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Energy efficiency and user comfort in the workplace:

Norwegian cellular vs. British open plan workplaces

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Abstract

Two office layouts with high and low levels of thermal control were compared, respectively Norwegian cellular and British open plan offices. The Norwegian practice provided every user with control over a window, blinds, door, and the ability to adjust heating and cooling. Occupants were expected to control their thermal environment to find their own comfort, while air conditioning was operating in the background to ensure the indoor air quality. In contrast, in the British office, limited thermal control was provided through openable windows and blinds only for occupants seated around the perimeter of the building. Centrally operated displacement ventilation was the main thermal control system. Users' perception of thermal environment was recorded through survey questionnaires, empirical building performance through environmental measurements and thermal control through semi-structured interviews. The Norwegian office had 35% higher user satisfaction and 20% higher user comfort compared to the British open plan office. However, the energy consumption in the British practice was within the benchmark and much lower than the Norwegian office. Overall, a balance between thermal comfort and energy efficiency is required, as either extreme poses difficulties for the other.

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Keywords: Thermal comfort; energy; indiviual control; workplace; cellular plan; open plan office

1. Introduction

The history of the workplace shows users' demand to control their thermal environment [1]. Nevertheless, the twenty-first century climate and economic challenges as well as organisational changes and new ways of working drive the office design further away from user control. The cellular plan offices in Scandinavia are being replaced by open plan offices [2,3] and user control by centrally operated

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thermal systems [4,5]. There is a contradiction in predicting the necessity of providing user control over the thermal environment in the future, as Leaman and Bordass (2005) recognised it as an essential asset [6], while Harris (2006) claimed that it is unnecessary, due to flexible ways of working and unnecessary application of assigned workstations [7]. This work compares the energy consumption and users' view of individual thermal control over the thermal environment in two offices that provide high and low levels of thermal control, the Norwegian cellular and the British open plan offices, respectively.

2. Previous related work

The comfort literature indicates that the application of thermal control increases user comfort and satisfaction [4,8-13] in the workplace. After the 1960s, Northern Europe and Anglo-Saxon countries followed two separate paths in designing offices: user-oriented and business-oriented, respectively. The significant difference is highlighted in 'the quality of the working environment between the Anglo-Saxon developer-based offices and custom-built Northern European offices' [14]. Albeit that employees demanded the same rights in both places, in the 1970s, the Workers' Council in Northern Europe succeeded in protecting the rights of workers, including access to thermal control, natural light and ventilation, while the movement was unsuccessful in the UK [1]. Thus, Scandinavian offices were designed according to users' demands and workers' rights. Therefore the traditional cellular plan office was reintroduced with individual control over the thermal environment, lighting and an outside view [1]. Individual environmental control is highly valued in the Norwegian regulations, while hardly mentioned in the British legislation [15,16]. The open plan layout was commonly designed in the UK, as they conveniently accommodated technological advances [17], flexible communication [18], organisational changes [14,19,20], and work and economic efficiency [21,22]. Although organisations gained from the open plan layout, the individuals did not benefit much [1], particularly distractions [23] and lack of individual climate control was a disadvantage [14]. The open plan layout is 'more generic and less responsive to individual control' [24]. Overall, the context of the two countries [25] and the impact of Works' Council and work regulations influenced their design of the workplace and environmental control [1]. In this study, energy performance and user comfort and satisfaction in two case study buildings in Norway and the UK were compared. The buildings were built within the last ten years and followed the work regulations and particular office layouts of these two countries.

3. Methodologies

Complimentary quantitative and qualitative methodologies were applied with a particular emphasis on grounded theory. A cellular plan office in Oslo was compared with an open plan office in Aberdeen for a period of a week per building during the summer 2012. In the Norwegian office, every individual was provided with control over an openable window, blinds, door and thermostat, while air conditioning was operating in the background to ensure a standard level of indoor air quality. In contrast, in the British office, displacement ventilation was the main thermal system and limited openable windows and blinds provided control for occupants seated around the perimeter of the building. Majority of the occupants seated further from the windows did not have access to any means of thermal control. Ninety five responses in the Norwegian practice and sixty nine responses in the British practice with a balance of age and gender were considered in this study. Environmental measurements were applied to evaluate the building performance and compare it to the standards and benchmarks. Simultaneous survey questionnaires were applied at each workstation to record the comfort and satisfaction of users using the ASHRAE seven-point scale [26]. A PCE-GA 70 air quality meter and the Tiny Tag Plus 2 TGP-4500 were used to record the dry bulb temperature (0.01oC and 0.1oC accuracy, respectively), relative

humidity (±3% RH accuracy, both of the instruments) and carbon dioxide level (up to 6000ppm, 1ppm resolution and ±50 ppm accuracy). The mean radiant temperature was calculated using surface measurements of the temperature and the ASHRAE Thermal Comfort Tool 2 [27]. Empirical regression analysis was applied to analyse the collected data.

4. Analysis

4.1. Building performance

The comparison of the carbon dioxide level to the ASHRAE [28] indicated acceptable indoor air qualities in the two buildings, below 600 ppm. The Norwegian practice had lower carbon dioxide level compared to the British practice. Thermal comfort of the workstations in the two buildings was similar and within the acceptable range of the ASHRAE Standard 55-2013 [29]. However, the thermal environment of both of the buildings was within the winter comfort zone rather than the summer zone, as presented in Fig 1.

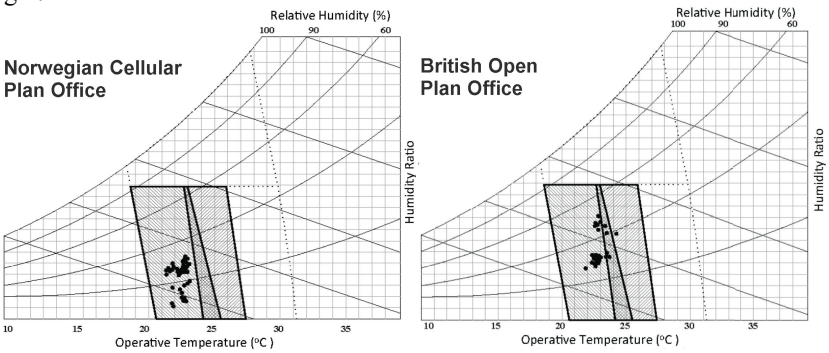

Fig 1. Comparing the thermal conditions of the two buildings in accordance with the ASHRAE Standard 55-2013 [29]

The energy performance of the buildings was calculated using the information received by the management of the two buildings and the comparison of them against the CIBSE benchmark [30] showed that the British practice had a much lower energy use within the acceptable range. In contrast, the energy consumption of the Norwegian practice exceeded the range and it was eight times more than the British practice, as presented in Fig 2.

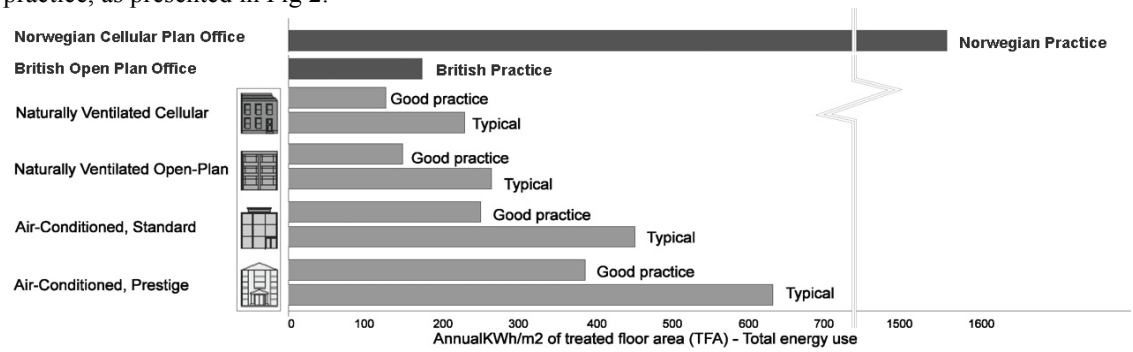

Fig 2. Comparing the energy performance in accordance with the CIBSE [30]

High energy consumption in the Norwegian practice was mainly due to contradictory thermal systems, which were operating at the same time: air conditioning, openable window and radiator, as presented in Fig 3. The air conditioning was centrally controlled. So in order to provide temperature control for the user, the radiator was running at the same time in case the occupant preferred a warmer condition that was offered by the air conditioning system. The openable window allowed extra control for the user. The operation of these three systems resulted in much higher energy use in the Norwegian practice. In contrast, the main source of fresh air and temperature control in the British practice was the displacement ventilation and the few openable windows were hardly used.

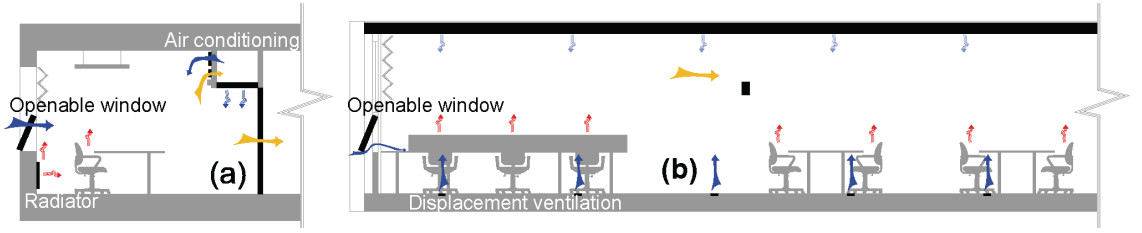

Fig 3. Thermal control systems in (a) the Norwegian and (b) the British offices

4.2. Users' view

Comfort and satisfaction of users based on the survey questionnaires in the two buildings were compared, as presented in Fig 4. Occupants of the Norwegian cellular plan office had higher comfort and satisfaction levels compared to the respondents of the British open plan office.

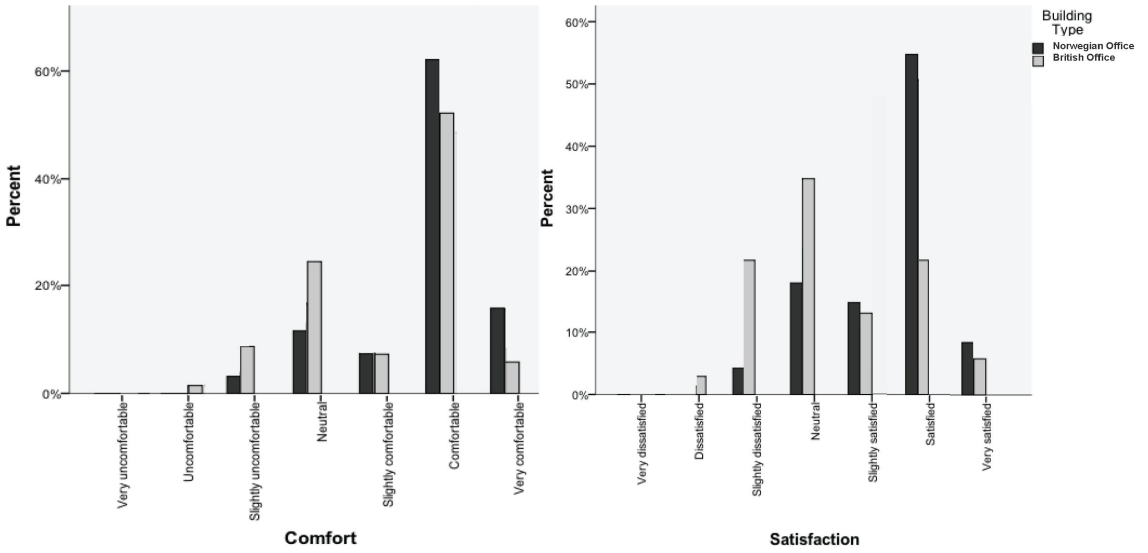

Fig 4. Comparing comfort and satisfaction of users in the two buildings

This research investigated high levels of user satisfaction and comfort therefore only 'satisfied' and 'very satisfied' responses, which represented a comfort status with confidence, were considered as a

'satisfied' response. The same instruction was applied to analyse the comfort level of users, as only 'comfortable' and 'very comfortable' responses were considered as a 'comfortable' status. Accordingly comfort and satisfaction of users in the two buildings were compared, as presented in Table 1. Users of the Norwegian cellular plan office had 20% higher comfort and 35% higher satisfaction levels compared to respondents of the British open plan office.

Table 1: User comfort and satisfaction in the two buildings

Buildings	Percentage of comfortable respondents	Percentage of satisfied respondents
Norwegian cellular plan office	78%	63%
British open plan office	58%	28%

Semi-structured interviews indicated that occupants of the Norwegian office were satisfied with the availability of thermal control in their personal office and applied it regularly. In contrast, respondents of the British practice complained about the lack of thermal control system in their workstation and explained that they had no other choice but to tolerate the conditions when feeling uncomfortable regarding the thermal environment.

5. Discussion and conclusion

The results confirmed other research indicating that thermal control increases user comfort and satisfaction [4,8-13]. The Norwegian cellular plan office provided higher levels of control over the thermal environment compared to the British open plan office, which provided limited thermal control for a small number of occupants. Therefore occupants of the Norwegian office had 20% higher comfort and 35% higher satisfaction level compared to the participants of the British office. The follow up interviews confirmed that availability of thermal control was the main reason for this difference in user comfort and satisfaction. The Norwegian context respected individual differences in perceiving the thermal environment and, therefore, the office layout was designed accordingly. The availability of thermal control for every individual occupant in the Norwegian practice was due to the context, workers' rights and regulations in Norway [1]. However, providing thermal control for individuals in this study came at a price, as the energy consumption was much higher in the Norwegian practice. A balance between user comfort and energy efficiency is required, as either extreme poses difficulties for the other. Therefore further research on cellular plan offices with passive systems, such as projects by Behnisch and Sauerbruch Hutton architects or the application of individual control in the open plan layout, such as the Personal Control System (PCS), is recommended.

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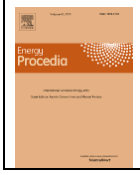

Biography

Sally is a Research Fellow in Civil Engineering at the University of Leeds. Her PhD was in Architecture at the University of Edinburgh. She was a tutor in environmental design, co-editor of the EAR Journal and organiser of the Prokalo seminars. She received the Edinburgh Award in 2012 and 2013.