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SIGNIFICANCE OF CONTROLS FOR ACHIEVING THERMAL COMFORT IN NATURALLY VENTILATED BUILDINGS

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ABSTRACT

During a field study of the thermal comfort of workers in natural ventilated office buildings in Oxford and Aberdeen, UK, were carried out which included information about use of building controls. The data was analysed to explore the effect the outdoor temperature has on the indoor temperature and how this is effected by occupants' use of environmental controls during the peak summer (June, July and August).. The proportion of subjects using a control was related to indoor and outdoor temperatures to demonstrate the size of the effect. The results suggest that the use of controls is also related to thermal sensation and their appropriate use is a significant part of adaptive behaviour to modify the indoor thermal conditions.

KEYWORDS

Buildings, thermal comfort, natural ventilation, energy, controls, indoor temperature, outdoor climate.

INTRODUCTION

The ability of building occupants to control their internal environment is usually available. The importance of control in reducing the need for high-energy solutions has become increasingly clear [Leaman & Bordass 1997, Baker and Standeven 1995]. In natural ventilated buildings, greater control over thermal environment and ventilation could be obtained by using common means of control.

Longitudinal and transverse surveys were carried out during a field study of the thermal comfort of workers in natural ventilated office buildings in Oxford and Aberdeen, UK. The surveys were spread over a period of one year. Openable windows and blinds are available in all buildings. Some individuals also have electric fans. The use of these controls was noted as part of the larger comfort study in buildings. The data was analysed to explore the use of environmental controls during summer.

The analysis shows that the use of controls plays a significant role in modifying the indoor thermal conditions. The proportion of 'open window' increases with the increase in outdoor or indoor temperature. The regression analysis of the each control on outdoor and indoor temperatures was used to demonstrate the size of the effect. Allowing cross ventilation (window and door both open) was found to lower the indoor temperature. The effect of the availability of controls is demonstrated. Occupants closer to the windows reported less discomfort than those away from the windows. Analysis of the change of use of each control was also carried out at different indoor and outdoor instantaneous temperatures and comfort votes. The results of the analysis are presented in this paper.

THE SURVEY.

Thermal comfort field surveys were conducted in Oxford, southern England, and in Aberdeen, on the north-east coast of Scotland, over a period of one year during 1996-97. Fifteen buildings were surveyed, nine in Oxfordshire and six in Aberdeen, 10 buildings natural ventilated and five air-conditioned. The study involved 909 subjects, 219 taking part in both longitudinal as well as transverse surveys, about two thirds of them in naturally ventilated (NV) buildings. Basic information about the NV buildings and number of subjects in them who were involved in the survey is given in Table 1. The buildings were a mix of heavyweight (HW) and lightweight (LW), old and newly constructed, in the private sector and in the public sector.

TABLE 1. Naturally ventilated buildings surveyed with details of the subjects taking part.

Building code	Location	HW/LW (NV only)	Total subjects	Longitudinal subjects	Transverse responses	Longitudinal responses
1	Oxford	HW	66	13	514	4,181
2	Oxford	HW	33	5	196	735
4	Oxford	HW	53	10	402	1,971
6	Oxford	LW	17	5	143	505
7	Oxford	LW	34	9	242	1,263
8	Oxford	LW	22	11	188	1,626
9	Oxford	HW	99	29	761	5,540
11	Aberdeen		83	29	389	4,150
13	Aberdeen	LW	75	23	394	4,255
14	Aberdeen		75	12	349	1,672
Totals			557	146	3578	25,898

Longitudinal Survey.

The longitudinal survey obtained information from the subjects every day allowing assessment of changes in the building's environment and occupants' response to these changes. Each subject was asked to fill a questionnaire three to four times a day recording his thermal sensation and preference, clothing, activity and use of controls. The positions of the subjects relative to doors and windows were also noted. The thermal environment close to each subject was monitored, recording the temperature, at an interval of 15 minutes.

Transverse Survey.

The transverse survey enables assessment of occupants' response to particular environmental conditions in the building with the participation of a larger population. The survey is usually completed in one day. The subjects in each building were visited once a month and a questionnaire was filled for each available subject. The questionnaire carried more details than the one used in longitudinal survey. The additional questions were related to their perception about air movement, humidity, light and noise level. The questionnaires were administered at the respondents' desk with simultaneous recording of the environmental variables. During the interview the questions were presented to subjects on flashcards and the responses recorded by the researcher.

Climatic Data.

The outdoor weather data for Oxford for the period of survey was obtained from the Radcliffe Meteorological Station of Oxford University and from a local meteorological observatory in Aberdeen. The Oxford data was recorded every 15 minutes, the Aberdeen data on an hourly basis. At some buildings outdoor temperature was also recorded locally. However for the analysis, the outdoor temperatures recorded at the Meteorological Stations were used.

INDOOR THERMAL CONDITIONS AND OUTDOOR TEMPERATURE

The influence of the outdoor climate on indoor thermal environment is shown in Table 2 and figure 1. These are constructed using th data for the summer months June, July and August when the buildings will be free-running. In Britain the heating season can extend over seven months of the year, from about October until April. There may be with periods of heating in May and September and occasional breaks in heating in March and November. In this paper we are concerned with the use of controls which do not involve the use of energy, when the building is free-running.

The statistics in the table are calculated from simultaneous indoor and outdoor temperatures for times at which comfort votes were cast. The tabulated results show that indoor and outdoor temperatures are well correlated. The values of the regression slopes suggest that the occupants are controlling the indoor conditions so that the change in indoor temperature is about one third of that outdoors. The use of controls is an important factor in explaining how thermal comfort indoors might be related to outdoor climate. Though the rate of change of indoor temperature with outdoor temperature is consistent between buildings, there is a noticeable difference in the mean indoor temperatures. In Oxford the lightweight buildings 7 and 8 have the highest mean indoor temperatures but building 6 where the controls were fully used is an exception. Indoor temperatures in Aberdeen are not comparable because the mean outdoor temperature at 15.8°C is 4.5K cooler than Oxford.

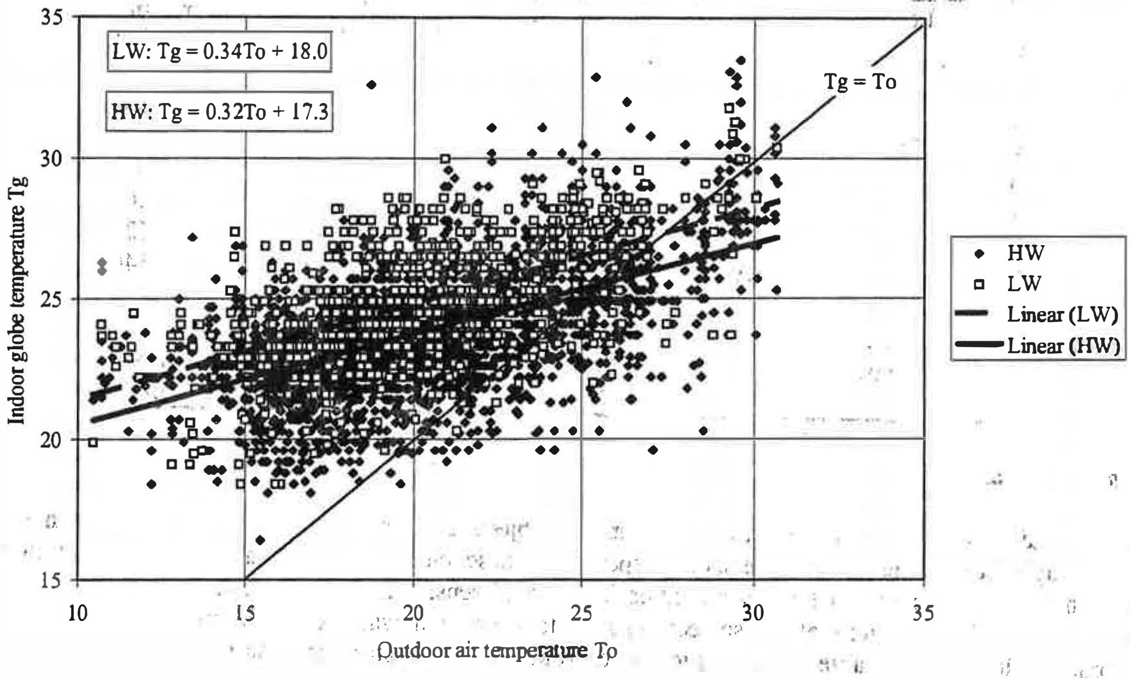

FIGURE 1. Showing the variation of indoor temperature with outdoor temperature for the summer months. The regression lines show that heavyweight (HW) buildings are generally cooler than lightweight (LW) buildings.

TABLE 2: Correlation 'r' and regression slope 'b' between instantaneous indoor temperature T_g and concurrent outdoor temperature T_o in naturally ventilated buildings in summer. Results from the longitudinal and the transverse surveys are shown separately

	Building	1	2	4	6	7	8	9	11	13	14
Long	Correlation (r)	0.63	0.65	0.62	0.59	0.57	0.65	0.59	0.29	0.61	0.41
	Reg. Slope (b)	0.37	0.29	0.30	0.41	0.30	0.35	0.29	0.16	0.41	0.24
	Mean T_g	24.8	24.3	23.8	23.7	25.3	25.3	23.0	23.7	23.4	23.5
Trans	Correlation (r)	0.66	0.16	0.79	0.90	0.63	0.73	0.75	0.42	0.80	0.62
	Reg. Slope (b)	0.45	0.13	0.67	0.84	0.38	0.21	0.42	0.12	0.36	0.48

USE OF CONTROLS.

A separate study [Nicol and Raja 1998] has shown that in NV buildings in summer the proportion of people recording discomfort is strongly correlated with the number of people who use the fans or windows and particularly (r = 0.80) if the two are used together. This implies that the controls are used in response to uncomfortable conditions.

The indoor climate, the outdoor climate or a mixture of the two may drive the use of controls in naturally ventilated buildings [de Dear and Brager 1998, Nicol and Raja 1998]. In naturally ventilated buildings the usual controls available to occupants in summer are doors, openable windows, blinds and curtains, fans and lights. Opening of doors or windows enhances natural ventilation and together these allow cross ventilation and may cool the building if the outdoor temperature is lower than the indoor. Fans provide forced convective cooling. Blinds and curtains reduce direct solar heating and glare.

Frequency of Use.

The use of available controls in various buildings is given in Table 3. The table is constructed with summer data collected from natural ventilated buildings during the longitudinal surveys. If any individual has not used a control over the period under consideration (June – August) it is assumed that no control is available.

TABLE 3: Discomfort and the frequency of the use of available controls in NV buildings during peak summer months.

Building	Discomfort (%)	Doors	Windows	Fans	Fans + windows	Blinds/ Curtains	Lights
1	30	0.59	0.75	0.22	0.97	0.19	0.40
2	11	-	0.81	0.17	0.98	0.86	0.43
4	35	-	0.70	0.67	1.37	0.06	0.55
6	10	0.67	0.40	0.18	0.58	0.40	0.76
7	51	0.60	0.66	0.61	1.27	0.05	0.69
8	33	0.75	0.71	0.40	1.11	0.28	0.83
9	21	0.76	0.79	0.17	0.96	0.07	0.98
11	16	0.60	0.71	0.08	0.79	0.19	0.78
13	23	0.75	0.54	0.23	0.77	0.26	0.85
14	19	0.76	0.11	0.80	0..91	0.06	0.79

Air Movement.

In warm or hot weather, the rate of air movement is one of the best means of improving thermal comfort. In summer to open or close a door or window or to switch a fan on or off is a common reaction to an environment that is either too warm or too cool. Natural ventilation can play an important role in controlling the indoor air quality and temperature in summer, preventing overheating by adopting adequate ventilation strategy.

Door Open:
The doors bear poor correlation with indoor and outdoor temperature. This suggests that an open door has little impact on thermal sensation and its use is not much influenced by indoor or outdoor temperatures. There are factors other than thermal comfort which influence the opening and closing of the doors.

Window Open:
Open windows aid air movement and may help to cool the building in summer. Of all available controls, windows have the biggest effect on indoor climate. On average 62% of the total responses reported open windows, ranging from as high as 81% in building 2 (Oxford) to as low as 11% in building 14 (Aberdeen), Table 3. The open window is closely related with thermal sensation, indoor and outdoor temperatures as shown in Figure 2. The proportion of windows open also increases as the subjects feels hotter on the comfort vote from 1 (= much too cool) to 7 (= much too warm). The graphs are plotted are for Oxford subjects only, but similar relationships are found to apply in Aberdeen. Reasons given for closed windows are "others want them shut", "to prevent draught", "to keep the noise level low", or "interference with blind".

In an earlier study, based on the data from one building 1, Raja & Nicol [1998] showed that cross ventilation (i.e. both door and window open) was effective in reducing the indoor temperatures.

Use of Fans:
In naturally ventilated buildings, fans play a significant role in reducing the heat stress. Use of fans modifies the indoor climate by regulating and increasing air movement. Figure 3 shows that the proportion using fans bear a strong correlation with indoor and outdoor temperatures and thermal sensation. The correlation coefficients are comparable to that for 'window open'. However, its use is relatively low (38% on the average, mostly below 30%), as shown in Table 3. Despite the increase in 'fan usage' with the increase in three parameters, the small proportion of people using fans suggests either that fans are not available or that the other means of ventilation are sufficient to achieve indoor thermal comfort.

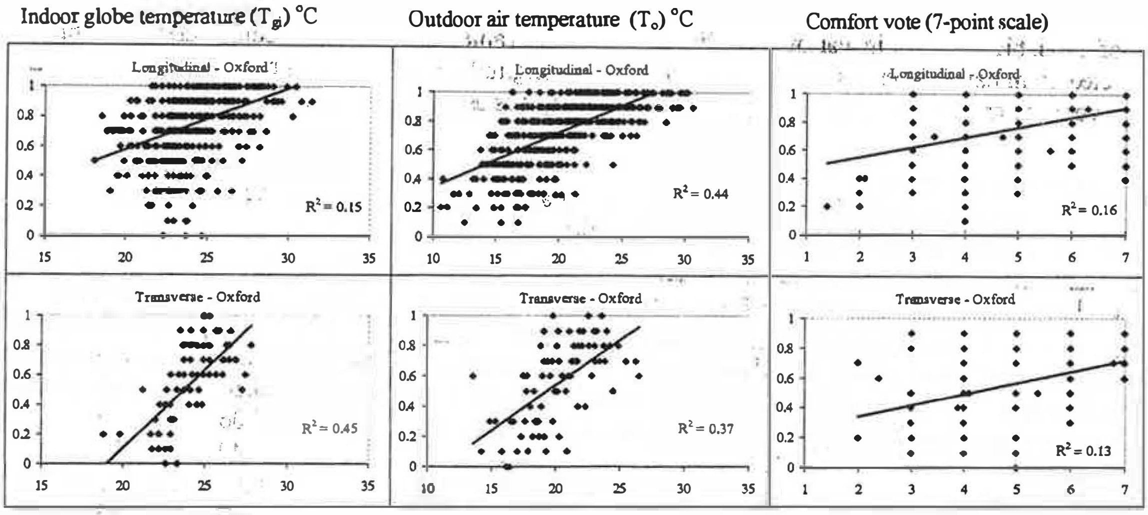

Figure 2: The proportion of windows open related to indoor temperature, outdoor temperature and comfort vote.

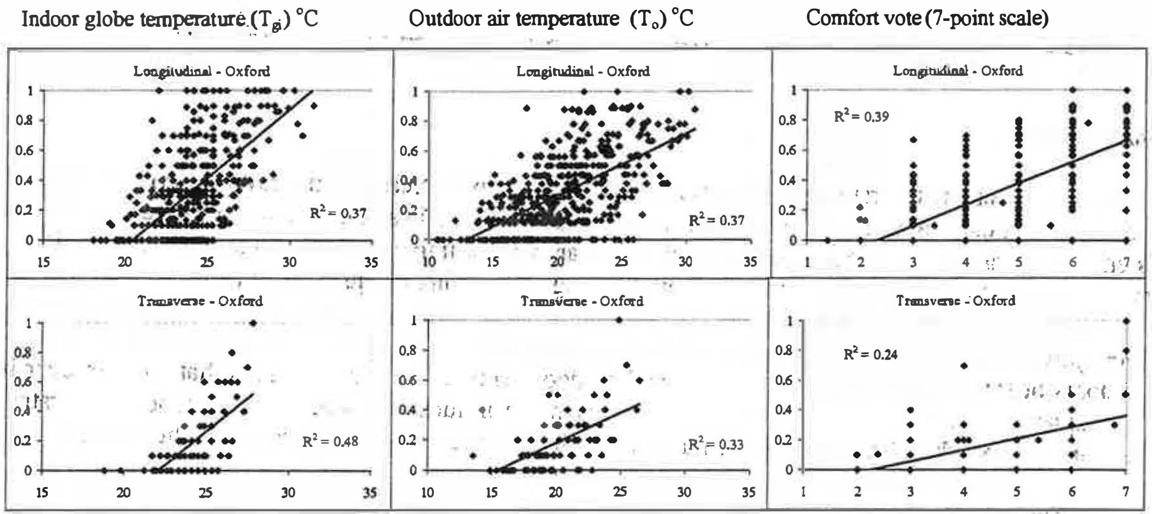

Figure 3: The proportion of fans running related to indoor temperature, outdoor temperature and comfort vote.

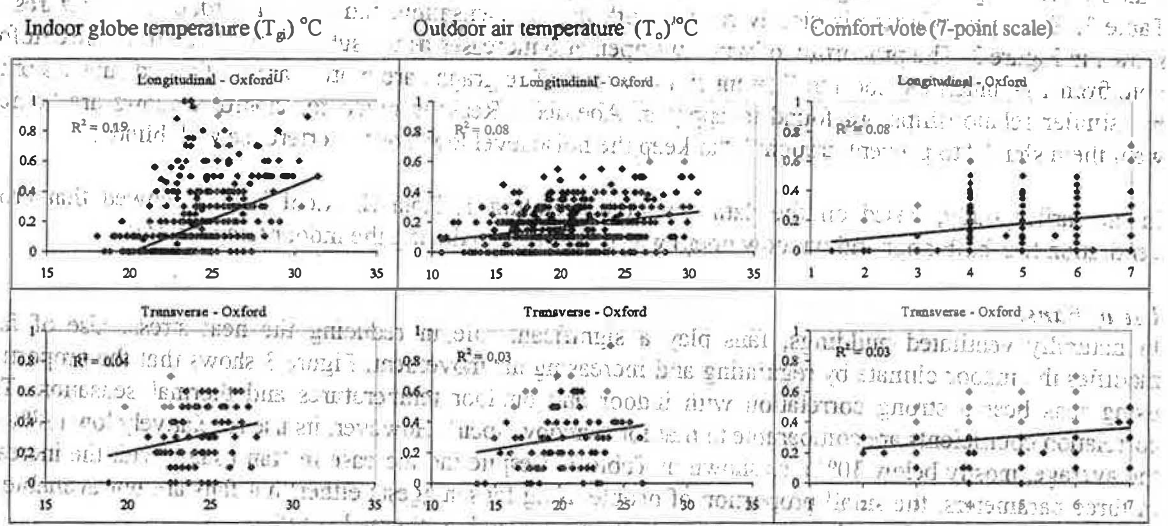

Figure 4: The proportion of blinds down or curtains closed related to indoor temperature, outdoor temperature and comfort vote.

Heat Gains.

Heat gains may be internal or external. Internal heat gain is due to the use of energy consuming equipment and occupancy. Artificial light is a significant source that can be avoided when the day-lighting is enough. External gain is mainly the solar. The controls used to limit the direct solar radiation are blinds or curtains.

Use of Blinds or Curtains:
One function of blinds and curtains is to intercept the direct solar radiation entering the building. They are used by all subjects where appropriate with "glare reduction on VDUs" and "reduction of direct sunlight" given as reasons. The use of curtain/blinds is usually less than 20%, being drawn in about 24% of responses overall (Table 3). The use of blinds/curtains varies from building to building and within a building from person to person with seating position [Raja & Nicol 1998]. People near to the window use blinds most extensively. The 'blind/curtain usage' increases with the increase in indoor and outdoor temperatures and thermal sensation, (Figure 4) but the rate of change is small compared to windows and fans probably because the reason for using blinds is to avoid glare rather than heat.

Use of artificial light:
In UK climatic conditions lights are more extensively used in winter than in summer. Regression analysis of light with thermal sensation, indoor and outdoor temperatures resulted in a very low correlation. However, on sunny days in summer people tend to switch off the lights. In open plan offices individual users have less control over general lights. Therefore despite adequate daylighting the lights have been found on in many places. Switching on the light in early morning often means that it stays on throughout the day.

CONCLUSIONS

Availability of controls and their appropriate use is key to better performance of the building and for improving occupant satisfaction. The analysis of the data collected during the present study show that building mass and the use of various controls plays a significant role in modifying the indoor thermal conditions.

Among various controls the opening of windows and drawing of blinds or curtains are the most extensively used. The proportion of windows open and blinds/curtains drawn increased with an increase in indoor or outdoor instantaneous temperatures.

The use of fans also showed a similar trend as for windows and blinds. However, the proportion using fans is relatively very high in buildings where proportion of open window is less. The incidence of discomfort is strongly correlated with the use of windows and fans suggesting that these controls are used in response to discomfort, in accordance with adaptive theory. Allowing cross ventilation also helps to lower the indoor temperature.

There are therefore, significant opportunities for adaptation by simply operating local controls: windows, doors and blinds/curtains. In buildings where more control is needed, fans can be used to increase air movement.

Occupants who have greater access to controls (e.g. those close to a window) report less discomfort than those who have less access (e.g. away from the window).

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