PSC-CUNY Research Awards (Traditional B)

Control No: TRADB-51-264 **Rank:** Assistant Professor **Tenured:** No **College:** NEW YORK COLLEGE OF TECHNOLOGY **Panel:** Physics & Engineering **Discipline :** Engineering Co-PI :	**Name:** Kang, Daeho **Address:** 1351 15th St Fort Lee, NJ07024 **Telephone:** 217-898-4475 **Email:** dkang@citytech.cuny.edu

Human Subject Use: No
Animal Subject Use: No
Supplementary Materials: No
List of Supplementary Material:
Will Interviews be Conducted?: No
Department: Environment Control Technology

Title of Proposed Project: Development of Analytical Model Predicting Natural Airflow Rates through Building Entrance Doors

Brief Abstract

Saving energy in buildings is of vital importance since the buildings sector is a major contributor to the global carbon footprint. The current methods that predict natural airflow rates through building entrance doors have been used for years while involved with a certain degree of uncertainty. This project is intended to develop an analytical model that can accurately predict such natural airflow rates. It designs field measurements to monitor local environmental parameters in two campus buildings that have a different entrance door configuration. The data collected through the field measurements will be used to validate the existing models. The collected data will also be used to develop an analytical model. I will implement the analytical model in a whole building simulation program such as EnergyPlus so that many scholars in the field can utilize the most accurate model. This process will be a proposal for the US Department of Energy (DOE)'s Building Technology Funding Opportunities.

Relevant Publications & Scholarship

Peer-reviewed Journal
1. Daeho Kang and Richard K. Strand. "Analysis of the system response of a spray passive downdraft evaporative cooling system." Building and Environment, 157 (2019) 101-111.
2. Daeho Kang and Richard K. Strand. "Performance control of a spray passive down-draft evaporative cooling system." Applied Energy, 222 (2018) 915-931.
3. Daeho Kang, Richard K. Strand. "Significance of parameters affecting the performance of a passive down-draft evaporative cooling (PDEC) tower with a spray system." Applied Energy, 178 (2016) 269–280.
4. Govinda Mahajana, Heejin Cho, Kevin Shanley, Daeho Kang. "Analytical modeling of air flow rate through automatic building doors." Building and Environment, 87 (2015) 72-81.

Peer-reviewed Conference
1. Daeho Kang and Richard K. Strand. "Competence of a Spray Passive Down-draft Evaporative Cooling (PDEC) System for Space Cooling." Proceedings of Building Simulation 2019: 16th Conference of IBPSA, Rome, Italy, Sep. 2-4, 2019.
2. Daeho Kang. "Quantification of Heat Flows Through Building Entrance Doors on a Winter Day." Proceedings of Building Simulation 2019: 16th Conference of IBPSA, Rome, Italy, Sep. 2-4, 2019.
3.Daeho Kang, Haxiang Cui, and Jelani Barro. "Measurement of Thermal Environment in a Building Entrance Area on a Winter Day." The 4th Asia Conference of International Building Performance Simulation Association, Hong Kong, Dec 3-5, 2018.

4. Daeho Kang and Heejin Cho. "Modeling of central ground-source heat pump system in EnergyPlus." Asim 2016, The 3rd Asia conference of International Building Performance Simulation Association, Jeju, Korea, Nov 27-29, 2016.
5. Daeho Kang and Richard K. Strand. "Implementation of analytical models for passive down-draft evaporative cooling (PDEC) tower with spray systems." 14th Conference of International Building Performance Simulation Association, Hyderabad, India, Dec. 7-9, 2015.

Presentation
1. Daeho Kang and Richard K. Strand. "Competence of a Spray Passive Down-draft Evaporative Cooling (PDEC) System for Space Cooling." Proceedings of Building Simulation 2019: 16th Conference of IBPSA, Rome, Italy, Sep. 2-4, 2019.
2. Daeho Kang. "Quantification of Heat Flows Through Building Entrance Doors on a Winter Day." Proceedings of Building Simulation 2019: 16th Conference of IBPSA, Rome, Italy, Sep. 2-4, 2019.
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4. Daeho Kang and Heejin Cho. "Modeling of central ground-source heat pump system in EnergyPlus." Asim 2016, The 3rd Asia conference of International Building Performance Simulation Association, Jeju, Korea, Nov 27-29, 2016.
5. Daeho Kang and Richard K. Strand. "Implementation of analytical models for passive down-draft evaporative cooling (PDEC) tower with spray systems." 14th Conference of International Building Performance Simulation Association, Hyderabad, India, Dec. 7-9, 2015.
6. Michael J. Witte, Edwin S. Lee, Lixing Gu, Richard Raustad, Tianzhen Hong, and Daeho Kang. "Strengthening EnergyPlus to Enable Advanced Building Energy Models" Special features of EnergyPlus presented at ASHRAE/ IBPSA-USA Building Simulation Conference, September 10-12, 2014, Atlanta, GA.

Education

Institution	Degree	Year(s)	Discipline
University of Illinois at Urbana-Champaign	Ph.D.	2011	Technology in Architecture

Other Current & Past Funding (last 5 years)

Period	Role	Title	Amount	Funding Source

Attachments

Description	File Name	File Size	Date Attached
Project Description	Project_Description.pdf	305535	12/10/2019 10:19:08 AM

Budgets

Description			Requested Amount
Research Staff	Fringe Benefit Expense MTA	0.00 0.00	0.00

	Payroll Tax		
Clerical Staff	Fringe Benefit Expense MTA Payroll Tax	0.00 0.00	0.00
Summer Salary (Principal Investigator)	Fringe Benefit Expense	0.00 0.00	0.00
Released Time	Fringe Benefit Expense	0.00 0.00	0.00
General Office Supplies/Xeroxing		0.00 0.00	0.00
Domestic Travel		0.00 0.00	0.00
Foreign Travel		0.00 0.00	0.00
Independent Contractors		0.00 0.00	0.00
Subject Payments		0.00 0.00	0.00
Laboratory Fees		0.00 0.00	0.00
Manuscript Preparation/ Publication Costs		0.00 0.00	0.00
Equipment A meter that measures air velocity across entrance doors will be purchased. The model and cost are as follows: TSI 9565-A VelociCalc Multi-Function Ventilation Meter with Articulated Probe ($2,520).		2520.00 0.00	2520.00
Research Supplies Following sensors will be purchased to monitor indoor and outdoor environment. Type of sensors Cost Qty Total Outdoor Temp/RH sensor 110 2 220 Indoor Temp/RH sensor 135 3 405 Occupancy & Lighting 250 3 750 Indoor Temp sensor 45 18 810 CO2 sensor 595 1 595 Tripod 350 2 700		3480.00 0.00	3480.00
		Total	**6,000.00**

Development of Analytical Model Predicting Natural Airflow Rates through Building Entrance Doors

INTRODUCTION

Saving energy in buildings is of vital importance since the buildings sector is a major contributor to the global carbon footprint. Natural ventilation has been widely used in various ways to reduce building cooling loads and to maintain indoor air quality (Chen, 2009). As ventilation and infiltration take a large portion of building loads, many studies have investigated methodology to implement various strategies for maintaining indoor environments in buildings (Chiu and Etheridge, 2004; Goubran et al., 2017; Gowri et al., 2009; Han et al., 2015). Methods have been developed to estimate wind pressure distribution on outside building surfaces (Chiu and Etheridge, 2004; Muehleisen and Patrizi, 2013; Shaw and Tamura, 1977; Younes et al., 2011). Swami and Chandra (1988) developed empirical models that predict the wind pressure coefficient Cp. Studies have done wind tunnel tests and presented surface-averaged wind pressure coefficient (Chiu and Etheridge, 2004; Ernest et al., 1992; Goubran et al., 2017; Muehleisen and Patrizi, 2013). These results and models have been implemented in building energy simulation programs such as EnergyPlus and ESP-r (EnergyPlus Engineering Reference, 2018; ESP-r Manuel, 2018). Also, many models have been developed to predict infiltration rates. They include single zone models such as LBL model and AIM-2 model (Walker and Wilson, 1990) as well as multi-zone models such as COMIS and CONTAM (Dols and Polidoro, 2015; Feustel, 1998).

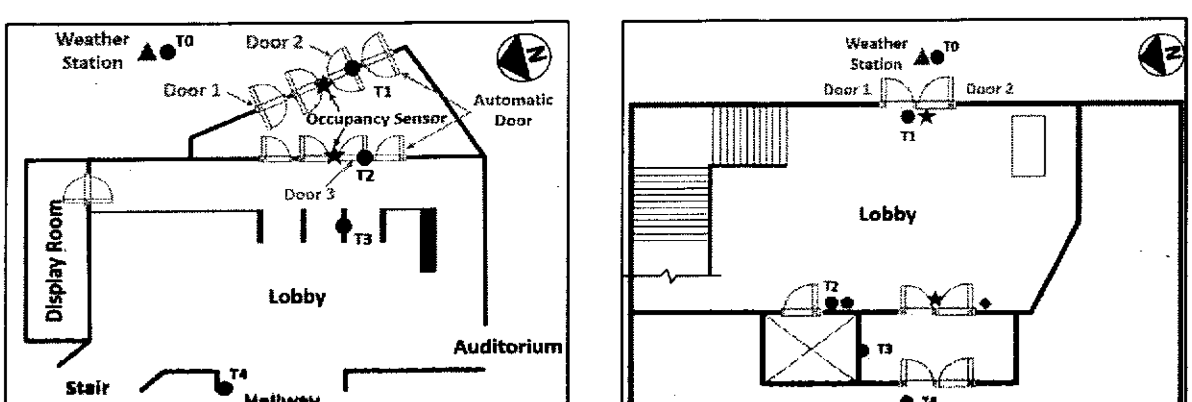
The majority of the previous works focused on natural ventilation and infiltration rates through openings and cracks on building envelope as discussed above. Airflow through building entrance doors have been relatively less studied while it involves considerable energy losses (Cho et al., 2010; Yuill et al., 2000; Han et al., 2015). Yuill et al. (2000) investigated infiltration rates through automatic doors and developed an empirical model to estimate infiltration as a function of door usage rate, the differential pressure across doors, and door geometry. Kohri (2001) developed a simulation method to estimate door opening areas and approximated outdoor airflow rates through two different doors in an office building. Cho et al. (2010) estimated the energy saving impact of ASHRAE 90.1 vestibule requirements by using EnergyPlus simulation program. The simulations predicted that vestibules in a strip mall resulted in an average percentage energy saving of 5.61%. Mahajan et al. (2015) proposed a model that predicts airflow rates through automatic doors for low-rise buildings. The results of a case study in a restaurant building showed that double sliding doors with a vestibule were more effective than double swing doors with a vestibule.

Building entrance doors have a great influence on the indoor thermal environment, building energy performance, and the indoor air quality as a large amount of air passes through building entrance doors (Marr et al. 2012, Mahajan et al, 2015, Vatistas et al. 2007, Wallace et al. 2002). Understanding the nature of the unwanted airflow through building entrance doors is very important to mitigate the adverse impact on the indoor thermal environment and energy performance of buildings. The estimation of the airflow through building entrance doors is very complicated as the physical phenomena occur simultaneously as the function of various factors such as the wind, a temperature difference between the inside and outside of a building, a differential pressure across door openings, and the area and frequency of door openings (Cho et al 2010, McGowan 2007, Marr et al. 2012, Mahajan et al, 2015). In general, the heat flows across building entrance doors have been determined based on the infiltration rates estimated by the methods discussed ahead. All the methods involve some degree of uncertainty and the predictions by the methods are typically inaccurate. To that end, accurate quantification of the natural airflow through entrance doors is critical.

METHODS

The estimation of the airflow rates flowing through building entrance doors is very complicated since wind direction and speed vary with time and all the physical phenomena in buildings and their surroundings occur simultaneously. The indoor thermal environment in the lobby area is also a function of many variables. As the existing computational methods are inaccurate as discussed above, I have developed an empirical method that would be the most accurate method. The empirical method that I developed can accurately quantify natural airflow through entrance doors []. It also allows a comprehensive analysis of the indoor thermal environment. I have done several measurements to confirm the validity of the empirical method and it enabled me to accurately calculate the heat loss due to infiltration. As I developed a reliable method, measurements will be performed in two campus buildings, Voorhees and Environmental Buildings, until a large volume of samples are collected.

Various environmental factors will be measured as shown in Figure 1. The wind speed and wind direction in front of entrance doors will be monitored by a weather station since the pressure profile by the wind on the building surfaces is a main driving force for infiltration. The weather station also will monitor the outdoor thermal environment (TO). The indoor thermal environment such as temperature and relative humidity in the breathing zone at multiple points in the vestibule, lobby, and adjacent space will be measured to see temperature gradients from the entrance doors to the inner side of the lobbies (T1 – T4). The introduction of outside air at a significantly different temperature affects air diffusion in the air-conditioning lobby areas. Vertical temperature variations are thus measured on the inner surface of the outer doors and an inner wall (T1 and T4). The frequency and the time of door openings will be monitored to quantify the infiltration rate at the top of the entrance doors (T1 and T2).



a) Voorhees Building **b) Environmental Building**

Figure 1 Plan view of measuring points for temperature in lobby in two campus buildings.

The door area was divided into six sections for pressure and velocity measurements. Both air velocity and differential pressure will be simultaneously measured at the center point of each section from the top-left point (1) to the bottom-right point (6) in order as shown in Figure 1b. Two outer doors and one inner door in Voorhees Building with vestibule and two outer doors in Environmental Building without vestibule will be selected. The dimensions of the inner and outer doors in Voorhees Building in Figure 1 are identical. The outer two doors open to the opposite direction outward and inward as shown in Figure 1a.

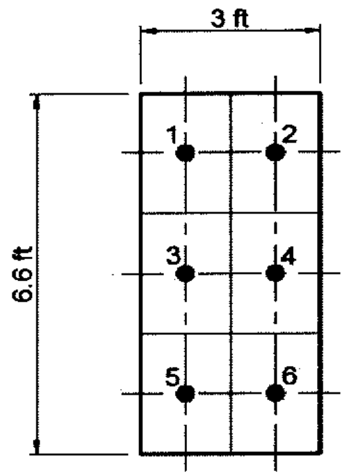


***Figure 2** Measuring points for differential pressure and velocity across the entrance doors*

Table 1 shows the instruments and sensors used for measurement. A HOBO U30 data logger will monitor local wind profiles in front of the entrance doors within approximately 15 feet. HOBO MX2301 temperature/RH data logger will record the outdoor thermal environment. An occupancy-light data logger HOBO UX 90 will collect data for the frequency and time of door openings every second. HOBO U10 temperature data logger will measure indoor air temperatures at the measuring points as indicated in Figure 1. Air velocity and differential pressure across the entrance doors will be manually measured by TSI Alnor Velometer and HOBO T-VER-PXU-L Differential Air Pressure Transducer, respectively. Hobo U 10 temperature sensors will measure the indoor air temperature in the two campus buildings.

***Table 1** Measurement parameters and the specification of the instruments and sensors*

Measurement	Instrument	Interval	Range	Accuracy	Resolution
OA Temp/RH	HOBO MX2301	1 min	-40 - 158°F	±0.36°F	0.072°F
Indoor Temperature	HOBO U10	1 min	-4 - 158°F	±0.95°F	0.25°F
Door Usage	HOBO UX90-6M	1 sec	39.4ft / 102°	-	-
Air Velocity	TSI Alnor Velometer AVM 430	-	0 – 6000fpm	±3%	1 fpm
Differential Pressure	HOBO Differential Pressure Transducer (T-VER-PXU)	-	10 W.C.	±1%	-
Wind Speed	HOBO U30	1 min	0 – 170mph	±4%	1.1mph
Wind Direction	HOBO U30	1 min	0-355°	±5°	1.4°

A differential pressure is measured to determine the direction of air flow. The velocity of the air flow will be measured simultaneously.

The differential pressure across the entrance doors P_{diff} in Pa was determined as follows:

$$P_{diff} = P_h - P_l \tag{1}$$

where P_h is the high-pressure side and P_l is the low-pressure side.

During the measurement of these two parameters, the readings from the instruments were made when the displayed values on the instruments became stable to avoid the impact of the highly inconsistent wind gusts. The measurement was restarted if any of the other doors than the measuring one was opened since the use of other doors causes a significant change in the pressure profile in the vestibule. The volumetric flow rate of the airflow Q in CFM through the entrance doors can be defined as follows:

$$Q = AV \tag{2}$$

where A is the area of the entrance doors in ft^2 and V is the velocity of the airflow in *ft/min*. As from the energy equation, the rate of heat transfer of the airflow $\dot{q}$ in *Btu/hr* is expressed as:

$$\dot{q} = 1.1Q\Delta t \tag{3}$$

where Δt is a temperature difference in °*F*.

SCHOLARLY CONTRIBUTION

The data collected from measurements will be used to validate the existing models. There have been analytical models that predict airflow rates through cracks on building envelopes and large openings such as windows and doors. As energy performance in buildings is becoming an important issue, accurate predictions of such natural airflows through building entrance doors are of importance in building sectors. I developed a new method that can accurately measure such natural airflow rates. I will use the collected data to validate the existing methods that have been used for years. The data will also be used to develop a new analytical model. The findings of this project will significantly improve the accuracy of the prediction.

The developed model can be available to a large volume of scholars in the field. Building energy simulation is being extensively used in evaluating the effects of building components such as building envelope systems, energy systems, and sustainable building technologies during decision-making processes. Building simulation allows solving the complex physical phenomena taking place in buildings and their surroundings. It can model physical phenomena simultaneously taking place in buildings by characterizing properties of building components and ambient environment. Building energy simulations will enable us to examine the impact of unintentional natural airflows on energy performance, indoor environment, and carbon footprint. I will implement the analytical model in a whole building energy simulation program such as EnergyPlus so that numerous end users can utilize the new model in their study.

The findings of the project will assure the necessity of the successive project for the longer-term. The collected data from this project will be enough to testify the validity of the existing methods. The findings will confirm the accuracy of the analytical model that will be developed. I will seek research funding for the successive research projects based on the findings. The buildings sector is the main contributor to the greenhouse effect and the reduction of carbon footprint in buildings is one of the main goals of the US Department of Energy (DOE). As the accurate predictions contribute to energy efficiency in buildings, the proposed project will be a good fit with various funding opportunities such as DOE, NSF, and EPA. The findings of the project will also be published in peer-reviewed scientific journals. The publications will be posted to CUNY Academic Works, expanding the reach of CUNY scholarly contributions.

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