ASTFE American Society of Thermal and Fluids Engineers

5th -6th Thermal and Fluids Engineering Conference (TFEC)
May 26–28, 2021
Virtual Conference

TFEC-2020-32539

EFFECT OF OCCUPANTS ACOUSTIC COMFORT ON ENERGY CONSUMPTION OF BUILDING SYSTEMS

Yong X. Tao, Pratik Sancheti

Cleveland State University, 2121 Euclid Ave, Cleveland, OH 44114, USA

ABSTRACT

This study focuses on the effect of acoustics on human comfort and building energy consumption due to cooling needs. From past studies, it has been known that energy consumption can be reduced by adopting passive building designs such as natural ventilation and operable windows. This will allow free air to circulate and cool the environment naturally, for example, during the part of cooling season when weather is subject to large diurnal temperature variation. However, this type of system may have negative effects in the urban setting where external environmental noises may reach uncomfortable levels. In many large urban centers like Chicago, New York City, Shanghai, Tokyo and Mumbai, medium and high-rise residential buildings and hotels represent significant part of population density. By quantifying the significance of acoustic comfort as part of human comfort in build environments, the benefit or the limitation of passive cooling and the impact to building energy consumption can be better understood.

KEY WORDS: Energy, Human Comfort, Acoustic, Temperature, Noise, Heating, Cooling

INTRODUCTION

In this study the focus is to link the urban noise level to human comfort and resulted building system energy consumption. Recently, more and more emphases were placed on designing and operating sustainable buildings for human wellbeing. For example, the WELL Building Standard [1] was launched in 2014 as the first, systematic attempt to define criteria that measure, certify, and monitor built environment features. Such features impact human health and wellness through air, water, nourishment, light, fitness, comfort, and mind [2]. One of human comfort factors is acoustic comfort. While the impact of acoustic comfort on the human wellbeing is perceived as important, the questions of how to quantify and measure the effects and what is the significance of being acoustically discomfort are difficult to answer [3].

We therefore limit the current scope to the following: First we assume that the acoustic discomfort is due to the urban noise from the outside of building when the windows open. We then define a simple schedule of window opening and closing to count for both the passive cooling needs (outdoor temperature is favorable to open the window) and the outside noise levels (unfavorable noise level to close the window). This study serves as a feasibility case to benchmark the acoustic effects characterized only by the measured sound level (dB data.)

There have been studies about the urban noise survey. One of the comprehensive studies was published by researchers in Taiwan [4]. In that study, the large population in City of Tainan were surveyed and 90% of them reported to have exposed to unacceptable noise levels. A city-wide mapping of dB data was developed to indicate the severity of the urban noise. However, there was large range of variation of sound measurements (dB data) that cannot clearly correlate to the acoustic comfort or discomfort survey data other than the high-level, qualitative conclusion.

*Corresponding Author: y.tao19@csuohio.edu

More investigations are needed to develop meaningful measures of acoustic discomfort that correlate to the human behavior and elements of built environment such as operation schedule for operable windows or doors. In the absence of such model, we focus on the effect of window closing due to urban noise on the energy consumption due to active cooling, which substitutes the otherwise energy-saving passive cooling measure of leaving the window open. The relationship between the sound measurement and human sensation to the acoustic discomfort will be included in the future study.

INTRODUCTION

A small-scale simulation is completed using EnergyPlus, a simulation tool for building energy performance, developed by US Department of Energy, in order to see the feasibility of above stated effect. The location selected for the simulation is Chicago, Illinois, USA (latitude: 41.78^0N, longitude: 87.75^0W). The sample building is chosen from a DOE sample building database and situated near the Chicago's O'Hare airport. Therefore, the weather file is chosen accordingly. According to Pre-Flight Airport Parking, busiest times for the Chicago airport are 6-8 am and 3-5 pm. Due to the lack of actual hourly noise data, we assume that in the busiest time there will be violation of noise norms given by ASHRAE (70dB [5]). As our building is an office building, 3-5 pm will be the time when the ASHRAE noise norms will be violated.

CONSTRUCTION OF BUILDING

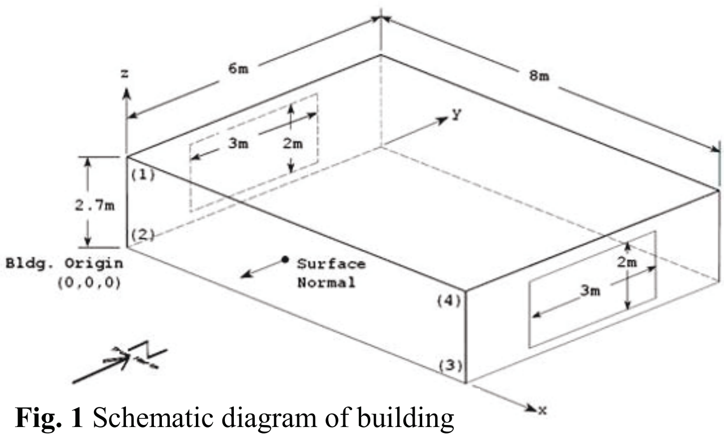

Fig. 1 Schematic diagram of building

The building selected for simulation is Fictional 1 zone building (Fig. 1) with light weight walls and 2 windows. Dimensions of building are 8m x 6m x 2.7m high, long side facing North and South. Windows are located on east and west walls. Setpoint temperature for heater is 20^0C and 24^0C for the cooling season. For the base line cases presented in this study, number of people in building are assigned 0 to focus on the minimum cooling needs of the building.

Table 1 Sample Building Specification

part	walls	floor	roof
dimensions	north and south wall : 8m x 2.7m	8m x 6m	8m x 6m
	east and west wall : 6m x 2.7m		
material	wood siding : outside layer	H5 – C5 – outside layer	roof deck – outside layer
	fiberglass quilt – layer 2		fiberglass quilt – layer 2
	plasterboard – layer 3		plasterboard – layer 3

Type of windows: Double-pane windows. Dimension: 3m x 2m. Window to wall ratio: 0.37

WEATHER PATTERN

Following graphs shows the weather pattern data for Chicago's O'Hare airport. Fig. 2 shows spring – week nearest average temperature for the period. This week is from April 26 to May 2 and is the nearest average week temperature for the whole spring period. Fig. 3 shows summer - week nearest average temperature for the period. This week is from August 24 to August 30 and is the nearest average week temperature for the whole summer period. Fig. 4 shows autumn - week nearest average temperature for the period. This week is from October 27 to November 2 and is the nearest average week temperature for the whole autumn period. Fig. 5 shows winter - week nearest average temperature for the period. This week is from December 22 to December 28 and is the nearest average week temperature for the whole winter period.

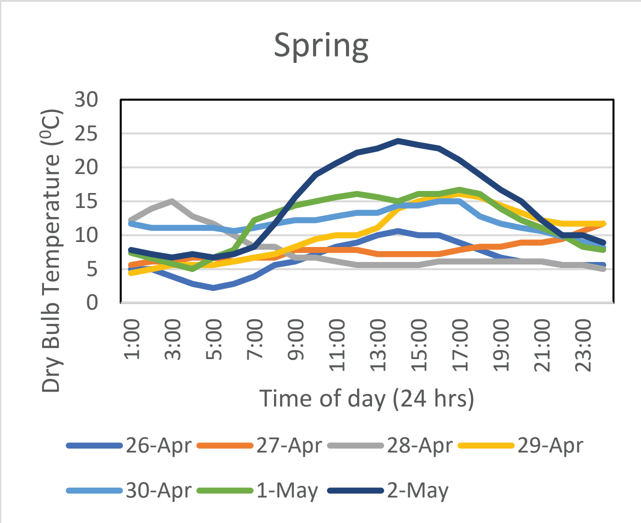

Fig. 2 Daily outdoor temperature in spring

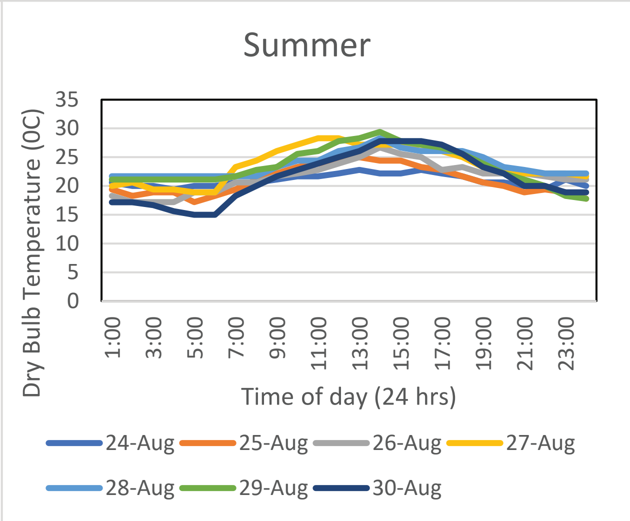

Fig. 3 Daily outdoor temperature in summer

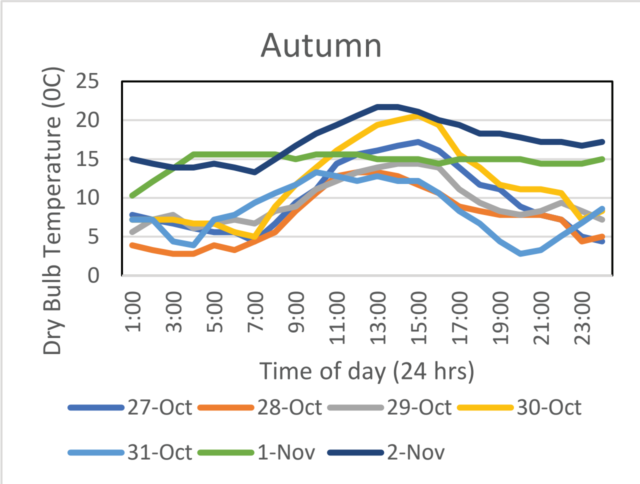

Fig. 4 Daily outdoor temperature in Autumn

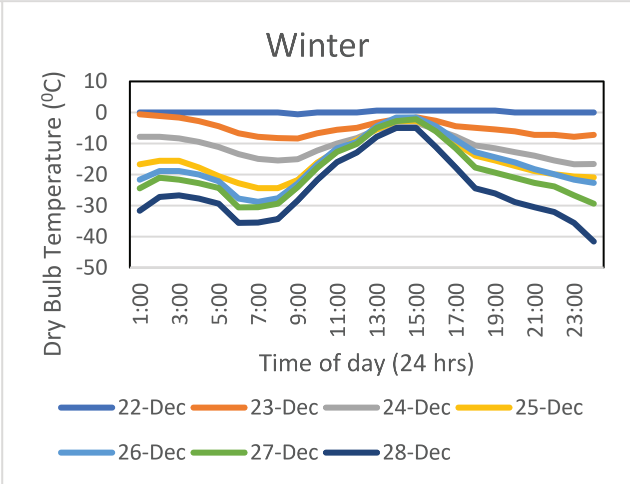

Fig. 5 Daily outdoor temperature in winter

From the above weather data, we can conclude that summer week is best to do the simulation as the temperature ranges from (15^0C – 30^0C) which is suitable for passive ventilation. Window opening schedule runs in the typical office hours from 8 am to 6 pm. Set point temperature for window openings are 24^0C High and 22^0C Low for both, Indoor as well as Outdoor Temperature. These opening temperatures are in accordance with human comfort. Three cases of simulations are considered under the span of different months to have clear visualization of the effect.

1) Simulation without window opening schedule
2) Simulation with window opening schedule
3) Simulation with window opening schedule along with the effect of noise

RESULTS FOR THREE CASES

The simulation results for the three cases are summarized in Table 2.

Table 2 Simulation Results

Month	Case	Total energy intensity (MJ/m^2)	% decrease in energy due to window opening Case 2 vs Case 1	% decrease in energy due to window opening with noise effect Case 3 vs Case 1

April-May (04/14-05/14)	CASE 1	21.87	2.743	2.01
	CASE 2	21.27		
	CASE 3	21.43		
May-June (05/14-06/14)	CASE 1	22.03	13.16	9.078
	CASE 2	19.13		
	CASE 3	20.03		
June-July (06/14-07/14)	CASE 1	24.09	9.42	5.894
	CASE 2	21.82		
	CASE 3	22.67		
July-Aug (07/14-08/14)	CASE 1	29.13	1.06	0.686
	CASE 2	28.82		
	CASE 3	28.93		
Aug-Sept (08/14-09/14)	CASE 1	21.56	20.03	13.358
	CASE 2	17.24		
	CASE 3	18.68		

CONCLUSION

We can see that there is decrease in energy consumption due to passive ventilation but because of noise there is slight increase in energy consumption. From Fig. 6, it is clearly visible that total amount of energy that can be saved due to passive ventilation is affected because of noise. The percentage decrease in energy consumption due to passive ventilation ranges from 2-13% (on an average). This range reduces to 1-9% (on an average) due to noise effect. Hence, we can conclude that noise do have effect on energy consumption and if we can control this factor, around 4-5% (on an average) of energy can be saved.

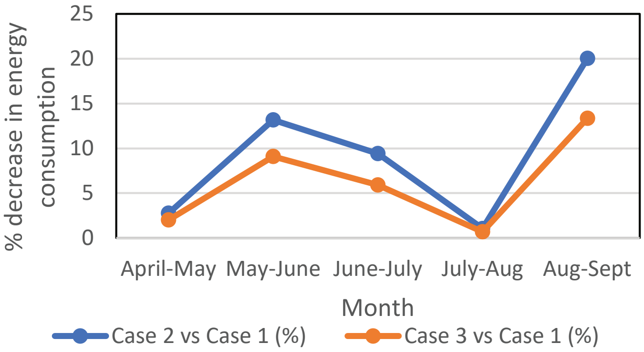

Fig. 6 Month-wide decrease in energy consumption comparison

FUTURE SCOPE

Future study should include data from various urban areas whose population density is higher. Data types include weather, occupancy schedule, indoor and outdoor acoustic levels. The relationship between those data and occupant behaviors in reaction or action to the perceived noise levels such as opening or closing windows or air-intakes needs further development. Goal is for the developed relations and results to be used for annual energy simulation.

Acknowledgement: This material is based upon work supported by the National Science Foundation under Grant No. 1338851/ 1640818).

REFERENCE

[1] "International WELL Building Institute." [Online]. https://www.wellcertified.com/. [Accessed: 26-Apr-2019].

[2] Yong X. Tao, Yimin Zhu, and Ulrike Passe, Modeling and Data Infrastructure for Human-Centric Design and Operation of Sustainable, Healthy Buildings through a Case Study, Building and Environment, accepted (2019)

[3] Nikolaos-Georgios Vardaxis, Delphine Bard, and Kerstin Persson Waye, Review of acoustic comfort evaluation in dwellings—part I: Associations of acoustic field data to subjective responses from building surveys, Building Acoustics, vol. 2, pp. 151-170, 2018. https://doi.org/10.1177/1351010X18762687

[4] Kang-Ting Tsai a, Min-Der Lin b,*, Yen-Hua Chen, Noise mapping in urban environments: A Taiwan study, Applied Acoustics, vol. 70, pp. 964–972 (2009)

[5] ASHRAE Handbook - HVAC Applications, Chapter 49. Noise and Vibration Control, ASHRAE (2019)