly through the atrium.
- When make-up air is provided at the end of the atrium, it should be provided at the end of the atrium farthest from the fire so that the smoke layer under study is moving against the make-up air flow.

Table 1. Baseline and example simulations to be included in the project

	Make-up Air Temp (Winter/ Indoor)	Make-up Air Location (End/Even)	Fire Size (1-5 MW)	Ceiling Height (7-15 m)	Atrium Width (10-60 m)	Thermal Transfer Rate, Ceiling[6]	Thermal Transfer Rate, Walls[2,6]
Baseline 1	Winter	End	1 MW	15 m	60 m	High	High
Baseline 2	Winter	**Even**	1 MW	15 m	60 m	High	High
Baseline 3	Winter	End	**5 MW**	**7 m**	**10 m**	**Low**	**Low**
Baseline 4	Winter	**Even**	**5 MW**	**7 m**	**10 m**	**Low**	**Low**
Example 1	Winter	Worst	**2.5 MW**	15 m	60 m	High	High
Example 2	Winter	Worst	**5 MW**	15 m	60 m	High	High
Example 3	Winter	Worst	1 MW	**11 m**	60 m	High	High
Example 4	Winter	Worst	1 MW	**7 m**	60 m	High	High
Example 5	Winter	Worst	1 MW	15 m	**45 m**	High	High
Example 6	Winter	Worst	1 MW	15 m	**30 m**	High	High
Example 7	Winter	Worst	1 MW	15 m	**20 m**	High	High
Example 8	Winter	Worst	1 MW	15 m	**10 m**	High	High
Example 9	Winter	Worst	1 MW	15 m	60 m	**Medium**	High
Example 10	Winter	Worst	1 MW	15 m	60 m	**Low**	High
Example 11	Winter	Worst	**5 MW**	**7 m**	**10 m**	**Low**	High
Example 12	Winter	Worst	**5 MW**	**7 m**	**10 m**	**Low**	High
Example 13	Winter	Worst	1 MW	15 m	60 m	High	**Medium**
Example 14	Winter	Worst	1 MW	15 m	60 m	High	**Low**

Note 1: Bold indicates a difference from the anticipated worst-case Baseline simulation.

Note 2: Within the height and width constraints defined for this project, the area of smoke in contact with the ceiling will always be greater than the area of smoke in contact with the walls. If the Thermal Transfer Rate from the smoke to the walls is expected to be higher than the Thermal Transfer Rate from the smoke to the ceiling, the Thermal Transfer Rate to the walls should be evaluated separately. If the Thermal Transfer Rate to the walls is expected to be less than the Thermal Transfer Rate to the ceiling, a single rate may be used for both, or it may be evaluated separately.

Note 3: The atrium should be long enough so that smoke descent will occur before reaching the end. For all simulations, the ends of the atrium should be closed so that the entire atrium has interior conditions. Since the horizontal travel distance is currently unknown, the baseline simulations should be run with an atrium length in excess of 1300 ft (400 m). Atrium length for non-baseline simulations should be adjusted to not less than 150% of the horizontal smoke travel distance determined in the baseline simulations.

Note 4: Make-up air velocity should be set at 200 ft/min (1 m/s) at each inlet when make-up air is distributed, to mimic designs that comply with current codes. When make-up air is provided at the end of the atrium, make-up air velocity should not exceed 200 ft/min (1 m/s). If additional make-up air is needed to satisfy the exhaust, the additional make-up air should be distributed evenly through the atrium.

Note 5: When make-up air is provided at the end of the atrium, the fire should be positioned toward the end of the atrium farthest from the make-up air so that the smoke layer under study is moving against the make-up air flow. The fire should be positioned far enough from the end to achieve an axisymmetric plume.

Note 6: Thermal Transfer Rates used in the simulations should be selected to be consistent with properties of materials found in long atria of typical buildings. The high and low Thermal Transfer Rates used in simulations should be justified by describing the materials, construction, and temperatures assumed.

It is anticipated that the horizontal distance that smoke can travel before it begins to descend will decrease somewhat linearly as the width of the atrium increases, will decrease exponentially as the height of the atrium increases, and will decrease by an exponent less than one as the fire size decreases. The results of this project are expected to be an equation that includes fire size, height and width of the long atrium, thermal transfer rate from the smoke to the ceiling and thermal transfer rate from the smoke to the walls. This equation should provide the horizontal distance from the fire at which the smoke layer is expected to start descending toward the floor, when using the worst case make-up air location (end vs. distributed), and winter make-up air temperature. No adjustment to the distance is to be made for smoke that is partially descended but may be well above the floor, since the use and layout of a specific building might result in occupants at higher levels. Since the resulting horizontal distance value should only serve to suggest to the designer whether a detailed analysis including heat transfer is required or not, the equation should be developed using conservative values, not averages.

Accuracy of the developed equation should be confirmed with one or more additional simulations using parameters identical to one or more of the variants used in the investigation, except that different Thermal Transfer Rates should be used. The Thermal Transfer Rates used to confirm the equation should represent different materials and/or construction than were used to develop the equation.

Deliverables/Where Results Will Be Published:

Progress, Financial and Final Reports, Technical Paper(s), and Data shall constitute the only deliverables ("Deliverables") under this Agreement and shall be provided as follows:

a. Progress and Financial Reports

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

Furthermore, the Institution's Principal Investigator, subject to the Society's approval, shall, during the period of performance and after the Final Report has been submitted, report in person to the sponsoring Technical Committee/Task Group (TC/TG) at the annual and winter meetings, and be available to answer such questions regarding the research as may arise.

b. Final Report

A written report in a form approved by the Society, shall be prepared by the Institution and submitted to the Society's Manager of Research and Technical Services by the end of the Agreement term, containing complete details of all research carried out under this Agreement. Unless otherwise specified, the final draft report shall be furnished, either electronically or in hardcopy format (6 copies) for review by the Society's Project Monitoring Subcommittee (PMS).

Since CFD models generate huge amounts of raw data, it is not necessary to include the raw data with the final report. In lieu of the raw data, animations showing the smoke movement should be created for each of the CFD simulations described in the project. These animations shall be provided in electronic form, in a format that can be played back on a computer running commonly available, non-proprietary software.

Following approval by the PMS and the TC/TG, in their sole discretion, final copies of the Final Report will be furnished by the Institution as follows:

- An executive summary in a form suitable for wide distribution to the industry and to the public.
- Two bound copies
- Two copies on CD-ROM disks; one in PDF format and one in Microsoft Word.

c. Science & Technology for the Built Environment or ASHRAE Transactions Technical Papers or ASHRAE Transactions Technical Paper

One or more papers shall be submitted first to the ASHRAE Manager of Research and Technical Services (MORTS) and then to the “ASHRAE Manuscript Central” website-based manuscript review system in a form and containing such information as designated by the Society suitable for publication. Papers specified as deliverables should be submitted as either Research Papers for HVAC&R Research or Technical Paper(s) for ASHRAE Transactions. Research papers contain generalized results of long-term archival value, whereas technical papers are appropriate for applied research of shorter-term value, ASHRAE Conference papers are not acceptable as deliverables from ASHRAE research projects. The paper(s) shall conform to the instructions posted in “Manuscript Central” for an ASHRAE Transactions Technical or HVAC&R Research paper. The paper title shall contain the research project number at the end of the title in parentheses, e.g., (1644-RP).

d. Data

The Institution agrees to maintain true and complete books and records, including but not limited to notebooks, reports, charts, graphs, analyses, computer programs, visual representations etc., (collectively, the “Data”), generated in connection with the Services. Society representatives shall have access to all such Data for examination and review at reasonable times. The Data shall be held in strict confidence by the

Institution and shall not be released to third parties without prior authorization from the Society, except as provided by GENERAL CONDITION VII, PUBLICATION. The original Data shall be kept on file by the Institution for a period of two years after receipt of the final payment and upon request the Institution will make a copy available to the Society upon the Society's request.

e. Project Synopsis

A written synopsis totaling approximately 100 words in length and written for a broad technical audience, which documents 1. Main findings of research project, 2. Why findings are significant, and 3. How the findings benefit ASHRAE membership and/or society in general shall be submitted to the Manager of Research and Technical Services by the end of the Agreement term for publication in ASHRAE Insights.

The Society may request the Institution submit a technical article suitable for publication in the Society's ASHRAE JOURNAL. This is considered a voluntary submission and not a Deliverable.

All Deliverables under this Agreement and voluntary technical articles shall be prepared using dual units; e.g., rational inch-pound with equivalent SI units shown parenthetically. SI usage shall be in accordance with IEEE/ASTM Standard SI-10.

Level of Effort:

For bidding purposes, it should be assumed that this project will include 25 CFD simulations, unless more are specified in the bid. The simulations will include the baseline simulations indicated in the table in Technical Approach / Method section, and other configurations determined from initial evaluation of the baseline configurations. The estimated cost of this project is $75,000 and it is expected to take 12-15 months.

Proposal Evaluation Criteria:

No.	Proposal Review Criterion	Weighting Factor
1.	Contractor's understanding of Work Statement as revealed in proposal. a) Any logistical problems identified are addressed b) Any technical problems identified are addressed	**20%**
2.	Quality of methodology proposed for conducting research. a) Organization of project b) Management plan	**15%**
3.	Contractor's capability in terms of facilities. a) Computing capabilities b) Managerial support c) Data collection	**7%**
4.	Qualifications of personnel for this project. a) Project team members' qualifications and experience with CFD modeling including heat transfer b) Experience and corporate position of Project manager directly responsible for this project c) Time commitment of Principal Investigator	**25%**
5.	Probability of contractor's research plan meeting the objectives of the Work Statement. a) Detailed and logical work plan with major tasks and key milestones b) All technical and logistic factors considered c) Reasonableness of project schedule	**25%**
6.	Student involvement a) Extent of student participation on contractor's team b) Likelihood that involvement in project will encourage entry into HVAC&R industry	**3%**
7.	Performance of contractor on prior ASHRAE or other projects. (No penalty for new contractors.)	**5%**

Project Milestones:

No.	**Major Project Completion Milestones** Note: Milestones must be completed and approved by the Project Monitoring Subcommittee (PMS) before continuing to next milestone.	**Deadline Month**	**Payments** % of project budget payable upon completion of Milestone
1	Milestone 1 - Setup and confirmation of the model Task 1. Determine the Thermal Transfer Rates to be used for contact with the walls and for contact with the ceiling. These values should be selected to be consistent with properties of materials expected in long atria of typical buildings. Task 2. Construct the model. Task 3. Using one of the planned simulations, run the model with different cell sizes to determine an appropriate cell size for the remaining simulations. Task 4. Using one of the planned simulations, run the model with and without heat transfer, and compare the results. If the heat transfer portion of the model is operating correctly, a difference will be noted between the two. In the model without heat transfer, it is expected that smoke will remain near the ceiling, but in the model with heat transfer, smoke should begin to descend at some distance from the fire. Task 5. Provide a status update to the PMS including: The high, medium, and low values to be used for Thermal Transfer Rates, Describe the materials, type of construction, and other assumptions represented by the high and low Thermal Transfer Rate values, Value and justification for the cell size to be used, and Confirmation that the heat transfer function is working. If a CFD model other than FDS is being used, provide data validating the CFD program against real fire data or against FDS.	3	25%
2	Milestone 2 - Run baseline simulations and preliminary analysis Task 6. Run Baseline 1 through 4 simulations. Task 7. Determine whether providing makeup air evenly or from one end represents the worst case (shortest horizontal travel distance before smoke descends). Task 8. Provide a status update to the PMS indicating the makeup air location selected as worst case, and a summary of the simulation results leading to this conclusion.	4	
3	Milestone 3 - Reach agreement on remaining configurations and run simulations Task 9. Provide a recommendation to the PMS regarding remaining simulations to be run, and receive agreement from the PMS on the configurations that will be evaluated. Task 10. Run remaining simulations as agreed by PMS, with makeup air located in worst case location. Note: Any departure from the Simulation Plan agreed between contractor and PMS must be approved by the PMS before simulations begin.	6	50%

Continued on next page

4	Milestone 4 - Analyze all simulations and develop draft equation Task 11. Develop equation for minimum horizontal smoke flow distance before descent as a function of fire size, ceiling height, atrium width, Thermal Transfer Rate to ceiling, and Thermal Transfer Rate to walls, under worst case makeup air location with unconditioned (winter) make-up air temperature. Task 12. Provide a draft report to the PMS offering a first look at the equation developed, together with the technical justification. This draft report only needs to include the data obtained, the technical analysis of the data, and the draft equation. Other sections of the final report (introduction, executive summary, detailed description of the model, etc.) are not required for completion of this task. Note: This is not considered to be "extra work" since the information in this draft report should become the main portion of the Technical Paper.	9	75%
5	Milestone 5 - Respond to PMS feedback on draft equation After review of the draft equation, the PMS will determine whether additional data are required to support the draft equation, or if the data are sufficient and additional simulations can be used to investigate the effects of alternate make-up air location and/or make-up air conditioned to indoor temperature. Task 13. Run additional simulations, as indicated by the PMS, up to the number of simulations defined in the accepted bid. Task 14. Analyze the additional simulations, and use the results to more fully develop the original equation, or expand the original equation to include the additional variables of make-up air location and/or make-up air temperature, as appropriate.		
6	Milestone 6 - Create and submit Final Report and Technical Paper Task 15. The report should contain: a description of the CFD model configuration; the list of simulations run; the data obtained from the simulations, including variables and horizontal distance before descent; and the equation that was developed during this project for minimum horizontal smoke flow distance before descent as a function of the variables under study. Task 16. In lieu of the raw data, animations showing the smoke movement should be created for each of the CFD simulations described in the project. These animations shall be provided in electronic form, in a format that can be played back on a computer running commonly available, non-proprietary software. Task 17. The report and animations shall be submitted to the PMS for review. Comments from reviewers are to be addressed in the final report. Task 18. A Technical Paper describing the project and results shall be submitted to ASHRAE. Task 19. Although optional, the researcher is encouraged to present the Technical Paper at an ASHRAE conference. TC5.6 will work with the researcher to schedule this presentation.	12	100%

Authors:

Paul Turnbull

References:

1. NFPA 92, Standard for Smoke Control Systems, National Fire Protection Association, Quincy, MA 2012.

2. Heselden, A. J. M. and Hinkley, P. L., Smoke Travel in Shopping Malls Experiments in Co-operation with Glasgow Fire Brigade – Part 1, Fire Research Note 832, Building Research Establishment, Borehamwood, UK, 1970.

3. Heselden, A. J. M., Smoke Travel in Shopping Malls Experiments in Co-operation with Glasgow Fire Brigade – Part 2, Fire Research Note 832, Building Research Establishment, Borehamwood, UK, 1970.

4. CIBSE, Guide E: Fire Safety Engineering, The Chartered Institution of Building Services Engineers, London, UK, 2010.

5. BS 7346-4: Functional Recommendations and Calculation Methods for Smoke and Heat Exhaust Ventilation Systems Employing Steady State Design Fires – Code of Practice , British Standards Institution, London, UK, 2003.

6. Morgan, H. P. Ghosh, B. K., Garrad, G., Pamlitschka. R. de Smelt, J-C. and Shoonbaert, L. R., Design Methodologies for Smoke and Heat Exhaust Ventilation, BR 368, Building Research Establishment, Garston, UK, 1999.

7. Home Office and Scottish Home and Health Department, Fire Precautions in Town Centre Redevelopment, Fire Prevention Guide No. 1, The Stationery Office, 1972 (section 7.2.1 page 34).

8. Langdon-Thomas and Hinkley, Fire Note 5, Fire Venting in Single Storey Buildings, HMSO 1965.

9. Thomas and Hinkley, FRS Technical paper 10, Design of Roof Venting Systems for Single-Storey Buildings, 1964.

10. Thomas et al, FRS Technical paper 7, Investigations into the Flow of Hot Gases in Roof Venting, 1963.

Other Information for Bidders (Optional):

This project requires expertise in atrium smoke control technology and fire modeling by CFD, with particular expertise in modeling heat transfer within CFD fire models. Proposals need to describe the capabilities and experience of the members of the project team in these areas.

As noted in the Technical Approach/Method section, the bid should clearly explain what criteria will be used to establish the distance at which the smoke layer begins to descend from the ceiling.

Bids should include a table of proposed simulations. The configurations are considered non-binding, and may be revised by agreement between the contractor and the PMS as the project progresses. Bids that include fewer than 25 configurations in the table of proposed simulations are deemed to include a total of 25 simulations, with some configurations not yet defined. Bids that include more than 25 configurations are deemed to include the number of simulations included in the bid. If other factors are equal, preference will be given to bids with more simulation configurations.

Feedback to RAC and Suggested Improvements to Work Statement Process

Now that you have completed the work statement process, RAC is interested in getting your feedback and suggestions here on how we can improve the process.

To: ASHRAE MORTS and RAC
cc: Dennis Loveday, ASHRAE Section 5 Research Liaison

From: Paul Turnbull, ASHRAE TC5.6 Research Subcommittee Chair

Date: May 07, 2018

Subject: 1644-WS, “Smoke Control in Long Atria”

In a letter dated February 15, 2016, the Research Administration Committee (RAC) indicated conditional acceptance of the subject RTAR for development into a Work Statement, provided that one comment was addressed to the satisfaction of the Research Liaison in the resulting Work Statement.

The way in which the Work Statement addresses the mandatory comment and other comments from RAC has been reviewed with, and addressed to the satisfaction of our Research Liaison. This letter provides a response to the mandatory comment and other comments received, and explains how each of the questions/comments was addressed in the Work Statement (attached).

Mandatory comment that needs to be fully addressed in the WS submission:

1. **TC need to clearly define the scope in the WS stating which variables should be studied and approximately how many CFD iterations are required**.

   TC5.6 response: *The variables to be studied and the number of CFD simulations to be performed are described in the third paragraph in the Technical Approach/Method section of the Work Statement, and in the table of simulations in this section. Variables to be studied are reiterated in Milestone 4, where the variables to be included in the equation being developed are again described. The number of CFD simulations is also covered in the Level of Effort and Other Information for Bidders sections of the Work Statement.*

Questions/comments from other reviewers:

i. **Reviewer #7: Although FDS is a validated software tool and no experimental work is expected from this project, it is necessary to verify the accuracy of simulation using some existing data. This could be considered in the WS development.**

   TC5.6 response: *The 2nd paragraph of the Technical Approach/Method section of the Work Statement describes two checks on the accuracy of the developed model; one for cell size and one to confirm operation of the Thermal Transfer function. This is additionally discussed in Milestone 1 in the Project Milestones section.*

ii. **Reviewer #7: 12 months may seem too rush. 18 months more feasible.**

   TC5.6 response: *Feedback that we have received from people familiar with CFD simulation indicates that 12-months is a reasonable duration for this number of simulations. In order to accommodate possible delays during PMS review of milestones, the duration has been changed to indicate that the project is expected to take 12-15 months.*

iii. **Reviewer #2: Check the references on smoke travel in automobiles tunnels.**
   Reviewer #2: It might be useful to refer the knowledge of smoke movement at tunnel in fire.

TC5.6 response: *TC5.6 includes members who have done extensive research into smoke movement in automobile tunnels, and other members who have designed smoke control systems for automobile tunnels. The construction and methods used in automobile tunnels is very different from what is found in buildings.*

Automobile tunnels are typically constructed with low, sloping ceilings to channel the smoke toward an exit, and powerful jet fans provide floor-to-ceiling horizontal movement of air and smoke within the tunnel. This project is investigating smoke movement in long atria typical of those found in buildings such as airports and shopping malls. In these spaces, the atrium has a level ceiling, and the only energy available to move the smoke horizontally along the ceiling is the upward flow in the plume.

Our literature search for research into smoke movement in long horizontal spaces did not uncover any research-based publications, as noted in the State of the Art/Background section. If Reviewer #2 is aware of relevant research, we would be happy to review the report from that research to determine whether it would affect this Work Statement.

iv. Reviewer #8: There are several variables that can affect the heat transfer between the smoke layer and adjacent components. These variables include type of construction, roof versus multistory, lighting and other sensible heat sources, obstructions to airflow at the ceiling level, etc. etc..

TC need to clearly define the scope in the WS stating which variables should be studied and approximately how many CFD iterations are required. This part should not be left for the contractor to decide.

TC5.6 response: *The variables to be addressed, the scope of the project, and the number of CFD simulations are addressed as described in the response to mandatory comment #1.*

The 3rd paragraph in the Technical Approach/Method section acknowledges that there are numerous variables that can affect the heat transfer - too many to address separately in a research project. Rather than making this project impossibly large or ignoring important variables, this project addresses all of these variables in aggregate by replacing all of these variables with the Thermal Transfer Rate between the smoke layer and the adjacent ceiling and walls. Users of this research would be expected to determine the Thermal Transfer Rate that corresponds to their particular project, using all of the variables that are identified by Reviewer #8 and described in this Work Statement.

Additional statement from TC5.6 regarding this project:

This project does not include a literature search in its deliverables because the literature search has already been done by TC5.6 as part of the justification for this project. The absence of relevant published information was additionally confirmed by researchers at BRE Global in the UK. The few documents that were located are described in the State of the Art (Background) section of the Work Statement, and support the need for this research.

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TO: Ahmed Kashef, Chair TC 5.6, ahmed.kashef@nrc-cnrc.gc.ca
Paul Turnbull, Research Subcommittee Chair TC 5.6, paul.turnbull@siemens.com
David John, Research Liaison Section 5.1, davidjohntarpon@gmail.com

FROM: Michael Vaughn, MORTS, mvaughn@ashrae.org

DATE: February 15, 2016

SUBJECT: Research Topic Acceptance Request (1644-RTAR), "Smoke Control in Long Atria"

At the winter meeting, the Research Administration Committee (RAC) reviewed the subject Research Topic Acceptance Request (RTAR) and voted to conditionally accept it for further development into a work statement (WS) provided that the RAC approval condition(s) below are addressed first to the satisfaction of your Research Liaison (RL) in a revision to the RTAR and then incorporated into the draft WS.

The following list summarizes the mandatory comments and questions that need to be fully addressed in the updated RTAR and WS submission:

1. TC need to clearly define the scope in the WS stating which variables should be studied and approximately how many CFD iterations are required

Please coordinate changes to the RTAR with the help of your RL, David John, davidjohntarpon@gmail.com or RL5@ashrae.net. After coordination with and the approval of your RL, send the revised RTAR to the Manager of Research and Technical Services (MORTS). This response to the approval condition(s) with the RTAR will be posted by ASHRAE as part of the Society's Research Implementation Plan.

After agreement has been reached on the revised RTAR and sent to MORTS, please develop a WS with the help of your RL prior to submitting it to the MORTS for consideration by RAC. The WS will include a cover letter to RAC, detailing how the comments/conditions from the RTAR were addressed in the WS. The WS must be approved by your RL prior to submitting it to RAC.

An RTAR evaluation sheet is attached as additional information and it provides a breakdown of comments and questions from individual RAC members based on specific review criteria. This should give you an idea of how your RTAR is being interpreted and understood by others. Some of these comments may indicate areas of the RTAR and subsequent WS where readers require additional information or rewording for clarification.

The first draft of the WS should be submitted to RAC no later than **December 15, 2017** or it will be dropped from display on the Society's Research Implementation Plan. The topic must be approved for bid by RAC by **February 1, 2020** or it will be dropped permanently from plan after four years on plan. The next submission deadline for WSs is **May 15, 2016** for consideration at the Society's 2016 annual meeting. The submission deadline after that for WSs is **August 15, 2016** for consideration at RAC's 2016 fall meeting.

Project ID	**1644**	
Project Title	**Smoke Control in Long Atria**	
Sponsoring TC	TC 5.6 (Fire and Smoke Control)	
Cost / Duration	$70,000 / 12M	
Submission History	**2nd Submission, 1st RTAR returned 2011 July**	
Classification: Research or Technology Transfer	Technology Transfer	
RAC 2016 Winter Meeting Review		
Essential Criteria	**Voted NO**	**Comments & Suggestions**
Background: The RTAR should describe current state of the art with some level of literature review that documents the importance/magnitude of a problem. References should be provided. If not, then note it in your comments.		**#8** - Sufficient background and justification is provided
Research Need: Based on the background provided is the need for additional research clearly identified? If not, then the RTAR should be rejected.		**#8** - Need is well justified
Relevance and Benefits to ASHRAE: Evaluate whether relevance and benefits are clearly explained in terms of: a. Leading to innovations in the field of HVAC & Refrigeration b. Valuable addition to the missing information which will lead to new design guidelines and valuable modifications to handbooks and standards. Is this research topic appropriate for ASHRAE funding? If not, Reject.		**#9**- Smoke control are difficult for the typical HVAC designer with the current guidance from ASHRAE, NFPA, model codes, etc. It almost requires a CFD model to be performed in order to know for sure that it's been done correctly, and Code enforcers generally defer to most extreme measures to be on the safe side. If clear-cut guidance comes out of this research, it will benefit ASHRAE's consulting engineer membership. That said, could the National Fire Protection Research Foundation be contacted regarding possible co-sponsorship? **# 3** - Validation of the recommendations.
IF ABOVE THREE CRITERION ARE NOT ALL SATISFIED - MARK "REJECT" BELOW & CONTINUE REVIEW BELOW		
Other Criteria	**Voted NO**	**Comments & Suggestions**
Project Objectives: Based on the background and need, evaluate whether the project objectives are: 1. Aligned with the need 2. Specific 3. Clear without ambiguity 4. Achievable If not, then appropriate feedback should be provided.	**#8**	**#7** - Although FDS is a validated software tool and no experimental work is expected from this project, it is necessary to verify the accuracy of simulation using some existing data. This could be considered in the WS development. **#8**- See below.
Expected Approach and Budget: Is there an adequate description of the approach in order for RAC to be able to evaluate the appropriateness of the budget? If not, then the RTAR should be returned for revision. Anticipated funding level and duration:		**#7** - 12 months may seem too rush. 18 months more feasible. **#8** - Budget is appropriate
References: Are the references provided?	**#2**	**#2** - Check the references on smoke travel in automobiles tunnels
Decision Options	**Initial Decision?**	**Final Approval Conditions**
ACCEPT AS-IS		**#8** - There are several variables that can affect the heat transfer between the smoke layer and adjacent components. These variables include type of construction, roof versus multistory, lighting and other sensible heat sources, obstructions to airflow at the ceiling level, etc. etc.. TC need to clearly define the scope in the WS stating which variables should be studied and approximately how many CFD iterations are required. This part should not be left for the contractor to decide. **#2** - It might be useful to refer the knowledge of smoke movement at tunnel in fire. **#15** - I feel the RTAR addressed the concerns from previous submission and made a fair case that guidance for smoke control systems needs to be updated.
ACCEPT W/COMMENTS		
REJECT		

ACCEPT Vote - Topic is ready for development into a work statement (WS).
ACCEPT W/COMMENTS Vote - Minor Revision Required - RL can approve RTAR for development into WS without going back to RAC once TC satisfies RAC's approval condition(s)
REJECT Vote - Topic is not acceptable for the ASHRAE Research Program

Research Topic Acceptance Request Cover Sheet

Date: December 14, 2015

(Please Check to Insure the Following Information is in the RTAR)

A. Title ☑
B Executive Summary ☑
C. Background ☑
D. Research Need ☑
E. Project Objectives ☑
F. Expected Approach ☑
G. Relevance and Benefits to ASHRAE ☑
H. Anticipated Funding Level and Duration ☑
I. References ☑

Title:

1644-RTAR, Smoke Control in Long Atria.

RTAR # 1644
(To be assigned by MORTS)

Results of this Project will affect the following Handbook Chapters, Special Publications, etc.:

HVAC Applications - Chapter 53, and ASHRAE special publication "Handbook of Smoke Control Engineering".

Research Classification:
Basic/Applied Research ☑
Advanced Concepts ☐
Technology Transfer ☐

Responsible Committee: TC 5.6 Fire and Smoke Control

Date of Vote: Letter Ballot, December 03-14, 2015

For		13
Against	*	0
Abstaining	*	0
Absent or not returning Ballot	*	0
Total Voting Members		13

RTAR Authors
Lead:
Paul Turnbull
Others:

Co-sponsoring TC/TG/MTG/SSPCs (give vote and date)
none

Expected Work Statement Authors
Lead:
Paul Turnbull
Others:

Potential Co-funders (organization, contact person information):
none

	Yes	No
Has an electronic copy been furnished to the MORTS?	☑	☐
Has the Research Liaison reviewed the RTAR?	☑	☐

* Reasons for negative vote(s) and abstentions

N/A

DRAFT RTAR Template

Title: Smoke Control in Long Atria

Summary

Describe in summary form the proposed research topic, including what is proposed, why this research is important, how it will be conducted, and why ASHRAE should fund it (50 words maximum)

This project will use CFD modeling to develop limits and guidelines for use in designing smoke control systems for long atria such as malls, airport terminals, and concourses in stadiums and arenas. The few guidelines that currently exist were based on committee beliefs about what might be appropriate, but were not determined from experimental data. Current design tools do not address cooling of smoke due to heat transfer and the resulting descent of the smoke into occupied space. This project will establish the maximum distance smoke can travel before it begins to descend, providing designers with guidance on when a smoke zone should be subdivided, or when additional exhaust fans are needed. Without this knowledge, systems may be under-designed resulting in a life safety hazard and a liability for the designer, or over-designed leading to additional cost and excess energy usage.

Background

Provide the state of the art with key references (at the end of this document) substantiating it (300 words maximum)

Interior building spaces with ceiling heights ranging from 7 – 15 m and large horizontal dimensions in one direction (e.g. malls, airport terminals, and concourses in stadiums and arenas) can be classified as long atria. These spaces are very different from the spaces used in the research that formed the basis for the guidelines provided in Chapter 53 of the ASHRAE HVAC Applications Handbook and the requirements in NFPA 92 [1], which focus on high spaces. For high atria, smoke is expected to rise to the ceiling, where it is exhausted, so the focus has been on developing engineering correlations to determine the smoke production rate in the plume rising above the fire.

Low and long atria present a different challenge for the design of smoke control systems because much of the smoke movement will be flowing horizontally below the ceiling rather than as a vertical plume. With large horizontal travel distances, the smoke will cool when it contacts the ceiling and walls, lose its buoyancy, and descend toward the floor, affecting the ability of occupants to safely evacuate. This was demonstrated in tests conducted in a 600 m long tunnel in Glasgow [2, 3]. The tests showed that as the smoke propagated along the tunnel, thinner smoke formed under the smoke layer, which could lead to smoke filling the full height and width of the space.

There are no requirements in North American codes and standards that limit the length or area of a smoke zone. UK guidelines for smoke control in shopping centers [4, 5] recommend a maximum area of 2000 sq. m for natural ventilation and 2600 sq. m for mechanical exhaust where the objective is to protect egress routes, or a maximum area of 3000 sq. m where the objective is to protect property and there is no significant life safety objective. The maximum recommended length of a smoke reservoir is 60 m [5].

No experimental test data has been identified to substantiate the 2000 - 3000 sq. m area limitation on smoke reservoirs, or to indicate that a hazard exists beyond this size. CIBSE Guide E [4] calls these values "historical" and an "arbitrary limitation". It is noted in [4, 6] that the maximum area of the reservoir could be increased once there is sufficient confidence in the ability of numerical models to calculate the heat transfer processes from the smoke layer to the surrounding structure.

According to [6], the origin of the 60 m limit on length has never been formally published, but anecdotally first appeared in 1972 [7] based on UK committee belief that people escaping below a buoyant smoke layer should be able to move out from below that layer in less than 30 m from any point. Earlier guidelines for fire venting [8] appeared in 1965, stating that, where possible, building subdivisions should not exceed 200 ft (~ 60 m) in length. This guideline based its recommendation on a technical paper describing roof venting systems [9] and the results of physical scale modeling of the flow of hot gases during roof venting [10].

In summary, even though the 200 ft (60 m) guideline for maximum length of a smoke zone has existed for over 50 years, no experimental data related to smoke and its behavior in long atria has ever been developed. This leaves designers with no data to guide them in selecting an appropriate maximum horizontal distance that smoke should be expected to flow before measures must be taken to prevent the smoke from cooling and descending to the floor.

Research Need

Use the state of the art described above as a basis to specify the need for the proposed effort (250 words maximum)

In recent years, there has been a rapid increase in the use of CFD models to simulate smoke movement in buildings. CFD is typically used to model smoke plumes and smoke movement in the vicinity of the smoke plume. Heat transfer is not an important parameter for this application, so it is generally not considered by most designers. For the long atria application, smoke will cool and lose its buoyancy as it contacts the walls and ceiling during its horizontal travel, and will eventually descend toward the floor and building occupants, thereby creating a hazard in the egress route. In order to predict the point at which smoke will lose its buoyancy and become a hazard, it is necessary to accurately model the heat transfer processes between the smoke layer and the surroundings in the far field.

In the hands of an experienced modeler, CFD simulations which include heat transfer evaluations can be developed, but this type of simulation is not normally performed, due at least in part to the complexity and additional computing time required. Currently, there is no data to help designers know when this additional investigation is necessary.

The proposed project will use CFD simulations which include heat transfer evaluations to determine the horizontal distance from a fire at which the smoke begins to lose its buoyancy in long atria of different aspect ratios. From this data, guidelines will be developed regarding the maximum sizes of smoke zones or maximum horizontal distances for smoke flow. System designs that would exceed these guidelines would indicate to the designer that the smoke zones should be divided into smaller spaces or would indicate the need for more detailed CFD simulations including heat transfer evaluation.

Project Objectives

Based on the identified research need(s), specify the objectives of the solicited effort that will address all or part of these needs (150 words maximum)

The main objectives of this project are:
1) Use CFD simulations which include heat transfer evaluations to determine the horizontal distance from a fire at which the smoke begins to lose its buoyancy in long atria of different aspect ratios.
2) Develop guidelines regarding the maximum sizes of smoke zones or maximum horizontal distances for smoke flow before detailed evaluation including heat transfer is required.

The specific deliverables of the project are:
1) Descriptions of the CFD simulations used in the investigation,
2) Concise recommendations for the maximum length of a long atrium, which could be used as prescriptive guidelines for atrium design that does not include heat transfer analysis.
Note: Since the intent of the guidelines is to alert designers to conditions which may be affected by heat transfer, these guidelines may be stated as generalities if the variables under study do not have a significant impact on the outcome, or may be stated in a form that is dependent on one or more of the variables under study (e.g. "for atria with H/W >x, the maximum length is xxx...; for atria with H/W between y and z, the maximum length is yyy...", etc.). Long atria exceeding the recommended length could still be constructed if they were subdivided into smaller spaces, or an engineering analysis which includes analysis of heat transfer characteristics was performed to justify greater distances.

Expected Approach

Describe in a manner that may be used for assessment of project viability, cost, and duration, the approach that is expected to achieve the proposed objectives (200 words maximum).

Check all that apply: Lab testing ☐, Computations ☑, Surveys ☐, Field tests ☐, Analyses and modeling ☐, Validation efforts ☐, Other (specify) ( )

In the proposed project, CFD modeling experiments will investigate horizontal smoke movement through long and low atria. The CFD model must include heat transfer between the smoke layer and the ceiling and wall materials. Heat transfer properties used in the model must be selected to be consistent with properties of materials found in long atria of typical buildings. The results of the CFD simulations are to be analyzed to determine the horizontal distance from the fire where the smoke layer begins to descend. This analysis may be by direct observation of smoke layer height, by determination of divergence from results of an identical CFD model without heat transfer properties, or other means to be explained in the bid.

Since Fire Dynamics Simulator (FDS), which is available at no charge from NIST, is the most commonly used CFD program for smoke control system design, it is expected that FDS will be used for the CFD analysis portion of this project. Multiple simulations should be conducted to investigate individual factors that affect the buoyancy of the smoke layer, including different ceiling heights from 7-15m, different atrium widths, end effects (open and closed ends), and wall and ceiling materials with different thermal properties. Approximately 12-25 configurations are anticipated to allow isolation of individual factors. Bidders should list the configurations to be tested in their bid. If other factors are equal, preference will be given to bids with more configurations.

Relevance and Benefits to ASHRAE

Describe why this effort is of specific interest to ASHRAE, its impact, and how it will benefit ASHRAE and the society. How does it align with ASHRAE Strategic Plans and Initiatives? How does it advance the state of the art in this area in general? Are there other stakeholders that should be approached to obtain relevant information or co-funding? (350 words maximum)

An increasing number of large building complexes are being constructed to include long atrium spaces. Airport terminals, shopping malls, conference centers, hotels, and sports arenas are examples of facilities with long atria, and all of these facilities have high population concentrations. With the present level of knowledge, it is impossible to provide fact-based guidelines for the maximum size of smoke reservoirs for such buildings before dangerous conditions occur that are not predicted by current tools. It is also impossible to provide guidance for the design of cost-effective and energy efficient smoke control systems for such spaces. Without better information, building designs that include long atria may unknowingly expose the public to hazardous conditions during a fire, which will result in liability issues for the designers of the HVAC and Life Safety systems.

There are very few guidelines, worldwide, for maximum area or length of low atria, and those guidelines that do exist are not based on any experimental data involving smoke movement, but instead represent committee beliefs of what might be appropriate. This research will significantly advance the body of knowledge regarding smoke movement in long and low atrium spaces by developing guidelines for maximum area or length that are based on data. Designers will then understand when current design practices are appropriate, and when it becomes necessary to subdivide the atrium into smaller spaces or use more advanced design tools that include heat transfer analysis to evaluate their designs.

The guidelines resulting from this research will be added to the ASHRAE Handbook (HVAC Applications-Chapter 53) and special publication Handbook of Smoke Control Engineering. This information will allow HVAC and Life Safety system designers to have confidence that their designs will result in the intended level of life safety for building occupants.

Anticipated Funding Level and Duration

Funding Amount Range: $ $70K

Duration in Months: 12 months

References

List the key references cited in this RTAR

1. NFPA 92, Standard for Smoke Control Systems, National Fire Protection Association, Quincy, MA 2012.

2. Heselden, A. J. M. and Hinkley, P. L., Smoke Travel in Shopping Malls Experiments in Co-operation with Glasgow Fire Brigade – Part 1, Fire Research Note 832, Building Research Establishment, Borehamwood, UK, 1970.

3. Heselden, A. J. M., Smoke Travel in Shopping Malls Experiments in Co-operation with Glasgow Fire Brigade – Part 2, Fire Research Note 832, Building Research Establishment, Borehamwood, UK, 1970.

4. CIBSE, Guide E: Fire Safety Engineering, The Chartered Institution of Building Services Engineers, London, UK, 2010.

5. BS 7346-4: Functional Recommendations and Calculation Methods for Smoke and Heat Exhaust Ventilation Systems Employing Steady State Design Fires – Code of Practice , British Standards Institution, London, UK, 2003.

6. Morgan, H. P. Ghosh, B. K., Garrad, G., Pamlitschka. R. de Smelt, J-C. and Shoonbaert, L. R., Design Methodologies for Smoke and Heat Exhaust Ventilation, BR 368, Building Research Establishment, Garston, UK, 1999.

7. Home Office and Scottish Home and Health Department, Fire Precautions in Town Centre Redevelopment, Fire Prevention Guide No. 1, The Stationery Office, 1972 (section 7.2.1 page 34).

8. Langdon-Thomas and Hinkley, Fire Note 5, Fire Venting in Single Storey Buildings, HMSO 1965.

9. Thomas and Hinkley, FRS Technical paper 10, Design of Roof Venting Systems for Single-Storey Buildings, 1964.

10. Thomas et al, FRS Technical paper 7, Investigations into the Flow of Hot Gases in Roof Venting, 1963.

To: ASHRAE RAC

From: Paul Turnbull, TC5.6 Research Subcommittee Chair

Date: December 14, 2015

Subject: 1644-RTAR, “Smoke Control in Long Atria

During the June 2011 meeting in Montreal, Quebec, the Research Administration Committee (RAC) reviewed the subject Research Topic Acceptance Request (RTAR) and voted to return it. This letter explains how each of the comments was addressed in the revised RTAR (attached).

General

This RTAR originally included both CFD modeling and validation via fire testing. After much discussion within TC5.6, and with considerable input from Dr. Kishor Khankari, this RTAR has been substantially rewritten to focus solely on the CFD modeling, and not include fire testing. The FDS model is now in its 6th release, and this model has been validated in many applications over the past decade or more, so it was determined that validation against fire tests would be an unnecessary expense for this project.

A significant motivation for this project is that there are very few guidelines anywhere in the world to help designers determine an appropriate length for a long atrium before it becomes necessary to divide it into multiple zones. During a literature search, the only guidance found was a recommendation in CIBSE Guide E: Fire Safety Engineering for the maximum size and horizontal distance of a smoke zone, but no experimental data could be identified to support the recommendations of this document. Dr. Hywel Davies, Technical Director of CIBSE attempted to identify the source of the CIBSE guidelines, but could not find any record of the technical substantiation for the length and area recommendations in this document. Dr. Davies enlisted the help of Dr. Debbie Smith, Director of Fire Sciences and Building Products at BRE, who traced the source of the recommendations back to some work done in 1963 on the flow of hot gases when firefighters cut a hole in the roof to vent the gases. This investigation has confirmed that there are no guidelines regarding maximum length of long atria, anywhere in the world, that are based on experimental data involving smoke and its tendency to descend as it cools. This finding has reinforced TC5.6's belief that a real need exists for published guidelines regarding the maximum length of long atria that are based on relevant experimental data.

Specific Responses to Comments in return letter:

1. **Lacks details about deliverables.**
   TC5.6 response: The project is now focused on one goal - well defined recommendations for the maximum length for a long atrium before it must be subdivided into smaller spaces or a performance-based design which includes heat transfer analysis must be done. This is stated in the Project Objectives, and Relevance and Benefit to ASHRAE sections of the RTAR.

2. **Please address budget concerns.**
   TC5.6 response: Fire testing has been removed from the scope of the project, and the budget has been reduced to $70K. Given that the FDS fire model has been validated against fire tests in many different applications, we don't feel it is necessary to include fire testing and validation in this project. A budget of $70K should be sufficient to develop, run, and analyze enough configurations to draw meaningful conclusions. Guidance for bidders regarding the number of simulations is included in the Expected Approach section of the RTAR.

Responses to other comments appearing on RTAR Summary Votes and Comments form:

3. **Where would the limits and design guidance…be instituted?**

TC5.6 response: The design guidance would be added to the ASHRAE Handbook (HVAC Applications-Chapter 53) and special publication Handbook of Smoke Control Systems. This information appears in the Relevance and Benefits to ASHRAE section of the RTAR.

4. **It is not clear…if a new CFD model is developed as part of this project.**
5. **No specifics are given which CFD model is used?**
   TC5.6 response: Fire Dynamics Simulator (FDS), which is available at no charge from NIST, is expected to be used for this project. FDS is the most widely used CFD model for design of smoke control systems. FDS has been validated many times against actual fires, so use of FDS removes the need for validating the model as part of this project. This information appears in the Expected Approach section of the RTAR.

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TO: Kai Kang, Chair TC 5.6, kk444@columbia.edu
Paul Turnbull, Research Subcommittee Chair TC 5.6, paul.turnbull@siemens.com
Piotr Domanski, Research Liaison Section 5.0, Piotr.domanski@nist.gov

FROM: Michael Vaughn, MORTS, mvaughn@ashrae.org

DATE: July 14, 2011

SUBJECT: Research Topic Acceptance Request (1644-RTAR), Smoke Control in Long Atria

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At their annual meeting, the Research Administration Committee (RAC) reviewed the subject Research Topic Acceptance Request (RTAR) and voted to return it. The following list summarizes the mandatory comments and questions that need to be fully addressed in the RTAR re-submission:

1. Lacks details about deliverables.
2. Please address budget concerns.

An RTAR evaluation sheet is attached as additional information and it provides a breakdown of comments and questions from individual RAC members based on specific review criteria. This should give you an idea of how your RTAR is being interpreted and understood by others.

Please address or incorporate the above information into the RTAR with the help of your Research Liaison Piotr Domanski, Piotr.domanski@nist.gov, or RL5@ashrae.net prior to submitting it to the Manager of Research and Technical Services for further consideration by RAC. In addition, a separate document providing a point by point response to each of these mandatory comments and questions must be submitted with the RTAR. The response to each item should explain how the RTAR has been revised to address the comment, or a justification for why the technical committee feels a revision is unnecessary or inappropriate. The RTAR and response to these comments and questions must be approved by the Research Liaison prior to submitting it to RAC.

The next submission deadline for RTARs is **August 15, 2011** for consideration at RAC's 2011 fall meeting. The submission deadline after that is December 15, 2011.

Project ID	**1644**	
Project Title	Smoke Control in Long Atria	
Sponsoring TC	TC 5.6, Fire and Smoke Control	
Cost / Duration	$150,000/18M	
Submission History	**1st submission**	
Classification: Research or Technology Transfer	Basic/Applied Research	
Annual 2011 (Montreal) Meeting Review		**RTAR SUMMARY VOTES & COMMENTS - Version 1**
Check List Criteria	VOTED NO	**Comments & Suggestions**
Is there a well-established need? The RTAR should include some level of literature review that documents the importance/magnitude of a problem. If not, then the RTAR should be returned for revision.		
Is this appropriate for ASHRAE funding? If not, then the RTAR should be rejected. Examples of projects that are not appropriate for ASHRAE funding would include: 1) research that is more appropriately performed by industry, 2) topics outside the scope of ASHRAE activities.		(C) - It would be very beneficial to obtain outside funding (with some from ASHRAE).
Is there an adequate description of the approach in order for RAC to be able to evaluate the appropriateness of the budget? If not, then the RTAR should be returned for revision.	E, N, M	**(C)** - Lacks details about deliverables. **(E)** - Where exactly would the limits and design guidance for smoke control systems be instituted? Whether in Handbooks, stand-alone guideline documents or some other products?! **(M)**-Output needs more specifics.
Is the budget reasonable for the project scope? If not, then RTAR could be returned for revision or conditionally accepted with a note that the budget should be revised for the WS.	D, K, B, E, F, N	**(C)** - Providing that a CFD model is NOT developed from scratch. ***(D)*** - The budget seems inadequate given that experimental work must be done and a CFD model must be validated and used to investigate factors affecting smoke logging. I also question whether 18 months is sufficient time to complete the study. ***(K)*** - Seems to be too expensive for the work and value of the research. ***(E)*** - Same reason as above. ***(F)*** - $150k for combined experimental validation, parametric simulation and development of design guidance seems like a tall order. Does the TC have relevant experience that could be referenced to show that this could be done within budget?
Have the proper administrative procedures been followed? This includes recording of the TC vote, coordination with other TCs, proper citing of the Research Strategic Plan, etc. If not, then the RTAR could be returned for revision or possibly conditionally accepted based on adequately resolving these issues.		

Decision Options	Initial Decision	**Additional Comments or Approval Conditions**
ACCEPT		***(D)*** - Please address budget concerns. ***(C)*** - It is not clear from this RTAR if a new CFD model is developed as a part of this project. The discussion is focused on obtaining experimental data to validate the CFD simulations of heat transfer. No specifics are given which CFD model is used. What would be the deliverables in details and how the results would be used by ASHRAE?
COND. ACCEPT		
RETURN	X	
REJECT		

ACCEPT Vote - Topic is ready for development into a work statement (WS).
COND. ACCEPT Vote - Minor Revision Required - RL can approve RTAR for development into WS without going back to RAC once TC satisfies RAC's approval condition(s)
RETURN Vote - Topic is probably acceptable for ASHRAE research, but RTAR is not quite ready.
REJECT Vote - Topic is not acceptable for the ASHRAE Research Program

Unique Tracking Number Assigned by MORTS 1644-RTAR

RESEARCH TOPIC ACCEPTANCE REQUEST (RTAR) FORM

Sponsoring TC/TG/SSPC: _TC 5.6 Fire and Smoke Control_________________

Title:
Smoke control in long atria.

Applicability to ASHRAE Research Strategic Plan:
This project targets Goal 7 (support development of tools, procedures and methods suitable for designing low-energy buildings) and Goal 9 ("improved system efficiency…and safety", specifically examples 14 & 15) of the 2010-2015 Strategic Plan. The purpose of this project is to develop design limits and guidelines for use in designing cost-effective and energy efficient smoke control systems for malls, airport terminals and concourses in stadium and arenas. The project would establish maximum distances in a smoke control zone before additional exhaust fans are needed, avoiding overdesign and excess energy use while enhancing life safety by providing requirements for when additional smoke exhaust is required.

Research Classification:
Basic/Applied Research

TC5.6 Vote:	**Reasons for Negative Votes and Abstentions**:
14 For, 0 Against, 1 Absent	N/A – no negatives or abstentions
Estimated Cost:	**Estimated Duration**:
$150K	18 months
RTAR Lead Author	**Expected Work Statement Lead Author**
Paul Turnbull (paul.turnbull@siemens.com)	Paul Turnbull (paul.turnbull@siemens.com)

Co-sponsoring TC/TG/SSPCs and votes:

Possible Co-funding Organizations:
N/A

Application of Results:
Chapter 52, HVAC Applications, and
ASHRAE special publication Principles of Smoke Management.

State-of-the-Art (Background):
There are a number of interior spaces in buildings that can be classified as low atriums with ceiling heights ranging from 10 – 15 m. A number of these spaces can have large horizontal dimensions in one direction producing long atria (malls, airport terminals and concourses in stadiums and arenas) or in both horizontal directions such as convention centers and casinos (large atria).

Most of the research that has been conducted regarding smoke control for atria has focused on high spaces. This research has formed the basis for the guidelines provided in Chapter 52 of the ASHRAE Handbook and the requirements in NFPA 92B [1]. For high atria, the fundamental assumption is that the fire will produce a smoke plume that entrains air as it rises to the ceiling. Engineering correlations have been developed for use in determining the smoke production rate for use in selecting and designing a smoke control system for atria.

Low atria present a different challenge for the design of the smoke control system as much of the smoke movement will be as a ceiling jet flow below the ceiling rather than as a vertical plume. There are concerns that with large horizontal travel distances the smoke may lose its buoyancy and descend toward the floor, potentially affecting the ability of occupants to safely evacuate.

The potential for the base of the smoke layer to descend to the floor in long spaces was demonstrated in tests conducted in a 600 m long tunnel in Glasgow [2, 3]. The tests showed that as the smoke propagated along the tunnel, thinner smoke was formed under the smoke layer, which could lead to smoke filling the full-height and width of the space (smoke-logging). Smoke-logging was most likely to occur at the ends of the tunnel with the closed end situation being particularly bad.

UK guidelines for smoke control in shopping centers [4, 5] include requirements for the maximum area and length of smoke reservoirs. These guidelines recommend a maximum area of 2000 m^2 for natural ventilation and 2600 m^2 for mechanical exhaust where the objective is to protect egress routes. The maximum recommended area is 3000 m^2 where the objective is to protect property and no significant life safety objective. The maximum recommended length of a smoke reservoir is 60 m. Smoke curtains are used to divide larger areas to meet these recommendations.

The requirement limiting the area of the smoke reservoir is based on the maximum size of reservoirs used for full-scale experiments [4], and not from test data indicating that a particular hazard exists beyond this size. It is noted in Reference 5 that the maximum area of the reservoir could be increased once there is sufficient confidence in the ability of numerical models to calculate the heat transfer processes for smoke layers.

The origin of the 60 m limit on the maximum length for the reservoir is not known. However, it is suggested that it was based on a committee belief that the maximum distance for occupants to travel under the smoke layer should be less than 30 m [5].

There are no requirements in North American codes and standards that limit the length or area of a smoke zone. An ad hoc limitation that is sometimes used is that the maximum distance between the fire and the exhaust inlet should be less than 61 m (200 ft) [6]. For large open areas, this can result in a large number of exhaust fans or complex duct systems being required. If all smoke control fans are activated simultaneously, there can be a substantial power requirement for the emergency systems. It can also be difficult to provide sufficient make-up air while meeting the airflow velocity limits in codes and standards (1 m/s).

One option is to use smoke curtains to create smaller smoke zones with a single exhaust system used to provide exhaust from multiple smoke zones. However, the installation of smoke curtains can be architecturally difficult and expensive. Also, ducting and damper systems with complex control systems are required to provide exhaust from the smoke zone with the fire.

An alternative option that has been suggested is that multiple fans be installed in the large area. The large area is divided into “virtual” smoke zones with no smoke barriers used to physically separate the smoke zones. The exhaust system in the smoke zone nearest the fire is activated. This approach does limit the amount of make-up air required. However, a basic assumption in this approach is that smoke has a tendency to be drawn towards the exhaust inlets for the operating fans and that there will be minimal smoke migration into adjacent smoke zones.

Smoke exhaust systems generally produce sink flows in the area adjacent to the exhaust inlet. High airflow velocities are induced at the exhaust inlet. However, the velocities decrease rapidly with distance from the inlet. This could lead to scenarios in which the fire induced smoke movement would exceed that produced by the exhaust system and cause smoke to enter adjacent smoke zones.

Problems with smoke exhaust systems can be found in both long and large atria spaces. The proposed project will focus on the long atria case. This is the situation for which the most concern has been raised by designers. Also, it is the easier of the two situations to deal with using a combined experimental and numerical modeling approach. Although the focus is on the long atria scenario, the project would also provide guidance for the large atria situation.

Advancement to the State-of-the-Art:

In recent years, there has been a rapid development in CFD models used to simulate smoke movement in buildings. There have been extensive efforts to validate these models for modeling smoke plumes and the smoke movement in the vicinity of the smoke plume impingement on the ceiling. These models are used extensively in the design of smoke control systems for atrium applications. For the long atria application, it is necessary to accurately model the heat transfer processes between the smoke layer and the surroundings in the far field to determine if the smoke will lose its buoyancy resulting in mixing with ambient air and smoke logging in egress routes. There has been limited or no validation of CFD models for use in modeling smoke movement in areas remote from the smoke plume. In the proposed project, full-scale (or physical model) experiments would be conducted for use in validating a CFD model for use in simulating smoke movement in the far field. The validated model would then be used to investigate the factors that affect the buoyancy of the smoke layer. These factors would include fire size, atrium dimensions (ceiling height, length), end effects (open and closed ends) and thermal properties of the ceiling materials.

Justification and Value to ASHRAE:
In recent years, there are an increasing number of large building complexes being constructed that include long atria spaces. With the present level of knowledge, it is impossible to provide guidelines for the maximum size of smoke reservoirs for such buildings before dangerous conditions occur that are not predicted by current tools. It is also impossible to provide guidance for the design of cost-effective and energy efficient smoke control systems for such spaces. This project would validate a CFD model for use in addressing the factors that could affect the design of smoke control systems that would limit the potential for smoke logging in egress routes to meet the life safety requirements in codes and standards. The results of the project would be used to develop limitations and guidelines for smoke control systems used in long atria.

Objectives:
The main objectives of this project are:

1. Conduct full-scale (or physical scale model) experiments to develop data for the validation of CFD simulations for heat transfer from the smoke layer and smoke movement in the far field for long atria.
2. Validate a CFD model for the long atria scenario.
3. Conduct CFD modeling to investigate the factors that could affect heat transfer from the smoke layer and result in smoke logging in egress routes.
4. Provide limits and design guidance for smoke control systems used in long atria.

Key References:

1. NFPA 92B, Standard for Smoke Management Systems in Malls, Atria, and Other Large Spaces, National Fire Protection Association, Quincy, MA 2009.
2. Heselden, A. J. M. and Hinkley, P. L., Smoke Travel in Shopping Malls Experiments in Co-operation with Glasglow Fire Brigade – Part 1, Fire Research Note 832, Building Research Establishment, Borehamwood, UK, 1970.
3. Heselden, A. J. M., Smoke Travel in Shopping Malls Experiments in Co-operation with Glasglow Fire Brigade – Part 2, Fire Research Note 832, Building Research Establishment, Borehamwood, UK, 1970.
4. CIBSE, Guide E: Fire Safety Engineering, The Chartered Institution of Building Services Engineers, London, UK, 2010.
5. Morgan, H. P. Ghosh, B. K., Garrad, G., Pamlitschka. R. de Smelt, J-C. and Shoonbaert, L. R., Design Methodologies for Smoke and Heat Exhaust Ventilation, BR 368, Building Research Establishment, Garston, UK, 1999.
6. Vaughn, A. J. and Geinzer, P. E., Practical Applications of Smoke-Control Systems, HPAC Engineering, March 2010, p. 40-45.