Building and Environment 133 (2018) 83–90

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

Indoor temperature, relative humidity and CO_2 levels assessment in academic buildings with different heating, ventilation and air-conditioning systems

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ARTICLE INFO

Keywords:
Indoor air quality
CO_2 concentration
Comfort assessment
HVAC systems
Academic building

ABSTRACT

Indoor air quality (IAQ) is a matter of immense concern for human health as people spend major portion of their lifetime indoor. Keeping in view, this study was aimed to investigate and compare the IAQ and thermal comfort in classrooms of four buildings of an educational institute having different types of heating ventilation and air conditioning system. On-site continuous measurements of indoor levels of CO_2, temperature and relative humidity were recorded at an interval of 1 min for both weekdays, including occupational and non-occupational hours as well as weekends. Simultaneous outdoor temperature and relative humidity measurements were also used in the analysis. Statistical analysis of mean hourly values of each studied classroom showed significant difference ($p < 0.05$) in CO_2 levels over the weekday and also among different buildings. Similarly, variation in hourly mean levels of thermal comfort parameters was also found significant ($p < 0.05$) among the buildings as well as over the weekday. However, variation in hourly mean temperature over weekday for one particular building and all three parameters over weekends for all buildings was not significant ($p > 0.05$). Exceedance in levels of CO_2 from ASHRAE standards was found to be more in buildings with non-centralized systems as compared to buildings with centralized systems during the occupational period. Moreover, thermal comfort parameters were found to be influenced by outdoor climatic conditions and buildings orientation.

1. Introduction

Indoor air quality (IAQ) is strongly controlled by indoor as well as outdoor sources of pollutants requiring proper control measures [1–6]. As human beings spend most of their life time indoor, they are more exposed to indoor air pollutants as compared those in outdoor [5,7–10]. Indoor air pollution has been reported to cause detrimental impacts on human health [3]. Besides, good indoor air quality (IAQ) and thermal comfort has also been linked to increase in productivity, concentration power, performance and well-being of a person [11–13,35]. Concentration of outdoor pollutants affecting IAQ is largely dependent on the type and present condition of ventilation system of buildings. An efficient building ventilation system is essential to maintain IAQ within acceptable limits.

Along with outdoor air pollutants, thermal comfort also contributes in affecting the indoor air quality [3,5,14,15]. Improved living standards demand high thermal comfort which increases energy demand. The demand varies from place to place with changing outdoor environmental conditions and physical features (orientation, building characteristics etc.) of the building [37] and also highly dependent upon occupant behavior [38]. Understanding thermal comfort is an essential factor to be considered while designing and operating a building [38]. Mechanical means of heating and cooling for maintain the environment thermally comfortable is not preferred due to its high energy demand [36] and thus passive techniques are generally preferred [35]. Tightening of buildings, with a focus on achieving energy efficiency, has reduced the IAQ by limiting the use of efficient ventilation system, resulting in harmful effects on human health [2,9,16,17]. Previous research on ventilation system concluded that an efficient ventilation system helps in diluting levels of indoor air pollutants [4,9]. Globally to assess IAQ, CO_2 levels are taken as a surrogate for ventilation quality assessment as CO_2 levels above a certain limit indicate poor ventilation which shows possibility of build-up of higher levels of other pollutants having negative impact on human health [1,7,8,14,15,18]. On the other hand, indoor temperature and relative humidity (RH) levels are taken as comfort indicators [7].

IAQ has been a focus of many researchers in past who investigated IAQ of museums [6,19], residential buildings [2,8,9,18,20], offices

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https://doi.org/10.1016/j.buildenv.2018.01.042
Received 20 August 2017; Received in revised form 21 December 2017; Accepted 30 January 2018
Available online 14 February 2018
0360-1323/

Table 1
Description of studied classrooms.

Building	Room	Floor	Windows	Windows Area (m^2)	Doors	Room Area (m^2)	Construction Year	Occupation[a]	Occupation Period	Sampling Days	Occupation Density (People/m^2)[a]
A	CR1A	Ground Floor	2	3.4 + 3.4	2	76	2005	37 + 20	09:00 a.m.-08:30 p.m.	3 + 2	0.5 + 0.3
	CR2A	Ground Floor	2	3.4 + 3.4	2	76	2005	35 + 25	09:00 a.m.-08:30 p.m.	3 + 1	0.5 + 0.3
	CR3A	1st Floor	2	2.5 + 2.5	2	76	2005	29 + 21	09:00 a.m.-08:30 p.m.	4 + 2	0.4 + 0.3
	CR4A	1st Floor	2	2.5 + 2.5	2	76	2005	30 + 24	09:00 a.m.-08:30 p.m.	2 + 2	0.4 + 0.3
B	CR1B	Ground Floor	2	2.6 + 2.6	2	77	2008	43 + 0	09:00 a.m.-08:30 p.m.	4 + 1	0.6 + 0
	CR2B	Ground Floor	2	2.6 + 2.6	2	86	2008	45 + 23	09:00 a.m.-08:30 p.m.	5 + 1	0.5 + 0.3
	CR3B	1st Floor	2	2.6 + 2.6	2	77	2008	41 + 33	09:00 a.m.-08:30 p.m.	3 + 1	0.5 + 0.4
	CR4B	1st Floor	2	2.6 + 2.6	2	86	2008	42 + 8	09:00 a.m.-08:30 p.m.	4 + 1	0.5 + 0.09
	CR5B	Ground Floor	1	2.8	1	93	2010	40 + 17	09:00 a.m.-08:30 p.m.	3 + 2	0.4 + 0.2
C	CR1C	1st Floor	2	3.5 + 3.5	2	59	2017	34 + 0	09:00 a.m.-05:00 p.m.	4 + 1	0.6 + 0
	CR2C	1st Floor	2	5.2 + 1.7	2	66	2017	30 + 0	09:00 a.m.-05:00 p.m.	4 + 2	0.5 + 0
	CR3C	1st Floor	5	3.5 + 3.5+3.5 + 1.7+1.7	2	61	2017	33 + 0	09:00 a.m.-05:00 p.m.	4 + 2	0.5 + 0
D	CR1D	Ground Floor	3	2.6 + 2.6+2.6	2	107	2010	40 + 0	09:00 a.m.-05:00 p.m.	4 + 1	0.4 + 0
	CR2D	Ground floor	3	2.6 + 2.6+2.6	2	107	2010	47 + 0	09:00 a.m.-05:00 p.m.	3 + 1	0.5 + 0
	CR3D	Ground floor	3	2.6 + 2.6+2.6	2	107	2010	42 + 0	09:00 a.m.-05:00 p.m.	4 + 1	0.4 + 0

[a] (Morning + Evening).

[12], hospitals [4] and schools [1,5,13,21–24]. Educational institutes are the places where students and teachers spend more time as compared to any other indoor environment after homes making them the most important indoor environment to be studied [25,26]. It is expected that academic buildings maintain good thermal comfort and IAQ that contributes towards increase in students' educational performance and minimize health risks [27]. Also learning ability of students is found to be associated with fresh air circulation in the classrooms [22]. In most of the educational institutes, natural ventilation is the only way of fresh air circulation inside the building, thus controlling and maintaining good IAQ is difficult in these buildings [14,23]. Additionally, in classrooms due to high occupation density, ventilation demand increases which makes IAQ and comfort a more important concern [11]. In most of the school environment, ventilation quality is found to be insufficient causing number of health related issues [24,28,29]. Performance and learning abilities of students have been observed to be affected due to high indoor CO_2 levels [17,24,30,31] as short-term and long term health problems associated with poor IAQ result in decrease in productivity of students and staff [5]. These high levels of CO_2 can be associated with poor building design and absence/insufficient use of ventilation provisions or occupation density higher than that considered while ventilation system design phase [30]. In Representatives of European Heating and Ventilating Associations (REHVA) Guidebook 13 limiting value for CO_2 level is 1500 ppm [32] while according to American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) standards 62.1–2016 limiting value during occupational period is 700 ppm above outdoor CO_2 levels (300–500 ppm) [33].

Multiple research studies have been conducted previously probing the IAQ and thermal comfort of educational buildings, taking CO_2 concentration as an IAQ surrogate. However, focus of those studies was kindergartens [14], pre-schools [25], day care centers [10,15], nurseries [11], primary schools [26], elementary schools [28,29], and very few investigated university buildings [27]. Most of them neglected the difference in IAQ of occupational period of buildings with non-occupational period by monitoring only during working hours [29]. Similarly, majority of the studied classrooms found in literature were naturally ventilated in which maintaining a target indoor CO_2 level is difficult as compared to mechanically ventilated ones. Mechanical ventilation is reported to reduce the average levels of indoor CO_2 by 4% as compared to that of natural ventilation which proves natural ventilation a less efficient system and not reliable for maintaining good IAQ [8]. Up to the authors knowledge, none of these studies have discussed IAQ and comfort parameters of buildings with different types of heating, ventilation and air conditioning (HVAC) systems.

The objective of this study is to analyze the impact of different HVAC systems on building IAQ (in terms of CO_2) level and thermal comfort indicators. Authors present the analysis of IAQ data monitored in three different types of buildings with respect to HVAC system; building A, with natural ventilation and no air conditioning, building B with natural ventilation and local air conditioning (split unit) system and building C & D with centralized HVAC systems. The data was monitored for both occupational and non-occupational hours. Comparative analysis of both CO_2 concentrations and comfort parameters in the buildings with respect to guidelines and relevant standards is presented accordingly. The dataset and the analysis will add to the readers' understanding of relationship of HVAC systems with IAQ and thermal comfort of buildings.

2. Methodology

2.1. Description of measurement sites

This study conducted an assessment of indoor air quality and comfort parameters of a semi-government university of Islamabad, Pakistan (33.73° N, 73.09° E) founded in 1991. Long term climatic