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Occupant acceptance of discomfort in an atrium building: to sweat or to shiver?

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Abstract: This paper describes research into occupant use of two cafe/seating areas in an atrium building. In particular it deals with two issues: firstly the distribution of temperatures at different points and different floor levels in the atrium over a year; and secondly the acceptance of thermal discomfort by occupants within those spaces. The study of temperature reveals some interesting variations which can be ascribed to wind and stack effects acting to move air in the space, creating variations between locations and changes over the course of a day. Seasonal variations also occur. Significantly there are many times when applying predictive techniques, occupants could be expected to feel thermal discomfort, yet continue to use the spaces when others are available. A survey of occupants taken over a shorter period of time found that despite thermal discomfort, they have some reluctance to change their location. This suggests that factors other than thermal comfort have a significant impact and some of these are investigated.

Keywords: occupant; thermal discomfort; adaptation; atrium

Introduction

Originally atriums were designed to be open courtyards between buildings but over a period of time they came to be defined rather more as enclosed version of the same space. In modern architecture, atrium spaces are used in and around buildings for several functions. Sometimes they are designed into a new building to provide a means for accessing light and ventilation in what would otherwise be a deep-plan building. In others a roof is added to an open court in order to protect from the external climate and allow circulation of occupants. Sometimes an atrium is created to bind together several separate buildings within a new complex. It has been reported (as described by Douvlou, 2004) that the environmental intention of using an atrium was to create external conditions as might be found in Mediterranean climates within buildings of more northern latitudes; in other words to moderate the external climate to make it less uncomfortable than its unenclosed counterpart.

This is not the same as making it fully comfortable however, as it should not be the intention to create a fully serviced space – atriums are more likely to be at least in part, free-running with a substantial degree of natural ventilation and lighting – and those more prone to variation. A difficulty can arise however when the atrium is designed (or evolves over a period of time) to be used as a more normally enclosed and occupied portion of the building – a role for which it may be unsuitable.

This paper deals with a case study of a particular five storey atrium at the heart of a complex of academic buildings. The space between the buildings was originally open but it is now enclosed with a glazed roof which encourages significant solar gain. Its walls are almost entirely formed from the sides of the bordering buildings except for a few narrow but full height external glazed strips, and a glazed entrance area which also slopes up to full height.

The atrium is used as a primary circulation route in the building group with an open staircase as its pivotal element. Also present are two relatively popular cafe areas – one at the base of the atrium (the Heartspace Cafe) and one at the top (the Cutting Edge Cafe); as well as a number of other seating areas and short-term use computer terminal areas. Thermal control is modest, mainly consisting of underfloor heating at the base level and openable windows in the roof and side panel glazing; uncontrolled heat gain also occurs from the surrounding buildings. The system is not capable of controlling to a high degree of comfort under cold winter or hot summer days respectively. The photographs shown in figures 1 and 2 illustrate the atrium and its surroundings.

Figure 1: Atrium Interior 1

Figure 2: Atrium Interior 2

This paper arose from research into environmental conditions in the atrium prompted by anecdotal evidence that despite discomfort, occupants of the cafe areas were prepared to accept a considerable variation from neutral before moving location. Under cold conditions occupants appeared to retain additional clothing (such as jackets/coats) and be prepared to occupy the spaces despite the conditions. The coldest conditions seemed to be experienced on the lower level of the atrium since a ‘corridor’ route led into this space from an external automatic door. This allowed ingress of cold air and cooling of the main space which progressed in proportion to the opening of the door (i.e. as the day and occupant traffic increased). Conversely in summer, warm conditions were found on the upper level cafe arising from convection of warm air upwards and the impact of solar radiation through the roof. Some areas of

the upper cafe (Cutting Edge) were provided with shading and in addition further shading from walkways, stairs and surrounding buildings also occurred. The exact impact of the heat gain deserves more investigation but is not covered in this paper.

A number of previous studies have been undertaken to investigate atrium and transition spaces in order to determine their specific attributes with regard to thermal comfort (see for example Jitkhajornwanich and Pitts, 2002, and Pitts and Douvlou-Beggiora, 2004). Air movement in atrium spaces has also been considered (Li and Pitts, 2007), but of particular relevance in prompting this study has been opportunity to reduce servicing and thus energy consumption (Pitts and Saleh, 2007) if occupants are prepared to accept a lower standard of comfort compensated for by other factors.

Layout of Atrium Space

The basic plan layout of the atrium is an 'L' shape in which the larger portion of the letter represents the main occupied area (5 storeys in height). The shorter potion of the L represents the principal direct connection with the outside through a wide access route/corridor with a glazed roof which gradually deceases in height from 5 to 1 storeys. This access route has double doors to the exterior and effectively performs as a buffer zone between the atrium interior and external weather conditions. The relationship between the spaces can be seen in figure 3.

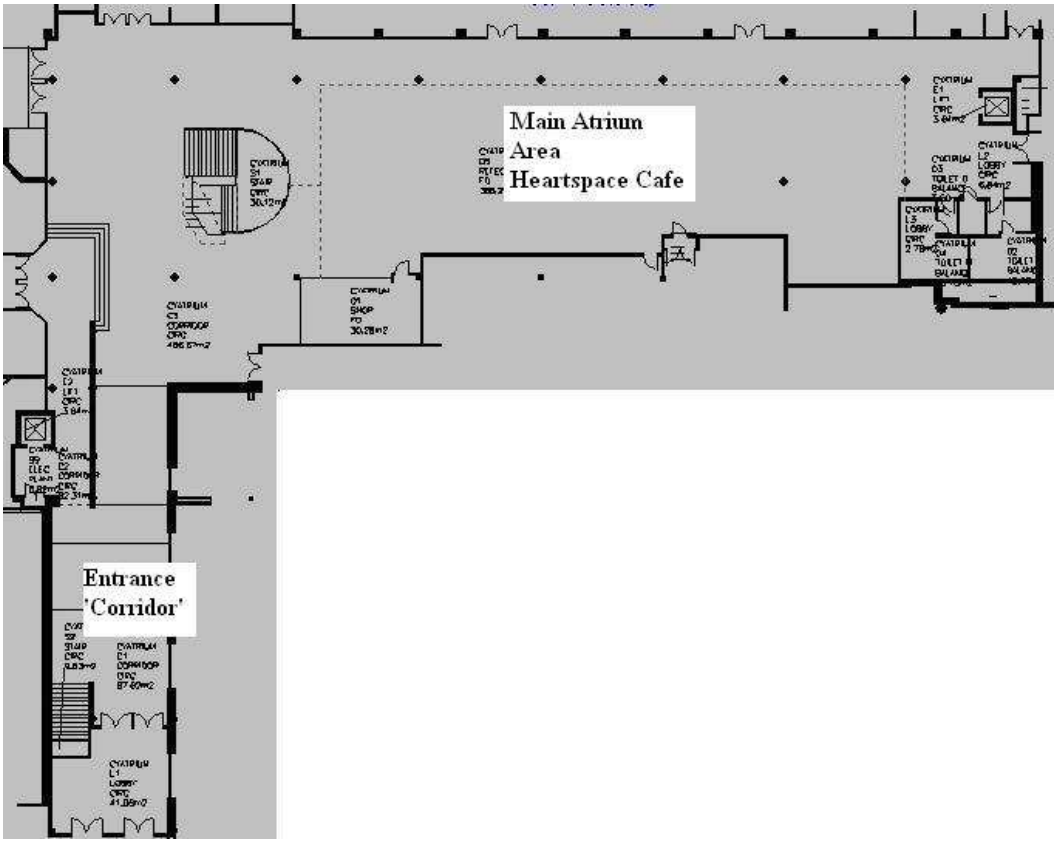

Figure 3: Plan of lower level showing link between atrium and exterior

The main portion of the atrium is bounded on most of its perimeter by the envelope of adjacent buildings which have a high proportion of glazing, but no openable windows

between the atrium and those spaces. Mechanically and automatically controlled windows in the atrium side walls and roof do operate however, in particular to provide summer ventilation and cooling.

Temperature Survey

Temperatures were monitored in the atrium and surrounding areas for almost the whole of the calendar year 2008. Measurements were not taken in January or December as these were considered to be anomalous months due the operating schedule of the University and the winter period when the atrium was little used. Small environmental dataloggers were initially checked for calibration purposes before being installed. Care was taken to avoid exposure to direct sunlight, thus to measure air temperatures. It was not possible to measure radiant temperatures over the longer term but relative humidity levels were recorded (though not used in this analysis). The data loggers were positioned at the following locations:

1. Outside in a shaded position on the roof of an adjacent building
2. At the Entrance to the atrium
3. Half way along the 'Corridor' linking the exterior to the main atrium space
4. In the lower level (Heartspace) cafe area close to the corridor (H1)
5. In the lower level (Heartspace) cafe area away from the corridor (H2)
6. At the upper level (Cutting Edge) cafe area (C)

Table 1 summarises the data collected for ten months individually and for the whole period of the data gathering. Average, maximum and minimum values are presented. Figure 4 provides an overview of the summary data for the whole period illustrating how the temperature varies between principal measurement locations.

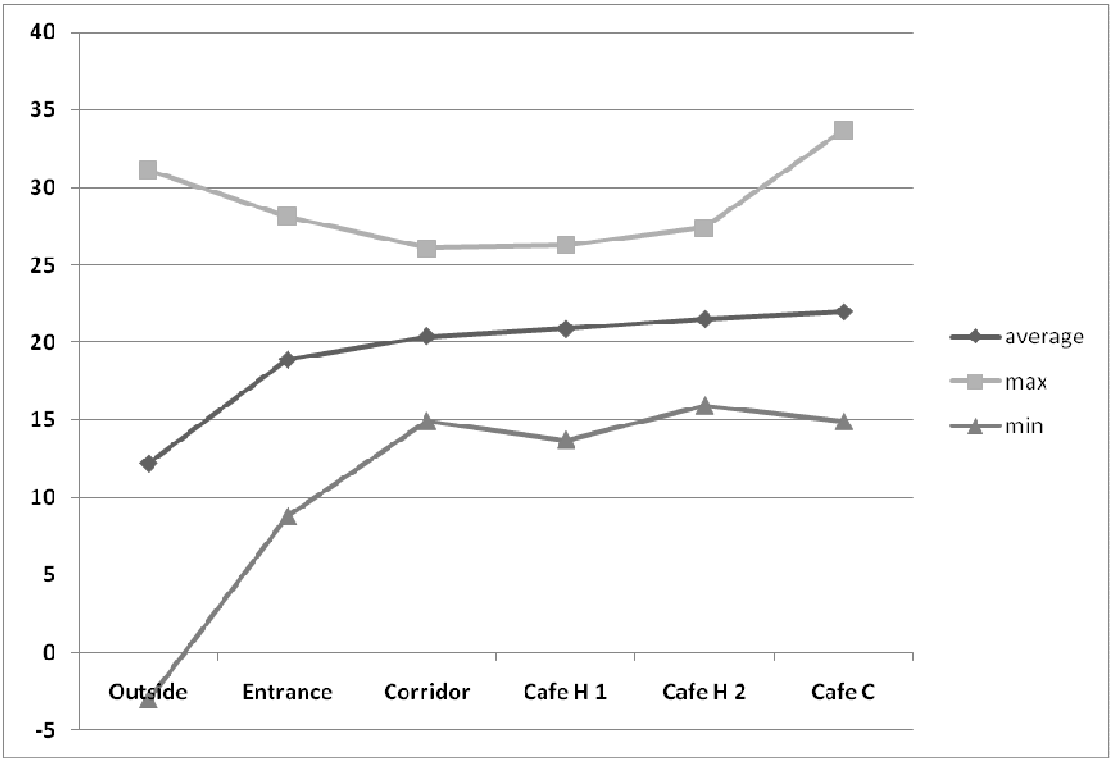

Figure 4: All months' temperature data for key locations around the atrium area (C°) (H1= heartspace position 1; H2= Heartspace position 2; C= Cutting Edge)

It is also interesting to consider the variations between particular measurement points in a more systematic way by choosing specific pairs of points. Those chosen (and shown in Table 2) were as follows:

- Difference between inside entrance door and outside
- Difference between corridor and entrance door
- Difference between cafe (position H1) and corridor
- Difference between cafe positions H2 and H1
- Difference between cafe position H2 and outside
- Difference between cafe positions C and H1

Table 1: Temperatures at selected points in and around atrium
Note: Cafe H1 = Heartspace Cafe (lower cafe) position 1; Cafe H2 = Heartspace Cafe (lower cafe) position 2; Cafe C = Cutting Edge Cafe (higher cafe)

Month	**Temp (C°)**	**outside**	**entrance**	**corridor**	**Cafe H1**	**Cafe H2**	**Cafe C**
February	maximum	16.3	16.6	19.5	21.2	21.2	24.7
	average	**9.7**	**18.5**	**18.7**	**20.0**	**20.3**	**20.1**
	minimum	5.1	14.1	17.7	18.2	19.2	17.4
March	maximum	19.9	21.0	20.2	22.2	22.3	29.7
	average	**6.4**	**16.2**	**18.2**	**19.7**	**20.0**	**20.1**
	minimum	-2.4	8.8	14.9	13.7	15.9	14.9
April	maximum	22.0	22.3	22.1	22.9	23.9	29.1
	average	**7.7**	**17.2**	**19.1**	**20.2**	**20.8**	**21.0**
	minimum	-2.9	10.0	16.7	14.9	17.2	16.6
May	maximum	29.1	27.0	25.2	25.4	26.3	32.6
	average	**13.7**	**20.7**	**21.5**	**21.5**	**22.2**	**23.2**
	minimum	0.4	15.4	17.8	15.6	17.1	17.1
June	maximum	28.0	26.9	24.7	25.3	27.4	33.4
	average	**15.4**	**21.2**	**21.7**	**21.5**	**22.3**	**23.4**
	minimum	4.9	14.9	18.8	18.4	20.0	19.4
July	maximum	31.1	28.1	26.1	26.3	27.4	33.7
	average	**17.5**	**22.5**	**22.7**	**22.3**	**23.0**	**24.2**
	minimum	8.0	19.1	20.4	18.9	21.0	20.1
August	maximum	27.4	25.8	24.8	24.6	24.9	33.7
	average	**17.3**	**22.4**	**23.0**	**22.4**	**22.9**	**24.2**
	minimum	6.9	19.6	21.2	19.4	20.1	20.9
September	maximum	24.1	22.8	23.2	23.3	24.2	28.6
	average	**13.9**	**18.5**	**20.4**	**20.6**	**21.4**	**21.6**
	minimum	5.3	14.6	18.4	18.5	19.7	19.7
October	maximum	21.3	20.7	20.8	22.2	21.8	25.2
	average	**9.7**	**15.7**	**18.5**	**19.6**	**20.2**	**19.9**
	minimum	-3.0	9.6	14.9	15.1	17.3	15.3
November	maximum	14.5	18.4	21.2	25.5	24.2	24.7
	average	**7.7**	**14.6**	**18.1**	**20.4**	**20.5**	**20.1**
	minimum	-2.0	10.2	15.9	16.5	18.2	17.0
All months	maximum	31.1	28.1	26.1	26.3	27.4	33.7
	average	**12.2**	**18.9**	**20.1**	**20.9**	**21.5**	**22.0**
	minimum	-3.0	8.8	14.9	13.7	15.9	14.9

Table 2: Temperature variations between measurement positions

Month	Temp (C°)	entrance to outside	corridor to entrance	H1 to corridor	H2 to H1	H2 to outside	C to H1
Feb	high	9.9	4.0	2.5	1.4	14.3	3.9
	average	**7.0**	**2.1**	**1.3**	**0.3**	**10.6**	**0.0**
	low	-0.1	0.7	-0.1	-0.5	4.5	-1.0
March	high	17.1	6.4	3.4	2.4	21.2	8.3
	average	**9.7**	**2.1**	**1.5**	**0.3**	**13.6**	**0.4**
	low	-4.3	-1.4	-1.4	-1.0	0.6	-1.4
April	high	19.3	6.9	3.0	2.5	22.4	7.3
	average	**9.6**	**1.9**	**1.0**	**0.6**	**13.1**	**0.8**
	low	0.3	-1.0	-1.9	-0.5	0.9	-1.1
May	high	16.8	4.8	2.2	2.4	20.4	9.9
	average	**6.9**	**0.8**	**0.0**	**0.7**	**8.5**	**1.7**
	low	-3.7	-2.4	-2.5	-0.9	-4.6	-0.6
June	high	12.9	4.1	1.0	2.9	15.6	8.8
	average	**5.5**	**0.5**	**-0.2**	**0.8**	**6.6**	**1.9**
	low	-2.2	-2.8	-2.4	0.0	-1.9	-0.6
July	high	12.3	2.6	0.8	2.7	14.1	6.7
	average	**5.0**	**0.2**	**-0.4**	**0.7**	**5.6**	**1.2**
	low	-4.3	-2.6	-2.3	-0.1	-5.1	-1.2
August	high	11.6	3.1	0.4	2.2	12.9	11.7
	average	**4.7**	**0.6**	**-0.6**	**0.5**	**5.2**	**1.8**
	low	1.9	-1.6	-2.7	-0.7	-2.2	-0.4
Sept	high	10.0	4.1	1.6	1.9	14.4	6.1
	average	**4.7**	**1.9**	**0.2**	**0.7**	**7.5**	**0.9**
	low	-3.6	-0.6	-1.7	-0.3	-2.4	-0.6
Oct	high	13.5	6.5	3.7	2.7	22.2	5.3
	average	**6.0**	**2.9**	**1.1**	**0.5**	**10.5**	**0.3**
	low	-1.1	-0.1	-2.5	-0.6	0.2	-1.4
Nov	high	12.8	7.1	5.0	1.8	21.8	2.5
	average	**6.9**	**3.6**	**2.3**	**0.2**	**12.8**	**-0.3**
	low	1.9	0.9	-0.1	-1.6	6.4	-1.9
All	high	19.3	7.1	5.0	2.9	22.4	11.7
	average	**6.9**	**1.5**	**0.5**	**0.6**	**9.5**	**1.0**
	low	-4.3	-2.8	-2.7	-1.6	-5.1	-1.9

Key features to note from the gathered temperature data are as follows:

- Temperatures are at their lowest close to the entrance and gradually increase as the space is entered (particularly noticeable during cool periods).
- The temperature at the position in the lower cafe closest to the entrance is quite cool on occasions (below 19°C during occupied periods) which could be expected to lead to sensations of discomfort unless additional clothing is worn.
- The temperature in the upper floor cafe is normally warmer than the lower level – it is suggested that this occurs due to thermal stratification and also because the lower level is more susceptible to the ingress of external air. During summer months temperatures are on average between 1 and 2 C° higher.

- The temperatures in the upper cafe area on occasion reached high values (up to 33.7°C) during warm periods

From this range of temperature data one might infer that the variability indicates a degree of free-running and external influence and that regular occupants of the spaces would be aware of such variability.

Occupant Survey

Four occupant surveys were carried out specifically to address issues of comfort and discomfort acceptance during the cooler part of the year. The survey questionnaire was completed by 72 occupants spread over 4 periods with two surveys each in the two cafe areas discussed earlier. Figures 5 and 6 give clearer impressions of these two cafe areas. The full questionnaire is shown in the appendix – not all information gathered is analysed and presented here however.

Actual Mean Vote (AMV) was computed for each survey and from these values an assumed Predicted Percentage Dissatisfied (aPPD) was determined using the equation normally used to derive this from the *Predicted* Mean Vote (PMV) analysis process:

$$aPPD = 100 - 95e^{-(0.03353AMV\hat{}4 = 0.2179AMV\hat{}2)}$$

This information is included in table 3 which has four subsections: one for each survey. Also drawn out from the questionnaire responses and included in the table are the data for the percentage of respondents replying that they were not comfortable and the percentage indicating that they would be prepared to change their location depending upon prevailing environmental conditions.

Since the sample sizes are relatively small, further research (including during other seasons) is required.

Figure 5: Heartspace Cafe Area (lower level of atrium)

Figure 6: Cutting Edge cafe Area (upper level of atrium)

If the data of table 3 are considered the following points might be inferred:

- That despite considerable levels of thermal discomfort, both predicted from the voting and measured from responses, occupants do not leave the space in which they are sitting
- That a relatively small proportion of all the respondents are prepared to change their position because of their perception of the thermal environment.

This leads to a consideration of the reasons why occupants decide to remain in what may be an uncomfortable space and also particular features, beyond the measured comfort parameters, impact on their perception. Table 4 provides some of the answers: the most reported reason for using the space was ‘it is close to the activity I have been doing or will be doing’ followed by ‘the people I am with chose to come/meet here’.

Taking account of the evidence gathered it would seem that the atrium space is recognised by its occupants to have a variable environment and thus a variable level of thermal comfort applying the normal standards for such analysis; but that despite this, occupants will accept the discomfort in order to benefit from its other attributes. It is not clear from the analysis and data so far gathered how far this ‘forgiveness’ extends, however it has some analogies with the situation of outdoor cafes in which thermally comfortable conditions do not often occur. The difference in this case is that the atrium space is being space conditioned, even if not effectively, and thus the control and services systems, might be operated in different modes with potential for energy saving.

Table 3: Summary of occupant comfort surveys

Survey 1: Heartspace Cafe (lower level)	
Number of respondents	15
Actual Mean Vote (AMV)	-2.0
Expected Percentage Dissatisfied based on AMV	76.7%
Percentage Not Comfortable	46.7%
Percentage changing position according to conditions	8%
Survey 2: Heartspace Cafe (lower level)	
Number of respondents	28
Actual Mean Vote (AMV)	-0.82
Expected Percentage Dissatisfied based on AMV	19.2%
Percentage Not Comfortable	25.0%
Percentage changing position according to conditions	16%
Survey 3: Cutting Edge Cafe (upper level)	
Number of respondents	18
Actual Mean Vote (AMV)	-0.7
Expected Percentage Dissatisfied based on AMV	15.3%
Percentage Not Comfortable	5.5%
Percentage changing position according to conditions	6%
Survey 4: Cutting Edge Cafe (upper level)	
Number of respondents	11
Actual Mean Vote	-0.27
Expected Percentage Dissatisfied based on AMV	6.5%
Percentage Not Comfortable	18%
Percentage changing position according to conditions	18%

Conclusions

The conclusions of this paper which reports on *work in progress* to investigate thermal conditions and comfort in an atrium building can be summarised in the following points:

- Atrium spaces unless provided with significant space conditioning systems and capacity, are likely to result in internal conditions which vary from accepted comfort normal for enclosed and occupied parts of buildings
- Significant variations from place to place in an atrium are also likely due to the impact of external doors and thermal stratification
- Occupants will still choose to utilise atrium and similar spaces for temporary activities such as taking refreshments despite the lack of ideal thermal comfort
- The reasons why such occupants utilise spaces lacking comfort are varied but are frequently linked to social activities and peer groups

- Potential for reducing energy use in atrium and transition spaces is once again confirmed however more information is required on the balance points for decision making by occupants about acceptable levels of discomfort

Further Work

This paper has presented information on a single building; clearly there is scope to advance and develop the analysis and the hypotheses by reference to a wider study of a larger number of buildings. An occupant study of a larger number of respondents and with more detail on particular aspects of decision making is also required.

Table 4: Frequency of reported reasons for choosing cafe seating area

Response	Survey Number			
	1 Lower cafe	2 Lower cafe	3 Upper cafe	4 Upper cafe
It is close to the activity I have been doing or will be doing	6	16	6	7
The food/drinks are good quality or there is a good range	0	4	4	3
The people I am with chose to come/meet here	3	10	8	7
There is a pleasant well designed environment here	2	4	4	7
I always sit here out of habit	0	2	3	2

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Appendix: Questionnaire: **COMFORT IN THE ATRIUM SPACE CAFES**

1. **Are you:** Staff / Student / Visitor (please circle) **Time and Date** .....

2. **Which space are you sitting in:** Heartspace (level 2) Cutting Edge (level 5)

3. **Thinking about the thermal environment, are you comfortable at the moment?**
   Yes / No

4. **How do you feel at the moment (your thermal sensation)?**

cold	cool	slightly cool	neutral	slightly warm	warm	hot

5. **Would you prefer to be?**

much cooler	cooler	no change	warmer	much warmer

6. **Before coming into the cafe area did you expect to feel?**

cold	cool	slightly cool	neutral	slightly warm	warm	hot

7. **If you are a regular user of the Atrium space cafes do you normally sit in this space or do you use another area?**
   normally use this space / normally use somewhere else / no set pattern

8. **Do you change the cafe area that you use according to whether it is hot or cold?**
   Yes / No

   If so which space do you prefer when it is ...
   warm/hot: Heartspace / Cutting Edge / other (please identify) .....
   cool/cold: Heartspace / Cutting Edge / other (please identify) .....

9. **What caused you to choose this space to sit in today? (tick as many as apply)**

   It is close to the activity I have been doing or will be doing

   The food/drinks are good quality or there is a good range

   The people I am with chose to come/meet here

   There is a pleasant well designed environment here

   I always sit here out of habit

   Any other reason?.....

10. **Are you currently experiencing discomfort from any of the following? (tick as many as apply)**

    There is a cool draught of air

    There is glare from the windows

    There is too much noise

    There is overheating from the sun

    There air is stuffy

    There are bad smells/aromas

    Any other discomforts? .....