Paper No: 591
Building Transition Spaces, Comfort and Energy Use

Adrian Pitts [1]*, Jasmi bin Saleh [2], Steve Sharples [2]

Sheffield Hallam University, Sheffield, UK[1]
*a.pitts@shu.ac.uk**
University of Sheffield, Sheffield, UK[2]

Abstract

This paper describes research concerned with comfort in transition spaces. Transition spaces are entrance foyers, lobbies, atriums, corridors and other spaces through which people pass in travelling between the exterior and interior environment, or between different interior spaces. Such spaces tend to have higher energy requirements because of their stronger linkage with variations in the external climate. Transition spaces also offer opportunities too: they can act to condition occupant response when moving between zones, and occupant expectations for comfort in such zones may also be less stringent than for more continuously occupied spaces. The paper discusses these issues and includes analysis of occupants surveyed whilst passing through transition spaces. Results indicate that a wider interpretation of comfort bands is possible and that energy savings could be made.

Keywords: transition spaces, energy, comfort

1. Introduction

Building transition spaces consist of entrance areas, foyers, atriums, corridors, lift lobbies and other areas. They are the parts of a building through which occupants move either between outdoors and the interior useable spaces or between separately located interior spaces. Such spaces are very important both from a design aesthetic point of view, and from an environmental standpoint. They are the spaces often first encountered by someone entering a building and so the quality of design, appearance and lighting levels create significant impressions on building users. They are also parts of a building that often have close links to the exterior because of the use of larger windows, ventilation openings and entrance doors. These factors mean heat, light, air, and noise can all be transmitted more easily between interior and exterior than other parts of the building. The ways in which such transition spaces are used are also clearly different: occupants will normally be walking or moving (rather than seated) and may experience conditions different to those found during occupation of more enclosed interior rooms associated with work or other activities.

This leads to a potential difficulty: the transition spaces should be comfortable but because of the degree of connection between interior and exterior, the amount of building services required to achieve comfort may be higher than for other parts of the building. As a result energy consumption may be higher on a unit area or volume basis, and the installed capacity (and costs) of systems may also be greater to cope with the more extreme loads.

This paper advances the argument that those people passing through such spaces are more tolerant (or forgiving) of variations in conditions needed for comfort. Previous studies have suggested energy saving can result from taking advantage of such adaptation and acceptance and thus allow for less precise servicing, with consequent energy savings [1], [2].

In this paper surveys of building occupants are reported upon in which actual thermal sensations and preferences are correlated with expected comfort bands arising from use of predicted mean vote (PMV) methodologies, originally proposed by Fanger [3]. The authors believe this type of analysis and its approach to energy saving in explores the topic from a new point of view and adds to knowledge of the topic in novel ways. It is also one of only a modest number of research activities concerned with the important topic of transition spaces

2. Transition Spaces

Transition spaces are necessary components of building design as they form both entrance areas and also means of movement around a building. They have both abstract and functional qualities and are perhaps some of the most important design components from an architectural point of view.

No building, except for the most basic shell, can exist without such spaces. They play important roles in guiding and impressing those within such areas: some are designed to create stunning visual impacts; some to create social and circulation areas; others to perform more mundane functional requirements (including health and safety), but in all cases they are likely to occupy significant areas and volumes of a building.

Office, educational, entertainment, and numerous other styles of building include transition zones or areas. They can take many forms and even within the same building, several different types will be found. The authors have collated information on the size of such areas and found them to account for between approximately 10% and 45% of the floor area. Figure 1 shows a typical situation (this is for an educational building), in which 25% of the total ground floor area is transition space.

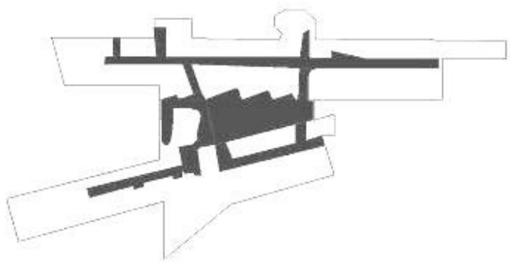

Figure 1: Typical transition space area in building

Though transition spaces are often used to produce key spatial and visual design outcomes, the amount of attention paid to the design of the environment from a thermal point of view is often significantly less. Basic comfort may be poor, and any lack in performance over-compensated for by extravagant use of servicing and incurring additional energy costs. These spaces however should be examined more closely since they represent an opportunity for optimisation and also one in which research can be valuable.

3. Comfort

Research and general interest into issues of comfort in outdoor as well as transition spaces has increased in recent years. This has normally involved the adoption of standards based on the work of Fanger [3], however over a period of time the limitations of the approach he first derived have become increasingly recognised.

The basis of comfort standards for interior environments has traditionally been the maintenance of environmental conditions within certain limits so as to minimise the number of occupants dissatisfied with their surroundings. The work of Fanger postulated the use of a calculation method to derive a prediction of how occupants would react under a given set of circumstances. This is known as the predicted mean vote (PMV). It was arrived at by questioning groups of test subjects located in a laboratory environment and exposed to a wide variety of environmental conditions (of air temperature, humidity, air movement and radiant temperature) and personal conditions (of activity level and clothing). The subjects recorded their thermal sensation vote on a scale of -3 to +3 shown in Table 1.

The PMV calculation algorithm was derived as a means to estimate how a group of people would vote (on average), under a given set of conditions. This provided a means for predicting performance and also for design of environments. Critics have pointed out however that the research is primarily suited to office type environments in which activity and clothing are mainly sedentary in nature and where there is little opportunity for adaptation of environmental factors (perhaps because accommodation is of a sealed air conditioned type). Nicol and Humphreys have produced several pieces of research suggesting an alternative adaptive approach can be used: see [4] for instance.

Table 1: Sensation scale for comfort

Sensation	**Scale value (or vote)**
Cold	-3
Cool	-2
Slightly cool	-1
Neutral	0
Slightly warm	+1
Warm	+2
Hot	+3

Analysis under the original Fanger model also permitted the derivation of a secondary value: the predicted percentage dissatisfied (PPD). This is the proportion of a space's occupants who would express dissatisfaction as their thermal sensation vote varied from '0'. Figure 2 illustrates this relationship from which one can infer that in order to reduce the percentage dissatisfied below the 10% level, sensation votes (or rather the combination of conditions created) should be between -0.5 and +0.5.

The impact of this work has been felt in the development of international standards such as ISO [5] and ASHRAE [6], where internal environments are supposedly controlled so as to achieve PMV between these limits.

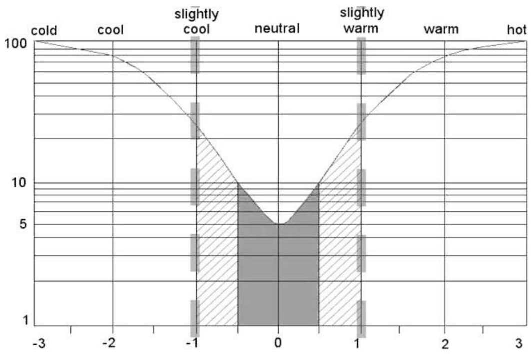

Figure 2: Predicted Percentage Dissatisfied (1-100) vs. Predicted Mean Vote (-3 to +3) showing impact of extended comfort range

The association between PMV and PPD can be determined and this is shown in Table 2. By inference it is possible also to determine a corresponding percentage of those assumed satisfied (% satisfied = 100 - %dissatisfied). The

proportion satisfied will be used for comparison purposes later in this paper.
The narrow limits for comfort of ±0.5 PMV are not universally applied however, with suggestions that in environments which use natural space conditioning (natural ventilation and daylight for instance), a wider limit may be set. This is because occupants are more forgiving of inconsistencies in such types of space, as well as having an expectation for adaptation (change of clothing or modification of window openings for ventilation). Some authors [7] already use three categories of limits for PMV variation depending on the type of space being designed. Others [8] have found that a wider range of PMV limit is particularly plausible in transition spaces.

Table 2: Relationship between predicted mean vote; predicted percentage dissatisfied; and percentage assumed satisfied

PMV	Approx. PPD (%)	Approx. Satisfied (%)
0.5	10	90
1.0	25	75
1.5	50	50
2.0	80	20
2.5	92	8
3.0	99	1

As a result of these previous findings, research has been carried out by the authors of this paper to investigate potential for expansion of the PMV limits to investigate if occupants are prepared to accept such differences.

4. Energy Use

Transition spaces generally use rather more energy than other parts of a building of equivalent size when both are conditioned to achieve the same comfort levels. Chun and Tamura [9] estimated that energy use in some transition spaces was as much as three times that of other parts of the building.
In order to examine and estimate the opportunity for energy saving one should first determine some typical conditions for the internal environment of the building and then assess the effect of potential variations in the conditions arising in the transition space.
Pitts and Saleh [2] suggested base internal conditions for comfort to be: air temperature = mean radiant temperature = 23°C; relative humidity = 50%; mean air velocity = $0.1ms^{-1}$; metabolic rate = 1.0met; and clothing level = 1.0clo. These parameters give a PMV of 0. Energy savings can be determined by calculating the energy required to maintain particular conditions with narrow variations for comfort and then to compare with energy use predictions with the wider limits.
First of all however it is necessary to adjust the likely required internal conditions for the situation of transition spaces. The above authors proposed the following variations to allow for the variations between transition space and internal room conditions: air movement increased to $0.3ms^{-1}$ due to greater natural ventilation and door opening; metabolic rate set to 1.4met to account for movement of occupants through the space (walking); clothing level was assumed to have the same value however as in transition spaces occupants may not have the opportunity to change clothing. These values also seem plausible to use here following environmental surveys of transition spaces before and during the main survey period described later.
Under these conditions a PMV of 0 results when air temperature and mean radiant temperature are 21°C. If PMV limits of ±0.5 are set, with other factors being equal, this means temperatures can be allowed to vary from about 18°C to 24°C; however applying a wider PMV limit of ±1.0 increases the effective range of temperatures to approximately 16°C to 26°C.
The impact of the wider temperature limits were reported to produce energy savings in transition spaces of between 7-11% for heating, and up to 2% for cooling energy use in a range of typical buildings set in the UK climate [2]. Further savings might accrue from reduced plant capacity and other capital costs.
These figures need to be further investigated but show potential for improved efficiency in operation if occupants of transition spaces are prepared to accept the variation in PMV to the wider limits. The investigation of this potential was the principal task of the surveys carried out

5. Transition Space Surveys

A survey was carried out to assess occupant reaction in six different transition spaces in and around educational buildings to which the researchers were granted access. These buildings were located in the north of the UK and the surveys were conducted on typical spring days (these being chosen so as to avoid climatic extremes which might impact on the findings). Longer term surveys of environmental conditions in and around the spaces surveyed were also conducted though these results are not reported here.
The majority of those surveyed were university students and staff, but respondents also included some visitors to the premises. Despite this limitation there is no reason at present to suppose any standardised variation from the public at large, though this might be investigated in the future.
One hundred and twenty three participants took part in the surveys: approximately 20 in each of six transition spaces. Transition space 1 was the entrance foyer of a library; transition space 2 was a mezzanine floor above a principal entrance to a large building; transition space 3 was in an open area between a main staircase and café area; transition space 4 was in the lift and circulation area of the entrance to a major building; transition space 5 was in a movement zone close to library turnstiles; transition space 6 was on a linking enclosed walkway between two buildings. Some of the survey locations are shown in Figures 3, 4, and 5.

Figure 3: Entrance foyer transition space (survey point 1)

Figure 4: Mezzanine area transition space (survey point 2)

Figure 5: Walkway transition space (survey point 6)

For each person surveyed information was collected on environmental and personal variables in order that individual PMVs could be calculated. This included clothing attributes and activity immediately prior to entering the transition space. Air temperature, mean radiant temperature, relative air velocity and relative humidity were each recorded at the time of each survey response.

Personal thermal sensation was assessed using a standard seven point scale: cold; cool; slightly cool; neutral; slightly warm; warm, and hot. Thermal preference was also queried using a five point scale: much cooler; slightly cooler; no change; slightly warmer; and much warmer.

Data for a new 'comfortability' rating were collated using categories of: not comfortable; slightly comfortable; and comfortable. This style of phrasing is not in common use however the researchers considered this would provide some additional evidence to examine their propositions.

The outcome of this process was that individual PMVs could be correlated with individual reactions before any averaging took place. This was important as occupants within transition spaces may be more likely to exhibit personal variations than those of interior offices for example. In particular it was possible to examine the range of PMV which participants would choose to vote for in the three questions posed, that is: when expressing feelings in the neutral thermal sensation category; when voting for no change in thermal preference; and when stating an overall evaluation of comfortable.

The reason for this focus is to examine issue of satisfaction and dissatisfaction. Those not voting within the categories above might be considered to be dissatisfied with their environment in some way, and this offers a means for exploring the relationship with the predicted percentage dissatisfied mentioned earlier.

6. Results

Data for each respondent in the survey were collated and correlated so that voting could be compared with predictions. Since the primary interest of the research project was to investigate the widening of comfort bands the method of correlation was to compare in which PMV band occupants voted for the most satisfied condition. PMV was defined in six bandings of: 0 to ± 0.5; ± 0.5 to ± 1.0; ± 1.0 to ± 1.5; ± 1.5 to ± 2.0; ± 2.0 to ± 2.5; and ± 2.5 to ± 3.0. Therefore, for each case the number of respondents who were found to be in each band was recorded together with the number of respondents who found the conditions satisfactory.

Table 3: Thermal sensation votes compared to PMV bands showing numbers and percentages voting 'neutral'

PMV band	**number of surveys in this band**	**number responding 'neutral'**	**%**
0 to ± 0.5	42	18	42.9
± 0.5 to ± 1.0	32	9	28.1
± 1.0 to ± 1.5	10	0	0
± 1.5 to ± 2.0	23	3	13.0
± 2.0 to ± 2.5	13	2	15.4
± 2.5 to ± 3.0	3	0	0

Table 3 shows the numbers responding 'neutral' in terms of thermal sensation, and this number as a percentage of respondents experiencing that band. The results suggest that fewer occupants described conditions neutral in the central portion of the PMV range than might have been expected (comparing with Table 2). However a significant number of those experiencing what would be predicted to be less comfortable sensations conditions also reported these to be neutral.

Table 4 shows the numbers responding 'no change' in terms of thermal preference, and this number as a percentage of respondents in that band. In a similar way to the sensation voting, the results suggest that fewer occupants required 'no change' in conditions in the central portion of the PMV range than might have been expected. And again a significant number of those experiencing conditions where change might be predicted to be voted for, reported these as 'no change' required.

Table 4: Thermal preference votes compared to PMV bands showing numbers and percentages voting for 'no change'

PMV band	**number of surveys in this band**	**number responding 'no change'**	**%**
0 to ± 0.5	42	19	45.2
± 0.5 to ± 1.0	32	15	46.9
± 1.0 to ± 1.5	10	1	10.0
± 1.5 to ± 2.0	23	3	13.0
± 2.0 to ± 2.5	13	8	61.5
± 2.5 to ± 3.0	3	0	0

Table 5 shows the numbers responding 'comfortable'' in terms of overall reaction, and this number as a percentage of respondents in that band. The results here are markedly different to the previous two, for whilst those responding as 'comfortable' in the central range of PMVs is slightly less than might be expected; many of those experiencing less comfortable conditions are still prepared to vote overall as comfortable.

Table 5: Comfortability rating compared to PMV bands showing numbers and percentages voting 'comfortable'

PMV band	**number of surveys in this band**	**number responding 'comfortable'**	**%**
0 to ± 0.5	42	34	81.0
± 0.5 to ± 1.0	32	25	78.1
± 1.0 to ± 1.5	10	3	30.0
± 1.5 to ± 2.0	23	14	60.9
± 2.0 to ± 2.5	13	11	84.6
± 2.5 to ± 3.0	3	1	33.3

Taking all three sets of result together it seems that occupants of transition spaces are rather less sensitive to the prevailing conditions than might be predicted from using a scale such as PMV. The causes of this are unclear at present but may be speculated as resulting from several factors:

- that in moving through a transition space, the occupants had not yet come to any sort of equilibrium with their surroundings;
- that their reaction was conditioned by the places they had been prior to entering the transition space; or
- that they were not concerned about the conditions they encountered in the space as they knew they would be moving into a further zone within a short space of time.

What is striking is that there seems to be evidence, whatever the cause, to accept less stringent environmental conditions and thus less need for precise comfort control, and hence potential for energy saving and reductions in installed capacity for space conditioning systems.

A further analysis was carried out (shown in Table 6) in which numbers of respondents and percentages were determined if totals were calculated within particular PMV ranges (rather than bands). Ranges were: 0 to ± 0.5; 0 to ± 1.0; 0 to ± 1.5; 0 to ± 2.0; 0 to ± 2.5; and 0 to ± 3.0. The results presented in this fashion suggest that whilst occupants can react negatively to questions about thermal neutrality and thermal preferences; that they are rather more forgiving when asked to comments on overall comfort. It is also possible that some degree of further semantic analysis is called for to investigate the phenomena or differences between phrases such as 'neutral', 'no change' and 'comfortable'.

Table 6: Satisfaction ratings showing percentages of respondents falling within the specified PMV ranges voting in the three categories

PMV range	**% voting**		
	neutral	no change	comfortable
0 to ± 0.5	42.9	45.2	81.0
0 to ± 1.0	36.5	45.9	79.7
0 to ± 1.5	32.1	41.7	73.8
0 to ± 2.0	28.0	35.5	71.0
0 to ± 2.5	26.7	38.3	72.5
0 to ± 3.0	26.0	37.4	71.5

7. Conclusions and Recommendations

Arising from the results presented here it seems possible to conclude that occupants of transition spaces react differently to thermal stimuli than predictions formulated based on the PMV model.

Significant proportions of occupants are prepared to accept as comfortable, conditions that would normally be predicted to require substantial change to produce satisfaction.

This evidence indicates that some of the hypotheses advanced in previous research; namely that PMV limits for transition spaces can be expanded beyond the conventional indoor limit of ±0.5; can be developed further.

The impact of widening effective PMV boundaries for transition spaces would be reductions in winter heating demand and summer cooling demand. The benefits of such impacts are enhanced by the fact that transition spaces already use more energy per unit area or volume than many other rooms in a building.

It may also suggest that larger proportions of buildings could be designated as transition spaces or buffer areas (providing thermal separation can be achieved between it and the interior) in order to take advantage of this benefit.

As a result of potential design changes for transition spaces, research into effective architectural strategies to accompany this might also be required

Recommendations following from this work include the need for more detailed study of occupants to determine how they react to particular questions about comfort. It is also important to ask how important it is to achieve thermally comfortable conditions in transition spaces.

Further study is also required to expand the database of evidence to include larger numbers of respondents in order to provide more statistically significant findings. Studies at different times of year in which more variable exterior climates are experienced should also be included. In addition factors such as gender and age could be considered.

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