PROPOSAL FORM

PITA ◆ FISCAL YEAR 2008

Institute for Complex Engineered Systems (ICES)
Carnegie Mellon University

Proposal Number: CMU ##
Awarded Amount: $

(For administrative purposes only)

INSTRUCTIONS: *Please use this form to submit your PITA proposal. Fill-in complete answers for all questions. Submit complete proposals along with your completed PITA budget form (see below) no later than September 28, 2007.* ***BUDGET INFORMATION:*** *A specific budget template has been created for PITA proposal submission. This template will automatically calculate the correct rates negotiated for the PITA program and provides fields for you to include salaries, equipment, consultants, travel (within PA only), supplies, industry cost share, and leverage funds. An electronic copy of the budget template is available on the Call for Proposals page on the PITA web site at www.ices.cmu.edu/pita or by request from Matthew Sanfilippo (mattsanf@cmu.edu).*

1. Project Title: Computation of Air Flow in CMU's Intelligent Workplace and Its Effect on Occupant Health and Comfort

A. Is this proposal a renewal or continuation of a previous PITA project? *(check one)* ☐ **yes** ☑ **no**
If yes, please provide the account string & title of that project:

B. If your project is funded, would you be interested in participating in the SURE Thing program? (ie. Accepting a qualified, non-CMU, PA college student to work as a research assistant on this project during the summer of 2008.) *(check one)* ☑ yes ☐ no
for more information visit *www.ices.cmu.edu/surething*

2. Research Team *(Projects should involve collaboration of 2 or more faculty)*:

- Principal Investigator -- Khee Poh Lam, Professor, School of Architecture, kplam@cmu.edu
- Co Principal Investigators – David H. Archer, Department of Mechanical Engineering, archerdh@andrew.cmu.edu, 412 268-2004

  Hongxi Yin, Research Associate, Department of Architecture, hongxi@andrew.cmu.edu

  Yongjie (Jessica) Zhang, Assistant Professor, Department of Mechanical Engineering, jessicaz@andrew.cmu.edu
- Graduate Student(s) - *(department information and names, if known)*:

  Mechanical Engineering: Rong Li

  Architecture: Rui Zhang
- Undergraduate Student(s) - *(department information and names, if known)*: TBD

3. Other Project Participants (including Participating Pennsylvania Companies):

- Industry - Traco Windows: Mike Manteghi, Joshua Early, Charles Schafer, mike.manteghi@traco.com, charles.schafer@traco.com
  - Somfy: James Campbell, jcampbell@somfy.com
  - Siemens Building Technologies, Osman Ahmed, osman.ahmed@siemens.com

4. Contact Information for Non-CMU Project Participants *(from #3 above)*:

Mike Manteghi
mike.manteghi@traco.com
Director of R&D
Traco
71 Progress Avenue
Cranberry Township, PA 16066

James Campbell
jcampbell@somfy.com
Somfy System, Inc
Business Development Manager
Commercial Building Solutions
47 Commerce Drive
Cranbury, NJ 08512
www.somfysystems.com

Osman Ahmed, Ph.D., P.E.
osman.ahmed@siemens.com
Head, Global Research and Innovation
Siemens Building Technologies-HVP division
1000 Deerfield Parkway
Buffalo Grove, IL 60089
www.sbt.siemens.com

5. Executive Summary of the Project

Carnegie Mellon's Center for Building Performance and Diagnostics has completed detailed plans for the installation of two engineered systems for cooling/heating/ventilation in its Intelligent Workplace, the

IW, to provide a healthy, productive, and comfortable environment for its student and faculty occupants and also to minimize the energy requirements for operating this space. These systems are

- advanced fan coil units with an innovative controls in 10 of the open offices in the IW.
- ten operable windows with actuators for opening/closing with innovative controls provide hybrid ventilation and cooling in the IW's large meeting room.

This proposed investigation will simulate air circulation in the IW equipped with these systems and analyze their effects on the comfort of the occupants. Computational fluid dynamics,CFD, will be used to consider and balance two key issues: thermal comfort and energy efficiency. First, a comprehensive geometric grid model will be constucted to represent the IW incluing the walls, floor, ceiling, windows, doors, fan coils, and furnishings. Then the air flow and accompanying heat exchange with the bounding surfaces of the IW will be calculated based on indoor and outdoor ambient conditions, the operating conditions of the fan coils and windows, and the occupancy of the space..

Five parameters will be utilized to indicate the occupants' comfort: the air temperature, humidity, velocity, CO_2 content, and the radiant temperature dependent on the surrounding surfaces. The computational results of the air flow, its conditions, and those of the surroundings will provide the data to establish whether comfort conditions have been established based on the outside conditions and on the design and operating conditions of the fan coils and the windows. The operating conditions of the fan coil, fan speed and chilled/heated water flow, will determine their operating costs.

This CFD air flow simulation will, therefore, when generalized, provide a design support system for architects and engineers calibrated and validated by empirical operational data from the fan coil and window installation in the IW that will enable the evaluation of the annual performance and operating cost of any given fan coil and window installation with its operational controls in a given building space.

6. Description of the Project:

A computational approach is proposed to simulate air circulation in CMU's Intelligent Workplace and analyze its effect on occupant health and comfort and also on operating costs. The research builds upon and integrates the expertise of the principal investigators, particularly in engineering, architecture, and CFD simulations.

CMU's Intelligent Workplace: The Robert L. Preger Intelligent Workplace, the IW, at Carnegie Mellon University is a collaborative effort among industry, government and the university. Opened in December 1997, the IW demonstrates the economic feasibility to:

- improve user satisfaction
- provide unprecedented levels of organizational flexibility
- provide unprecedented levels of technological adaptability
- maximize energy and environmental effectiveness.

The mission of the Intelligent Workplace is to research, develop, and demonstrate advanced building operating systems and their integration for total building performance.

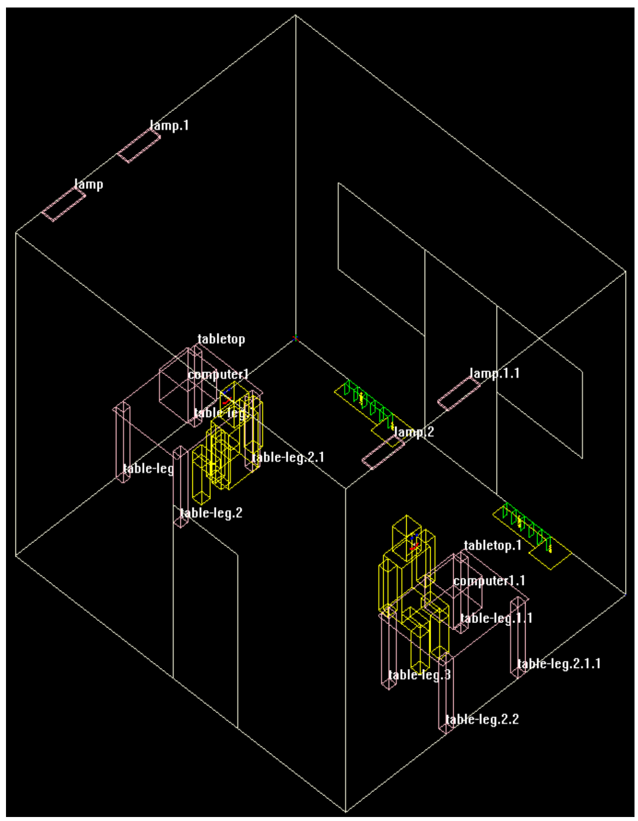


Figure 1: A simple geometric model of IW.

The IW demonstrates the economic feasibility of a significant improvement of quality of life as measured by occupants' satisfaction and of a significant reduction in energy consumption and environmental impact. About 40% of both primary energy consumption and greenhouse gas emissions in the U. S. are attributable to cooling, heating, lighting, and ventilating buildings. The Intelligent Workplace has demonstrated the potential of reducing energy consumption and greenhouse gas emissions by a factor of four.

Computational Approach: In this project, we will simulate air flow and heat transfer inside IW, analyze its effect on occupant health and comfort, and then utilize the computational results to optimize the design, operation and location of cooling/heating units and operable windows in IW, considering both comfort provision and energy consumption.

A commercial software package, Airpak, will be used to model air flow, heat transfer and thermal comfort in the IW. Airpak provides an interface to construct the geometry of the IW, including all bounding surfaces, windows, doors, fan coils, and furnishings. Some model components can be adjusted according to different outdoor conditions, for example, windows can be opened or closed, fan coil air flows and temperatures can be varied. The process of geometry construction requires considerable manual work. Consideration will first be given to data interoperability between Airpak CFD modeling and AutoCAD where a current description of IW geometry resides. Plug in codes have been developed to minimize manual work and facilitate the transfer of information.

Figure 1 shows one simple model constructed to represent a typical office of the IW. The office space (4.6m×4.1m×3.9m) has one door and two windows on the west wall. Both windows are double pane glass. Along the west wall, there are two fan coils incorporating fresh air supplies. Beside them are the vents for exhaust air. On the east wall, there is a door. There are two 34 W lamps on the ceiling on the east and the west side of the space. Two occupoants are in the room operating 173 W computers on two tables.

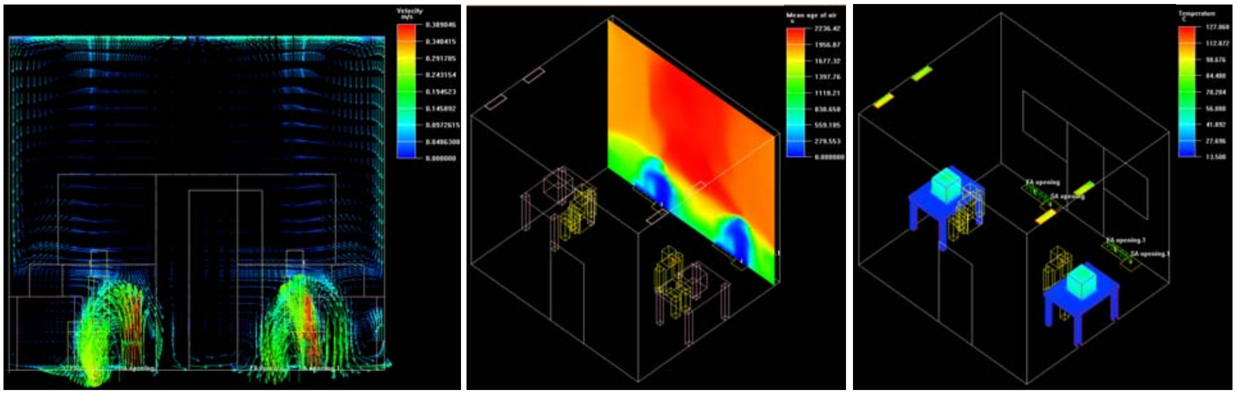
After creating the geometry, tetrahedral meshes are generated in Airpak. Some gaps, however, may exist in the generated meshes due to non matching geometry. In order to remove all gaps and to avoid any air leakage, hanging nodes will be detected by checking all the connectivity information in the geometry, and then fixing non matching geometries. High order geometric partial differential equations will be used to further improve the mesh quality, adjust mesh adaptation and anisotropy with respect to the distribution of air velocity and temperature. The mesh quality and mesh size will be balanced in order to improve the CFD solver's convergence and stability as well as to minimize the computational time.

CFD Simulations: A sample situation can be considered to illustrate the proposed overall simulation process: the room temperature is 25 °C; the outside temperature, 30 °C; the temperature of air from the fan coil, 15 °C; and the relative humidity of the air, 50%. The steps in the overall CFD computation process to simulate conditions in the IW with its fan coils are as follows:

- Analyze the air flow under isothermal conditions, without considering heat transfer. The ventilation scenario of the room can be varied flexibly: windows may be open; fan coil air flow may be on or off.
- Couple air flow and heat exchange to calculate the air velocity and temperature distribution, as well as the interaction between them.
- Consider solar radiation through glass windows, the transmitted and the absorbed radiation dependent on the glazing, the heat exchange between in- and outdoors by convection and conduction, the complex boundary value condition for energy transfer at windows.
- Include operational fan coils and operable windows in the simulation. The air flow through the fan coil and the temperature of its outlet air are determined by the controls and are boundary conditions for the CFD simulation. The air flow and temperature through open windows are dependent both on outdoor and indoor conditions. Special boundary value conditions are required.
- Study intelligent control, for example, establish desired set point operating conditions for the IW based on the presence or absence of occupants in the space.

These computational steps will be followed to determine: the air velocity, mean age of air, temperature, humidity, and trace particles throughout the IW space. A parametric study will be conducted to optimize the design, operation, and location of fan coil units and operable windows in order to achieve occupant comfort and to minimize energy consumption. Figure 2 shows an example of the calculated air velocity, the mean age of air and the temperature distribution for a simple model under isothermal conditions.

Parallel Computing: The IW system is a very complicated system, resulting in large number of degrees of freedom and introducing a huge linear system. Long times are required to conduct a single iteration in one workstation. For example, it may take about several hours even one day to obtain a convergent result using the sequential code. Parallel computing may be necessary in our case. Airpak supports parallel processing, and we will apply for computational time from Pittsburgh Supercomputer Center to run our parallel CFD code. An important issue in our future work is determining how to decompose the system into small pieces, send each piece to one processor, and finally merge the results without losing accuracy. Communication among processors is the main technical issue in carrying out parallel computing.



(a) (b) (c)

Fig. 2 Simulation Results under Isothermal Conditions: a, the velocity vectors on a horizontal plane cut through the office; b, one contour plot of the mean age of air; c, the contours of temperature on the block surfaces in the office.

7. Anticipated Results and Strategy for Follow-on Funding of the Project:

This project will result in two deliverables: 1. parametric CFD simulations of air flow in CMU's IW space; 2. an operational study demonstrating the effect of fan coils and operable windows on air flows and heat transfer affecting occupant health and comfort. The principal benefit of this project will be the ability both to improve comfort and to minimize energy costs. The computational results will provide significant information regarding building and cooling/heating/ventilation equipment design, location, and operation.

The milestones of this project and projected deadlines are:

- Geometric model construction and mesh generation (2 months): checking hanging nodes in geometry to detect gaps, quality improvement, mesh adaptation and anisotropy control.
- CFD simulations using Airpak (8 months): computing air velocity, temperature distribution, humidity, and energy efficiency.
- Validation and conclusion (2 months): comparing computational results with measurements, and optimizing building design such as the selection and location of fan coils and operable windows.

The above efforts directly target follow on funding, particularly from the DOE. The general applicability of the proposed research to applications and fundamental studies in architecture will be appealing to numerous DOE programs. The general capabilities of the research project also imply significant potential for technology transfer to the private industrial sector, and our developed software will be copyrighted and marketed once its feasibility is established.

8 Relationship to PITA Goals and Potential Impacts on PA:

A number of companies have contributed the hardware for an advanced building cooling/heating/ventilation system in the IW. LTG has contributed fan coils; Traco, a local Pennsylvania company, windows; Somfy, window opening actuators; Siemens Building Technologies, instrumentation and controls for a wireless system planned by CMU students and faculty. The U. S. DOE/EERE has provided the funds for Astorino Engineers to prepare detailed drawings for the installation of the system following preliminary engineering by CMU students and faculty. This effort has fostered close cooperation among the industrial participants and CMU. Funds are now being sought to complete the installation.

The need for a computational design support system for a building space, to analyze data, to evaluate the performance, and to inform the design, location, and operation of the system components in the building to achieve occupant satisfaction and efficient operation has become clear. This system proposed for PITA support will complement CMU's effort to develop and demonstrate an innovative building cooling/heating/ventilation facility for research and development. And it will certainly provide additional opportunities for funding from industry and from the U. S. DOE.

9. Past Results Enabled by PITA Funding:

Archer has one proposal funded by PITA last year, "Biodiesel Fuel Effectiveness in a Power/Cooling/Heating/Ventilation System for a Building". The installation of this facility has been completed with over $650 k in funds provided by the Pennsylvania DEP and the U.S. DOE/EERE. Testing and operation is now underway with bioDiesel fuel provided by CTI Biofuels, a Pennsylvania company.

CARNEGIE MELLON UNIVERSITY SUBMISSION
Institute for Complex Engineered Systems (ICES)
PITA (FY 07-08) BUDGET

Please fill in the blue cells only. Benefits, F&A, leverage, GTR tuition cost-sharing, and totals will be automatically calculated.	This color block =	Manual Enter
	This color block =	Automatic Calculation

Oracle String *Administrative Use Only*

Principal Investigator Name Khee Poh Lam — **PI Phone Extension** 8-2350

PI Department Architecture — **Submission Date** 9/28/2007

	FT PERSONNEL (Last, First)	HOME DEPT	% Effort	AY/CY/SU		Amount
1						$ -
2						$ -
3						$ -
			Subtotal			$ -

	GRAD STUDENT NAME	HOME DEPT	% EFFORT		FY06/07 PITA	Amount
1	Rong Li	Mechanical Engineeri	50%	*PITA TUITION*	$ 23,120	$ 11,560
			50%	*DEPT. GTR TUITION SHARING*	$ 10,880	$ 5,440
			50%	*ICES 12 MONTH STIPEND*	$ 23,485	$ 11,743
2	Rui Zhang	Architecture	50%	*PITA TUITION*	$ 23,120	$ 11,560
			50%	*DEPT. GTR TUITION SHARING*	$ 10,880	$ 5,440
			50%	*ICES 12 MONTH STIPEND*	$ 23,485	$ 11,743
			Subtotal for PITA stipend/tuition only			46,605.00

UNDERGRADUATES	Name if Known	Amount
Undergraduate 1		$ -
Undergraduate 2		$ -
Subtotal		$ -

BENEFITS	Amount
Benefits at 27.2%	-
Subtotal	-

OPERATING	EXPENDITURE TYPE	Amount
	Books/Periodicals	$ -
	Consulting	$ -
	Copying	$ -
	Data Processing	$ -
	IC Computing Facilities	$ -
	IC Postage	$ -
	LD Telephone	$ -
	Maintenance	$ -
	NC Equipment	$ -
	NC Software	$ -
	Technical Supplies	$ -
	Publishing	$ -
	Other - please explain below	$ -
	Subtotal	$ -

TRAVEL - MUST BE WITHIN PENNSYLVANIA	Amount
Destination/Purpose	
1	$ -
2	$ -
Subtotal	$ -

CAPITAL EQUIPMENT/SOFTWARE	Price	Qty	Amount
Description			
1			$ -
2			$ -
Subtotal			$ -

9/28/2007

SUBCONTRACT **(please attach subrecipient budget, SOW and contact information)** — Amount

Subrecipient name

	$ -
Subtotal	$ -

OTHER (Please justify)	Amount
	$ -
	$ -
Subtotal	$ -

SUBTOTAL	46,605.00
INDIRECT = Subtotal of all direct costs* 11.11.%	5,177.82
TOTAL REQUESTED PITA AMOUNT	**51,783**
TOTAL GTR SHARED BY GRADUATE STUDENT'S HOME DEPARTMENT(S)**	**10,880**

**If students are budgeted from multiple departments, shared GTR will be allocated to each student's home department.

*****Please note that all sources of leverage (cost-sharing, matching, etc.) SHOULD NOT be included in the above budget, but listed below.**

OTHER JUSTIFICATION

This CFD project will provide new insight in an ongoing program of research and development in building cooling/heating/ventilation systems that both provide for the health, productivity, and comfort of occupants while reducing the cost of building operation. The CFD air circulation models will be useful in data analysis and also in the design and operation of systems.

LEVERAGE

Amount Requested	$ 51,783
Leverage Requirement	$ 103,566

SOURCES OF LEVERAGE

	SOURCE (Company, Agency, etc.)	**CATEGORY TYPE** (Please see below chart or RFP)	**AMOUNT**	**ORACLE STRING (if known)**
1	Traco Windows	A	$12,000	Operable windows
2	Somfy Window Actuators	C	$10,000	Window actuators, motor controls
3	Siemens Buildign Tecnoloiges	C	$60,000	Instrumentation, control for fan coils
4	U.S. DOE/EERE/NETL	C	$48,000	16096.1.3.1070068

The guideline is $2 of expended leverage for each $1 of expended PITA funds. The leveraged funds identified in a project proposal must be in place before PITA funds are released to the project and must be expended during the duration of the PITA project.

Check here if leverage pending ______________

Leveraged Funds. Leveraged funds fall into four broad categories (in general order of importance):
A. New Cost Matching from Pennsylvan
B. Existing cost matching from Pennsylvania industrial partners related to the proposed project goals
C. New cost matching from non-Pennsylvania sources (e.g. federal government, out-of-state industrial partners)
D. Existing funds related to the proposed project goals that do not fall into the categories above and that are not from Pennsylvania State government sources.

Please call Rhonda Moyerat 268-6410 or send email to rm7q@andrew.cmu.edu with any questions.

TRACO™

The Windows And Doors That Greet The World

September 27, 2007

Dr. David Archer
Intelligent Workplace, MMCH 415
Carnegie Mellon University
500 Forbes Avenue
Pittsburgh, PA 15213-3890

Dear Dr. Archer,

After discussions between TRACO and CMU we understand that you are applying for a grant from the Pennsylvania Infrastructure Technology Alliance, PITA, to conduct CFD analyses of the air circulation in the Intelligent Workplace (IW). In effort to assist in the project, TRACO will donate 10 NX-250 windows equipped with Somfy actuators, which you will install and operate. This hybrid system will be accompanied by an operating and control system for which you will provide the algorithms. In addition, this system is to provide for the health and comfort of the IW occupants while reducing the costs for cooling and ventilation of the space.

Developing this smart window system will be a step forward in energy efficient building systems and a potential feature we could offer our customers. For these reasons we have met with you, have designed and manufactured 10 windows with actuators for your façade, and will put together a demonstration model of the system. We await your operating algorithms. The estimated donation of windows, hardware, and engineering is $12,000.

Once the CFD analysis is validated, it will be a useful tool in developing, designing, and evaluating this smart window ventilation system and its controls.

We look forward to working with Carnegie Mellon University and are pleased to assist in this project. Best wishes in receiving the PITA grant that you are requesting.

Sincerely,

Mike Manteghi

TRACO
Director of R&D

somfy®

24 September 2007

Dr David H. Archer
Center for Building Performance and Diagnostics
Department of Mechanical Engineering
Carnegie Mellon University
5000 Forbes Avenue, MMCH 415
Pittsburgh, PA 15213-3890

Dear David,

The Center for Building Performance and Diagnostics at Carnegie Mellon is planning to install a hybrid ventilation system in the Intelligent Workplace, the IW. And you are seeking a grant from PITA, the Pennsylvania Infrastructure Alliance, to support a CFD analysis of the performance of this system. The system will comprise 10 operable windows with Somfy actuators, 3 transformers, and 3 motor controllers. You will write the algorithms and supply the overall control system that will operate the windows providing for the health and comfort of the IW occupants while reducing the costs for cooling and ventilation of the space.

Your development of this hybrid ventilation system represents significant progress in building systems and will provide a significantly increased market for our products. For these reasons we have supplied have supplied the actuators, transformers, and motor controllers for your system. The estimated retail value of this contribution is $10,000. We will also be pleased to work with you supplying technical support in the installation and operation of the system.

You are requesting a PITA grant for CFD analyses of the air circulation in the IW resulting from the hybrid ventilation system. These analyses, proved out by operating data, will be an extremely useful tool in developing, designing, and evaluating your hybrid ventilation system and its controls.

We are very pleased to work with Carnegie Mellon in this project. It will, we believe, provide a significant benefit in our business. Best wishes in receiving the PITA grant that you are requesting.

Sincerely,

James Campbell

James Campbell
Somfy System, Inc
Business Development Manager
Commercial Building Solutions

Dr. David Archer
Intelligent Workplace, MMCH 415
Carnegie Mellon University
500 Forbes Avenue, Pittsburgh, PA 15213-3890
Dated: Tuesday, September 25, 2007

Dear David,

In the Intelligent Workplace of Carnegie Mellon, you are progressing with the installation of advanced fan coil cooing/heating/ventilation units with an innovative control system. You are developing this overall system that will assure health and comfort to the student, staff and faculty occupants of the IW with a minimal requirement for energy in its various forms: electricity and chilled or heated water.

Siemens Building Technologies has proposed to supply instrumentation and control, software and hardware, for a wireless system that will implement the fan coil control strategy that you have proposed. Our lawyers are working out the legal arrangements to transfer this software and hardware to Carnegie Mellon. This estimated retail value of the itemized list of supply that we have jointly worked out is about $60 k. Siemens intends to supply this equipment along with consulting and yearly service related to its installation at no charge. Your students have taken the Siemens Apogee programming course and this prepares them to do the necessary programming of the hardware for control and data processing.

You are now proposing to PITA, the Pennsylvania Infrastructure Technology Alliance, to fund a project that will construct CFD analyses of the air circulation in the IW spaces where fan coils will be installed. Such analyses, when validated by experimental data, will be a valuable tool in the design, operation, and evaluation of such fan coil systems and their controls. They will also facilitate transferring the technology beyond the IW to a wide variety of applications.

We will follow your proposed fan coil cooling/heat/ventilation project with great interest. A carefully planned and executed control system will be a key to its success. Your proposed CFD modeling and analyses will be of great value in your work. Siemens Building Technologies and I are pleased to assist you in this effort.

Sincerely,

Signed by

Dr. Osman Ahmed, Ph.D., P.E.
Head, Global Research and Innovation
Siemens Building Technologies- HVP division
1000 Deerfield Parkway
Buffalo Grove, IL 60089
USA
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