Occupant feedback questionnaire producing a fingerprint and a score

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Title; Occupant feedback questionnaire producing a fingerprint and a score

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Abstract

In order to ensure that buildings and HVAC plant are truly for people and actually satisfy the occupants it is necessary to obtain feedback from the occupants. This can be done by a novel questionnaire, which produces a readily understandable fingerprint and score to indicate occupants liking of their environments. The questionnaire uses a double-Likert section rating the liking and importance of up to 24 environmental, organisational and human factors. It has been used primarily in UK offices to date including modern deep-plan naturally ventilated buildings. Comparison is made to previous results from 1400 occupants from 12 offices that are air conditioned and naturally ventilated where scores ranged from +17% (greatly liked by the occupants) to -15% (greatly disliked). However, four UK offices with 1300 occupants are discussed in detail, which produced very low scores, -14% to –39%, the latter for a building with no windows. The fingerprints and scores were supported by an independent consultant’s survey of the buildings and plant and also detailed Factor Analysis. The latter indicated that the 18 factors used in the questionnaire could be reduced to 5 general factors. The most important factors for the occupants for their ideal office were temperature, health, ventilation and heating control and the least important were the appearance of the building, distance to a window, humidity and glare. It is proposed that this questionnaire is a useful management tool and suitable as a final commissioning tool.

Key words; questionnaire, occupant, feedback, fingerprint, score, building, commissioning, management, satisfaction.
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Abstract

In order to ensure that buildings and HVAC plant are truly for people and actually satisfy the occupants it is necessary to obtain feedback from the occupants. This can be done by a novel questionnaire, which produces a readily understandable fingerprint and score to indicate occupants liking of their environments. The questionnaire uses a double-Likert section rating the liking and importance of up to 24 environmental, organisational and human factors. It has been used primarily in UK offices to date including modern deep-plan naturally ventilated buildings. Comparison is made to previous results from 1400 occupants from 12 offices that are air conditioned and naturally ventilated where scores ranged from +17% (greatly liked by the occupants) to -15% (greatly disliked). However, four UK offices with 1300 occupants are discussed in detail, which produced very low scores, -14% to –39%, the latter for a building with no windows. The fingerprints and scores were supported by an independent consultant’s survey of the buildings and plant and also detailed Factor Analysis. The latter indicated that the 18 factors used in the questionnaire could be reduced to 5 general factors. The most important factors for the occupants for their ideal office were temperature, health, ventilation and heating control and the least important were the appearance of the building, distance to a window humidity and glare. It is proposed that this questionnaire is a useful management tool and suitable as a final commissioning tool.

1) Introduction

Although there are standards and calculations for the design of comfortable environments in terms of temperatures, humidities, draughts, noise and lighting etc, rarely do engineers measure what has been designed in any depth or ask the occupants how satisfied they are with their building and its HVAC services. This is for a variety of reasons including cost and possible legal implications. However, with the advent of Sick Building Syndrome and the rising awareness of the interior environment on occupant productivity, there is more interest in determining the feedback from the occupants. When feedback is obtained it is often by a questionnaire survey [1,2,3,4,5].

Questionnaires often require detailed statistical analysis, making understanding for management and users difficult. This paper discusses a questionnaire that can elicit a liking score and a fingerprint, combining up to 24 factors relating to satisfaction with the building. The questionnaire also asks occupants what are the important factors in the design of their ideal office.

2) The questionnaire employed

This questionnaire has been developed in the UK and is used by a number of organisations including a consultancy in London whose results are analysed here.
In this questionnaire there are 5 sections, (A, B, C, D, E), the first dealing with personal information, and work details, hours at work, PC use etc. Section B deals with summer and winter comfort using semantic differential rating questions. Section D is a Sickness Symptoms questionnaire for deriving a Building Sickness Score and is discussed in another paper, [6,7]. Section E is a new section on stress and has been derived from Cooper’s work, [9]. These sections are not discussed further in this paper.

2.1) Liking score

Section C is the novel feature of the questionnaire in that it is a double Likert scale for liking and importance of a number of factors relating to the interior environment and the organisation. A seven point scale for like and dislike is used for the questionnaire, shown below:

Do you like the... How important is this in the design of your ideal office?

<table>
<thead>
<tr>
<th>dislike</th>
<th>like</th>
<th>unimportant</th>
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<tr>
<td>-3</td>
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Comments:

A like, dislike scale, rather than the more commonly used scale of satisfaction and dissatisfaction, is used to increase the ease understanding, which is important for a self-administered questionnaire. For instance there could be connotations with satisfaction with colleagues.

Alongside the seven point like/dislike scale is another seven-point scale for the respondent to indicate how important he/she considers the factor should be in designing his/her ideal office. Although few respondents considered any factors were unimportant, and therefore negative, the seven-point scale was not reduced to four points to maintain consistency and avoid confusion.

From this a score and fingerprint can be calculated to simplify the results. In this study the questionnaire was discussed with the consultant’s client and a few of the standard questions were left out, primarily those relating to management and colleagues, [6,9]. The 18 factors used were;

- noise level
- electric lighting
- amount of daylight
- glare level in the room
- glare level around your desk or VDU
- your distance away from the window
- office temperature
- ventilation
amount of air movement
freshness of your room
humidity level in the room
state of your health when in the room
the control you have over the heating
the control you have over the ventilation
the control you have over the lighting
amount of working space you have in the room
office in general
the outward appearance of your building

From these questions a score can be derived [1], by basically multiplying and normalising the liking and importance scores for each factor and for each respondent. This yields a score between +21 and -21. The overall liking score for an individual, ILS, is the average of all the question multiplications normalised by dividing by the maximum possible score and expressing as a percentage. The group overall liking score, OLS, is the average of the ILS's for the group. The importance votes, i, for each question, have 4 added to them to ensure that all votes are positive so that a negative liking vote multiplied by a negative importance vote does not give a positive response. The importance is effectively a weighting factor. Two factors may be equally liked but one may well be more important to the occupant than the other, so it scores slightly higher. The Overall Liking Score from the returned questionnaires in a building is:

$$ OLS = \left[ \frac{\sum_{j=1}^{n} \sum_{k=1}^{m} i_{j,k} l_{j,k}}{m_{\text{max}} l_{\text{max}}} \right] \times 100$$

where $j = \text{questionnaire number}$
$k = \text{question number}$
$i = \text{importance rating} \quad 1 \leq i \leq 7$
$i_{\text{max}} = \text{maximum value of } i, (7)$
$l_{\text{max}} = \text{maximum liking rating } l (+3)$
$l = \text{liking rating} \quad -3 \leq l \leq +3$
$m = \text{number of filled in questionnaires}$
$n = \text{number of questions in the score}$

The score is normalised between +100 and -100, the positive scale increasing with liking and importance and the negative scale showing disliking and unimportance. Zero indicates a neutral position.

Multiplying the liking rating by the importance rating allows a degree of freedom in the questions asked. In changing the questionnaire for a different building, e.g. a school, then...
the occupants' ratings of the importance of a question allows the questionnaire designer some freedom.

The score is expressed as a percentage and most occupants’ scores range between +30% and -30%. A positive score indicates a degree of liking and a negative score the degree of disliking. Most overall scores from respondents in the dozen buildings surveyed before this study have ranged between +19% and -15%.

The score is a useful index but like most indices it hides a lot of other information and variability. This may partly be overcome by quoting the standard deviation of the score. In this study the four scores and standard deviations, S.D., were; -27%, (S.D. = 20%), -17%, (S.D. = 10%), -39%, (S.D. = 23%) and -14%, (S.D. = 15%).

2.2) Likeness fingerprint

The responses to the questionnaires can also be drawn graphically to provide a "fingerprint" of the building as shown in Fig.1. This fingerprint normalises each question to a score between +100% and -100%. For question, or factor, x the Factor Liking Score, FLS is;

$$FLS = 100 \frac{\sum_{j=1}^{m} I_{j,x} l_{j,x}}{m_{i,\text{max}} l_{\text{max}}}$$

The FLSs are then ranked to form the fingerprint.

Figs.1 to 6 show a number of fingerprints of buildings. Fig.1 and Fig.2 show the fingerprints of buildings tending to the extremes of the liking scores from previous surveys, while Figs. 3 to 6 are for buildings discussed in detail in this paper. Fig.1 is for an open plan office with an underfloor delivery from a VAV system, the air being extracted via two atria, [4]. Generally most factors here are liked except the privacy and noise, (not uncommon in an open plan office). The occupant control of the environment is also disliked as well as the occupants’ distances from the windows.  The occupant control of the environment is also disliked as well as the occupants’ distances from the windows.  Fig.2 is from a learning resource centre at a university [10]. It is a deep plan naturally ventilated building. This fingerprint has added control questions relating to the control of the ventilation, heating and lighting as controllability was found to be important. Two of these control factors are greatly disliked. This is not surprising as the control strategies for day and night ventilation and also the heating were still being improved when it was surveyed. However, glare on the PC screens was the second greatest dislike.

3) Buildings A, B, C, D

The four buildings discussed in this paper, called A, B, C and D are on the same large site and under the same management. A consultant was called in to examine them as
there had been some dissatisfaction expressed by the staff on the site. The consultant did a survey of the HVAC plants and the buildings’ fabric and wrote a report of his findings. A questionnaire survey was then conducted by sending out the questionnaire discussed above to the 1,350 staff in the buildings with a letter from the management and consultant. 884 completed questionnaires were returned, 65% of those sent out. 64 were not used, as the building number was not correctly filled in on the questionnaire. The questionnaires were then sent to the academic developers of the questionnaire to analyse the results. This was done blindly, i.e. the analysers had not seen the consultant’s report, did not know any details of the buildings or the staff. In fact it was so independently blind that 64 questionnaires were analysed but not included in the results as the building numbers were incorrectly filled in on the questionnaires. However, it later transpired that there was in fact a small fifth building that the analysers had not been informed of. Most of the rejected questionnaires had this building number on them.

In the following sections the buildings’ descriptions and analyses of the HVAC plants are taken from the consultant’s report. These are followed by the occupant questionnaire scores and fingerprints. The reports and fingerprints are then compared.

3.1) Building A

3.1.1) Brief description

Building A, (floor area, 6244 m$^2$, [67,190 ft$^2$]), is a 1970's two storey concrete framed structure with mostly open plan areas with an unusually high density of PC workstations. It is fully air conditioned and controlled by a BEMS. The lighting is appropriate for PCs.

3.1.2) The consultant’s summary on Building A.

This is an air-conditioned building circa 1970's. It has an unusually high level of computer workstations and this, together with the basic deep plan design of the building, means that air conditioning is inevitable. It is inadequately heated because of an undersized and incomplete perimeter heating system. Occupant discomfort is exacerbated by excessive air velocities from the air conditioning terminal units. The heating system should be replaced with a system which is able to cope with the down draughts and cold radiation from the large windows. In some offices, doors and windows are badly fitting causing excessive air infiltration or cold air transfer from unheated parts of the building. The basic components of the air conditioning appear to be well maintained although the system is giving poor service. It should therefore be thoroughly investigated to ensure all components are sound, modified as necessary and re-commissioned.

3.1.3) The consultant’s observations and analysis of Building A

• There is excessive down draught from the slot diffusers in some areas and no flow in other areas.
• Down draughts are exacerbated by turbulent downdraughts from high external glazing.
• The perimeter heating system is inadequate and does not counteract the turbulent down draught from the windows during cold weather.
• In some rooms to the rear (east) of the building, there is no perimeter heating.
• Airflow seems to oscillate from high to low velocity over a period of about two hours.
• Many gaps are apparent where cold air can infiltrate.

3.1.4) Fingerprint and score for Building A

145 responses OLS = -27%

This building scores very low primarily because of winter coldness. 40% of respondents are too cold for more than 30 days in the winter compared to 28% being too hot in the summer. The fingerprint, Fig.3, shows that heating control, temperature, ventilation control and ventilation are the most disliked factors. This is consistent with the consultant’s report, especially the draughts as is reflected in air movement being the second greatest dislike. The lighting and its control seem well designed from the consultant’s report but this is also disliked although ranked much higher, (5th to 7th), than the heating control, (18th).

3.2) Building B

3.2.1) Brief description

This office building, (floor area: 9163 m², [98,600 ft²]), was constructed in 1974 with extensive single glazing and forms an outer block around an inner courtyard. There is a restaurant on the first floor. Each floor is mostly sub-divided by internal partitioning. This results in some office areas being deep plan with poor natural ventilation and with the lighting being on for the whole of the working day in areas away from the windows. There is a high density of workstations in some areas but the lighting is designed for PC use.

3.2.2) The consultant’s Observations and analysis

The heating is adequate since the modifications in 1994. There is uncontrolled heat emission from the heating distribution pipework, which causes an additional load on the air conditioning units in the areas, which have them. The plan depth of each floor is mostly sub-divided by internal partitioning resulting in some office areas being deep plan, with low ventilation and the lighting on in areas away from windows. This together with a high density of workstations gives rise to summer overheating. Some office areas, which are deep plan and have high densities of PC workstations, exceed 30°C (86°F) for more than 2.5% of the peak summer month, suggesting air conditioning is required.

Flexibility of partitioning is a benefit of modern offices, which has been made possible, in the main, by air conditioning and comfort cooling systems. Much of the partitioning in Building B has resulted in relatively deep plan areas which will not
benefit from the cross-flow ventilation and the installation of some form of air conditioning is the inevitable conclusion. This will be in addition to that already applied to 10% of the area.

3.2.3) The consultant’s observations and analysis of Building B

Like Building A this is also a 1970's building but with a narrower floor plan allowing cross ventilation from the windows. The partitioning arrangement is such that some open plan office space is deep plan with no cross ventilation making summer conditions very uncomfortable. Comfort cooling has already been installed in various areas. It is recommended that comfort cooling be extended to those areas where it is required. This can be justified in areas away from windows, where there are high densities of PC workstations and where the lighting needs to be on all day.

3.2.3) Fingerprint and score for Building B

300 responses OLS = -17%

This building scores low with freshness, air movement, temperature and ventilation scoring lowest. This corresponds with the consultant’s report of partitions obstructing the natural cross ventilation. Summer conditions are the problem according to the consultant, whereas the heating is satisfactory. This is borne out by the fingerprint with heating control ranked 6th.

3.3) Building C

3.3.1) Brief description

Building C, (floor area; 1635 m², [17,600 ft²]) was designed about 1970 as a mainframe computer building and office. It has a single storey corrugated metal building with high eaves. Half of the original service floor area is partitioned off and used as office space but it is still served by the original air conditioning plant. There are no windows.

3.3.3) The consultant’s observations and analysis

Judging by the amount of cooling the system was producing during the site visits the existing plant is considerably over sized for its current duty. This is partly because much of the building is now used as office accommodation and partly because the current computer equipment does not produce as much sensible heat as the original computer equipment.

The present air conditioning system gives rise to conditions of air movement and turbulence intensity which are unsuitable for office staff. The air conditioning system is over 20 years old, and, although still giving good service, it is not an appropriate design for comfort nor efficiency and the cost of maintenance is increasing due to the age of the plant.
This building has two functions which are as follows: (1) a process area for the main computer equipment requiring constant load, 24 hour cooling and humidity control driven by the constant sensible heat gains of the equipment. This was part of the original design intent of the building. (2) Office accommodation used in normal office hours requiring variable heating/cooling primarily dominated by external conditions. This is essentially a change of use from the original building.

The office space, which represents half the original floor area, has been partitioned off although it shares a common plenum ceiling air supply and a common floor void extract. It should be recognised that the original system design will not be capable of dealing with the type of air conditioning load imposed by that half of the floor area.

This is a 1970's designed computer centre. It is inappropriate for its present function. The existing floor space has been partitioned to provide half computer space and half office space, without windows. The air conditioning is oversized for its current duty, and, since it was originally intended for a constant cooling load of mainframe computer equipment, it cannot cope with the fluctuating heating and cooling demands of the office space. The system cannot easily be modified. It is recommended that the building be replaced with a separate computer and office space. Considerable operation and maintenance cost savings will result.

3.3.4) Fingerprint and score for Building C

19 responses  OLS = -39%

These respondents have no windows and not surprisingly the OLS is extremely low. The greatest dislikes are the distance from the window, daylight and the lighting control. The ventilation control is also disliked, and the consultant has criticised it, but the lack of windows and daylight seem crucial to the lowest score recorded with this questionnaire.

3.4) Building D

3.4.1) Brief description

This office building, (floor area: 10,468 m², [112,635 ft²]), provides accommodation for around 800 staff. The building was fully occupied in 1994. The building has three levels, ground, 1st and 2nd, with double pitched roofs which enclose one courtyard to the north and two courtyards to the south of a central spine. It is linked on its north side to office buildings A and B and the computer centre (building C) by glazed walkways. The main entrance and conference facilities form a two-storey block linked to its north east corner. Office space is a mixture of open plan and cellular. The plan width of each wing is 10.5 metres. The courtyards are 17 metres square on plan. Double internal blinds are fitted to east, south and west elevations. North facing elevations have single blinds for the control of daylight. Ventilation is provided by the windows being opened by the occupants.

3.4.3) The consultant’s observations and analysis
With the lighting off, the summertime temperature, using the CIBSE method of prediction, will be reduced from 27.8 to 25.4°C, (82, 78°F). The building fulfils the project brief with reference to plan width, conventional design and construction with raised floors, natural ventilation and natural lighting. The project brief for the design and construction of the office block called for conventional design and construction. It is considered that this may have had the effect of deflecting the designer from innovative techniques to minimise summer overheating. For example, it may have been advantageous to extend the walls to the courtyards upwards to form a semi enclosed space or atrium such that buoyancy effects would encourage cross ventilation through the office space. The relatively high ceiling is beneficial for summer operation as it allows more space for heated air to rise above head height. No other measures have been employed to reduce summertime temperatures. The use of high density internal finishes, solid floors, external shading and exposed ceilings would each have contributed to reducing summertime temperatures.

The TRVs are not controlling the room temperature because of excessive differential pressure. There is a high level of heat emission from the heating distribution network because there is no thermal insulation on the pipework where it is routed between floors and in some cases there is exposed pipework in the room.

This is a new building which was designed without air conditioning. It has both a narrow floor plan and a relatively high floor to ceiling height which enhances the use of natural light and natural ventilation. There is no significant external shading. The structure and fitting out of the building is such that peak summer internal temperatures are higher than they need be. One option is to replace internal lightweight partitions with brick-built partitions. Our predictions are that this should decrease peak internal temperature in the order of 1°C (2°F). Heat gain from the designed lighting system is higher than it need be.

Problems of design and control of the heating system, that must cause significant overheating in mild weather when the heating system is on, have been identified. It must be recognised that modern buildings are highly thermally insulated and that heat gains from lighting and PCs become very significant. For example, calculations predict that the peak internal temperature would reduce by 2.4°C (75°F) if the lights were not switched on in a south facing office, over a 24-hour period.

3.4.4) **Fingerprint and score for Building D**

354 respondents  OLS = -14%

Although it has a poor score this building is the best of the four. Air movement, temperature, ventilation and freshness are the most disliked factors, similar to the other naturally ventilated Building B. Other sections of the questionnaire reveal that the low score is mainly due to the high internal summer temperatures, with 39% of respondents being too hot in summer for more than 30 days.

3.5) **Discussion of the fingerprints**
It is interesting that for the two naturally ventilated buildings, B and D, the bottom four dislikes are the same; air movement, temperature, ventilation and freshness. However, for the two air conditioned buildings control factors feature significantly in the lowest scores; ventilation control and heating control for A and ventilation control and lighting for C. Other work has shown that lack of control is a significant negative factor in air conditioned buildings. In naturally ventilated buildings, however, the ability to open a window allows the occupant more freedom of control. In buildings B and D, the naturally ventilated ones, the natural ventilation and the ability to open windows do not stop air movement, freshness and ventilation being the most disliked factors.

Independent surveys have been conducted at the same time as this fingerprint questionnaire has been used and the results are very similar, [4,6,8], although the fingerprint and score allow easier understanding initially.

4) Importances

Fig.7 shows the ranked order of the importance votes of all the four buildings’ 818 respondents. These are generally in agreement with previous results from a number of different buildings [6], with temperature, health, ventilation and heating control being the most important factors. The appearance of the building was by far the least important factor followed by distance from a window, humidity, room glare and VDU glare. The latter two may result from the lighting being carefully designed for VDU use. There is also some agreement with Rohles et al’s work [5], in that the thermal factor was considered the most important, (this work also considered lighting, air quality and acoustic factors).

One disagreement with past work, [6], is the low importance of distance from the window in Fig.7. For Buildings B and C, (C has no windows), this factor is considered important, (mean importance votes are actually 1.7 and 1.9, respectively), whereas for A and D it is 1.2 and 1.0. In terms of the fingerprints, distance from the window is either the top or second most liked factor whereas for C with no windows it is the least liked. It could be that as the majority of occupants consider disliked factors as more important than liked factors. This will be investigated further.

5) Factor analysis

Factor analysis was used to establish the underlying dimensions of the occupant questionnaire on interior environment conditions. The factorability of the data was determined by examining the correlation matrix among the questionnaire's 18 items. This revealed correlations over 0.3 with some considerably higher. The Kaiser-Meyer-Olkin Measure of Sampling Adequacy was calculated and equalled 0.85, suggesting a "meritorious" sample for factor analysis. Similarly, the Measures of Sampling Adequacy (MSAs) for each item were also examined, these ranged from 0.64 to 0.95, confirming that all items should be retained.

Initially principal component extraction with varimax rotation was used. The number of factors extracted, dictated by Kaiser's criterion, (those with eigenvalues greater than one), produced a five-factor solution. A scree plot was generated and indicated that the true number of underlying dimensions lay between four and six factors.
Principal axis factoring and maximum likelihood extraction, common factor models, were attempted but produced communality estimates greater than one, which produced imperfect solutions. Principal component extraction is, therefore, reported. Four, five and six factor solutions were performed with an oblique (Oblimin) rotation, and after inspecting the factor loading matrices the five-factor solution was computed. The factor correlation matrix revealed correlations greater than 0.3 indicating that an oblique rotation would be appropriate.

The communalities were inspected to assess if the variables were well defined by the solution. This indicated that many communality values were very high and all were greater than 0.35. The variables were, therefore, adequately defined by this factor solution. Simplicity of structure was assessed by inspection of the factor loading, this revealed some very high correlations and many low correlations between variables and factors. Three variables were complex, but no variable failed to load with a factor greater than 0.3. Eigenvalues ranged from 5.90 for factor one to 1.14 for factor five and the solution accounted for 64.0% of the total variance in the occupant questionnaire on interior environment conditions. The internal consistencies of the five factors were measured by the squared multiple correlations (SMCs). At 0.88 for factor one, 0.77 for factor two and 0.74 for factor three they were internally consistent. Variables were ordered and grouped by size (Table 4) and interpretative labels suggested.

Factor one is labelled Air Quality. It is associated with the factors; amount of air movement, ventilation, freshness of the room, humidity, state of health and office temperature.

Factor two is labelled Glare. It is associated with the factors level of glare in the room, glare around your desk or VDU, electric lighting and control of lighting.

Factor three is labelled Lighting - it is associated with the amount of daylight, distance from the window, electric lighting and control of lighting.

Factor four is labelled General - it is associated with the amount of working space, noise level, the office in general and the outward appearance of the building.

Factor five is labelled Control - it is associated with the level of control over the heating, ventilation and lighting plus office temperature. The validity of these dimensions is supported by Vischer [2] who found seven factors from 35 factor; thermal comfort, privacy, noise control, spatial control, lighting comfort, building noise control and air quality. Rohles et al [5] also used four general factors for the environment; acoustics, air quality, lighting and thermal.

5.1) Differences in the factor scores of the occupant questionnaire on interior environmental conditions

Five factor scores were generated from the four buildings’ occupant responses using the regression method for further analysis. The results are presented in table 5.

5.1.1) Analysis one; staff job
The questionnaire had four subgroups based on work categories: group one - clerical and secretarial staff (n = 216), group two - professional staff (n = 143), group three - managerial staff (n = 174) and group four - other staff (n = 47).

ANOVA revealed a significant difference at the 5% level in the Glare factor score. The Kruskal-Wallis test revealed a very highly significant differences at the 0.1% level in the Control factor score and a highly significant difference at the 1% level in the Air Quality factor score.

For the Control factor the professional staff's scored significantly lower than the managerial and 'other' staff.

For Air Quality no two groups were significant at the 5% level.

For Glare the 'other' staff scored significantly higher that of the clerical and secretarial and managerial staff.

5.1.2) Analysis two; age

The questionnaire had five subgroups based on age: group one - less than 20 years old (n = 10), group two - 21-30 years old (n = 91), group three - 31-40 years old (n = 180), group four - 41-50 years old (n = 196) and group five - 51-60 years old (n = 118).

The Kruskal-Wallis test revealed highly significant differences at the 1% level in the General factor score. Closer examination revealed the 31 - 40 year old group's median score was significantly lower than that of the less than 20 year old group, the 21 - 30 year old group, the 41 - 50 year old group and the 51 - 60 year old group. The less than 21-year-old group's median score was significantly higher than that of the 41 - 50 year old group.

5.1.3) Analysis three; desk position

The questionnaire had four subgroups based on the position of the window in relationship to the occupant's desk:
Group one, or the window in front group, where the window is in front of the occupant (n = 109)
Group two, or window behind group, where the window is behind the occupant (n = 159),
Group three, or window to side, where the window to the side of the occupant (n = 223)
and group four, or window combination, where the window is a combination of in front, behind or to the side of the occupant (n = 93).

The Kruskal-Wallis test revealed highly significant differences at the 1% level in the Glare and Lighting factor scores. For the Glare factor the window in front group, not surprisingly, scored significantly higher than that of the window behind and the window to side group.

For the Lighting factor score the window combination group’s median score was significantly higher than that of the other three groups. The window behind group’s median score was significantly higher than that of the window to side group.

5.1.4) Analysis four; distance from window

There were three subgroups based on the distance of the occupant's seat from the window: group one - 1-2 metres (n = 313), group two - 2-5 metres (n = 194) and group three - greater than 5 metres (n = 89).

The Kruskal-Wallis test revealed very highly significant differences at the 0.1% level in the Glare and Lighting factor scores.

For the Glare factor the group 1-2 metres scored significantly lower than that of 2-5 metres and the >5 metres group, i.e. the glare was more disliked by those close to a window. However the lighting, Lighting factor, was more liked by the 1-2 metres group than by the 2-5 metres and the >5 metres. The 2-5 metres group median score was significantly higher than that of the > 5 metres. This may explain the low importance vote of the factor, distance from the window, which was surprising. Perhaps windows were associated with the glare rather than the lighting.

5.1.5) Analysis five; sex

There were two groups based on the sex of the occupant: group one - female (n = 189) and group two - male (n = 412).

The Mann-Whitney U-Wilcoxon Rank Sum test revealed a very highly significant difference at the 0.1% level in the Lighting factor score, a highly significant difference at the 1% level in the Air Quality factor score and a significant difference at the 5% level in the General factor score. In all factors the male median score was higher, indicating a greater liking.

5.1.6) Analysis six; the four buildings

Analysis was conducted on Building A (n = 112), Building B (n = 212), Building C (n = 10), and Building D (n = 255). The results are presented in Table 5.

The Kruskal-Wallis test revealed highly significant differences at the 1% level in the Glare and Lighting factor scores.

For Glare Building D had a significantly worse score than Buildings A, B and C but for Lighting it was significantly higher than A, B and C. C scored significantly lower than A and B, but then it had no windows.

For the General factor Building D scored significantly higher than Buildings A and B.

For the Control factor score Building B's median score was significantly higher than those of Building A, Building C and Building D, while Building A's score was significantly lower than that of Building D. Although Building B is naturally ventilated Building D, the more modern naturally ventilated building, does not have a
higher control score. But then the consultant identifies control problems in Building D.

6) Conclusion

The fingerprints for the four buildings complement and in general support the consultant’s report. There is, however, no easy way of testing this, except that the buildings and HVAC systems are constructively criticised by the consultant and the occupants’ votes seem to agree. The factor analysis sheds further light on the agreement.

Building A had an inadequate heating system and excessive air velocities from the ac terminal units. The fingerprint showed the heating control and temperature as the least liked factors.

Building B had poor natural ventilation to parts of its offices and summer overheating, but its heating was good. On the fingerprint freshness, air movement and ventilation were in the four least liked factors but heating control was the 6th most liked.

Building C with no windows gave the worst fingerprint to date; -39%, although there were only 19 respondents. However, windows are vitally important and previous questionnaires from occupants in rooms with no windows also have shown low scores.

Building D was the most recently built and was a purpose-built naturally ventilated office. The design could have allowed for more fabric storage to reduce summer overheating reflected in the fingerprint with air movement, temperature, ventilation and freshness as the least liked factors.

The factor analysis adds information to the questionnaire results, e.g. glare with window position in relation to the occupant, as well as age, job and sex differences. The analysis also suggests that the fingerprint may be condensed to five factors based on a combination of factor scores. However, this may add a sense of manipulation to the results.

This study does show the validity of the double Likert methodology and the usefulness of the fingerprint and score. Indeed the double Likert liking importance methodology has been used independently by Lowry to assess users’ satisfaction with building energy management systems, [10]. It also shows the surprising dislike of the occupants for these four buildings, although it is less surprising for the building with no windows.

There are similarities with the results of Rohles et al on the importance of different factors, although the latter initially required the respondents to allocate percentages to 5 general environmental factors. The current work does not require allocation of percentages and may explain the shallower differences in importance achieved.

Further work is being carried out using the questionnaire in the commissioning and management of new and existing buildings.
Nomenclature

FLS = average liking score for all the occupants in a group, normalised to a percentage, for a particular factor in the questionnaire, e.g. noise. The fingerprint is a graph of the FLSs.
OLS = overall liking score, normalised to a percentage, for a group of occupants for all 22 or 24 factors in the questionnaire.
ILS = overall liking score, normalised to a percentage, for an individual occupant in a group for all 22 or 24 factors in the questionnaire.
NV = naturally ventilated
AC = air conditioned
p = significance level for correlation, as a probability.

References