Transition Spaces and Thermal Comfort – Opportunities for Optimising Energy Use

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ABSTRACT: This paper reports on research that examines the role of transition spaces in buildings and the energy use therein, with particular reference to occupant thermal comfort. Transition spaces include: entrance foyers, corridors, buffer zones, lobbies and other transitory areas used within buildings but not permanently occupied. Such spaces have a different impact on people passing through than either outdoor or fully indoor areas. They also take up a significant fraction of the total floor area of many buildings and give rise to significant energy use in the provision of comfort by means of heating, cooling or ventilation systems. The work reported here develops some initial stage concepts that concern opportunities to operate the comfort conditioning systems in modes and to control points that may differ from the main interior spaces of the building. In this way it may be possible to take advantage of the comfort perceptions of temporary occupants so as to offer a less energy intensive solution. Initial trial calculations have been conducted using standardised building layouts and basic modelling programme in order to determine the potential for change and energy savings, which appear substantial. As this paper represents only the initial stages of the study, more complete and complex investigations are already underway

Keywords: transition spaces, comfort, energy

1. INTRODUCTION

An interesting and potentially fruitful topic for research into improved energy efficiency concerns transition spaces in buildings. These include such areas as foyers, lobbies, certain atria and ancillary spaces not directly occupied in relation to the activity of the building. Such spaces act to modify experience and expectation of persons moving through them. The opportunity for such areas to be provided with environmental conditions lying between internal and external conditions may offer benefits such as reduction of thermal shock for occupants moving into and out of spaces as well as modifying comfort expectations.

An additional feature of such spaces is that they are often located at the perimeters of buildings; frequently have large areas of glazing and also experience significant air exchange with the outside environment. Therefore they may require considerably higher levels of heating and cooling system capacity for comfort conditioning and consequently also have higher energy consumption. Some research has previously shown that transitional spaces can help to save energy if they can be developed according to their climatic needs [1].

2. BACKGROUND

The inclusion of transitional and circulation spaces, in the form of corridors, draught lobbies, atriums and stairwells, is unavoidable in the design of most non-domestic buildings. The percentages of such areas may vary between 10 to 40 percent of the total volume in different building types.

Transitional spaces are defined as spaces located in-between outdoor and indoor environments acting as both buffer space and physical link. Other than being functional as circulatory routes for the building, the designs of these spaces is considered very important by building designers for reasons of aesthetics, health and comfort, and as emergency exit routes in the event of fire. The importance of optimum energy consumption in transitional spaces is also important in non-domestic buildings, as these spaces do not generate income, hence any wastage associated with higher energy cost is economically difficult to justify.

Currently, to sustain comfort levels for these environments, as prescribed by various building standards, requires considerable amounts of energy. The energy consumption may even be as high as the energy use in all other occupied areas of the building taken together; thus buildings that have sizable circulatory spaces face higher operational costs. Indeed some researchers have suggested that the energy consumption in transitional spaces, per unit area or volume, may be as high as three times that of the remainder of the inside of a building [2], [3].

This paper aims to investigate the impact of transitional spaces and their influence on energy consumption in buildings as a result of variations in the following: building envelope: form, fenestration, layout and orientation, and ventilation rates.

Further studies concerned with different climates will be undertaken in a later part of the project.

Several notional types of buildings layout that are typically found have been used for simple investigative modelling of energy consumption. The shapes are indicative of a single floor but multi-storey expansions of these shapes could be accommodated. The study initially assumed comfort levels that conformed to the recognised building environmental standards. The levels of comfort in circulatory spaces based on the set-point temperature are investigated in various models and variations in temperature are used to gauge/predict effects of modifying the spaces' environmental parameters [4] and the consequential effect on its energy consumption. This may lead to better understanding of how to manage energy consumption in transitional spaces by making adjustments and alterations or choosing alternatives to existing design, as well as taking note of peoples' sensation and expectations.

The investigation also broadens to consider other factors associated with this dynamic type of building space and takes into account how the climate, solar gain, the building form, and location of the transitional spaces, give different values of energy consumption for the whole building throughout the year. At this stage a simplified version has been used taking four average sets of climatic information representing each major season, and being concerned principally with heating requirements.

In practice, the levels of energy consumption in buildings and their transitional spaces may differ from those anticipated at the design stage, (which were probably based on assumption of annual average thermal requirements of the building). The investigation also highlights the different levels of energy consumption that result from what are in effect irreversible design decisions made at the outset. The critical evaluations arising from modelling of notional buildings and from initial evidence on energy consumption may lead to development of a more holistic energy analysis.

3. REVIEW OF COMFORT ISSUES

Contemporary research on thermal comfort has been well document over a period of more than three decades, but mostly in relation to human thermal response to stable environmental conditions. However, the realities of building design and building use by occupants have created a rather more complex situation. Fanger's research in this field, commencing over 30 years ago [5] has led to the specification of international standards for thermal comfort that have been widely adopted. A consequence of this is that an approach which is perhaps best applied to well-controlled, mainly air-conditioned, buildings is used as a benchmark for all space type thermal environmental design in many parts of the world.

The predicted mean vote (PMV) is commonly used as a measure of the average response from a large group of people voting on scale as shown in the left-hand column of table 1.

The Predicted Proportion Dissatisfied (PPD) calculation used in Fanger's comfort equation combines air temperature, mean radiant temperature, relative humidity, and air speed together with estimates of activity and clothing levels. The PPD index provides a measure of the percentage of people who will complain of thermal discomfort in relation to the PMV. Based on the PPD, there is no condition where everyone will experience comfort, and there is an assumption that there will always be proportion of people who will experience discomfort [6].

Table 1: The Fanger and Bedford comfort scales

Hot	+3	Much too hot
Warm	+2	Too hot
Slightly warm	+l	Comfortably warm
Neutral	0	Comfortable
Slightly cool	-1	Comfortably cool
Cool	-2	Too cool
Cold	-3	Much too cool

Reviews of recent research reveal a lack of information and investigation for occupant response to conditions in transitional spaces. Such spaces increase the dimensions of complexities in maintaining comfort levels; air-changes, number of people, clothing and the time spent in transit such as to give more variable results for what is a more variable environment.

In recent times, various different approaches for assessment of thermal comfort have been put forward as proposed revisions to the current standards; for example, the adaptive methods [7] that take into account human adaptability in various environments. This work might be linked to the current environment under study since research on adaptive approaches might also be used to justify assumptions about how people (using or passing through transition spaces over relatively short periods of time) might react. It has also been suggested by some researchers that occupants are willing to tolerate wider ranges of comfort in certain situations. One might infer an opportunity whereby a wider band of the PMV scale than the usual ±0.5 can be exploited for transition spaces.

It is the intention in the project, of which this paper forms a part, to extend the research and focus on how energy consumption in transitional spaces can be optimised; also to enhance the understanding of peoples' adaptability and to include the practicality of extending adaptability by design of sequential thermal experiences. Also studied will be the impact of different building designs and the types of controls of energy systems that allow potential for better low-energy building design.

4. METHODOLGY

Initially, four different types of notional buildings, described as Models A, B, C and D of 1000m^2 each, have been investigated. These simplified buildings are single storey but of differing forms and layouts; they have been evaluated taking into account variations in orientation and fenestration, principally to assess heat gains and losses. Some, but not all of the options are reported in this paper.

Identical floor areas for different plan variations were picked as examples as they show variations often developed at the design stage that are based on a building's cost budget. This is normally the key information received as part of the design briefs and often used by designers a rule of thumb to develop a building design.

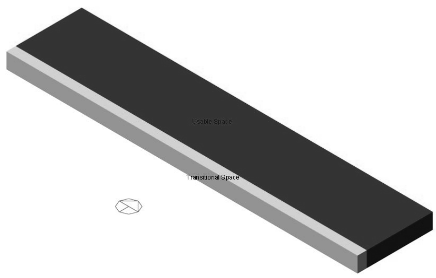

Figure 1: building model A

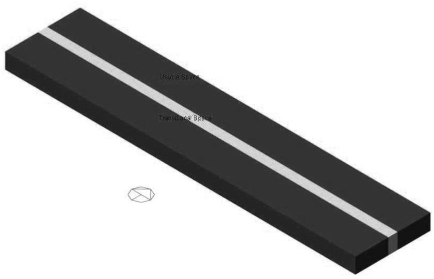

Figure 2: building model C

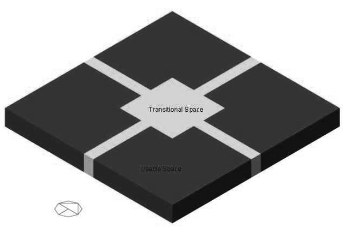

Figure 3: building model C

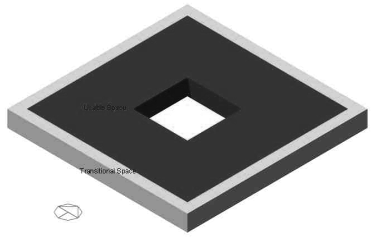

Figure 4: building model D

Model A has a linear corridor transition space along the south façade of a rectangular plan building; Model B has its linear corridor along the long central axis of a similar building. Model C has a square plan with a central circulation space and radial corridors to the perimeter; Model D also uses a square plan but has a central opening and an external perimeter corridor running around the outside. These are simple building types and variations however they do permit some comparisons to be made.

The main spaces identified in each model were differentiated as the 'usable' (that is the internal occupied zone) and 'transitional' spaces. Transitional spaces were organized into four notional plan geometries that provide various proximities to interior and exterior environments. Different wall to glazing ratios of 50:50, 60:40, 70:30 and 80:20 were examined to give various levels of heat loss/gains and then related to the usable and transitional areas of the notional buildings to indicate relative quantities of energy consumption for those spaces.

In the second stage, different temperature control set points were tested in these spaces. For the transitional space occupants could be expected to have different and varied behaviours compared to the usable space as they would be walking and standing, compared to the sedentary behaviour normally found in an internal office space. The frequent opening of doors that connect transitional spaces either directly or indirectly to the outdoors would allow greater air-change in these spaces. Hence, in this investigation a higher air-change was used for the transition zone (one air-change per hour) as compared to the usable interior occupied space at half an air change.

In the third stage, analysis was carried out for the sample buildings set against meteorological data. The modelling has also examined the effect of architectural shape of transitional spaces in relation to the corresponding meteorological conditions.

Average seasonal temperatures for the four different seasons were used (shown in table 2). Sources of heat gains other than from climate were ignored (such as heat gains from building appliances and people). The heat capacities of the building fabric and heat transfer between the two types of space (occupied and transitional) were not taken into account at this stage in order to allow basic comparisons. The affect of controls and complex occupancy patterns were also ignored. These variables that will certainly have impact on the energy consumption and comfort levels will be investigated at a later stage of the current project.

Table 2: Seasonal mean temperatures in 2005 (Source: UK Met Office)

Seasons	Seasonal Mean Temperature (ºC)
winter	5.04
spring	8.8
summer	15.74
autumn	11.17

In the modelling study simple mathematical calculations of the total design heat loss of the notional buildings (based on a spreadsheet methodology devised by the authors) were used as a basis for comparison.

The internal temperatures chosen for investigation were determined by consideration of the heat balance equation and prediction of PMV. Several calculation techniques for determining PMV are available from software and internet sources and are also given in the major internationally recognised standards [8]. The main usable occupied space was assumed to have the following conditions which equate to a PMV of 0.

Air temperature = 23°C
Mean radiant temperature = 23°C
Relative humidity = 50%
Mean air velocity = 0.1 ms^{-1}
Metabolic rate = 1.0 met
Clothing level = 1.0 clo

For the transition space alternative values were chosen for several parameters – firstly the air movement was assumed to be slightly higher at 0.3 ms^{-1}; the metabolic rate was also assumed to be slightly higher at 1.4 mets to account for movement; clothing level was assumed to be the same. Under these conditions a PMV of 0 results when air temperature and mean radiant temperature are 21°C. Adjusting air temperature and mean radiant temperature to either 18°C or 24°C gives a range in PMV of approximately ±0.5; adjusting to 16°C and 26°C gives a range in PMV of ±1.0 which can be argued as appropriate for a transition space which might be in effect equivalent to a more naturally conditioned space. Therefore for the energy analysis the values for internal temperature in the transition spaces were varied to take the following values: 16°C, 18°C, 21°C, 24°C, and 26°C. Though the analysis here has been mainly concerned with heating it can be seen that allowing temperatures to rise in transition spaces would also allow for reductions in cooling requirements to be analysed.

5. MODELLING OUTCOMES AND DATA ANALYSIS

Initially versions of Model A with wall to glazing ratios of 50:50, 60:40, 70:30 and 80:20 were tested. In all of the tests the temperature in usable spaces were set at 23°C with 0.5 air change rate. The air change in all the transitional spaces is set at one air change. The whole building energy consumption with various different transitional spaces in buildings with different wall to glazing ratios are calculated as in table 3 below for the winter season.

The findings indicate that approximately 6% saving for the whole building energy consumption can be achieved when temperature in the transitional space is set with a 3ºC variation in the winter and approximately 10% with a 5ºC variation. The process was repeated for the other 3 seasons and the data are shown in tables 4, 5 and 6.

Table 3: Total Building Heat Loss (W) with various temperature set points in transitional space for winter

Transitional Space Temperature (Ti)	Winter Heat Loss (W)			
	Wall: Glazing % ratio			
	50/50	60/40	70/30	80/20
26°C	36653	35907	33397	31769
24°C	35293	33736	32179	30622
21°C	33253	31803	30353	28903
18°C	31213	29870	28527	27184
16°C	29853	27699	27309	26037

Table 4: Total Building Heat Loss (W) with various temperature set points in transitional space for spring

Transitional Space Temperature (Ti)	Spring Heat Loss (W)			
	Wall: Glazing % ratio			
	50/50	60/40	70/30	80/20
26°C	29654	28334	27015	25696
24°C	28294	27046	25798	24550
21°C	26254	25113	23971	22830
18°C	24214	23180	22145	21111
16°C	26254	21892	20927	19964

Table 5: Total Building Heat Loss (W) with various temperature set points in transitional space for summer

Transitional Space Temperature (Ti)	Summer Building Heat Loss (W)			
	Wall: Glazing % ratio			
	50/50	60/40	70/30	80/20
26°C	16735	15986	15237	14487
24°C	15375	14697	14019	13341
21°C	13336	12764	12193	11621
18°C	11296	10831	10367	9902
16°C	9936	9543	9149	8756

Table 6: Total Building Heat Loss (W) with various temperature set points in transitional space for autumn

Transitional Space Temperature (Ti)	Autumn Building Heat Loss (W)			
	Wall: Glazing % ratio			
	50/50	60/40	70/30	80/20
26°C	25242	24117	22993	21868
24°C	23882	22829	21775	20722
21°C	21842	20896	19949	19002
18°C	19803	18963	18123	17283
16°C	18443	17674	16905	16137

The tables 7, 8, 9, 10, which follow, show summaries of the heating energy savings with various temperatures in the transitional spaces for all building models, set against the four seasonal mean temperatures as in table 2 above; values relating to cooling energy reduction have been ignored for temperatures above 21ºC at this stage.

Table 7: Energy saving potential in winter

Transitional Space Energy - Temperature (Ti)	Winter Energy Saving %			
	Wall: Glazing % ratio			
	50/50	60/40	70/30	80/20
21ºC	0.0%	0.0%	0.0%	0.0%
18ºC	6.1%	6.1%	6.0%	5.9%
16ºC	10.2%	10.1%	10.0%	9.9%

Table 8: Energy saving potential in spring

Transitional Space Energy - Temperature (Ti)	Spring Energy Saving %			
	Wall: Glazing % ratio			
	50/50	60/40	70/30	80/20
21ºC	0.0%	0.0%	0.0%	0.0%
18ºC	7.8%	7.7%	7.6%	7.5%
16ºC	13.0%	12.8%	12.7%	12.5%

Table 9: Energy saving potential in summer

Transitional Space Energy - Temperature (Ti)	Summer Energy Saving %			
	Wall: Glazing % ratio			
	50/50	60/40	70/30	80/20
21ºC	0.0%	0.0%	0.0%	0.0%
18ºC	15.3%	15.1%	14.0%	14.8%
16ºC	25.5%	25.2%	24.0%	24.7%

Table 10: Energy saving potential in autumn

Transitional Space Energy - Temperature (Ti)	Autumn Energy Saving %			
	Wall: Glazing % ratio			
	50/50	60/40	70/30	80/20
21ºC	0.0%	0.0%	0.0%	0.0%
18ºC	9.3%	9.2%	9.1%	9.0%
16ºC	15.6%	15.4%	15.3%	15.1%

The above results show the energy improvements when the temperature in transitional spaces is allowed to differ from the specified set 21ºC. For Model A (50:50 glazing), a 3ºC difference provides a saving of 6.1%, 7.8%, 15.3% and 9.3% in winter, spring, summer and autumn seasons respectively. Similar trends of results are also achieved with different wall to glazing ratios. At this stage the results are indicative and are by no means definitive, further details of daily or even hourly data of temperature will give more complete analysis and this is now planned.

Table 11: Potential energy saving (%) for wall glazing ratio of 50%

Temperature of Transitional space	Potential energy saving (%)			
	Model A	Model B	Model C	Model D
21°C	0	0	0	0
21°C $\pm$ 3°C	6.7%	3.9%	5.1%	9.2%
21°C $\pm$ 5°C	11.2%	6.4%	8.5%	15.3%

Table 12: Instantaneous energy consumption in different building configurations (W)

	Energy Consumption	%Difference over the lowest
Model A 50:50	33870	4.9%
Model B 50:50	32709	1.3%
Model C 50:50	32276	(lowest)
Model D 50:50	35491	9.9%

Table 11 demonstrates the ranking of energy consumption in four different models with wall-glazing ratio of 50:50 and the energy saving that can be achieved by making adjustments in the set point temperature in their respective transitional spaces. Model D with the wrapped-around circulation space that has the largest circulation volume seems to benefit the most from this change in temperature set points but also has the highest consumption at the start.

Table 12 indicates the energy consumption for different models with wall-glazing ratio of 50:50 and their respective ranking in energy consumption. Even though the areas and volumes of these models are identical they have different energy levels. Since the buildings are much simplified versions of reality it is now necessary to develop the analysis further.

6. CONCLUSIONS

This study has investigated energy saving potential if more flexible approaches to defining comfort in transition spaces can be accommodated in building design. This has been tested for four basic building layouts. The results clearly show substantial opportunity for energy saving which can be quantified (for winter) in the region of 6% if set point control temperatures are allowed to vary by ±3ºC and 10% if a ±5ºC variation is permitted.

Further detailed analyses are required for a more holistic picture for the energy consumption of common non-domestic building configurations, which will be investigated as the current project progresses. It is recognised at this stage that many simplifications have had to be made with the methodology; however the task was to assess indicative values of potential heating energy savings in order to determine the future strategy for the subsequent elements of the research project.

The potential practical significance to the building industry, especially in the current climate of energy uncertainties is considerable. This type of information will be most valuable at stages of making the irreversible decisions about basic layout and circulation with considerable implications for future operational costs. It is clear that this will have to incorporate interactions with building services systems and issues arising from occupants and their use of buildings.

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