Building and Environment 84 (2015) 181–188

Contents lists available at ScienceDirect

Building and Environment

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

A comparison of student performance between conditioned and naturally ventilated classrooms

Asit Kumar Mishra*, Maddali Ramgopal

Department of Mechanical Engineering, Indian Institute of Technology Kharagpur, 721302, India

ARTICLE INFO

Article history:
Received 9 September 2014
Received in revised form
5 November 2014
Accepted 9 November 2014
Available online 17 November 2014

Keywords:
Adaptive thermal comfort
Classrooms
Natural ventilation
Student performance

ABSTRACT

This study presents a comparison of classroom learning performance between courses taught in naturally ventilated (NV) rooms and air-conditioned (AC) rooms. This is done to examine effect of thermal comfort standard followed — PMV based or adaptive thermal comfort — on learning. The same group of students, attending different courses in the two classroom types over two years, was chosen to avoid inter-student difference of aptitude and ability. Performance was measured on basis of final grades scored in the particular courses. Data from a set of transverse thermal comfort surveys was used to find levels of satisfaction prevalent amongst students about their thermal environment in the two room types. Statistical tests were carried out to do pair wise comparisons of the performance of students. Comparison results did not show significant difference in performance for the courses considered. It is concluded that ability and avenues to adapt may help maintain long term average performance over a range of thermal environments.

1. Introduction

It is rather obvious that indoor environment would affect occupants' physiology. Along the same lines, several studies and meta-analysis of studies confirm the important role indoor environmental quality (IEQ) plays in performance and productivity of occupants [1–4]. With introduction of the alternative, adaptive comfort approach into ASHRAE Standard 55 [5], a major turn of philosophy regarding thermal comfort in indoor environment began. The adaptive comfort standard was based upon the results from several field studies on thermal comfort. Since introduction of these standards, many more fields studies have been conducted whose results support the conclusions presented by the standard i.e., occupants in NV buildings are comfortable and satisfied over a wider range of temperatures than occupants in AC buildings. Studies done across India have also shown this for Indian climatic conditions [6–11]. However, how this alternate comfort standard affects performance of occupants has not yet been studied in detail.

A study on this aspect, for office buildings, has been reported by Toftum et al. [12]. They used a Bayesian Network approach to simulate and compare occupant performance between buildings using PMV model for thermal comfort and buildings using the adaptive model of thermal comfort. Their results showed that the indoor temperatures varied considerably between the two building configurations — especially for the building simulated in tropical climate — but the simulated performance did not differ much. Maximum decrement in estimated performance was found to be only 0.8%. One important factor contributing to these results could have been that their simulation used different thermal sensation distributions, as appropriate for indoors using PMV and adaptive comfort standard. Toftum et al. concluded that using the adaptive comfort model can result in considerable energy savings without having a significant effect on productivity.

To the best of our knowledge, any other such comparison, of performance between buildings adhering to two thermal comfort standards, has not been reported and specifically, none has been reported for educational buildings. Hence, the current study was designed to look at performance of undergraduate students in courses taught in AC and NV classrooms. The study compares grades secured in such courses to find out if any statistically significant difference can be found between performance in the two classroom types.

2. A brief review of previous works

While there are a few studies focusing on such aspects of IEQ as lighting, noise, odour, and wall colour, researchers have mainly

* Corresponding author.
E-mail addresses: asit.mishra@mech.iitkgp.ernet.in (A.K. Mishra), ramg@mech.iitkgp.ernet.in (M. Ramgopal).

http://dx.doi.org/10.1016/j.buildenv.2014.11.008
0360-1323/

focused on two aspects of indoor environment: ventilation and thermal environment. As the current study is about performance in buildings with different thermal comfort standards, we pay more attention to the studies dealing with thermal environment's effect on performance while only summarily discussing ventilation.

2.1. Effect of ventilation

Ventilation is an important aspect of indoor environment and studies show that improving ventilation rates improves performance both in office [13–15] and classroom [16] environments. Further, low ventilation rates in classrooms have also been associated with lowered attention, ability to concentrate [17], and increases absenteeism from class [18]. The work by Haverinen-Shaughnessy et al. [19] is among the few that relate IEQ to long term performance — in terms of scores in national standardized tests — and not with performance in simulated classroom tasks. Their work also shows a significant positive association between ventilation rates in classrooms and academic performance of students.

2.2. Effect of thermal environment

Fisk and Rosenfeld [20] mention of an early study by the New York State Commission on Ventilation, during 1923, which found a significant relation between performance of manual tasks and air temperature but no such correlation for mental work. A later reanalysis of a portion of the Commission's data refuted the earlier finding [21]. Hancock et al. [22] in their meta-analysis, conclude that thermal stress, caused by either of heat or cold, has a significant depreciative effect on performance. Their analysis showed that both types of thermal stressors have similar magnitude of impact on performance. Ngarmpornprasert and Koetsinchai [23], in a study of productivity of office workers, concluded that optimal productivity can be achieved by air-conditioning set points at 26–28 °C during morning and at 24.5–26 °C for the afternoon and evening hours. There are some studies done for offices [13,21,24] and one for classrooms [16] in all of which, an optimal temperature for performance has been found around 21 °C. One must however keep in mind that these studies were in conditioned buildings and occupant control over thermal conditions was all but absent.

Mendell and Heath [1] discuss of the work done by Wittersech and his group where performance of office workers did not change with increasing temperature but participants rated their own performance at lower levels. They also made mention of the work done by Pepler and Warner with school students wherein it was found that as temperature rose from 16.7 to 26.7 °C, work speed decreased by 7% and errors also decreased by 17%. As the temperature further increased from 26.7 °C to 33.3 °C, work speed and error rates both increased [20]. Other studies investigating influence of thermal environment on work speed have shown a significant improvement in work speed when room temperatures were lowered, though error rate in simulated tasks was not affected [16,25,26]. Along similar lines is the finding by Lan et al. [27] that thermal discomfort had a greater impact on speed than on accuracy.

2.2.1. Role of task nature

In a typical office or classroom environment, occupants are engaged in a broad range of mental activities. It stands to reason that since different types of activities require different levels of exertion of mental faculties, performance of these activities should be affected to different levels by the indoor environment. Meta-analysis results of Hancock et al. [22] showed that task nature as well as duration and intensity of the stressor have an impact in determining the optimal thermal environment. They put forth that if task types be categorized into perceptual, cognitive, and psychomotor classes, thermal stress has maximum impact on perception, followed by psychomotor response and finally cognition. A similar opinion — regarding nature of task being important in how and how much thermal environments affect performance — has been expressed in some other studies as well [3,20,25]. Fisk and Rosenfeld [20] even state that for a few types of tasks that involve high complexity or creativity, optimal thermal comfort and optimal performance may coincide while for most other task types, a slight thermal discomfort may raise arousal level to improve performance of mental work. A couple of studies also found that time of day can affect optimal environment for productivity [23,25]. Thus, apart from an expected variation due to individual preferences, task nature, duration, and time of execution can influence the optimal thermal environment for productivity. Therefore, greater occupant control over thermal environments has been suggested as an approach for enhancing task efficiency [20].

2.2.2. Importance of subjective occupant satisfaction

Findings in certain studies stress upon the fact that more than the IEQ itself, subjective satisfaction (with temperature, air quality etc.) of the occupants impacts productivity [3,15,28–30]. In the studies by Hoque and Weil [28] and Bell et al. [30], subjective comfort ratings are able to explain 34% and 48% of the variance in test scores, respectively. It is pertinent in this case to mention that the study by Hoque and Weil [28] found a significant relation between discomfort votes and score but only a weak correlation between the actual air temperature and comfort votes.

2.3. Occupant adaptation and performance level

As of this date, numerous thermal comfort field studies provide evidence of the ability of occupants to adapt across a broad range of thermal conditions when they are provided with adaptive opportunities. It should be interesting to review here how behavioural or psychological adaptations may aid task performance. Any environmental stress, thermal or otherwise, would require occupants to cope by exerting additional mental faculties [22]. Over certain ranges of thermal stressors (temperatures) and task durations, this kind of conscious additional effort can overcome the negative impacts of thermal stress on performance [3,25]. As also observed by Wyon et al. [3], among the different tasks given to subjects, such activities where the subjects had ample practice were not affected by moderate heat stress.

As far as behavioural adaptations go, Mendell and Heath [1], in their review of studies on thermal conditions and student performance, discuss of two studies where performance was not affected with varying temperature because either subjects had an ability to fine tune temperature to their own liking or they could adjust clothing to stay thermally neutral. A similar effect was observed by Wyon [21] in the study of heat stress effect on typewriting. Subjects rated two temperatures, 4 K apart, as being equally comfortable even though they had no option to adjust clothing. Wyon suggests that subjects adapted to the increased temperature by working slower (as observed from performance data) and thus maintaining thermal comfort level.

Hancock et al. [22] present a perceptive analysis of such observations. Instead of the traditional “inverted U” model for associating stress and performance, they advocate the use of an “extended” U model. In the extended U model, there is no single point of optimal performance but an extended plateau over which performance keeps stable. Over this region, stress is tolerable because of compensatory measures — psychological or behavioural in nature. Beyond a certain point, ‘adaptive’ measures are unable to