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Constructing thermal comfort: Investigating the effect of vegetation on indoor thermal comfort through a four season thermal comfort quasi-experiment

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ABSTRACT

Several short term studies have found evidence that plants may improve occupant thermal comfort, yet this phenomena has not yet been rigorously evaluated. The aim of this paper is to present the results of a quasi-experiment that evaluated the effect of indoor plants on the thermal comfort of 67 office workers within an office building in De Lier, The Netherlands, for four months, one month each season, in 2013.

The participants' thermal comfort was recorded twice a day, while the globe temperature, relative humidity, and light levels of the workspaces were monitored. The indoor operative temperature of the test rooms were varied between typical and more extreme indoor operative temperature ranges throughout the quasi-experiment in a controlled manner.

The presence of a substantial quantity of plants in the work environment was found to have a significant effect on the thermal comfort of the participants. For example, the occupants of the two rooms in which the presence of plants was alternated, were both, on average, approximately 12.0% more thermally comfortable when plants were present in the room. In addition, they were approximately 1.79 and 1.95 times more likely to be thermally comfortable when plants were present in the room, respectively.

These results indicate that the incorporation of a substantial quantity of plants in office buildings can lead to reduced building energy consumption and carbon emission rates, by allowing the temperature setpoint to be raised in the summer and lowered in the winter.

1. Introduction

Numerous research studies have found that plants have a positive impact on people in respect to a diverse range of performance categories. For instance, the presence of attractive vegetation has been found to improve people's general perception of the quality and value of building environments. Plants also have been found to improve people's perception of specific qualities of the indoor environment, such as how relaxing, stressful, noisy, beautiful, and interesting the space is perceived to be [1–6]. The stress levels, creativity, and productivity rates of office workers have been found to be improved by plants, as well as occupant satisfaction with indoor air quality, glare, light levels, and perceived and physiological overall comfort [2,5,7–13]. However, the effects of plants on occupant thermal comfort have not yet been evaluated in detail.

Several researchers have measured the short term effects of plants on occupant thermal comfort. In one of the more extensive experiments, 30 office workers completed a Subjective Assessment of workplace Productivity (SAP) questionnaire at the end of each workday for two weeks: one week with plants, and one week without plants [7]. This questionnaire included a six point scale to measure occupant thermal comfort. The participants' thermal comfort was found to improve when plants were present in the workplace, although the scale of the effect of plants on thermal comfort was not quantified. However, the majority of existing literature, as well as thermal comfort experiment standards such as the International Standard 10551, use a standardized seven point ASHRAE or Bedford Thermal Comfort Vote scale to evaluate occupant thermal comfort [14,15]. Moreover, a seven point thermal comfort vote scale, as well as a three point occupant thermal preference vote scale, such as the McIntyre thermal preference

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scale, have been found to be necessary in accurately assessing occupant thermal comfort by a number of researchers [15–18]. Furthermore, Matsumoto (2012) did not take into account the potential influence of a variety of influential environment parameters, such as internal and external temperatures, relative humidity, seasons, gender, clothing insulation values, metabolism rates, sunlight, and the short term and long term effect of plants on people [7].

In a separate study, Mangone et al. (2013) evaluated the thermal comfort of 16 office workers for one month: two weeks without plants and two weeks with plants [19]. The participants' thermal comfort was measured with the seven point ASHRAE Thermal Comfort Vote and McIntyre thermal preference scale measures. The presence of plants was found to improve occupant thermal comfort by 19.0–25.0% at typical indoor operative temperature ranges (approximately 22.0 °C). At more extreme operative temperatures, the presence of plants was found to improve occupant thermal comfort by at least 35.7%. However, this experiment did not evaluate the effect of potentially influential environmental variables on the participants' thermal comfort, such as possible long term psychological effects of plants, the effect of various seasons, and the influence of plants on different genders. Furthermore, the data analysis in this experiment relied primarily on descriptive analysis, rather than statistical analysis. This limited the ability of the researchers to adequately assess the potential influence of the various measured environmental variables [19]. Thus, further research is necessary to evaluate the potential influence of plants on thermal comfort.

It is important to note that individual thermal comfort has been found to be due, in part, to the influence of psychological parameters. Research indicates that quantifiable, physiological parameters can only account for approximately 50% of the variation between subjective and objective comfort evaluations. This means that up to 50% of people's thermal comfort may be due to the influence of psychological parameters [20]. For instance, occupants' perceived sense of control over their thermal environment has been identified as a key factor for determining one's thermal comfort when inside a building [21,22]. Occupants' perceived sense of control is used in building thermal comfort standards' as one of the most important factors that determine if a more adaptive thermal comfort model, which requires less energy use, than the more restrictive and typical predictive mean vote (PMV) and predicted percentage dissatisfied (PPD) models, can be used for the design and specification of a building's climate system [21,23]. Moreover, outdoor thermal comfort models that do not take into account psychological factors have been found to be inadequate for predicting outdoor thermal comfort [24]. In addition, one of the primary reasons for people's outdoor thermal comfort range being wider than their indoor thermal comfort range has been hypothesized to be due to the fact that people assume that the outdoor thermal microclimate cannot be controlled through architectural design or mechanical control, and thus they perceive a broader range of conditions as 'acceptable' in regards to climate [20]. In addition, the results of a large scale survey of buildings in the UK found a correlation of 0.7 between temperature and comfort vote [25]. This is quite high in relation to other surveys where the indoor temperature does not vary too much. This correlation value indicates that 49% of the variation in comfort is due to temperature, which suggests that more than the physical parameters of an environment influence comfort [15]. Furthermore, short term thermal comfort has been found to be affected by people's emotions. For instance, people who feel lonely tend to feel thermally colder [26]. People that have come into contact with someone that feels 'creepy' have been found to feel that the temperature in the room has become colder [27]. These findings indicate that plants can affect people's thermal comfort in several ways. Plants can function as figurative cues, wherein they remind building occupants of outdoor environments, and in doing so, people's thermal comfort range broadens, as if they were outside. Plants can also function as figurative cues in the sense that in the winter, green, living plants might cause people to feel like they are in a warmer environment than they really are, thereby increasing their thermal comfort. In the summer, plants may remind occupants of the cooling effects that a vegetation canopy's shade provides, particularly if there is overhead vegetation. Furthermore, since plants have a positive effect on people's valuation of a space, as previously discussed, then this positive effect of plants may have a larger influence on people's sense of thermal comfort than the negative effect of uncomfortable temperatures. To this end, researchers have found that the presence of plants reduces the negative effects of visual glare and low light levels on office workers [9].

An in depth analysis of the effect of plants on thermal comfort therefore may lead to the use of plants to improve occupant thermal comfort and broaden the thermal comfort range of building occupants, thereby reducing the energy demands of the building and improving occupant thermal comfort. In addition, the productivity of office workers has previously been found to be diminished when they feel uncomfortably hot [13,28,29]. Thus, if plants are found to improve occupant thermal comfort, they may also mitigate the negative effects of uncomfortable temperatures on worker productivity in the process. This paper describes a yearlong field study that investigated the short term, long term, and seasonal effects of plants on occupant thermal comfort.

2. Methodology

2.1. Quasi-experiment overview

The effect of plants on occupant thermal comfort was investigated through the development of a quasi-experiment that began in January 2013 and was completed in October 2013. The quasi-experiment took place in an office building in De Lier, The Netherlands. A pilot study was conducted in November 2012 with the participants in one of the test rooms, E1, in order to ensure the effectiveness of the experiment. In general, plants were found to increase the thermal comfort of the participants by approximately 19.0–25.0% in typical indoor operative temperatures. The methodology and results of the pilot study were reported in Mangone (2013) [19].

2.2. Experiment methodology design and limitations

Since experiments typically take place in a laboratory environment, they are commonly critiqued, and avoided, by organizational psychologists [30]. This is because the results obtained from laboratory experiments typically are not able to be generalized and applied to real world office environments and employees [31]. For example, a review of existing behavioral research found that students are used in the majority of laboratory experiments, and an analysis of thirty-two published experiments found that the results of laboratory experiments are generally affected by the type of experimental subject, with a number of authors concluding that students were insupportable substitutes for nonstudents [31]. Laboratory experiments are further criticized as having a lack of external validity, because in many cases the research seems to evaluate the ability of the experimenter to produce conditions in the laboratory test environment that show that a clearly true hypothesis is, in fact, true [32].

An alternative to laboratory experiments are field experiments, which avoid the external validity issues by conducting experiments