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BEES INTERIM REPORT

Building energy end-use study - Year 4

TEMPERATURE CONTROL

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BEES (BUILDING END-USE STUDY) YEAR 4: TEMPERATURE CONTROL

BRANZ Study Report SR 260/5

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Reference

Bishop, R., Camilleri, M & Burrough, L. (2011). BEES (Building energy end-use study) Year 4: Temperature Control, BRANZ study report 260/5, Judgeford.

energy solutions

BEES publications can be downloaded from the BEES website - http://www.branz.co.nz/bees

Following is a list of other reports in the BEES Year 4 series:

- Saville-Smith, K. (2011). BEES (Building energy end-use study) Year 4: Insight into barriers, BRANZ study report 260/1, Judgeford.
- Camilleri, M., & Babylon, W.M (2011). BEES (Building energy end-use study) Year 4: Detailed monitoring, BRANZ study report 260/2, Judgeford.
- Bishop, R., Camilleri, M & Isaacs, N. (2011). BEES (Building energy end-use study) Year 4: Delivered daylighting, BRANZ study report 260/3, Judgeford.
- Bishop, R., Camilleri, M & Isaacs, N. (2011). BEES (Building energy end-use study) Year 4: Achieved conditions, BRANZ study report 260/4, Judgeford.
- Bishop, R. (2011). BEES (Building energy end-use study) Year 4: Electrical loads, BRANZ study report 260/6, Judgeford.
- Isaacs, N. (2011). BEES (Building energy end-use study) Year 4: From Warehouses to Shops - Changing Uses in the Non-residential Buildings Sector, BRANZ study report 260/7, Judgeford.

PREFACE

Understanding how energy and water resources are used in non-residential buildings is key to improving the energy and water efficiency of New Zealand's building stock. More efficient buildings will help reduce greenhouse gas emissions and enhance business competitiveness. The Building Energy End-use Study (BEES) is taking the first step towards this by establishing where and how energy and water resources are used in non-residential buildings and what factors drive the use of these resources.

The BEES study started in 2007 and will run for six years, gathering information on energy and water use through carrying out surveys and monitoring non-residential buildings. By analysing the information gathered, BEES aims to answer eight key research questions about resource use in buildings:

1. What is the aggregate energy and water use of non-residential buildings in New Zealand?
2. What is the average energy and water use per unit area per year?
3. What characterises the buildings that use the most energy and water?
4. What is the average energy use per unit area for different categories of building use?
5. What are the distributions of energy and water use?
6. What are the determinants of water and energy-use patterns e.g. structure, form, function, occupancy, building management etc?
7. Where are the critical intervention points to improve resource use efficiency?
8. What are the likely future changes as the building stock type and distribution change?

Understanding the importance and interaction of users, owners and those who service non-residential buildings is also an important component of the study.

For the BEES study, non-residential buildings have been defined using categories in the New Zealand Building Code, but in general terms the study is mainly looking at commercial office and retail buildings. These vary from small corner store dairies to large multi-storey office buildings. For more information on the building types included in the study please refer to BRANZ report SR224 Building Energy End-use Study (BEES) Years 1 & 2 (2009) available on the BEES website (www.branz.co.nz/BEES).

The study has two main methods of data collection – a high level survey of buildings and businesses, and intensive detailed monitoring of individual premises.

The high level survey initially involved collecting data about a large number of buildings. From this large sample, a smaller survey of businesses within buildings was carried out which included a phone survey, and collecting records of energy and water use and data on floor areas. The information will enable a picture to be built up of the total and average energy and water use in non-residential buildings, the intensity of this use and resources used by different categories of building use, answering research questions 1-4.

The detailed monitoring of individual premises involves energy and indoor condition monitoring, occupant questionnaires and a number of audits, including: appliances, lighting, building, hot water, water, and equipment.

This report presents data and analysis drawn from the detailed monitoring carried out during the fourth year of this six year study. This report looks at measured temperature data to examine how well controlled temperatures are within spaces. This work is of particular value to thermal modellers and designers, through having a greater understanding of how buildings are performing they can model spaces more realistically or design the heating/cooling system to control temperatures. The data and analysis in this report contributes to answering research questions three and six. This is one of seven interim reports giving a snapshot of analysis completed to date. When all data collection has been completed further analysis will be reported on with the full sample including relationships between end-uses, building types and services.

At this stage of the project, not all the data we need to fully answer the research questions is available. This report only provides analysis and results on buildings less than 9,000 m^2 (size strata 1-4 of the BEES sample). It does not cover the full range of buildings sizes, so these results are not representative of the non-residential building stock. In the remaining two years of the BEES study, further analysis will be carried out using the full sample which will include buildings greater than 9,000 m^2. Further work that is planned is to use the learnings for standard thermal modelling templates, explore the relationships between energy use and temperature control as well as looking at spaces within buildings over 9,000 m^2.

SUMMARY

- With monitored temperature data from about 240 spaces within BEES buildings analysis has been done to see how tightly controlled temperature are within these spaces.
- The outdoor temperature was found to have an influence on indoor temperature
- About 10% of spaces can be considered to have well controlled temperatures and about 40% mostly controlled.
- Retail spaces are more likely to be less controlled than Office and Other spaces.
- The indoor temperature is more likely to be influenced by the outside temperature during Autumn and Spring.
- The spaces looked at are all in buildings that are less than 9,000 m2, larger buildings will be looked at during Year 5 and 6 of BEES. Larger buildings are more likely to have centralised heating/cooling systems that allow greater control over temperatures.

This report is a preliminary analysis of the temperature response of spaces to determine how well space temperature was controlled, as opposed to being influenced by outside temperature ('floating').

Frequently it is assumed by thermal modellers (and those that use the results from models) that spaces have abundant heating and cooling capacity, with good thermostat control, repeatable set-points and buildings users or a manager that can operate the system effectively, resulting in the spaces being kept comfortable with little effort.

Initial building monitoring within BEES has shown that few of the buildings monitored to date have had temperatures that can be considered well controlled.

This was determined by comparing the variation of the temperature indoors over the 10 am – 4 pm weekday period, to the variation in day-to-day temperature differences between indoors and outside.

When a space is well conditioned it will have relatively constant temperatures (so low hour-to-hour and day-to-day internal temperature variation). Conversely, spaces that are not well conditioned will show a relatively constant day-to-day temperature difference compared to outdoors (with what we call a "floating" temperature).

Most spaces were seen to be controlled, but also influenced by outdoor temperature. There was not significant differences between different types of spaces (Retail, Office or Other) in terms of how well controlled their temperatures were. In intermediate seasons, more space temperatures were seen to be "Floating", especially retail spaces.

From this sample, only about 10% of spaces were classified as "well-controlled". However, when added to those classified as "mostly controlled" this comprised about half of the sample. There were distinct seasonal differences, with much better control in winter than in swing seasons, as would be expected.

Table A shows the percentage of spaces in each temperature control zone (Well Controlled through to Floating) by season (Intermediate seasons, Summer and Winter) and space type (Offices, Retail and Other).

Table A: Percentage of spaces in each temperature control zone by season and space type

	Offices			Retail			Other		
	I	S	W	I	S	W	I	S	W
Well Controlled	8%	13%	5%	13%	20%	0%	0%	0%	13%
Mostly Controlled	33%	35%	22%	40%	20%	0%	53%	40%	25%
Both	44%	52%	70%	13%	45%	100%	35%	27%	63%
Mostly Floating	14%	0%	3%	20%	15%	0%	6%	27%	0%
Floating	0%	0%	0%	13%	0%	0%	6%	7%	0%

This type of analysis will be extended to look at the performance of larger buildings, which probably have better controlled temperatures.

The results can be applied to thermal modelling of buildings, by using systems with shorter schedules, and smaller sized heating/cooling equipment, to see how closely the performance of modelled buildings can approach that of real buildings.

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1. INTRODUCTION

One of the most misunderstood elements of Building Science is the control of space temperatures in commercial buildings. Thermal modelling traditionally assumes that spaces have abundant heating and cooling capacity and thermostatic temperature control, with repeatable setpoints so that temperatures are maintained at comfortable levels consistently and automatically.

Initial building monitoring within BEES has shown that few of the buildings monitored to date have had temperatures that would be considered well controlled.

This report is a preliminary analysis of the temperature response of each space to determine how well space temperature was controlled, as opposed to "floating" and influenced by outside temperature. Further analysis will be completed once the full set of BEES buildings are monitored. This analysis contributes to BEES research questions three and six.

This was determined by comparing the variation (standard deviation) of the space temperature over the 10 am – 4 pm weekday period, to the variation in day-to-day temperature difference between the space and outdoors.

The rationale for this analysis is spaces that are well conditioned (with adequate heating capacity and control) will have relatively constant temperatures (so low day-to-day temperature variation). Conversely, spaces that are not well conditioned (with temperatures "floating") will show a relatively constant day-to-day temperature difference compared to outdoors.

Most spaces were seen to be controlled, but also influenced by outdoor temperature. There were not significant differences between different types of spaces in terms of how well controlled their temperatures were. In intermediate seasons, more space temperatures were seen to be "Floating", especially retail spaces.

This report uses monitored data from approximately 240 spaces within 75 premises within 60 BEES buildings. Monitoring was done at a premise level with usually at least three temperature loggers in spaces per premise and up to seven loggers for larger premises. Each premise was monitored for 2-3 weeks with data collected during this time at 10 minute intervals. HOBO U12 data loggers were used to collect the temperature data.

2. SUMMARY OF PREMISES MONITORED

The spaces that were monitored, by type (Office, Retail and Other) and season (Winter, Intermediate seasons and Summer), are shown in Table 1.

Table 1: Spaces monitored by type and season

	Offices			**Retail**			**Other**			**Total**		
	Winter	Int.	Summer	W	I	S	W	I	S	W	I	S
Number of spaces monitored	55	56	31	6	22	20	12	24	15	73	102	66

"Office" spaces included those recorded as Offices (99), Reception (22), Meeting Rooms (15), Conference Rooms (3), and Laboratories (3). "Retail" spaces included those recorded as Shops (47) and Showroom (1). "Other" spaces included those recorded as Kitchens (28), Storerooms (10), Workrooms (7), Warehouses (2), Lounges (2), Dining Room (1), and Bakery (1).

All statistics reported here are for weekdays (Monday – Friday) between 10 am and 4 pm. The conditions in the monitored spaces had generally stabilised during these times, and were considered to be representative of normal working conditions.

3. OBSERVED SPACE TEMPERATURE PATTERNS

Examples of typical temperature profiles recorded in spaces are shown in Figure 1 through to Figure 4. Each of these represents the temperature for each weekday as a thin solid grey line, for each weekend day as a thin dashed red line, the mean value for all weekdays as a thick solid black line, and the mean value for all weekend days as a thick dashed red line.

The main temperature statistics used from these profiles are the mean and standard deviation of the daily temperature on weekdays between 10 am and 4 pm (the middle of the normal working day, when temperatures would be expected to be controlled and reasonably stable).

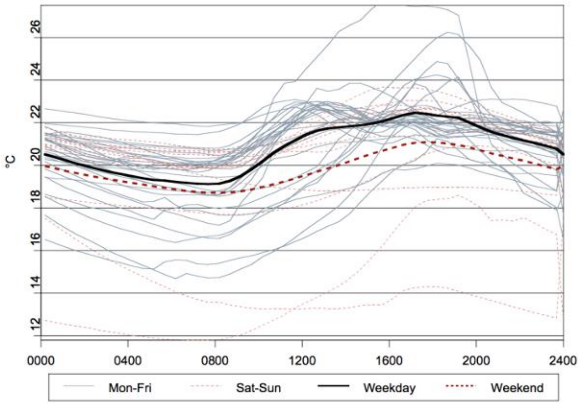

Figure 1: Well controlled wave temperature profile – 21.4±0.8°C

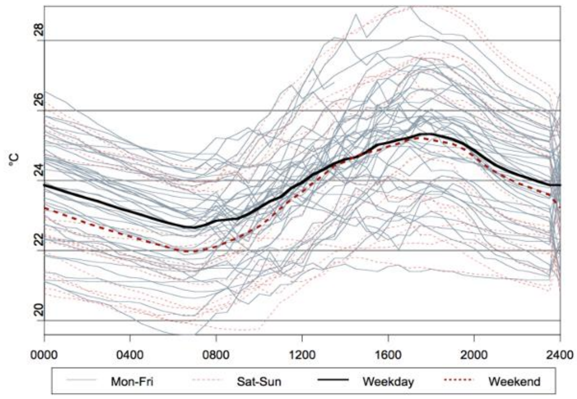

Figure 2: Less well controlled wave temperature profile – 24.3±1.5°C

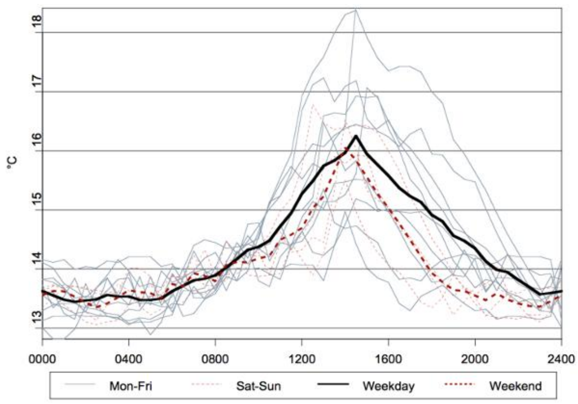

Figure 3: Spiky temperature profile – 15.6±1.3°C

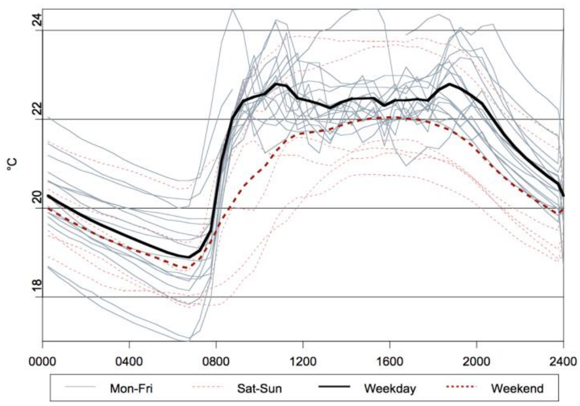

Figure 4: Well controlled and flat temperature profile – 22.3±0.9°C

Figure 1 shows the temperature profile for a space where the temperature varied roughly as a sine wave, with the daily minimum temperature reached about 19°C about 8 am. The temperature rose all day to a peak of about 23°C at about 5 pm, then dropped overnight. Most weekdays showed a pattern similar to this, as seen by the sheaf of thin grey lines above the dark one. The lowest temperature recorded was about 15°C, and the highest about 27°C. Weekend temperatures, as shown by the dotted red line, usually showed a similar pattern about a degree lower.

The weekday 10 am to 4 pm mean temperature was 21.4°C, with a standard deviation of ±0.8°C.

Figure 2 shows the temperature profile for another space with a similar sine-wave shaped temperature profile. This building has much more day-to-day variability than that the previous one. This building showed a weekday 10 am to 4 pm mean temperature of 24.3°C, with a standard deviation of ±1.5°C. This is the standard deviation of the weekday average temperature; the effect of the day-to-day variability is not addressed in this statistical analysis.

Figure 3 shows a different shaped profile, one that has a distinct afternoon peak. This is for a workroom, apparently intermittently heated, which varied from about 13.5°C from 10 pm – 6 am, to a peak of just over 16°C in mid-afternoon. Weekend temperatures were similar, but slightly lower. The weekday 10 am to 4 pm mean temperature was 15.6°C, with a standard deviation of ±1.3°C.

Figure 4 shows a different shaped profile, with a quite well-controlled and constant temperature during working hours. This space typically cooled to about 19°C overnight, but was rapidly heated to over 22°C at 8 am, and generally maintained this temperature until about 8 pm.

There was some variation from day to day, with peak temperatures observed over 24°C at various times on different days, and minima of about 21°C during working hours.

Weekend temperatures were similar, but lower, and showed more of a sine wave pattern, which might indicate that it was free-running. The weekday 10 am to 4 pm mean temperature was 22.3°C, with a standard deviation of ±0.9°C. This is one of the few locations that showed temperatures consistently in the accepted "comfort zone".

4. ANALYSIS OF SPACE TEMPERATURE RESPONSE

The temperature response of each space was analysed to determine how well space temperature was controlled, as opposed to "floating" i.e. influenced by outside temperature.

This compared the variation (standard deviation) of the space temperature over the 10 am – 4 pm weekday period, to the variation in day-to-day temperature difference between the space and outdoors.

This analysis was only possible for premises where good (official daily outdoor) temperature records existed. The rise above outdoor air temperature is defined as the difference between mean weekday 10 am – 4 pm indoor temperature and mean weekday 10 am – 4 pm outdoor temperature, calculated daily.

The rationale for this analysis is that spaces that are well conditioned (with adequate heating capacity and control) would have relatively constant temperatures (so low day-to-day temperature variation), while spaces that are not well conditioned (with temperatures "floating") would show a relatively constant day-to-day temperature difference compared to outdoors.

Figure 5 shows all the results of this analysis, not segregated by space type or season. Points in the "blue" area indicate premises that appear to be more "floating" and influenced by outside temperature, and those in the red area, with better temperature control.

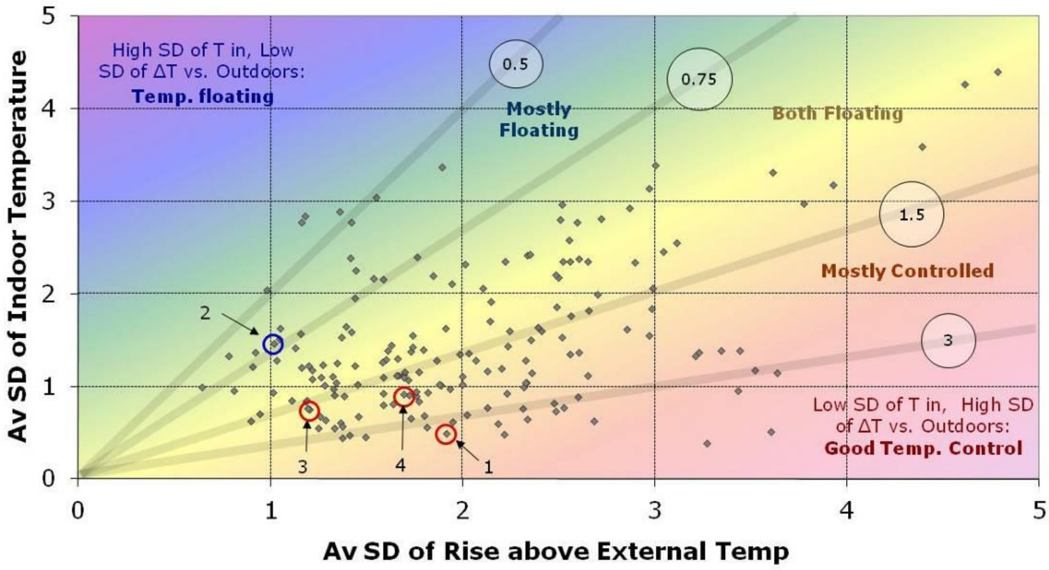

Figure 5: Variation of office temperatures vs. variation in rise above outdoors

Four diagonal lines cross this graph, marked 0.5, 0.75, 1.5 and 3, separating it into five areas. Each line represents a ratio of the standard deviation of the space temperature to the standard deviation in day-to-day temperature difference between the space and outdoors. Points falling in the area with ratios less than 0.5 are considered to have floating temperatures. Those with ratios above 3 are considered to be well controlled, and those with ratios in the intermediate ranges.

The four points representing the temperature profiles shown in Figure 1 through to Figure 4 are circled on Figure 5, so this can be related to temperature patterns. As can be seen, the point marked "2", where the space temperature profile varies each day, is in the "Mostly Floating" zone.

Note that the Standard Deviations of the temperatures analysed here are different from the "Temperature Swings" reported previously, which were the greater of the Standard Deviation, or half of the difference between daily average maximum and minimum.

The analysis was performed and is presented for each group of premises, and each season. The results for Office premises are shown in Figure 6, below.

Figure 6 shows the distribution of these ratios for Offices, with blue squares representing winter conditions, red and yellow circles representing summer, and green triangles representing intermediate season measurements.

As can be seen, there were no Offices in the "Floating" area (with ratio of the standard deviation of the space temperature to the standard deviation in day-to-day temperature difference between the space and outdoors less than 0.5). There were also only a few in the "Good Temperature Control" range. Most ratios fell into the intermediate ranges.

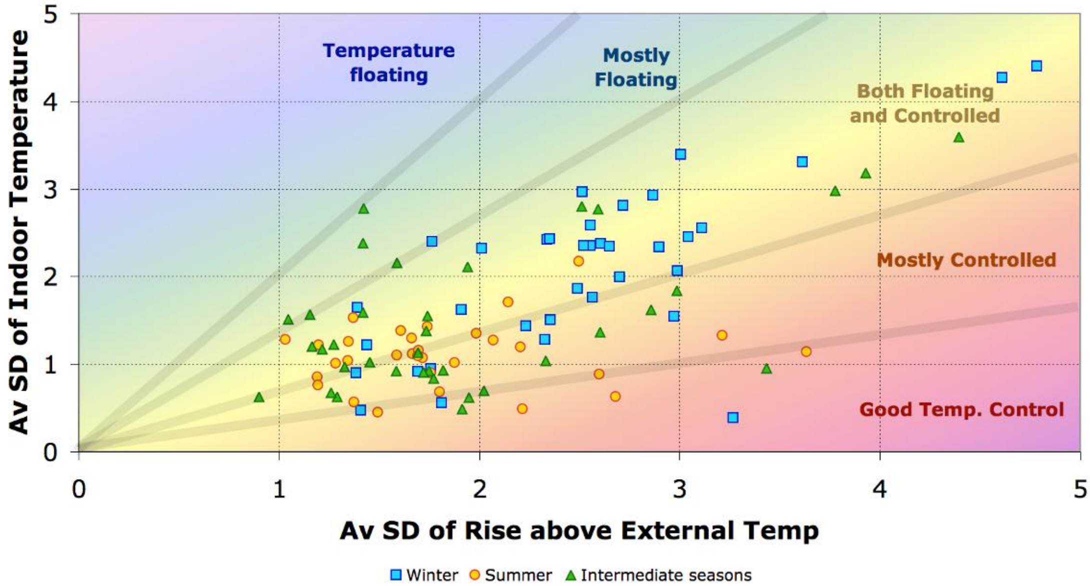

Figure 6: Variation of office temperatures vs. Variation in rise above outdoors

Figure 7 shows the distribution of temperature control for Offices, by season. As can be seen, in all seasons most temperatures seem to be affected by both outdoor temperature and space conditioning equipment and control. However, there were many more spaces in the "Mostly Controlled" and "Well Controlled" zones than "Mostly Floating". Only during intermediate seasons were significant numbers of spaces in "Mostly Floating", when it is less likely that heating and cooling would be used as regularly as winter and summer.

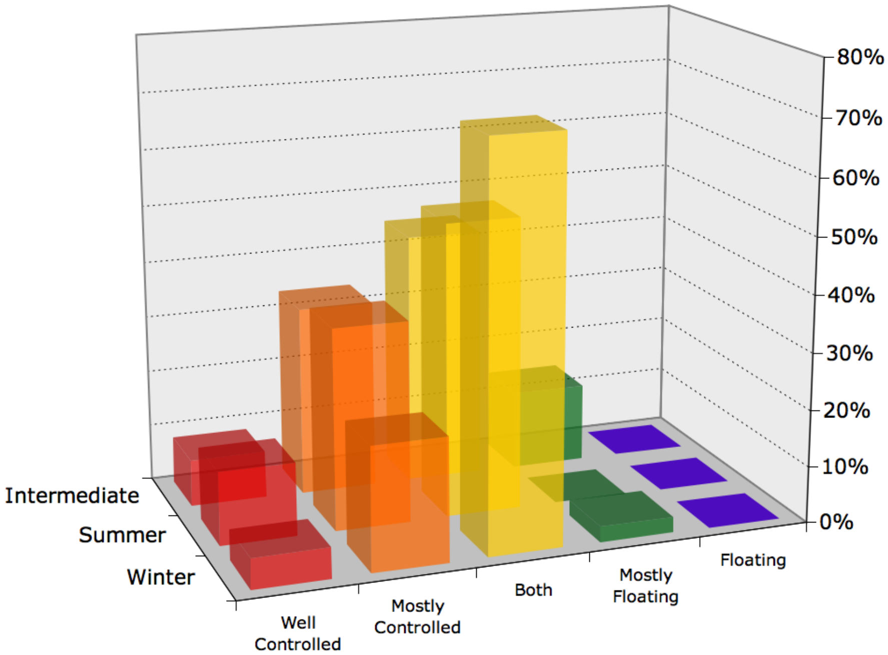

Figure 7: Control of office temperatures vs season

Figure 8 shows the same type of analysis, for Retail spaces. As can be seen, though there are far fewer points, the results are generally similar to those for Offices. More spaces have the temperature well-controlled than not, though most spaces have their temperatures significantly influenced by outdoor temperature.

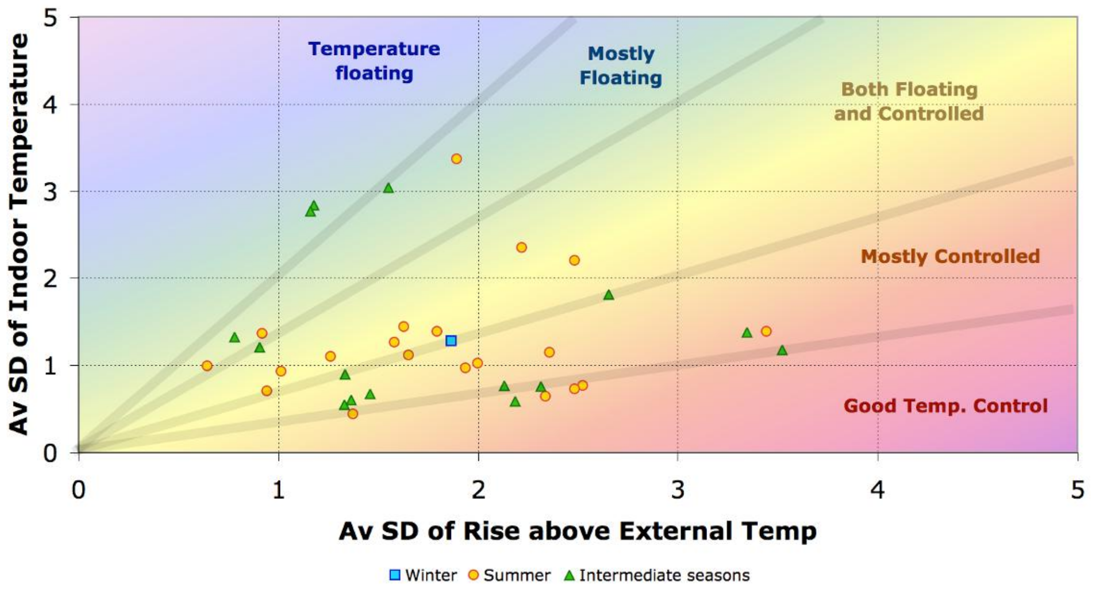

Figure 8: Variation of retail temperatures vs. Variation in rise above outdoors

Figure 9 shows the distribution of temperature control for Retail spaces, by season. More spaces showed "Good Control" than Offices, and only in the intermediate seasons were there spaces in the "Floating" zone. Since there was only one space measured in Winter, its importance was reduced in this graph (from 100% to 10%, for ease of viewing).

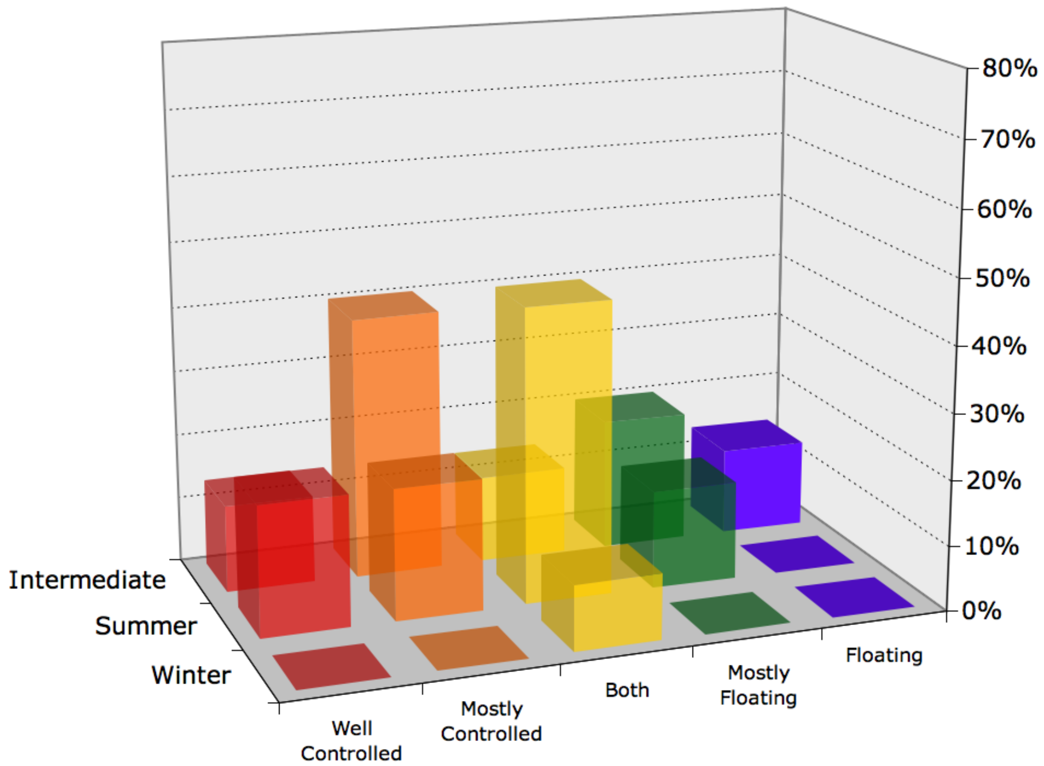

Figure 9: Control of retail temperatures vs. season

Figure 10 shows the same analysis, for Other spaces. The results are generally the same as for Offices and Retail, with more points in the better controlled zones than the floating ones.

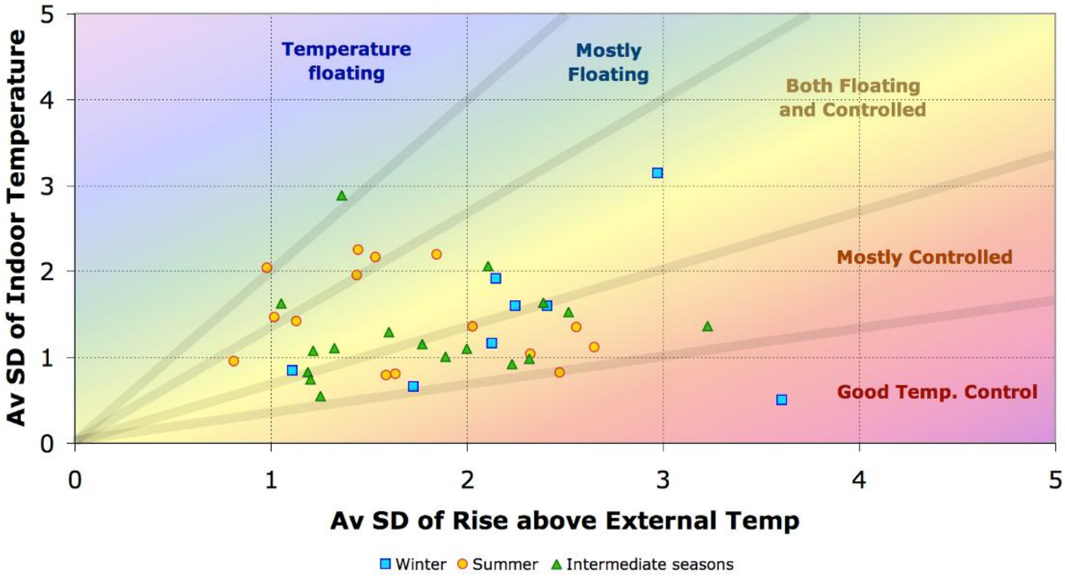

Figure 10: Variation of other temperatures vs. Variation in rise above outdoors

Figure 11 shows the distribution of temperature control for Other spaces, by season. In all seasons, most spaces were in the “Mostly Controlled” and “Both” zones, and only in Summer were there significant spaces in the “Mostly Floating” zone.

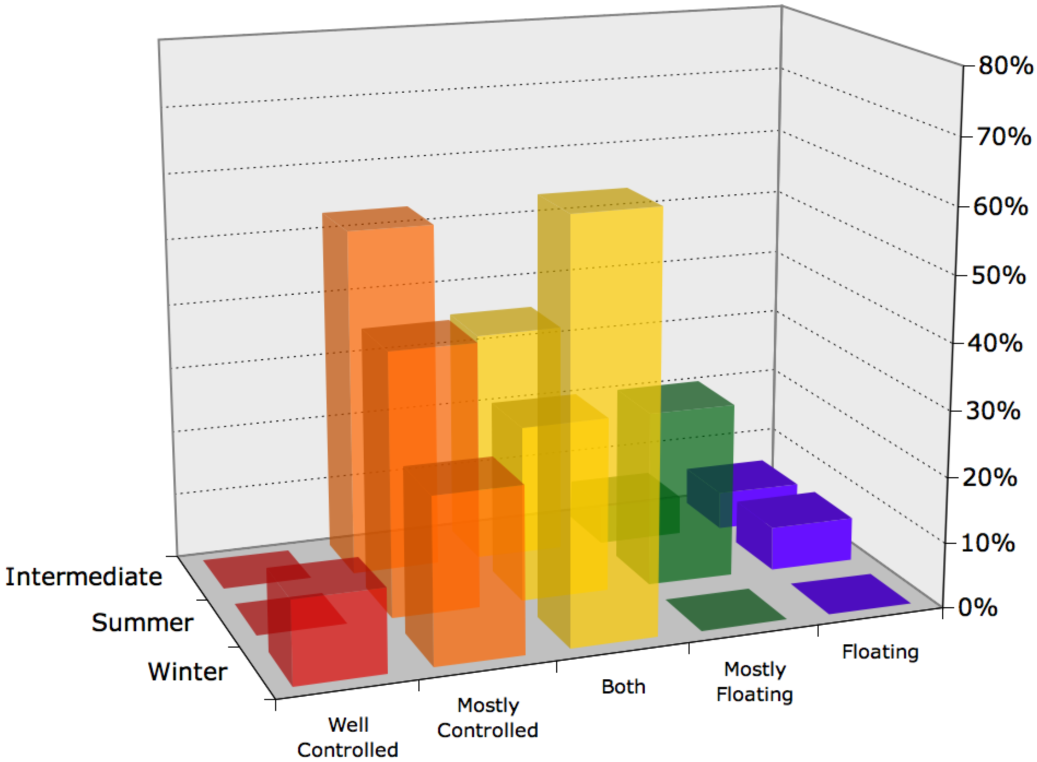

Figure 11: Control of other temperatures vs. season

Figure 12 shows the analysis of temperature control, for all spaces measured in Winter. Offices are shown as green-grey circles; Retail spaces are red-orange triangles, and Other spaces as blue squares. In Winter, most spaces of all types were in the "Both" zone.

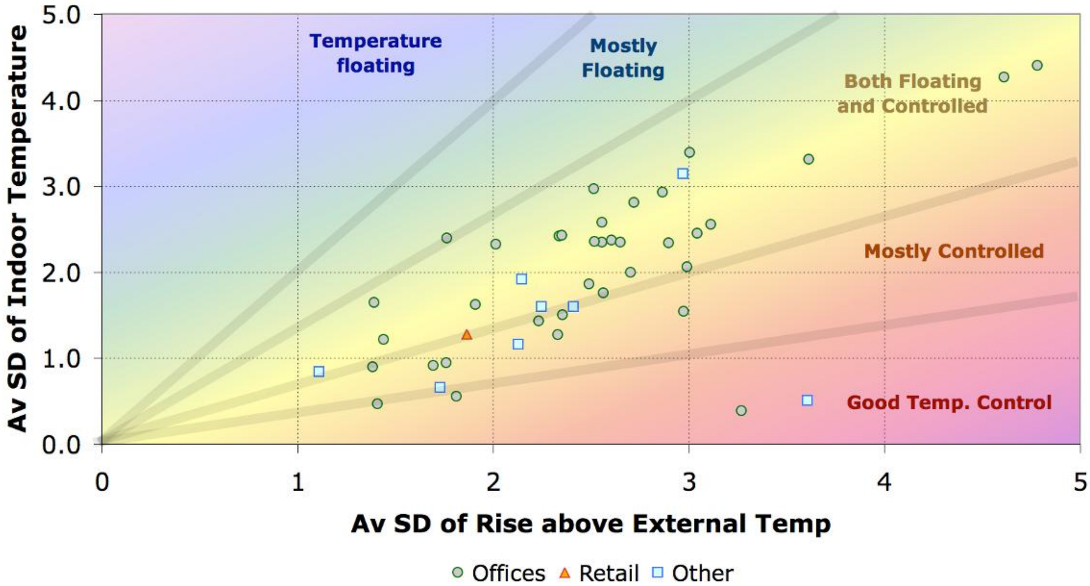

Figure 12: Variation of winter temperatures vs. Variations in rise above outdoors

Figure 13 shows the analysis of temperature control, for all spaces measured in Winter. The results are generally similar for all three types of spaces. About two-thirds of spaces are both Floating and Controlled, and the rest are either "Well Controlled" or "Mostly Controlled". Since there was only one Retail space measured in Winter, its importance was reduced in this graph (from 100% to 80%, to make the graph easier to read).

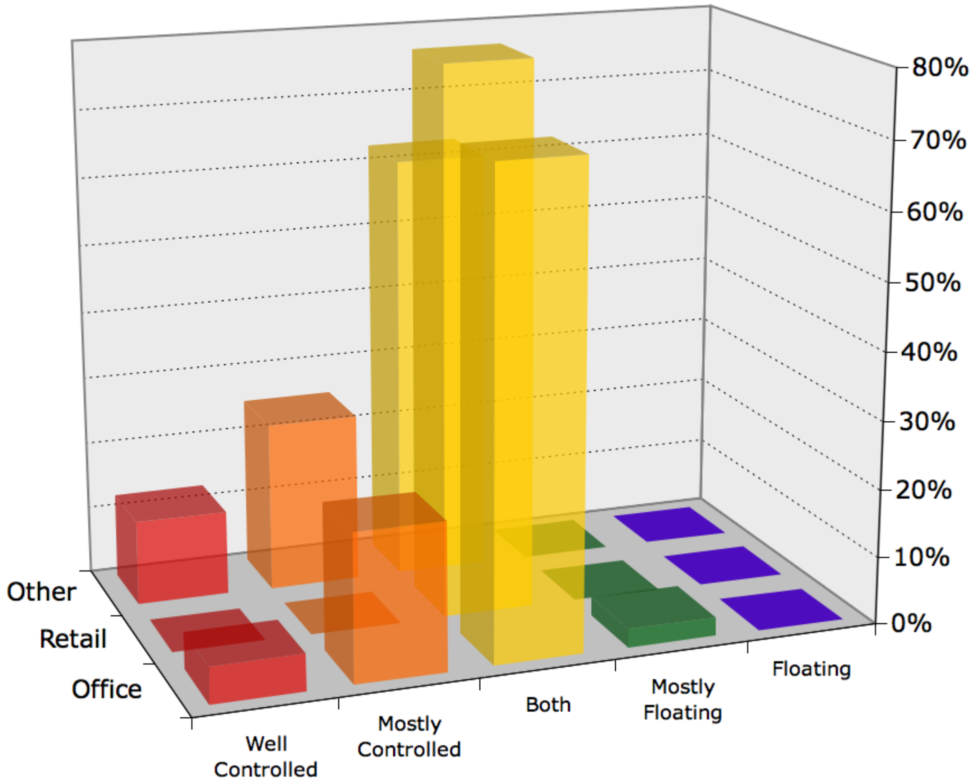

Figure 13: Control of winter temperatures vs. Space type

Figure 14 shows the same type of analysis of temperature control, for all spaces measured in Summer. Again, most spaces of all types show a combination of Floating and Controlled behaviour.

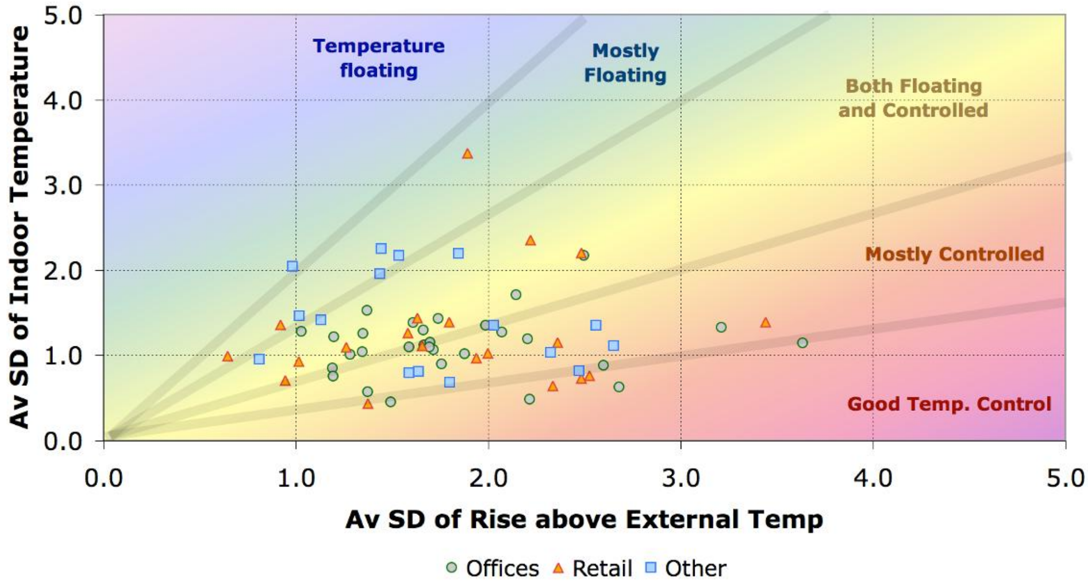

Figure 14: Variation of summer temperatures vs. Variation in rise above outdoors

Figure 15 shows the analysis of temperature control, for all spaces measured in Summer. Compared to Winter, more spaces of all types are either “Well Controlled” or ”Mostly Controlled”. A few of the Retail and Other spaces are “Floating” or ”Mostly Floating”. In general, control of space temperatures is much better in Summer than Winter.

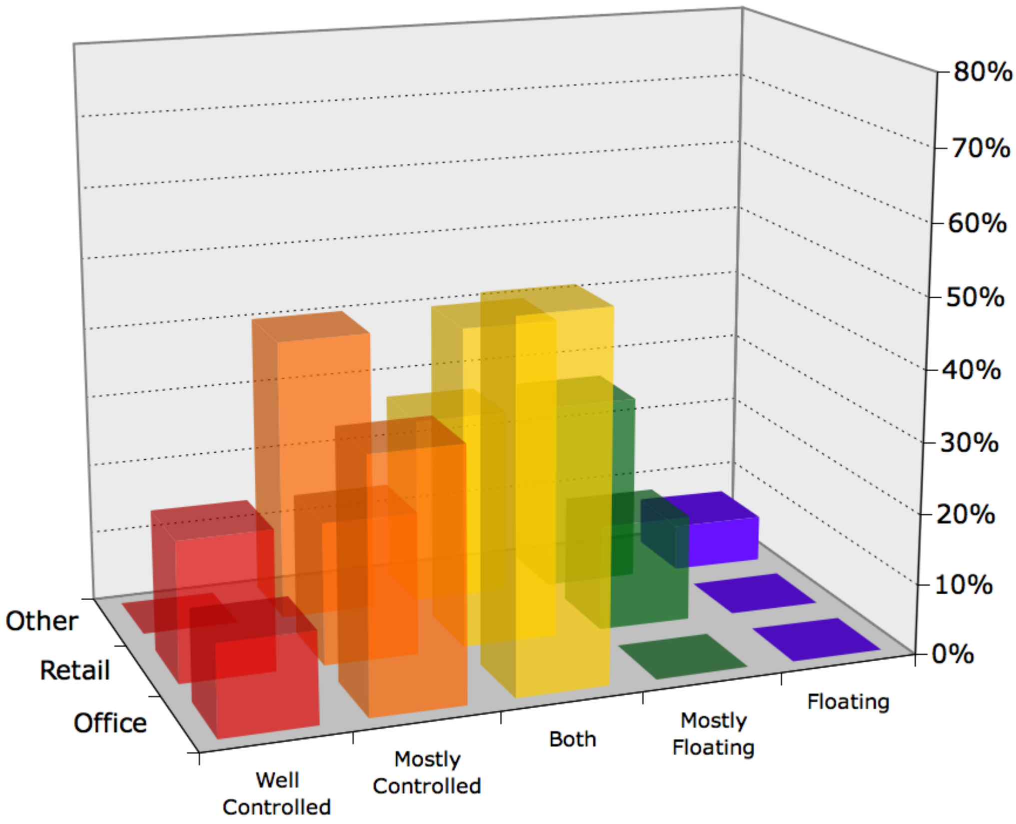

Figure 15: Control of summer temperatures vs. Space type

Figure 16 shows the same type of analysis of temperature control, for all spaces measured in Intermediate seasons. In these seasons, a higher proportion of spaces are Floating than other seasons, but more spaces are also "Mostly Controlled".

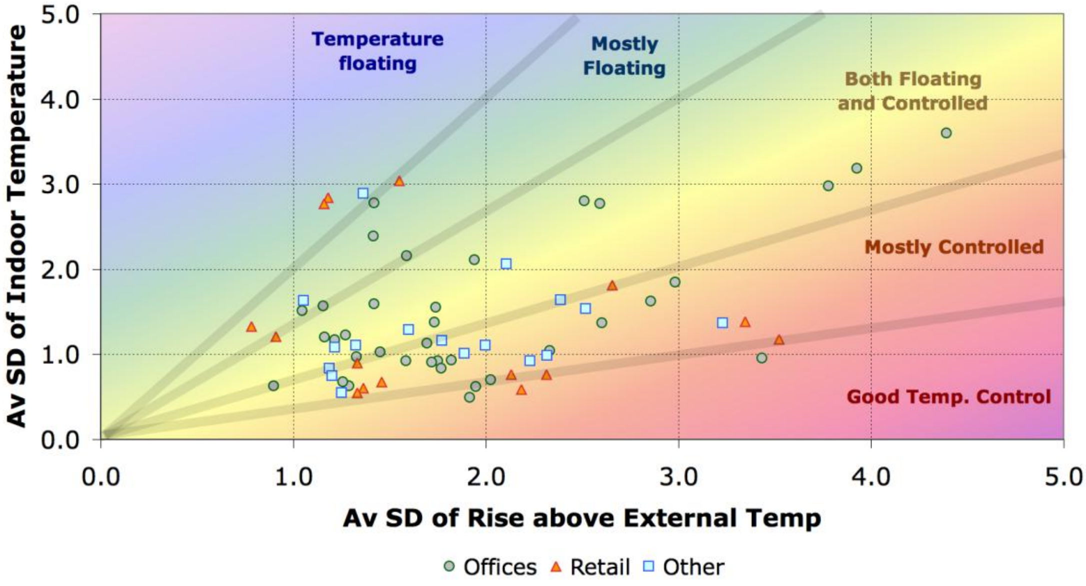

Figure 16: Variation of intermediate seasons temperatures vs. Variation in rise above outdoors

Figure 17 shows the analysis of temperature control, for all spaces measured in Intermediate seasons. The results are generally similar for all three space types, except that there are more Retail spaces Floating, and less Both than for the other two space types.

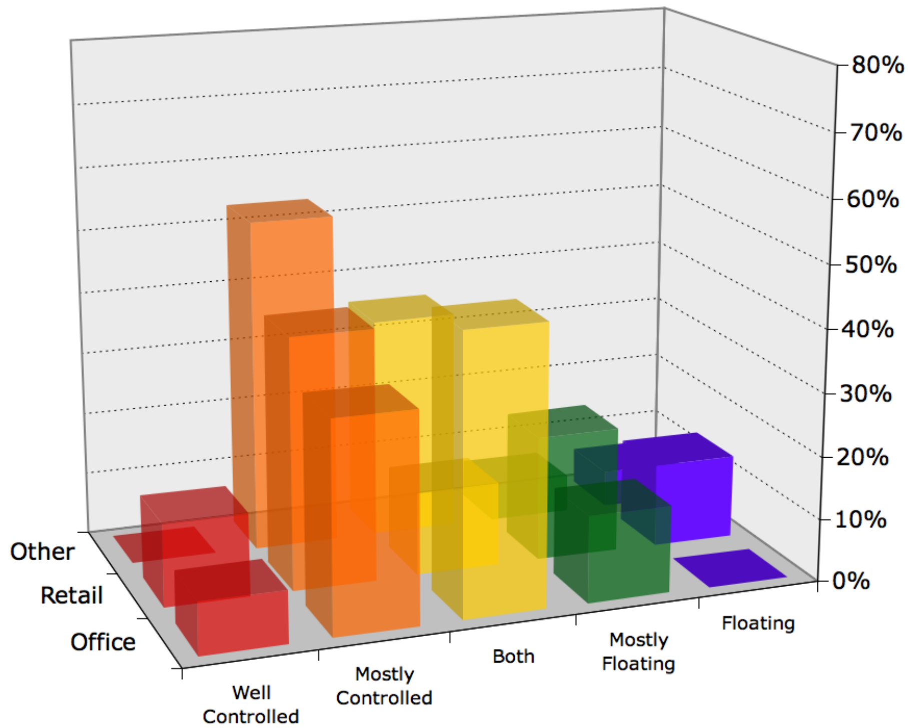

Figure 17: Control of intermediate season temperatures vs. Space type

The following Tables show the number of points in each temperature control zone, by season and Space type.

Table 2 shows the number of points in each zone. The total number of spaces analysed in each season are shown in the bottom row, and the total number of spaces in each temperature control zone are shown in the last column.

Table 2: Number of spaces in each temperature control zone by season and space type

		Offices			Retail			Other			
Ratio		I	S	W	I	S	W	I	S	W	Total
>3	Well Controlled	3	4	2	2	4		0	0	1	*16*
1.5 - 3	Mostly Controlled	12	11	8	6	4	0	9	6	2	*58*
.75 - 1.5	Both	16	16	26	2	9	1	6	4	5	*85*
0.5 - .75	Mostly Floating	5	0	1	3	3		1	4	0	*17*
<0.5	Floating	0	0	0	2	0		1	1	0	*4*
	Total	36	31	37	15	20	1	17	15	8	180

Table 3: Percentage of spaces in each temperature control zone by season and space type

		Offices			Retail			Other		
Ratio		I	S	W	I	S	W	I	S	W
>3	Well Controlled	8%	13%	5%	13%	20%	0%	0%	0%	13%
1.5 - 3	Mostly Controlled	33%	35%	22%	40%	20%	0%	53%	40%	25%
.75 - 1.5	Both	44%	52%	70%	13%	45%	*100%*	35%	27%	63%
0.5 - .75	Mostly Floating	14%	0%	3%	20%	15%	0%	6%	27%	0%
<0.5	Floating	0%	0%	0%	13%	0%	0%	6%	7%	0%

5. NEXT STEPS

This report was a first attempt to analyse the temperature response of spaces to determine how well space temperature was controlled, as opposed to “floating” and influenced by outside temperature.

From this sample, only about 10% of spaces were classified as “well-controlled”. However, when added to those classified as “mostly controlled” this comprised about half of the sample. There were distinct seasonal differences, with much better control in winter than in swing seasons, as would be expected.

Future work for the project will look at extending this analysis to larger buildings, which probably have better controlled temperatures.

The results can be applied to thermal modelling of buildings, by using systems with shorter schedules, and smaller sized heating/cooling equipment, to see how closely the performance of modelled buildings can approach that of real buildings.