7 -11 GILMOUR'S CLOSE

Performance Evaluation – Jan' 2012

Preface

This report has been produced by the Mackintosh Environmental Architecture Research Unit (MEARU) in conjunction with Assist Architects (AA), as a new CIC Start Online academic consultancy project. In broadest terms it analyses the theoretical and in use performance of 5 refurbished flatted dwellings and one office space in Gilmour's Close, Edinburgh with a particular focus on energy use and the user experience.

The authors would like to thank Hillcrest Housing Association, their residents and Gowrie Care for their input, time and assistance during the process of this study and analysis.

CIC Start Online is funded by European Regional Development Fund and Scottish Government SEEKIT programme that is managed by Scottish Funding Council.

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1.0 Introduction

Gilmour's Close is a 4 storey, 19^{th} Century stone tenement, with commercial ground floor, located in the World Heritage site of Edinburgh's Grassmarket. Refurbishment of this building was completed by Assist Architects, in 2008, to provide social rented and supported housing for Hillcrest Housing Association.

In the refurbishment process Assist sought not only to conserve the historic aspects of this Category B listed structure but also to incorporate low energy principles to the design in the form of ground source heating, passive solar strategies, mechanical ventilation with heat recovery (MVHR) and upgrade of the fabric's thermal performance by internal lining.

This project aims to asses the performance of this development in terms of energy use and user experience, through a 3 week monitoring process and subsequent analysis of the small office space within the development and 5 individual dwellings (2 mainstream social rented and 3 supported).

2.0 Executive Summary

2.1 Overview

From analysis of the building the following key points are identified along with recommendations for improvement where applicable.

Recommendations are split into 4 categories of;

I. Future design improvements (for new proposals)
II. Building alteration/ upgrade (for Gilmour's Close)
III. Occupant behaviour
IV. Areas for further study

2.2 Comparison of Predicted and Actual Energy Consumption

Key Points;

I. The space and water heating primary energy requirements were found to be 92.22kWh/m^2 of habitable area – a figure that compares well with contemporary energy efficient dwellings.
II. The use of the ground source heat pump was found to provide significant benefits in terms of CO_2 savings compared to a more conventional system of high efficiency gas fired combi boilers installed in each dwelling. Savings of 33% were identified based on a median range of manufacturers COP rating. Even if the lowest level of COP only was achieved then a CO_2 saving of 9% would result.
III. Actual energy use for space and water heating was found to be 2.1 times greater than predicted. This, however, reflects a situation common with thermally efficient building performance evaluations. The reasons for this disparity were identified as;
    a. Limitation of prediction using SAP.
    b. Energy consumption data was only representative of a 9 month period and not a full year.
    c. Excessive ventilation rates caused by occupant activity during the heating season.
    d. Constructed insulation envelope may not achieve the same levels of thermal insulation as design intent.
IV. In relation to (c) above it was seen that significant improvements to building performance and energy consumption could be made by consideration of the recommendations made below.

2.3 Passive Design – Sunspaces

The analysis of the sunspaces is undertaken on the basis that, as was the design intent, these constitute a heated extension of the building envelope providing further amenity to relevant dwellings.

Key Points;

I. The extension of the building to include this volume was found to have benefits in terms of the potential to improve air quality of any adjacent apartments.
II. Direct heat gains occurring in the sunspace were not found to be beneficial to the dwellings as there was no means of storing or effectively distributing the heat.
III. The lightweight construction of these volumes and large extent of glazing was found to be relatively weak in terms of thermal insulation, compared to the rest of the thermally upgraded fabric.
IV. Use of a heating system in this space appears to result in a significant energy penalty due to the amount of glazing and lightweight construction.
V. Note was made of the MVHR extract contained within each sunspace although the benefits of this, in terms of providing useful heat to the rest of the dwelling, were unclear.

Recommendations;

a. Requirement to heat such spaces should be better considered in relation to the external envelope and whether purely a ‘buffer’ space would be more appropriate – i.e. the insulation envelope and heated space terminates at the junction between apartments and sunspaces with intermediate windows and doors being constructed to external quality.
b. Sunspace (and perhaps adjacent apartment) designed to incorporate greater thermal mass to allow heat retention and to buffer extreme heat gain and loss.
c. This could be achieved simply through massive floor and wall coverings such as ceramic tiles or by incorporating more mass in the internal fabric through heavyweight wall linings or exposing the original stone wall. With the latter proposal this would retain the atmosphere of a captured outdoor space (rather than a semi-glazed indoor room) and would lend itself toward recommendation ‘a’ above.
d. Analysis of the spaces should be undertaken over the summer period to understand how they perform outwith the heating season.
e. Consideration of means of air transfer from these spaces to the rest of the dwelling should be fully considered and discussed with specialist consultants at design phase to make the most of heat gains with minimal or no additional energy input.
f. Effective use of blinds and solar shading will help to mitigate unwanted heat gains.

2.4 Dwelling Heating System/ Controls

Key Points;

I. Individual heating controls/ or systems in dwellings appear to have limited response resulting in poor thermal comfort.
II. Heating controls provide limited information to users and make maintenance of thermal comfort challenging.

III. The office ground floor heating system appears to be struggling to perform effectively due to a lack of clear floor space.
IV. The office upper level is being overly heated in the mornings and is affecting the thermal comfort of this space and the perception of those at lower levels.

Recommendations;

a. Heating controls and systems to be checked to assess efficacy and suitability of response time. This should include a thermostatic response to casual and solar heat gains to minimise the burden on the heating system and improve thermal comfort.
b. Thermostats should be changed to ones that provide users with more information (i.e. scales which relate to temperature) allowing informed responses to thermal comfort to be made.
c. Office layout could be reconsidered to allow heat to be more effectively emitted from under-floor system.
d. The use of a significant heating boost in the mornings should be reassessed and trials should be undertaken to derive a lower heating requirement which provides preferable working temperatures.

2.5 Mechanical Ventilation (with Heat Recovery)

Key Points;

I. There appears to be a disparity in the use of MVHR systems with some dwellings having no mechanical air supply despite being constructed to the same standards of air tightness as those which do have a full system.
II. Positions of air delivery registers do not correspond with provision of fresh air to spaces where it is most needed – i.e those under high occupancy. Reliance on migration from a well sealed hall space is insufficient.
III. Position of MVHR unit itself does not allow for ease of maintenance or changing/ cleaning of filters
IV. Efficacy of MVHR and extract system appears to be questionable particularly with respect to controlling moisture levels in some spaces and in the removal of cigarette smoke and the associated smell from dwellings.

Recommendations;

a. Early design discussion should assess the suitability of the systems and approaches employed to provide suitable internal air quality.
b. Air delivery valves should be positioned to provide fresh air to the rooms where it is needed most – i.e. bedrooms over night and communal rooms under intense periods of occupation. If used in bedrooms it is also important that appropriate acoustic separation from the fan is maintained.
c. MVHR units should be positioned within the dwelling in a space that promotes frequent maintenance in accordance with manufacturer's recommendations.

d. A maintenance regime for MVHR units should be defined and put in place by Hillcrest HA.
e. Future uses of MVHR should be clear about what the requirement and therefore specification is. For whole house ventilation (as opposed to heat recovery from kitchens and bathrooms) a higher performance specification is required.

2.6 User Behaviour

Key Points;

I. In dwellings, user behaviour, in terms of window opening and energy efficiency, appears to be poor, but is conditioned by poor controls and response times.
II. In the office space clutter and poor use of natural light appears to be affecting the performance of the heating system and 'feel' of the internal environment.

Recommendations;

a. While recognising the limitations of the heating system and controls at present, educating residents on efficient use of systems should result in a better understanding and improved energy efficiency.
b. Creating financial incentives within the rental scheme for energy conservation use may promote more efficient energy use. Such a scheme would require installation of additional metering but could ultimately save energy and save residents money. It is key that to avoid fuel poverty this scheme is run as one which rewards energy efficient behaviour and not one which penalises efficiency or inefficiency, noting that current tariff systems all penalise efficiency.

3.0 Comparison of Predicted and Actual Energy Consumption

Context:

In the Gilmour's Close development heat and hot water are supplied to all dwellings via a communal ground source heat pump system with and electric back up heater.

The specifications of the two heat sources are as follows;

Heat pump specification - Thermia Robust 45
Auxiliary heater specification - Värmebaronen EK 15E

Analysis of the efficiency and carbon respective carbon impact of this installation will be made using data on the direct electrical consumption of the installation and with the information available from the heat pump control panel.

Heat Pump Use:

Readings from the heat pump control panel have been recorded as follows;

Gilmour's Close Heat Pump Timers

Date	HPA	HPA Heat	AUX
15/03/2010	5415	29%	2985
03/05/2010	5934	27%	3021
02/09/2010	6378		3021#
10/11/2010	6890	24%	3021
21/12/2010	7403	23%	3463
25/02/2011	8369	22%	3794
27/05/2011	9388	20%	3794
16/09/2011	10126	19%	3794

Immersion replaced 02/09/10

HPA is the number of hours that the heat pump has been running (for this and the AUX time the value given is cumulative from the date of commissioning).

The HPA Heat is the percentage of that time that the pump has been delivering heat to the radiators (or under floor heating).

The AUX value is the number of hours that the auxiliary electric heater has been called into action to supplement the ground source heating system – this is principally due to the passive heating system not being able to meet demand in particularly cold spells and forms part of the original design.

Hillcrest HA noted that the system was specifically designed in this way as it was deemed more efficient to have a smaller heat pump running closer to maximum capacity with an electric heating back up/ boost than to have a larger heat pump running below capacity but with the capability of meeting increased demand at limited intervals.

In addition to this readings were taken from the 2no. electrical meters which sit adjacent to the heat pump installation.

Meter	Installation Date	Reading Date	Start Reading	Current Reading
N907P03436	07/03/08	27/05/11	000002	226810
3310P22923	14/09/10	27/05/11	000000	062628
N907P03436	07/03/08	14/09/11	000002	241852
3310P22923	14/09/10	14/09/11	000000	03541
3310P22923	14/09/10	16/09/11	000000	03563

Meter 3310P22923 is the sub-meter dedicated to the heat pump electrical installation.

Heat Pump Energy Use

Heat pump use;

15/03/10 to 16/09/11	= 1 year and 216 days = 581 days
Heat pump, daily mean activity	= (10,126 – 5,415) ÷ 581 = 4,711 ÷ 581 = 8.11 hrs
Heat delivery to dwellings	= 8.11 x 0.19 = 1.54 hrs

Note – the above values provide a mean over the longest measurable duration but in reality this figure will vary depending on season.

Therefore the heat pump is in use, on average, for 8.1 hours per day and is delivering heat (or hot water) to the dwellings for 1.5 hours per day.

Auxiliary Heating Use

Proportional requirement for auxiliary heating over full duration;

HP to AH ratio	= 3,794 ÷ 9,388 = 0.404 = 40.4%

Auxiliary in use for 40.4% of time that heat pump is

Proportional requirement for auxiliary heating from 15/03/10 to 27/05/11;

HP to AH ratio = (3,794 – 2,985) ÷ (9,388 – 5,415)
= 809 ÷ 3,973
= 20.4%

Auxiliary in use for 20.4% of time that the heat pump is.

Proportional requirement for auxiliary heating from 15/03/10 to 16/09/11;

HP to AH ratio = (3,794 – 2,985) ÷ (10,126 – 5,415)
= 809 ÷ 4,711
= 17.2%

Auxiliary in use for 17.2% of time that the heat pump is.

With the middle, vastly improved, figure it should be noted that the auxiliary heater was not functioning for a significant period between 15th March 2010 and 2nd September 2010. As such, this lower reliance on the back up heating could be viewed as slightly skewed in favour of better performance of the heating system and building in general.

While this may be the case it is worth noting that from 2nd September to 10th November the auxiliary heating was not required indicating that, while it may have been called into action from mid March to early September, the duration of use could have conceivably been limited as the mean low ambient temperatures during this period are not dissimilar to those prevailing in October and November.

The figure of 20.4% can, therefore, be seen as more reliable for an annual period than the ratio identified in the full duration as this first figure will include significant periods of testing, commissioning and a settling in period where the whole system requires further balancing while in use. This settling in and balancing period is often lengthy when dealing with ground source heating systems and would go some way to explaining higher reliance on the auxiliary heating early on in the period of occupation.

Predicted Energy Input/ Carbon Footprint

Based on SAP 2005 calculations for the dwellings (supplied by Assist Architects) the predicted electric energy use for hot water and space heating is;

Space Heating - 13,066kWh
Water Heating - 29,588kWh
Total - **42,654kWh**

For the full development this equates to a square metre annual energy consumption of;
42,654kWh ÷ 972m^2 **= 44.88kWh/m^2**

In terms of CO_2 footprint this equates to;
42,654kWh x 0.54522[1] = 23,255 kg CO_2
= **23.255 tonnes CO_2**

Actual Energy Input/ Carbon Footprint

Note; later readings from the sub-meter do not provide a consistent progression and therefore cannot be used until further investigation of values is undertaken.

During the period 14/09/10 to 27/05/11 62,628kWh of electric energy was used by the heat pump and auxiliary heater.

This equates to a daily electrical input of;
62,628kWh ÷ 255 days = **245.6kWh**

This can be scaled up to an annual consumption of;
245.6kWh x 365 days = **89,644kWh**

For the full development this equates to a square metre annual primary energy consumption, for space and water heating, of;
89,644kWh ÷ 972m^2 = **92.22kWh/m^2**

In terms of CO_2 footprint this equates to;
89,644kWh x 0.54522 = 48,875 kg CO_2
= **48.875 tonnes CO_2**

All figures represent the primary energy consumption in terms of CO_2.

Ratio of actual energy consumption to predicted;
= 89,644 ÷ 42,654
= **2.10**

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[1] Conversion factor of kWh to kg CO_2 for electric energy – Carbon Trust, 2011
[2] Conversion factor of kWh to kg CO_2 for natural gas – Carbon Trust, 2011

CO_2 Savings

With the Thermi Robust 45 the manufacturer's literature notes that the pump has a coefficient of performance (COP) of between 4.2 and 2.9. This means that the actual heat load for the dwellings will be between 2.9 and 4.2 times that which is stated above – i.e. the corrected space heating and hot water requirements are actually between 267.44kWh/m^2 and 387.32kWh/m^2.

If a traditional heating system had been used in each dwelling (90% efficient gas combi boiler for example) this would equate to an annual space heating and hot water demand of between 288,834kWh and 418,305kWh with an associated CO_2 output of between 53,153kg and 76,800kg[2].

If a median value is assumed for this, as the true COP is unknown, then a CO_2 output of 64,976kg CO_2 would be the resultant.

Comparing this to the actual output of 48,875kg CO_2 we can see that there is a significant saving (approximately 33%) in terms of CO_2 footprint with the use of the ground source heat pump. Even with the lowest rated COP a saving of 9% is achievable.

Conclusions

From the results above it can be seen that the actual energy use of the building in terms of space heating and hot water load, is 2.1 times greater than the predicted consumption.

This may not initially represent an entirely favourable outcome, in terms of actual performance, but Gilmour's Close does not stand alone in this regard as this level of disparity and greater, has recently been identified in several other performance evaluations of thermally efficient buildings.

For instance, two exemplar energy efficient dwellings in Glasgow were recently found by MEARU to have space and water heating energy consumption figures 1.79 and 2.86 times greater, respectively, than predicted. Similarly a building performance evaluation of the energy efficient Elm Tree Mews development, published by the Joseph Rowntree Foundation, found that actual performance, in terms of space and water heating, was around 2.4 times greater than had been predicted at design stage.

Factors which may have influenced this outcome are as follows;

1. The standard assessment procedure used to calculate regulated energy use at design stage, i.e. the predicted energy consumption, represents a fairly simple and blunt approach to predicting building performance. Compared to dynamic simulation methodologies the

[2] Conversion factor of kWh to kg CO_2 for natural gas – Carbon Trust, 2011

accuracy of these figures is limited. Deviation from such values should, therefore, not immediately present a cause for concern; it may be more indicative of the limitation of the assessment methodology rather than the performance of the building itself.

2. The use of electrical consumption data from 14/09/10 to 27/05/11 only will give the quasi-actual consumption an overly high value as it takes in data from the heating season where the heat pump use will be high but omits data from the summer season where the electrical draw on the heat pump will be much lower. This skews the results to the detriment of the scheme. Electrical input information for a whole year (unavailable at time of publication) would provide a fairer reflection of the heat pump performance.
3. Issues identified in terms of building overheating, subsequent occupant window opening and the heating of the sunspaces are noted in other sections of the report as resulting in a significant energy penalty. In light of the results above it would seem that this frequent emission of heat energy has indeed resulted in the building having a much poorer thermal performance than is predicted by the SAP 2005 software. This does, however, also reflect another limitation of that measurement tool as it does not readily account for occupant behaviour.
4. As constructed U values may be higher than the designed values.

For all values the most significant matter to note is that while the figure of 92.22kWh/m^2 represents a relatively good value (one of the previously mentioned dwellings in Glasgow achieved a value of 89.9kWh/m^2) in terms of total energy consumption for space and water heating, there is much than can be done to better this in terms of improving occupant behaviour and addressing the issues identified elsewhere in this report and the Executive Summary.

4.0 Building Monitoring/ Analysis

4.1 Introduction

As part of this CIC Start Online project, the building's in use performance and user satisfaction were monitored and recorded as follows;

Building Performance

Over approximately a three and a half week period (from 17.03.11 to 12.04.11) the internal temperature, relative humidity and carbon dioxide concentration were monitored in all apartments, the hall and kitchen of five flatted dwellings and throughout one office space (noting in each case that bathrooms/ WCs were omitted).

Measurements of these parameters were made at 10 minute intervals using Eltek RX250AL Transmitters and recorded on the Eltek 1000 Series Data Logger. In the case of the hall spaces of Dwellings 1 and 2 and the office, measurements of temperature and relative humidity only were made using Gemini Tinytag Ultra data loggers.

On completion of the monitoring, all recorded data was collated and analysed using Microsoft Excel.

User Satisfaction

Residents and office users were asked a series of questions (a copy of the questionnaire is presented as Appendix A) in order to gain an insight into their general satisfaction with the building and to identify any specific areas where performance may be either better or worse than could be expected.

The most pertinent responses from this process are contained within the analysis of each individual dwelling.

Analysis

Analysis of each dwelling and the office space has been undertaken using a combination of the recorded data and the survey responses to identify both strengths and weaknesses in the building's performance. Generally the analytic process has been undertaken from a macro to micro level working from broad based values, derived over the full monitoring process, down to specific daily values and events that affect the internal environs.

Presentation and discussion of this analytic process follows with the order of review running from the mainstream affordable housing to the supported housing and finally analysis of the office space.

Summary of the main issues identified along with recommendations for improvement are presented in the Executive Summary.

MAINSTREAM HOUSING

4.2 Dwelling 1

Description;
Mainstream social rented dual aspect flatted dwelling comprising;
- Living room and kitchen to the north elevation
- Double bedroom and twin bedroom off sun space to the south elevation
- Internal bathroom and hall space off communal close

Flat is occupied by a mother, who works during the day, and by her son who is of school age.

3 week monitoring period (refer appendix B)

Dwelling Overall;

	Temperature (°C)	Relative Humidity (%)	CO_2 Concentration (ppm)	Vapour Pressure (haPa)
Max.	39.80	58.40	1619.00	17.84
Min.	18.50	16.70	422.00	7.28
Mean	23.39	38.52	714.59	9.52

The mean temperature for this dwelling over the monitored period is one which appears to be edging towards being uncomfortably high at 23.39°C. The mean RH maintains an acceptable level throughout although the true moisture content of the air may be masked by the high air temperatures. As such, vapour pressure will be used as a more robust representation of air moisture content throughout this report.
The average CO_2 concentration is at a good level suggesting a reasonable internal air quality.

Specific rooms;

LIVING ROOM
Temperature;
Generally sitting within a fairly constant range of approximately 22 to 25°C with, what appears to be, daily highs and lows dependant on heating cycles. This is as would be expected from a structure with a fast thermal response.

CO_2 Concentration;
The mean value of 737ppm suggests a reasonably good air quality and while this is generally the case there are several (14) instances where values greater than 1000ppm[3] are achieved lasting, on average, for 1 hour 38 minutes. The peaks in CO_2 concentration are generally cyclical over a 24-

[3] 1000ppm, equivalent to air delivery rate of 8l/s per person, represents the upper threshold of desirable air quality relative to the 'bad company' that can be harboured if air change rates are not sufficient.

hour period and suggest a routine of higher intensity occupation of this space. Further daily analysis of fine grain data is required to gain further insight into occupation regime and relationship to changes in vapour pressure and temperature – e.g. is heating regime commensurate with best practice for typology and for achieving energy efficiency in a high thermal response dwelling?

Vapour Pressure;

As above, peaks in vapour pressure (VP) tend to relate to peaks in CO_2 concentration and can, therefore, be assumed to relate to high occupancy. The average level of 10.70haPa can be seen to be acceptable. However, like the room CO_2 values, the higher peaks up to 14.50haPa may present a cause for concern relative to mould growth[4].

KITCHEN

Temperature;

With a mean temperature of 23.73°C this space has a temperature profile which is not dissimilar to that of the living room but with more pronounced peaks occurring on a daily basis. These peaks are as expected for a kitchen space and relate to cooking activity.

CO_2 Concentration;

The mean CO_2 concentration of 672ppm suggests good air quality in the kitchen as could be expected from a space with a mechanical extract fan – in this case part of the MVHR system. Peaks of over 1000ppm are evident but are relatively limited, of short duration and are generally related to periods of cooking activity as they coincide with rapid increases in temperature and vapour pressure.

Vapour Pressure;

As could be expected from a kitchen, several rapid increases in vapour pressure are evident over the monitoring period. With a peak value of 17.75haPa and a mean value of 11.60haPa the vapour pressure in this area has the potential to promote dust mite colonisation[5] and, given that the room has a mechanical extract system designed specifically to deal with moist air expulsion, does not suggest that moisture/ air extraction rates are currently appropriate.

SUNSPACE

Temperature;

A review of the mean temperature only, at 22.7°C, would suggest that the sunspace has a comfortable internal temperature. This temperature is achieved, however, by a series of overly hot peaks (up to 39.8°C) and troughs of 18.5°C.

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[4] Aden (1989) identified that even short term peaks in high humidity can support fungal growth
[5] Platts-Mills and De Weck (1989) identified vapour pressure values of below 11.3haPa (or 7g/kg mixing ratio) as a measure in limiting the growth of dust mite populations.

In general the temperature profile of this space raises questions over its suitability and ability to provide an appropriate source of passive heating, particularly in relation to the construction methodology and fabric specification.

Throughout the entire dwelling this space is the one which achieves the lowest temperature and, backed up by anecdotal evidence, is overly cold in winter, impacting on the adjacent child's bedroom. This appears to be in contrast to the design intent of such a space where the approach should be to make use of thermal solar gains to provide free energy or offset energy demand during the heating season. Over the monitored period there were limited times when the temperature of this space was within a comfortable range due.

CO_2 Concentration;

At an average of 542ppm this space can be seen to have good air quality. Very rarely does this level reach or exceed the benchmark figure of 1000ppm. This is perhaps not unexpected given the large number of trickle vents to the glazed screen were all in the open positions at the time of survey.

Vapour Pressure;

As with the temperature profile, the mean value for vapour pressure would appear to be relatively good, at 10.10haPa. Having noted this, there is a clear correlation between the peaks in temperature and vapour pressure which suggest that the absolute moisture content of the space is not significantly varying and the pressure is mainly being affected by the significant rises in temperature.

DOUBLE BEDROOM

Temperature;

The mean temperature of 22.69°C is again significantly above what would normally be desirable for a bedroom and this situation is exacerbated by the significant rises in temperature which are apparent on several occasions around midday where temperatures of over 26°C are reached. In several instance this rise in temperature appears to be attributable to the rise in temperature of the adjacent sunspace, suggesting a need for responsive ventilation in this space (e.g. by passive green house vents) as well as increased thermal capacity.

This relationship would seem to suggest that the efficacy or use of the sunspace should be brought into question as it appears to be resulting in heat gains above the desirable range for thermal comfort which are not being moderated either through thermal storage or ventilation in the sunspace itself, or adjacent rooms.

CO_2 Concentration;

A mean value of 802ppm suggests that the air quality in the bedroom is reasonably good but with a pattern of peaks and trough which can be expected from a bedroom – i.e. CO_2 concentration rising over night to just over 1000ppm and then rapidly falling in the morning to a base value of circa

600ppm. In the worst instance a CO_2 level greater than 1000ppm was maintained in this room for 6 hours and 15 minutes.

The frequency and duration with which values greater than 1000ppm is achieved is worth noting with respect to the ‘bad company’ that this can lead to and the air change rate of this room should be carefully considered. This is of particular relevance to this bedroom as it is effectively an internal room, with a self-closing fire door (limiting ventilation opportunities to adjacent rooms or hall) and no separate air supply as part of the MVHR system.

As all air supply grilles are located in the hall spaces, throughout the development, the occupant’s capacity to access fresh air appears to have been compromised by the design of the whole house ventilation system and specifically the position of air supply grilles.

This arrangement is repeated elsewhere in the development with more pronounced peaks in CO_2 concentration which are also exhibited for longer durations.

Vapour Pressure;

The room maintains an acceptable mean VP of 10.80 haPa with fluctuations closely matching the temperature profile and thus suggesting limited variation in absolute moisture content of the air. As above the maximum value of 13.79 haPa may be of concern along with the fact that in one instance a value greater than 11.30haPa is maintained for over 2 days.

TWIN BEDROOM

Temperature;

The average temperature of the child’s bedroom is significantly above that which would normally be desirable at 24.48°C. The fluctuation in this temperature is very limited and a relatively constant temperature is maintained throughout the monitoring period.

CO_2 concentration;

Concentration pattern is very similar to that for the double bedroom with similar associated issues. In this case the mean value of 817ppm is marginally higher than the double bedroom and there are a greater number of instances of the concentration being greater than 1000ppm.

Vapour Pressure;

Results are similar to the double bedroom but with a mean value of 11.13haPa identified including peak values and durations which may promote dust mite colonisation (e.g. a value greater than 11.3haPa was maintained for more than 2 and a half days from 4th March to 7th March inclusive).

HALL

Temperature;

A reasonably stable temperature profile was identified in the hall area with a relatively high mean value of 23.71°C over the monitoring period.

CO_2 Concentration;

Not monitored in hall.

Vapour Pressure;

A relatively high mean vapour pressure of 12.23haPa was recorded over the monitoring period. This is significantly higher than any of the connected rooms which were monitored and may initially seem strange but can most likely be accounted for by migration of moisture and water vapour from the bathroom. While this provides a reasonable explanation of the high figure it does not alter the fact that mean VP is at a level greater than the maximum desirable level identified by Platts-Mills and De Weck and may be aiding the colonisation of dust mites. There is now an evidenced association that high densities of dust mites are linked to asthma[6] and are problematic for atopic occupants and, therefore, measures should be taken to minimise the opportunity for colonisation and population growth.

Conclusions

Through the interview process the resident noted that the temperature within the house was generally fine although the twin bedroom was prone to becoming overly cold during winter.

These responses do not appear to correspond with the recorded data as the dwelling generally seemed to be too warm and the room which suffered *least* from low temperatures was the child's bedroom.

With respect to the first of these points it is possible that the occupant has a preference for higher internal temperatures and therefore, those recorded are in fact exactly within the range the occupant finds comfortable. This is an example of the subjectivity of temperature perception and shows why assumed means can be used as a guide only and not as an absolute benchmark.

While the temperatures recorded in the child's bedroom were found to be both relatively high and stable it is possible that, during particularly cold spells, the room has suffered from heat loss to the sunspace and this has stuck in the mind of the respondent.

From the recorded data, and with reference to the above point on the child's bedroom, it is the performance of the sunspace which is of most interest in this dwelling.

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[6] *Clearing the Air*, Institute of Medicine, National Academy Press, Washington DC, 2000.

Fig 4.2.1 below illustrates one daily profile for this space and the large swings in temperature which are evident. The rate and intensity of heat gain and loss means that the space is uncomfortable for long periods and it is unusable as a habitable space for significant periods. In conjunction with this, the high response fabric means that it is difficult for the heat gains to be effectively used as there is a clear tendency to shut off adjacent rooms from the sunspace to try and protect them from these intense peaks in temperature.

While this space is considered during the heating season it would be of interest to investigate the heat gains during the summer months as these will inevitably be more severe and prolonged and may make for a more inhospitable volume.

In both summer and winter scenarios the addition of thermal mass would improve the space as it would help reduce the intensity of the variation in temperature and would provide a heat store, allowing useful heat gains to be released to the rest of the dwelling over a longer period of time.

In this respect the use of the space as a 'buffer' rather than a habitable zone would improve it's contribution to the energy efficiency of the dwelling but for this to be feasible it would also require the additional alterations further discussed in the analysis of Dwelling 2.

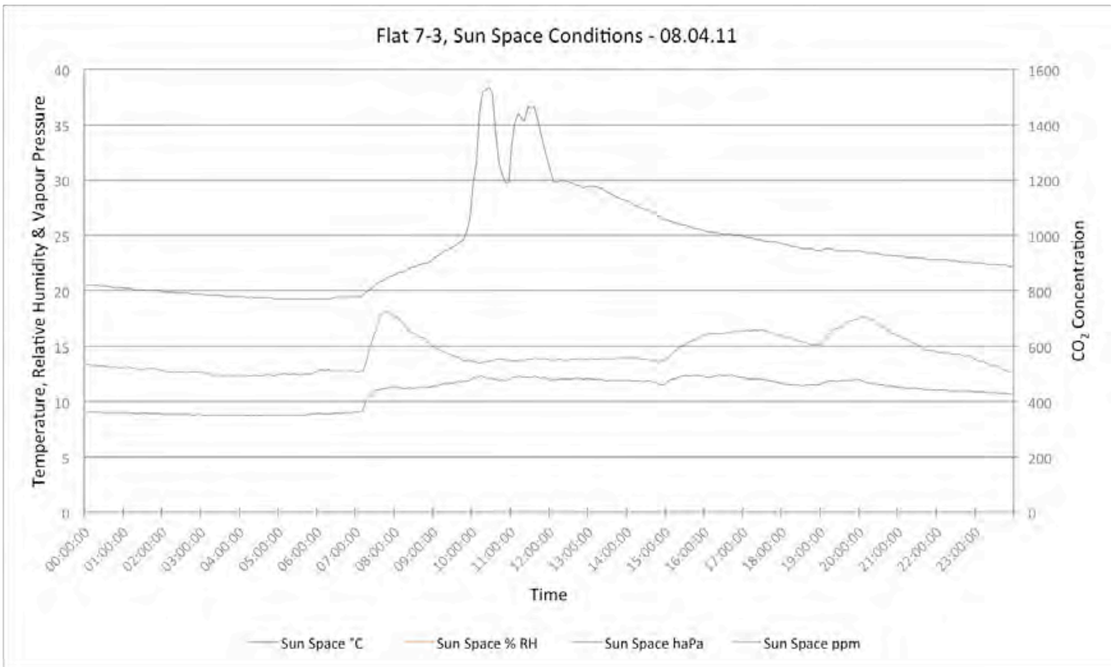


Fig 4.2.1 – Sunspace recorded data for 08.04.11

With respect to the levels of vapour pressure experienced in the hall, the efficacy of the whole house ventilation system should be assessed in greater detail as it appears to be underperforming in terms of it's ability to remove moist air and provide suitable internal air quality.

4.3 Dwelling 2

Description;
Mainstream social rented dual aspect flatted dwelling comprising;
- Separate living room and kitchen to the north elevation
- Double bedroom and twin bedroom off sun space to the south elevation
- Internal bathroom and hall space off common close

Flat is occupied by a couple, working pattern unclear, and by their son of school age.

Layout is generally as Dwelling 1

3 week monitoring period (refer appendix C)

Dwelling Overall;

	Temperature (°C)	Relative Humidity (%)	CO_2 Concentration (ppm)	Vapour Pressure (haPa)
Max.	40.90	70.20	2074.00	20.10
Min.	19.70	11.70	456.00	5.67
Mean	22.53	44.42	956.11	9.64

The mean temperature for this dwelling over the monitored period sits slightly above the accepted norm for winter indoor thermal comfort (21°C).

The mean VP maintains an acceptable level throughout although the mean CO_2 concentration, compared to Dwelling 1, is moving close to the maximum desirable level of 1000ppm.

Specific rooms;

LIVING ROOM
Temperature;
A good mean temperature of 21.88°C is recorded in this room but this is achieved by a daily cycle of thermal peaks and troughs. While this is similar to Dwelling 1 it represents a more extreme cycle of heating and cooling and is indicative of a typically poor, in terms of energy efficiency, occupant controlled heating cycle.

This type of behaviour is often observed in dwellings with a fast thermal response and is characterised by consecutive daily peaks and troughs where there is a high heating demand placed on the dwelling until it becomes too hot and the occupant then emits the excess heat energy via manual window opening.

CO_2 Concentration;

The mean value of 787ppm represents a reasonably good level of air quality but is not surprising given the above hypothesis relative to window opening. In fact, a review of the CO_2 profile shows a direct correlation between drops in temperature and reduction in CO_2 concentration. At this level, this would seem to confirm the theory of the energy intensive method of occupation and environmental control.

Vapour Pressure;

Overall the vapour pressure in the living room is at an acceptable level (mean of 10.62haPa) although it is open to considerable fluctuation. Factor's influencing this may be high occupancy, moisture production within the space (from drying laundry, etc.) and moisture migration from exterior to interior during days of high humidity. In this case, the occupant's frequent window opening could feasibly have a detrimental impact both in terms of energy efficiency *and* in terms of the quality of the internal environment (i.e. overly moist and warm). With the collected data the cause of these peaks cannot be accurately assessed but there is evidence of maximum VP levels of 15.49haPa and levels frequently exceeding the 11.3haPa benchmark for prolonged periods. As previously discussed this can be problematic.

KITCHEN

Temperature;

The kitchen has a mean temperature of 22.53°C but over the course of each day has a significant variation, from high to low, of around 4ºC to 5°C. The fluctuations are similar to those recorded in Dwelling 1 but much more pronounced and with much more rapid changes, particularly in temperature decline.

The greater number of increases could simply be explained by a higher frequency of cooking within the space. The apparently rapid declines may be indicative of window opening to facilitate ventilation and moisture removal, expulsion of excess heat or it may be that the position of monitoring equipment was such that it was susceptible to recording localised peaks in heat and moisture producing activity. For example, if the sensors are too close to a kettle they will pick up intense but short bursts in additional heat and moisture production which may skew the graphic output when viewed over a long time period.

CO_2 Concentration;

Compared to the rest of the dwelling the CO_2 concentration in the kitchen is relatively high. With a mean value of 1055ppm it is above desirable levels and is characterised by prolonged daily intervals where levels up to 1250ppm are not uncommon. This relatively poor air quality suggests that the kitchen is often densely populated and that, in the main, the temperature drops explained above are not due to window opening as this would result in better air quality generally. It does however raise questions over the efficacy of the MV system in the kitchen as, although this is only an extract, it should be operating at a level which draws sufficient fresh air into this part of the dwelling from the supply grilles located in the hall or through trickle vents.

Vapour Pressure;

The vapour pressure in the kitchen has a relatively mean high value of 11.39haPa as well as several daily peaks at levels up to 18.76haPa. High levels in a kitchen are obviously not unexpected but at these levels they represent poor air quality and, as above, may require that the review of the efficacy of the mechanical extract system to remove moisture from this 'wet' space.

SUNSPACE

Temperature;

As with Dwelling 1 the mean temperature for this area appears to be reasonable for an internal environment, if a couple of degrees below the ideal. Again, however, is achieved by a cycle of overly hot peaks and overly cold troughs with a range of 13.50°C to 40.90°C and consideration of the mean alone can be seen to provide a poor reflection of the overall performance or thermal comfort of the space.

CO_2 Concentration;

Because of the poor thermal comfort, this space appears to be little used during the heating season yet it still has a relatively high CO_2 concentration of 977ppm as well as daily peaks of circa 1200ppm. From the timing of these peaks this appears to be as a result of air infiltration from the adjacent bedrooms as it coincides with what are obviously the occupant's sleeping/ bedroom occupation patterns. In this sense it appears useful as it is assisting in maintaining good air quality in the double bedroom. This is a better approach than directly ventilating to the cold outside or not ventilating at all and as such this is a reasonable task for a buffer space.

Vapour Pressure;

Compared to the rest of the dwelling the VP value of 11.11haPa is not overly high although the profile does show significant peaks above desirable levels. This is not unexpected as visual survey identified that the space is used for internal drying but it does present an environment which is frequently too moist and may promote problems as previously identified.

DOUBLE BEDROOM

Temperature;

On the whole the temperature of this room appears to be fairly comfortable with a mean value of 20.13°C over the monitoring period. There are daily fluctuations characteristic of a fast response construction system and heating system but nothing that would not be expected. Interestingly this room does not suffer from the spikes in heat gain which were evident from the similar room in Dwelling 1. This may be due to the occupant's use of window coverings which, at the time of survey (mid-afternoon), were completely closed. As an explanation for protection from unwanted heat gains this is a good example of how occupant behaviour can affect environmental control and if occupants were better educated on this then the general comfort levels could be improved.

CO_2 Concentration;

The air quality in this room appears to be relatively good with a mean value of 698ppm and only very limited instance where this value exceeds 1000ppm. These low values may, in part, be aided by the opportunity to ventilate to the sunspace as detailed above.

Vapour Pressure;

Despite the good ventilation of this room the mean vapour pressure (11.24haPa) is perilously close to the maximum desirable level of 11.3haPa with several peak levels which exceed this figure (in the worst case this level was exceeded for a period of 2 days).

TWIN BEDROOM

Temperature;

An overly high mean temperature of 22.31°C is maintained throughout the three week period. Generally the daily profile is characterised by the highest temperatures achieved during the night and daily low's, approximately 2 to 3°C lower, occurring in the early evening. While the increase in temperature occurs during the period of occupation (as shown by the CO_2 profile) it is likely this is as a result of the heating system and not by metabolic gains alone.

CO_2 Concentration;

The mean value of 1261 ppm suggests poor air quality over the monitoring period and as an average is bolstered by frequent daily highs of well over 1500ppm. The poor ventilation of this space may be explained by the low temperatures experienced overnight in the adjoining sunspace and the occupant's desire to maintain a high temperature in the child's bedroom. In the survey the occupant noted that the cool temperatures of the sunspace were a particular problem and as such this explanation is highly feasible. It does, however, highlight the problems that can arise from not appropriately ventilating and as this appears to be in response to the low temperatures in the space, strengthens the case for the addition of thermal mass.

Vapour Pressure;

The mean VP value of 11.39haPa is above the Platts-Mills benchmark value and as such has the potential to promote dust mite colonisation. It is likely that the poor ventilation rate, associated to the poor thermal comfort of the sunspace, has impacted on this value.

HALL

Temperature;

As with Dwelling 1 reasonably stable temperature profile was identified in the hall area with a mean value of 22.09°C

CO_2 Concentration;
Not monitored in hall.

Vapour Pressure;
A relatively high mean vapour pressure of 11.76haPa was recorded over the monitoring period. As with Dwelling 1 this is the highest recorded value of all rooms in the household and is likely to be caused by moisture migration and limited ventilation potential. The issues identified in Dwelling 1 relative to the MVHR system remain relevant here.

Conclusions

The occupants noted that the principal issues with the dwelling were that bedrooms and the living room were too cold in winter and too warm in summer. The 3 week monitoring period does not necessarily support this assertion however, and far from being too cold, the house appears to frequently achieve uncomfortably high temperatures.

Fig 4.3.1 – Living room recorded data for 27.03.11

While the occupant of Dwelling 1 appears to enjoy above average temperatures, the occupants of this dwelling appear to be finding the overheating an issue as they are frequently opening window's to reduce the high internal temperatures with survey responses indicating that the occupants opened the windows as every day to 'air' the house.

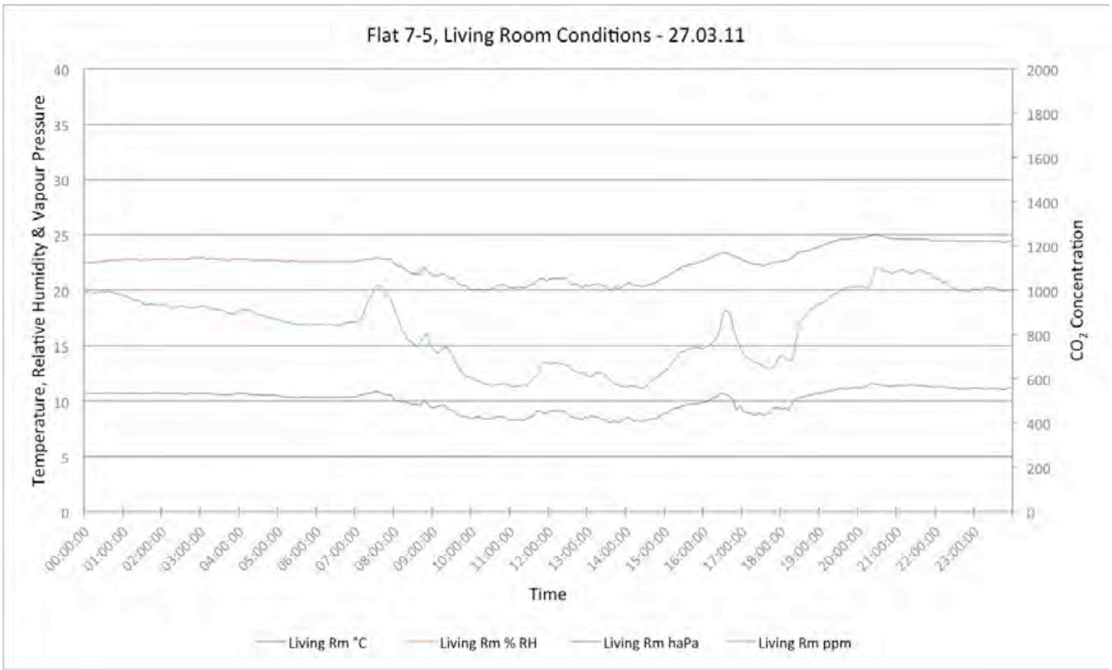


Fig 4.3.2 – Living room recorded data for 07.04.11

Figures 4.3.1. and 4.3.2, above, illustrate this behaviour (sharp fall in room temperature) and also clearly show that this is a response to overly high temperatures and not poor internal air quality.

This type of behaviour comes at a considerable cost in terms of wasted heat energy and is hugely inefficient. The extent of this inefficiency is exacerbated when the role of the MVHR system is also considered. As this system is perpetually running then it will be drawing electricity when there is no need for additional ventilation, due to the open windows.

As high temperatures are seen to be the reason to increase ventilation rates, it would appear that if a steady and lower internal heat were achievable then the need for window opening would be mitigated. The temperature profile for the child's bedroom in Dwelling 1 shows that a stable temperature can be achieved in this quick thermal response structure so the question remains as to why the temperature is being brought up to an uncomfortable level where the occupants are then forced to manually exhaust the heat.

One possible explanation could lie with the simplicity of the household thermostats and the limitations these have in terms of occupant control. This aspect is discussed further in reference to Dwelling 5.

As with Dwelling 1, the sunspace provides a focus for investigation. The space experiences the similar profiles of heat gain and loss but with markedly lower minima as illustrated by Fig 4.3.3 below.

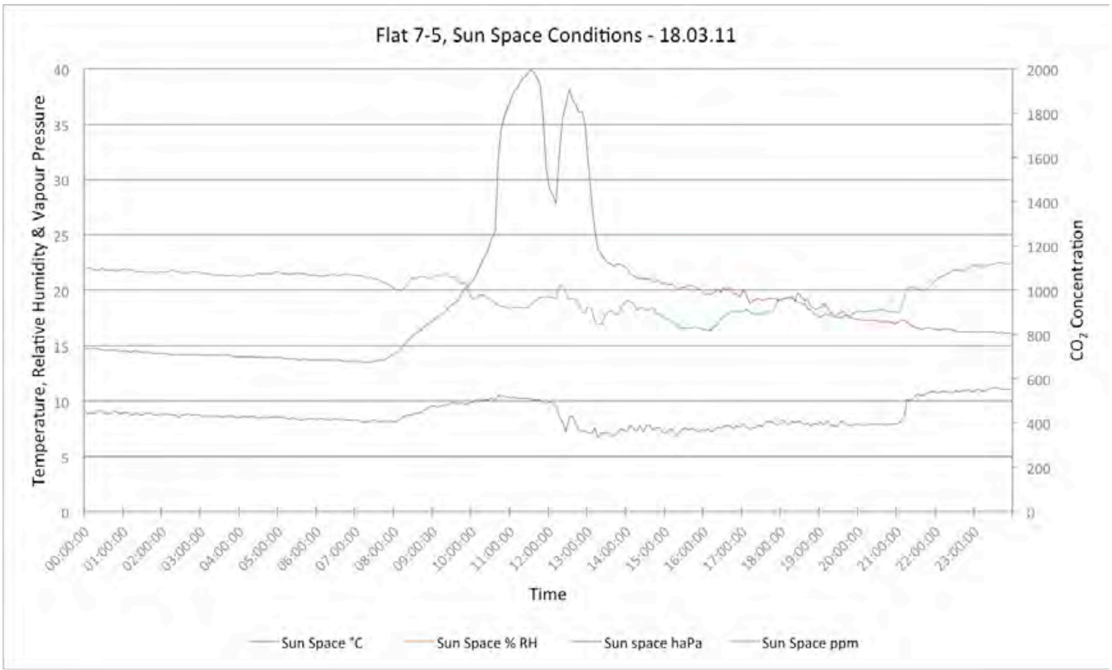


Fig 4.3.3 – Sunspace recorded data for 07.04.11

The low temperatures this space experienced overnight, show the limitations of the relatively lightweight construction with limited thermal mass and therefore little capacity for storing heat overnight. They also show why the dwelling may experience low temperatures in the adjacent bedrooms as heat loss from these spaces to the sunspace will be prevalent with such a significant temperature differential and only a single glazed timber window or door as an intermediary. If a better thermal barrier was installed between these zones then heat loss would be mitigated but the opportunity to ventilate to a space with warmer air than the exterior would remain. This would present an improved arrangement and, as a scenario, is particularly pertinent when the severity of the two preceding winters are considered. Under such conditions it is clearly feasible that the bedrooms would have suffered and may explain the survey responses.

With this scenario it is also important to note that providing heating to a sun or buffer space undermines endeavours for achieving thermal energy efficiency. The apparent need for heating in this space could be negated by, again, improving the thermal barrier between inhabited apartments and the sunspace.

SUPPORTED HOUSING

4.4 Dwelling 3

Description;
Supported housing single aspect dwelling comprising;

- Open plan living room/ kitchen to the north elevation
- Double bedroom to the north elevation
- Internal bathroom and hall space off common close

Flat is occupied by a single female adult who has retired.

3 week monitoring period (refer appendix D)

Dwelling Overall;

	Temperature (°C)	Relative Humidity (%)	CO_2 Concentration (ppm)	Vapour Pressure (haPa)
Max.	25.30	72.20	1786.00	22.57
Min.	18.20	27.10	309.00	6.53
Mean	22.17	38.88	686.55	10.38

The mean temperature for this dwelling over the monitored period is one which sits very slightly above the accepted norm for winter indoor thermal comfort (21°C) but overall appears to be comfortable.
The mean RH maintains an acceptable level throughout as does the CO_2 concentration, suggesting a reasonable air quality.

Specific rooms;

LIVING ROOM
Temperature;
An average temperature of 22.03°C is maintained in the living room with relative stability and daily highs and lows generally sitting 2 to 3°C apart. The variation in this is to be expected as the occupant noted that they open the windows every day to aid ventilation as they are a smoker and they find the house to be very stuffy. In conjunction with this routine of window opening they note that the internal temperature is very comfortable and as such the maintenance of this temperature must come at the cost of a substantial penalty in terms of energy consumption.

CO_2 Concentration;
The air quality in the living room is very good with a mean value of 590ppm and very few significant spikes in CO_2 concentration. With reference, again, to the routine of window opening this is not surprising.

Vapour Pressure;
The vapour pressure for this room is low at just 9.91haPa over the monitored period. Compared to dwellings 1 and 2 this is surprisingly low as the flat arrangement is such that the monitored space was a combined kitchen and living/ dining space. As such, it could be expected that cooking or the use of kettles and laundering would result in higher vapour pressure figures.

As an explanation for the low values it either must be that the MVHR system is performing very effectively or, as is more likely, the high manual ventilation rate is assisting in maintaining a low vapour pressure. If this is the case then it is in opposition to the

If the latter is true then it is worth noting that there is an additional energy penalty in a constantly running MVHR system operating in such a well-ventilated environment, particularly during the heating season.

BEDROOM
Temperature;
A mean temperature of 20.93°C was recorded and this remained very steady throughout the project with small fluctuation of 1 or 2°C only, evident.

CO_2 Concentration;
The average value of 765ppm represents good air quality generally and is achieved by a very constant cycle of low values during the day, when the room is unoccupied, and steadily increasing values overnight up to a regular maximum of approximately 1300ppm – i.e 30% over the maximum desirable level.

The regularity and extent of these peak values suggest that there should be some increased ventilation of this space overnight. As the resident notes that ventilation to the street is not feasible at this time, due to traffic noise, then this should be addressed by a separate mechanical air supply as part of a whole house ventilation system.

Vapour Pressure;
The profile of vapour pressure has a very similar shape to that of the CO_2 concentration with peak values reached overnight when the room is occupied, with the door closed and reduced ventilation than during the day.

HALL
Temperature;
The temperature of this zone is, at 23.56°C, higher than would normally be desirable and is maintained at this level very steadily throughout.

CO_2 Concentration;
The air quality in the hall is generally very good but this is as expected given that it will only be populated for very brief spells. Where spikes in CO_2

concentration do occur it can be assumed that this is from migration from other occupied rooms as doors are opened and closed.

Vapour Pressure;

The vapour pressure in the hall is, as elsewhere, reasonably low but with regular daily spikes occurring in the morning; presumably as a result of moisture migration from the adjoining bathroom.

Conclusions

When questioned, the occupant had only been living in this flat for a limited period of time and so had not experienced the dwelling through different seasons in order to provide a full appraisal of the dwelling. Not withstanding this, she generally reported a high degree of satisfaction with the only issue being that the internal environment was stuffy.

Review of both weekly and daily data confirms that air quality, in terms of CO_2 concentration and VP, is generally good yet the occupant still felt the environment was stuffy. This perception must, therefore, be attributed to either high temperatures or a ‘close’ air quality and smell that results from smoking.

As a response to this stuffiness the occupant notes that they open the windows every day, similar to Dwelling 2, and during the heating season there will be an energy penalty for doing so. While this regime emulates that of Dwelling 2, fig 4.4.1 below shows that the where windows are opened (signified by simultaneous drops in CO_2 and temperature) the drops in temperature, and therefore the apparent energy loss, are less severe than those of fig 4.3.2 with fluctuation generally no greater that 1ºC.

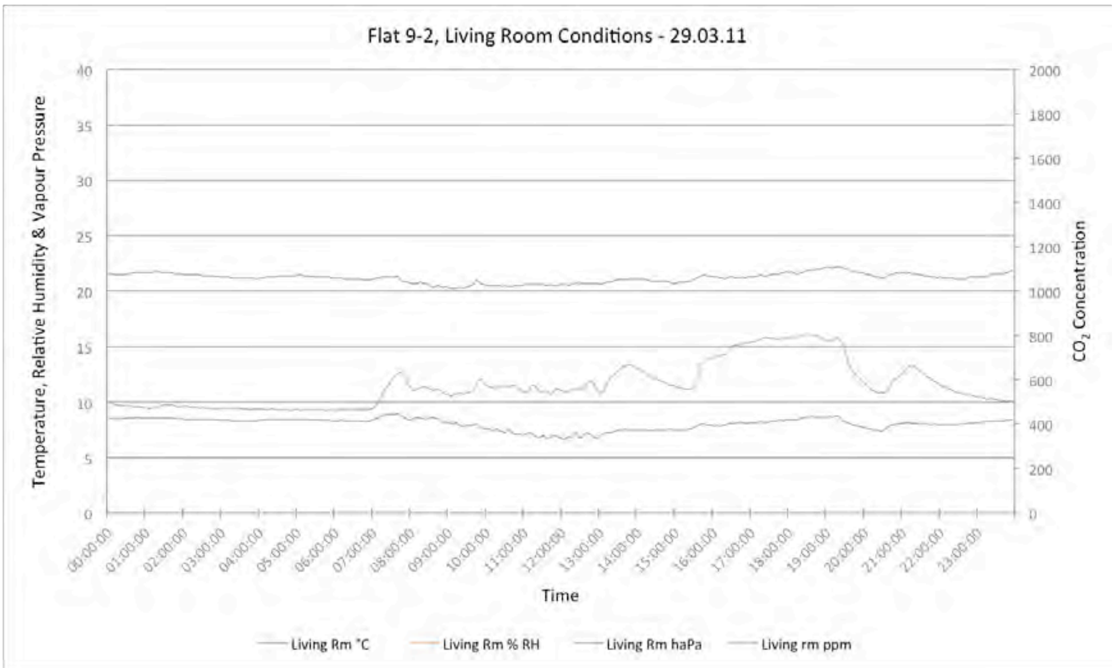


Fig 4.4.1 – Living room recorded data for 29.03.11

This indicates that the area of window opening is likely to be less than in Dwelling 2 and also that the primary objective of the action is not one of heat control. This seems to support the resident's happiness with internal temperatures and, despite being higher on average than would normally be expected, goes some way to confirming the sustained and reasonably stable thermal comfort of this dwelling – the only one monitored which is entirely North facing and which has does not have a sunspace.

As the key influencing factor in the ventilation regime seems to be related to the removal of smells from the living space this raises the performance of the mechanical ventilation system as an issue.

In this instance the house only has mechanical extracts from kitchen and bathroom spaces and not a full MVHR system. It is not intended to be a whole house mechanical ventilation system, and would not be able to respond to such a pervasive pollutant as cigarette smoke or other environmental 'peaks' such as smells or heat. If the system is unable to cope with such demands then the occupant response will be, as in this case, to open a window, creating an extra energy burden for the dwelling during winter months.

Generally, the efficiency of MVHR systems is based on the principle of "build tight, ventilate right" and with overly frequent window opening air tightness is lost and the system becomes irrelevant.

In this particular instance there is a concern that the inability of the system to cope with the internal air may not be due to specification alone but also to the installation and maintenance regime.

At inception, this project initially proposed to assess the cleanliness of each individual MVHR system by checking the filters. During equipment installation, however, it quickly became clear that this was not feasible as the units had been installed in an inaccessible position. This makes routine maintenance very difficult and, as is human nature, less likely. This issue is compounded by the fact the, at present, Hillcrest HA have no maintenance regime in place for the checking or cleaning of MVHR systems or filters. As the manufacturer recommends a 3 monthly check and 12 monthly clean or replacement as standard it is clear to see that failure to maintain this will impact on the internal air quality and, as has been seen, will cause residents to seek alternative means of ventilation at the cost of both heat and electrical energy efficiency.

The analysis of MVHR efficacy generally relates to both the extract *and* supply of air from dwellings. As this small dwelling has no mechanical air supply and all fresh air comes via the fenestration it raises a question over the design of the system in general; if some properties are constructed to a standard that benefits from MVHR then why would it not be suitable for this dwelling?

This question becomes more pertinent when the specific context is considered. Without a separate mechanical air supply this dwelling is liable to rely solely on the windows for ventilation (with the associated energy penalty) and due to the heavily trafficked street, where windows are likely to be closed overnight, a secondary penalty is paid in terms of air quality, evidenced by the daily peaks in CO_2 concentration.

4.5 Dwelling 4

Description;

Supported housing single aspect dwelling comprising;

- Kitchen to the north elevation
- Double bedroom and living room off sun space to the south elevation
- Internal bathroom and hall space off common close

The flat was unoccupied at the start of the monitoring period. After 4 days the dwelling came into occupation by a single male adult who is unemployed. Monitoring equipment was switched off by occupant a further 5 days after occupying the dwelling and was not restarted again during the project period.

During the unoccupied period only the sunspace was artificially heated.

Monitoring period (refer appendix E)

Dwelling Overall (vacant period – 4 days);

	Temperature (°C)	Relative Humidity (%)	CO_2 Concentration (ppm)	Vapour Pressure (haPa)
Max'	32.30	44.90	896.00	11.03
Min'	15.70	16.10	514.00	5.89
Mean	20.10	31.90	642.15	7.48

Dwelling Overall (occupied period – 5 days);

	Temperature (°C)	Relative Humidity (%)	CO_2 Concentration (ppm)	Vapour Pressure (haPa)
Max'	30.70	55.00	1383.00	14.89
Min'	17.60	24.80	525.00	8.69
Mean	22.24	37.84	817.24	10.12

The mean temperature for this dwelling over the monitored period represents a reasonably good level relative to the recognised norms for internal comfort. The mean RH maintains an acceptable level throughout as does the CO_2 concentration, suggesting a reasonable air quality.

With respect to this particular dwelling it is important to note that the occupied period of monitoring was limited to just 5 days of the 3 weeks. This will have undoubtedly affected the results but, on a positive note, will provide a good example of a ‘control’ for the period when the dwelling was unoccupied. In general the commentary below will refer to the occupied period but separate reference may be made to the vacant results as a ‘control’.

Specific rooms;

LIVING ROOM

Temperature;

The mean temperature of this space during the period of occupation was above the ideal internal temperature at 23.04ºC. As with the living spaces in the previous dwellings this exhibits the characteristics of a high thermal response with daily highs and lows varying by around 3ºC in the most severe cases.

With 3 of the 5 recorded daily peaks there appears to be a relationship with the peak values recorded in the sunspace. This strongly suggests that solar heat gains are being achieved in the living room or that heat gained in the sunspace is capable of being transferred to the living room. As with Dwellings 1 and 2, however, the usefulness of these gains must be brought into question given that they tend to exist in short intense bursts which are more likely to cause discomfort than be of benefit.

CO_2 concentration;

The mean CO_2 concentration, at 969ppm, is close to the maximum recommended limit and would indicate that air quality could be better. This value appears to have been slightly skewed, however, by abnormally high readings during the first day of occupation – presumably as the occupant was moving in and heavily respiring while moving their personal effects. If this day is omitted then a mean value of 925ppm is achieved which, although still high, is markedly better. Peaks of over 1000ppm were recorded on a daily basis.

Vapour Pressure;

A reasonably low mean vapour pressure of 10.16haPa was recorded with small peaks evident relative to periods of occupation. There are only very limited instances where these values exceed the benchmark value of 11.3haPa.

KITCHEN

Temperature;

A good mean temperature of 20.82ºC was recorded over the 5 day occupation period with a profile which had only very slight peaks and troughs which corresponded with periods of occupation (increased CO_2 concentration) and moisture producing activity – either through metabolic activity or cooking.

As a north facing room it is likely that the stability of this temperature profile was also helped by low solar gains.

CO_2 Concentration;

Over the course of the project the kitchen maintained a low CO_2 concentration with a mean value of just 657ppm and daily maxima generally below 800ppm. This could either represent good performance of the MVHR system or it could simply be a reflection of the intensity of occupation of the space.

Vapour Pressure;
As with the other monitored parameters in this room, the vapour pressure, at 9.76haPa mean, was found to be relatively low, particularly in comparison to the other kitchens in the development.

SUN SPACE
Temperature;
The pattern of extreme highs and lows seen in Dwellings 1 and 2 are again evident in this space. During the period of vacancy this area was heated yet on the 18th April the temperature shifts from the overly cold level of 16.5ºC up to a high of 33.0ºC. While the very high readings are maintained throughout the period of occupation the low level temperatures experienced are not as severe as those during the time the dwelling was vacant. As the heating in the rest of the house was switched on for the new tenant then it is possible that the increased minimum temperature is as a result of the adjacent heated zones.

While this is of benefit to thermal regulation of the sun space it is to the detriment of the rest of the dwelling as heat is being drawn from the warmer part of the dwelling to the cooler, lightweight construction of the sun space. This, as previously noted, may represent a significant energy penalty during periods of cold weather unless it is a deliberate tactic to draw air-flow from the sunspace to the interior.

CO_2 Concentration;
Daily peaks of over 1000ppm are evident and generally coincide with those in the living room suggesting that openings between the two spaces are maintained and allow a free passage of air from one to the other. This theory would seem to be supported by the fact that the living room and sun space have very similar CO_2 concentrations of 925ppm and 939ppm respectively; noting that the less frequently occupied sun space actually has the slightly higher reading.

Vapour Pressure;
A reasonable value of 10.22 haPa was recorded over the 5 day occupation with small peak values obtained relative to peak temperatures.

BEDROOM
Temperature;
The temperature profile for the bedroom is remarkably similar to that of the living room despite having a very different occupancy regime. Temperatures are again above the desirable comfort level in the mean and with peaks, in the early afternoon, which would be uncomfortable. The timing of these, their intensity and the rate of rise all point to the, not necessarily positive, influence of the adjoining sunspace.

It is interesting to note that during the period of vacancy and with the heating switched off (with the exception of the sun space) the mean temperature for this space was far closer to the desirable level and more than 2.5ºC lower than the value achieved during occupation. With the thermal comfort seemingly better with the heating off, questions should again be raised over the suitability of the heating system design and it's associated controls.

CO_2 Concentration;

On what seems to be the first night of occupation there is a prolonged period where the CO_2 concentration is above 1200ppm but for the remaining three nights this level drops to a more acceptable value below 1000ppm. This coincides with an increase in the sunspace CO_2 concentration and would suggest that the tenant is now venting from the bedroom to the sunspace over night.

While this may be coincidental it is perhaps an indicator of the individual's ability to perceive a 'stuffy' atmosphere at just 1200ppm and to be moved to take action and vary the ventilation regime. Similarly, it is after this first night that the profile of the bedroom more closely matches that of the sunspace, again giving weight to the theory of an air path between the spaces being created.

Vapour Pressure;

Over the monitored period the vapour pressure achieved a reasonable mean level of 10.67. As above it is worth noting that over the last 2 days this value falls from the previous peaks even as temperature profiles increase. This would again be suggestive of an improved ventilation regime for the space.

HALL

Temperature;

As with Dwelling 3 a reasonably steady profile is maintained with limited fluctuation although there is, as would be expected, a steady increase in temperature over the first two days after the heating is switched on. After this point the temperature stabilises at a too warm 22 to 23ºC.

CO_2 Concentration;

The air quality of the hall was seen to be good throughout. When peaks in concentration become evident they are generally short lived, suggesting good air movement through the space. This is what could be expected given that this area contains the two fresh air supply grilles for the dwelling.

Vapour Pressure;

With a mean value of 9.78haPa, the vapour pressure in the hall is lower than that recorded in other rooms. This is in variation to the other dwellings analysed thus far and is indicative of variations in occupant behaviour with respect to moisture producing activities. Regardless of the cause, the low recorded values are of no concern with respect to the quality of the internal environment and air quality.

Conclusions

With the resident's short period of occupation, limited information only can be gleaned from their survey responses although they seemed to be happy with the internal environment and had little need to open windows to manually affect the dwelling conditions. Similarly, the limited period of recorded data, due to the occupant switching monitoring equipment off, means that there are inherent limitations on the available data, particularly when trying to form a robust analysis. There are, however, two key findings from the analysis of this dwelling.

Firstly, as illustrated by fig 4.5.1, the temperature profile of the sunspace is, as with Dwellings 1 & 2, seen to fluctuate from overly low temperatures to overly high ones. The profile of 18th March shows that despite the under-floor heating being on in this zone a low of 15.7ºC is reached.

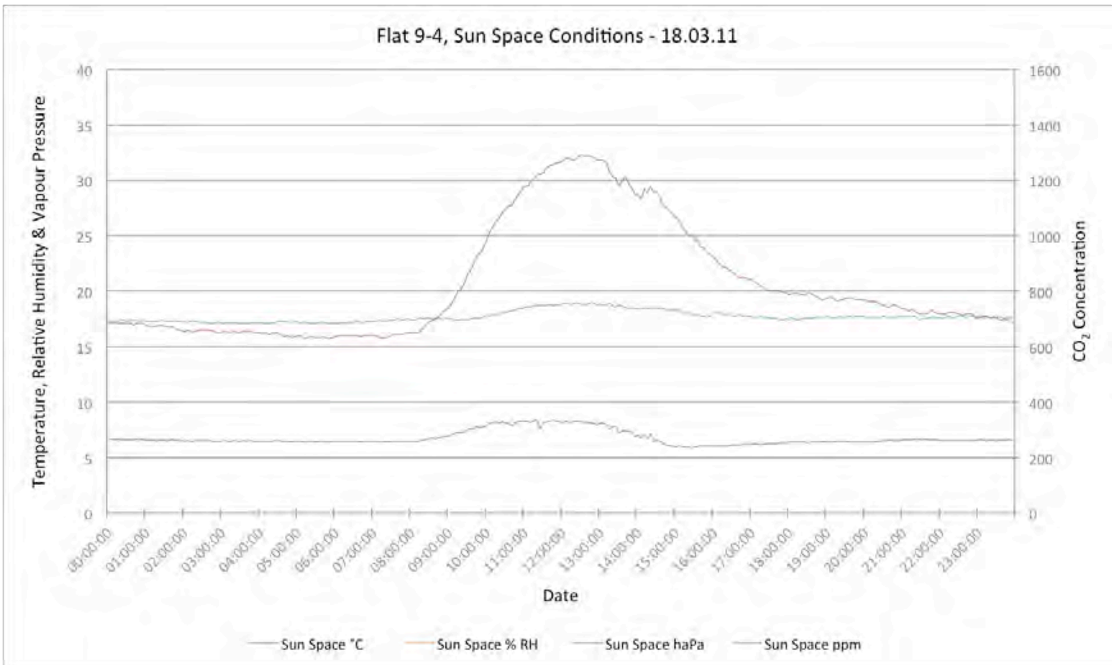


Fig 4.5.1 – Sunspace recorded data for 18.03.11

With this space being artificially heated and of lower insulation levels, compared to the rest of the building, it represents a weaker point in terms of fabric heat loss.

The profile also illustrates the high temperatures which are characteristic of these spaces as the volume reaches a peak of 32.3ºC just 4 hours after the recorded low. The impact that these high heat gains can have on the adjacent spaces, depending on the degree of openings and window coverings, is further illustrated by the comparative analysis of figs 4.5.2 and 4.5.3

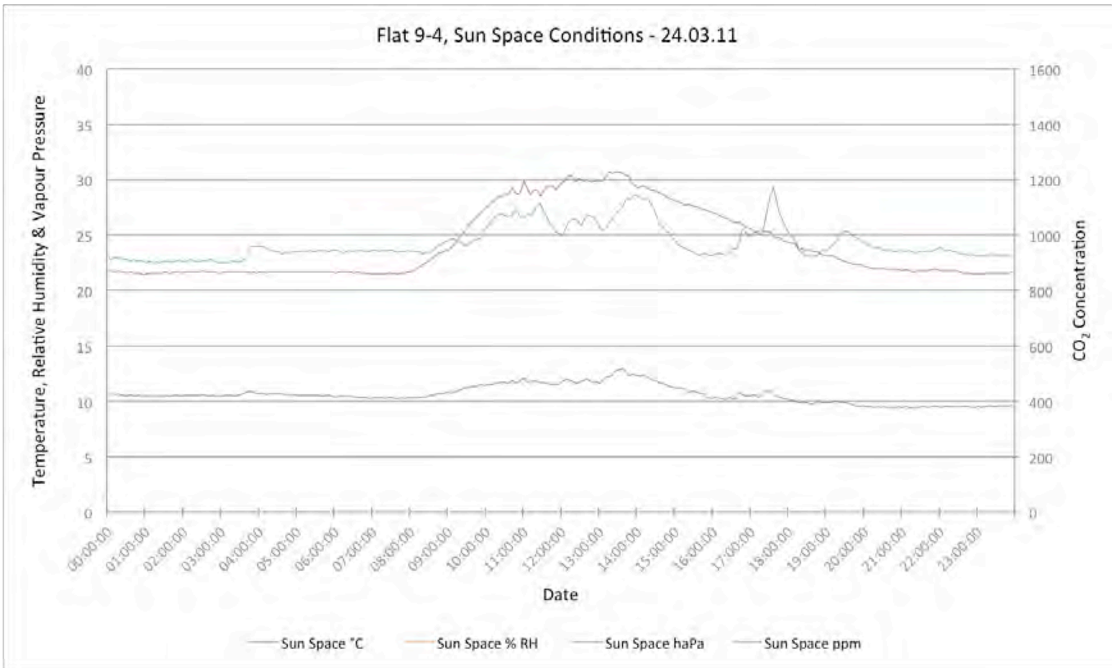


Fig 4.5.2 – Sunspace recorded data for 24.03.11

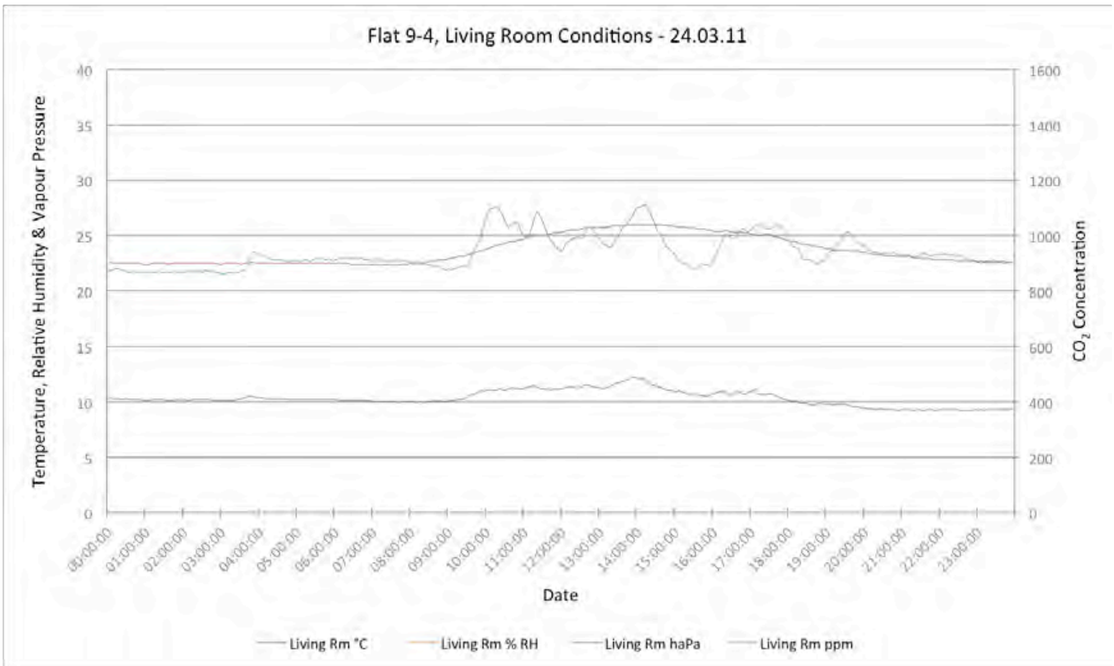


Fig 4.5.3 – Living room recorded data for 24.03.11

Here we see heat gains in the living space coinciding with those in the sunspace. While of a lesser intensity they still take the temperature in the living room above a comfort norm and can therefore be seen to be unwanted. These gains could, however, be useful if the heating system was able to respond to the solar input and not draw from the heat pump during this period. This would lead to a more stable temperature and to a reduction in energy burden from the dwellings. The apparent issue with unwanted heat gains is further supported by the daily profiles from the hall and kitchen over the same time period.

Figures 4.5.4 and 4.5.5 illustrate the heating profile for the 24th March for the kitchen and hall areas and show the greater degree of thermal stability which is maintained in these areas. As these have the same construction type and heating system as the living room it can be reasonably assumed that the more comfortable conditions are as a result of the reduced solar gains.

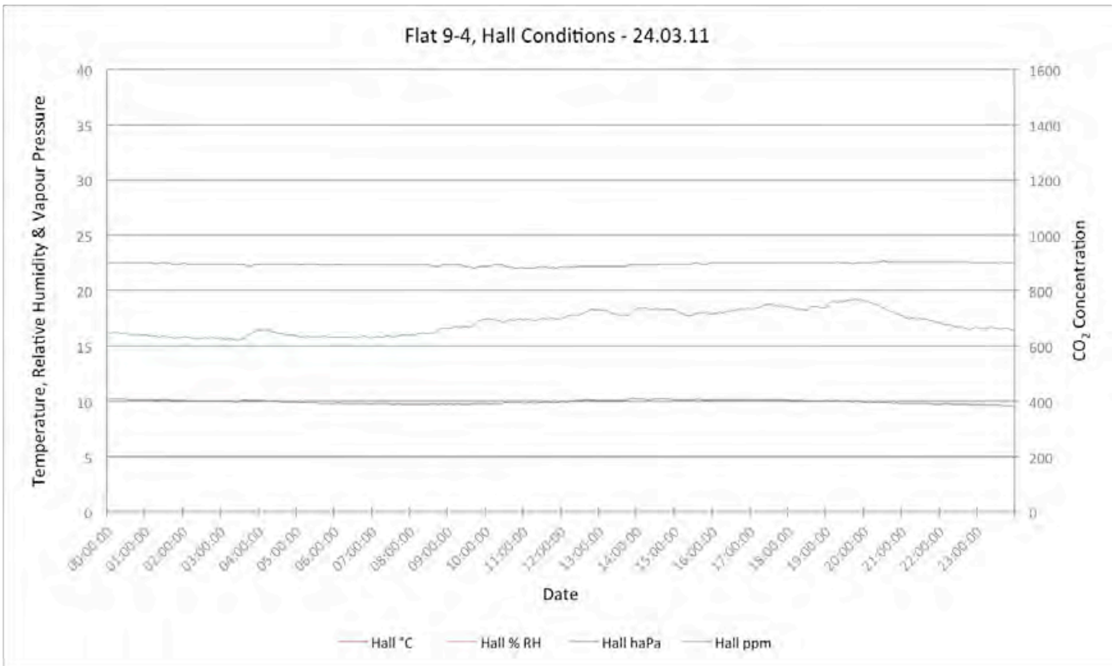


Fig 4.5.4 – Hall recorded data for 24.03.11

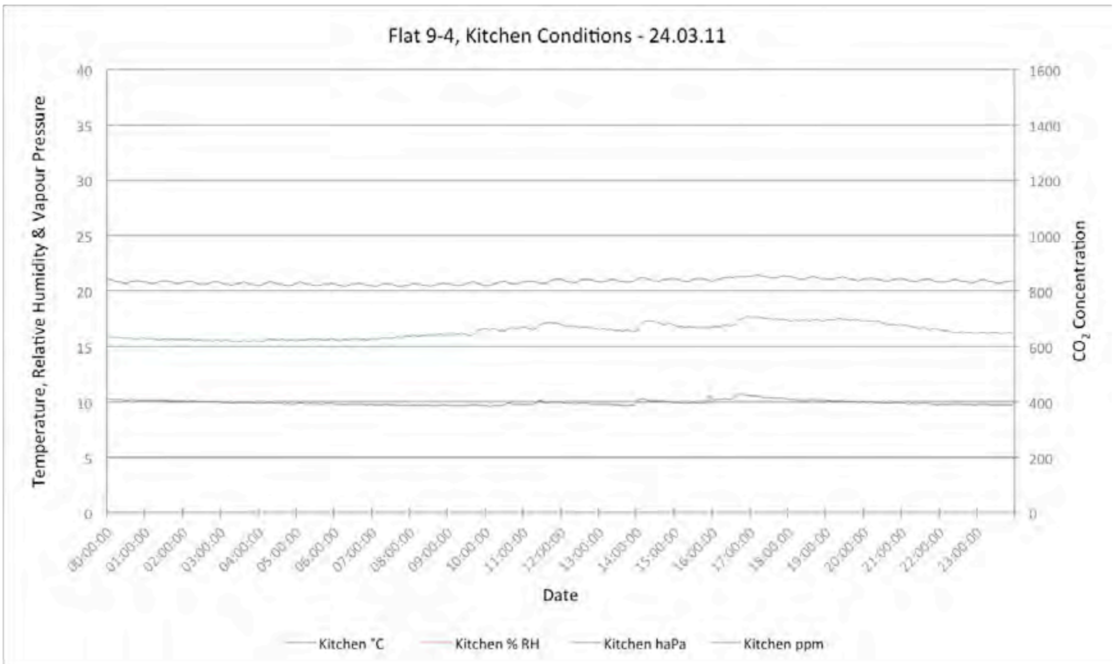


Fig 4.5.5 – Kitchen recorded data for 24.03.11

The second finding from this dwelling comes from analysis of when it was not under occupation. During this period the under-floor heating was on in the sunspace but nowhere else in the dwelling and is clearly illustrated by the thermographic images of fig 4.5.6 and 4.5.7 which show;

1. Under-floor heating (lightweight proprietary system in insulated trays) in sun space with high surface temperature of 26.5ºC
2. Very stable internal surface temperatures to bedroom

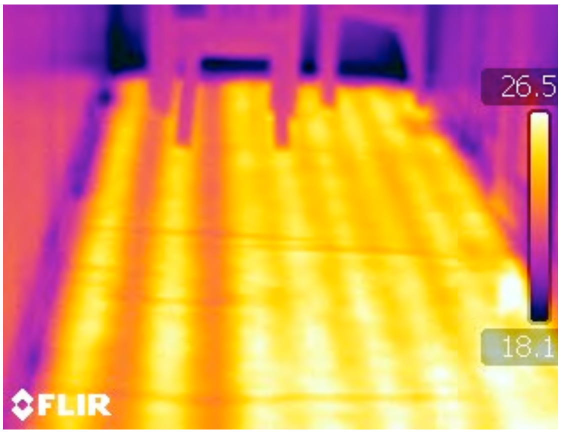


Fig 4.5.6 Under-floor heating in sunspace

Fig 4.5.7 Stable bedroom temperatures

During this period the mean values for temperature, and heating profiles in general are more stable and comfortable than those recorded during the occupied period. With respect to the rooms adjacent to the sunspace this appears to be due to a greater degree of protection from significant solar gains. Over the vacant period this is evidenced by the greater degree of stability in the living space (with closed curtains) as compared to those of the bedroom (no curtains to French doors). Not withstanding the variation in solar gain, it can be seen that the thermal comfort during the vacant period is better than during the period of occupation.

This raises questions over the suitability and efficacy of the heating system in terms of its position, size, response in relation to the fabric conditions and it's usability. The first of these points again raises the appropriateness of the design decision to artificially heat the 'lightweight' sunspaces given the underlying effect in terms of heat loss.

In terms of user interface and understanding, the last observation could relate to the fact that the resident had only been living in the dwelling for a matter of days and was still getting to grips with the system controls (thermostat, etc.) and trying to work out the comfort parameters but if this is the case then it perhaps represents a scenario where tenant education and training is required on the effective use of system along with the installation of more illustrative/ intuitive controls.

These matters are further investigated and discussed in the analysis of Dwelling 5.

4.6 Dwelling 5

Description;

Supported housing single aspect dwelling comprising;

- Living room to the north elevation
- Double bedroom and kitchen off sun space to the south elevation
- Internal bathroom and hall space off common close

Flat is occupied by a single male adult who is unemployed.

3 week monitoring period (refer appendix F)

Dwelling Overall;

	Temperature (°C)	Relative Humidity (%)	CO_2 Concentration (ppm)	Vapour Pressure (haPa)
Max'	34.70	70.30	1988.00	15.78
Min'	10.00	19.20	447.00	5.33
Mean	24.39	32.87	698.32	9.89

The mean temperature for this dwelling over the monitored period is an uncomfortably high 24.39°C.
The mean RH maintains an acceptable level throughout as does the CO_2 concentration, suggesting a reasonable air quality.

Specific rooms;

LIVING ROOMS

Temperature;

The mean temperature over the three week duration was recorded as 24.04ºC and while this is obviously overly hot this long term average does not give a full picture of the complexity of the temperature profile.

As has been evident elsewhere in the development, the profile is characterised by a series of peaks and troughs ranging from a low of 17.30ºC to a high of 28.00ºC. As a north facing room it can be assumed that the high temperatures are the caused by the heating system and not significant solar gains. With the occupant complaining that the flat is overly warm and stuffy there is little doubt that the low temperatures experienced are as a result of window opening. This theory is supported by the rate of temperature decay, the change in CO_2 concentration (see below) and the fact that windows were seen to be wide open during the survey – a practice that the occupant noted was daily.

As previously noted this practice comes with a significant energy penalty and so, with such severe changes in temperature, the question must be raised over why this ventilation regime exists. Is it, as the occupant notes, due to 'stuffiness' and poor air quality or is it the *perception* of poor air quality caused by an overly hot internal environment?

CO_2 concentration;

The mean value of 769ppm suggests good air quality but this is clearly facilitated by the energy intensive regime of window opening. Peak values of almost 2000ppm illustrate that the room has the potential to achieve poor air quality but as the peaks in CO_2 coincide with those in temperature it is not possible to ascertain which factor is more instrumental in causing the window opening.

Vapour Pressure;

The profile of the vapour pressure fluctuates greatly, as could be expected given the ventilation regime and with the exception of some limited peaks over 11.3haPa does not appear to indicate any issues in terms of internal air quality.

KITCHEN

Temperature;

Similar to the living room of this dwelling, the kitchen temperature profile exhibits a great degree of fluctuation with fairly dramatic peaks and troughs. In the worst case, from 2^{nd} to 3^{rd} April, the temperature drops by almost 10ºC from 28.6ºC to 18.7ºC in less than 19 hours.

With a mean temperature of 24.94ºC it can be seen that, as the occupant reports, the temperature of this room is too high and that attempts to cool it are made by borrowing cooler air from the sun space when it in turn has been ventilated to the exterior. This can be assumes as the troughs in both profiles often match and this path of heat transfer represents the most sensible explanation for such marked changes.

CO_2 Concentration;

Generally the air quality of the kitchen is good with a mean value of 685ppm. There are significant peaks, particularly in the first week of monitoring, over 1000ppm but these rise and fall fairly rapidly and indicate that the mechanical extract in this room is coping reasonably well with the issue of air quality.

With respect to temperature profile, there are several instances where the occupant affected ventilation (window opening) is evident, when the room temperature is high but CO_2 concentration is low. In this instance this would seem to point to temperature having greater significance in the causal relationship to window opening than the air quality itself. It supports the idea that high temperatures can affect the perception of air quality and subsequently have a negative impact on energy efficiency.

Vapour Pressure;

Fluctuations in this parameter are as expected given the nature of the space and the variations in temperature which are evident with the low mean value indicating that the mechanical extract is again performing effectively in terms of moisture removal.

SUNSPACE

Temperature;

This sunspace suffers from similar levels of temperature fluctuation to the others previously analysed, Dwellings 1, 2, and 4, although there are some notable differences. Firstly, while there are pronounced peaks in temperature, up to 34.70ºC, the intensity of these is generally lower than with other dwellings. The more sheltered positions of this sunspace provides a likely explanation of why solar gains in this space are less problematic.

Secondly, and perhaps of greater concern, is the minima values achieved. On one occasion, 27th March, 07.10, the temperature drops as low as 10ºC. Beyond this there are several other instances where temperatures below 15ºC are recorded. From the rapid nature of these temperature drops it appears that the resident's ventilation regime has impacted on these figures but this in itself is as a result of the problems inherent of the construction and its high thermal response.

There can be little doubt from review of the erratic temperature profile that this space would be uncomfortable to inhabit on a prolonged basis and, therefore, its use in the dwelling should be clarified.

CO_2 Concentration;

The air quality of the sunspace is generally good which again seems to point towards high temperature as being the primary factor in manual ventilation as opposed to air quality.

Vapour Pressure;

The vapour pressure is, as with the rest of the dwelling, reasonably low. There are strong similarities between all VP profiles throughout the dwelling which appears to be representative of the high levels of ventilation and perhaps indicative that the internal VP profile closely matches that of the exterior conditions. Unfortunately the exterior conditions were not monitored during this period to allow comparison although this seems to provide a likely explanation for these results.

BEDROOM

Temperature;

Compared to the rest of the dwelling the temperature of the bedroom appears much more stable although there are still significant fluctuations. The most severe fluctuations are in the region of 4ºC to 5ºC and are seen to coincide with the much larger drops in temperature from the adjoining sunspace – the bedroom and sunspace are separated by a single glazed sash and case internal window. Despite being more stable the mean temperature of this space is recorded as 24.57ºC and is, therefore, well above the normal desirable value of 18ºC. This strengthens the case for a more robust form of thermal barrier between these spaces than is currently installed, for the installation of thermal mass for buffering and for not providing an artificial heat source.

CO_2 Concentration;

For the majority of the monitoring period the CO_2 concentration is low and represents good air quality for the space. There are, however, three daily periods in immediate succession on the 22nd to 24th March inclusive, where peak levels of over 1350ppm are recorded. Values of this magnitude are not unexpected in bedrooms overnight but the fact that this pattern is not repeated every night is slightly strange and inexplicable.

Vapour Pressure;

Ref notes on sunspace vapour pressure above.
There are also peaks in VP which coincide with peaks in CO_2 concentration and may be as a result of metabolic moisture production.

HALL

Temperature;

The hall exhibits the same fluctuating temperature profile seen elsewhere in the dwelling. The mean value of 27.27ºC is, again, overly high and confirms the comments of the resident that the dwelling is too warm.

CO_2 Concentration;

Overall the air quality in the hall is good with select peaks over 1000ppm which coincide with much higher peaks in the living room and are, likely, as a result of air migration between the two spaces.

Vapour Pressure;

Ref notes on sunspace vapour pressure above.
As with other dwellings the hall exhibits the highest mean VP value, at 10.10haPa presumably as a result of moisture migration from 'wet rooms'.

Conclusions

The resident of this flat made particular note of the dwelling being overly warm, very stuffy (noted as a nasty dry heat) and with the thermostat being particularly ineffective. As a result of these issues, they had resorted to a regime of daily window opening, which, as previously described, comes with a significant energy penalty.

With respect to the first two observations, there are indeed daily events which indicate frequent window opening as described by fig 4.6.1 and 4.6.2, below.

The profile of fig 4.6.1 indicates window opening to the cold exterior with sudden drops in temperature on 3 separate occasions. As the CO_2 concentration is relatively low at the start of each of these events, with the exception of the one occurring at 21.30, it can be reasonably assumed that temperature is the main cause for the occupant choosing to increase the ventilation rate and cool the room. With this profile it is also particularly interesting to note the rate of temperature increase once windows have been closed. This is, again, symptomatic of the high thermal response structure and shows how rapidly temperatures can fluctuate without thermal mass to buffer and stabilise heat gain/ loss.

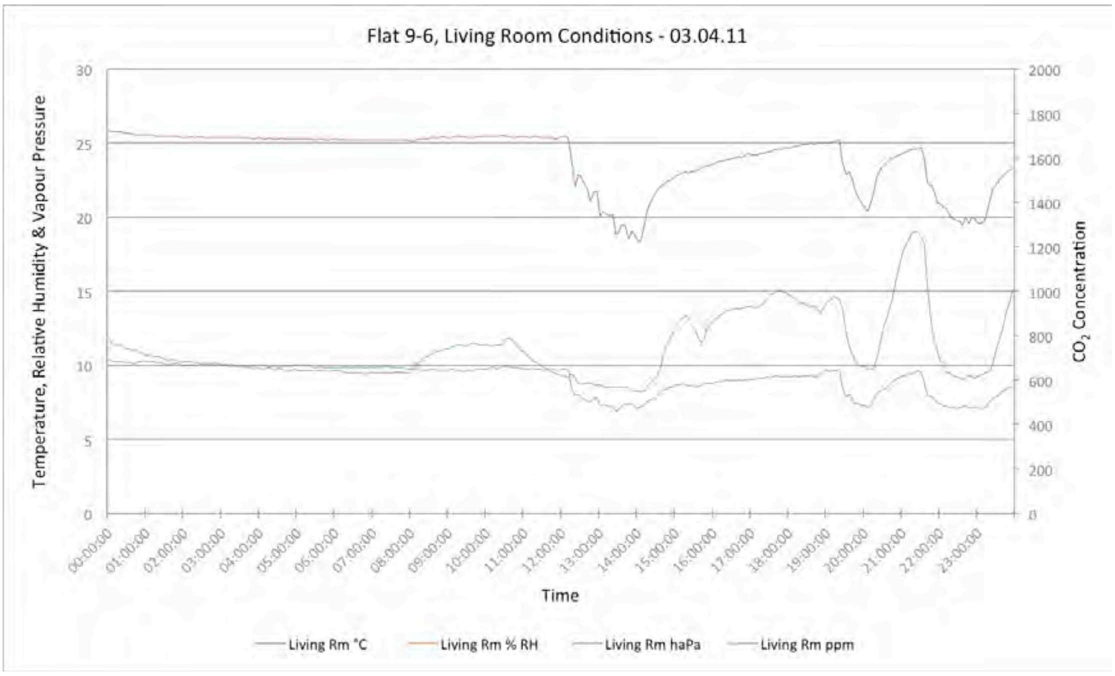


Fig 4.6.1 – Living room recorded data for 03.04.11

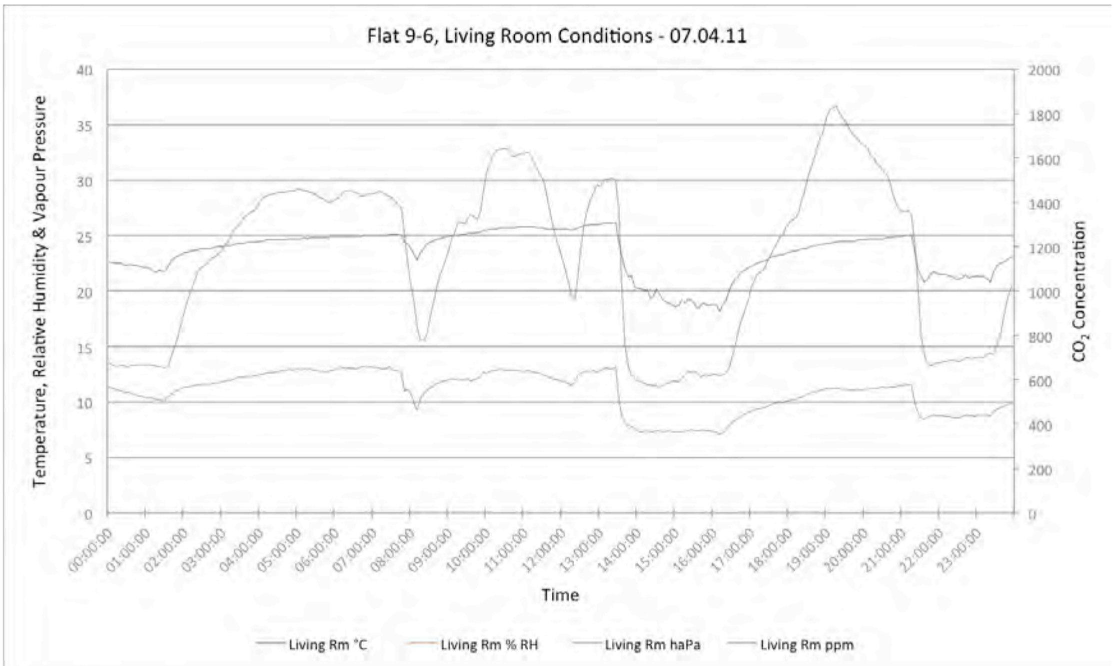


Fig 4.6.2 – Living room recorded data for 07.04.11

With fig 4.6.2 the window opening events correspond with significant peaks in CO_2 concentration. While it cannot be stated that either air quality or temperature was the principle cause for increased ventilation, in this instance, it is clear that there is a causal relationship between these factors and the need to ventilate. It should also be noted, that in the first example, while temperature appears to be the clear cause of the requirement for additional ventilation there could be other contributing factors such as smell, as seen in Dwelling 3, which are less evident. While the occupant is a smoker they do not make reference to the smell being an issue and this is, therefore, less likely than the identified issues of 'stuffiness' and overheating.

As with dwellings 1, 2 and 4, the issue of overheating is prevalent in the sunspace but it is also evident throughout the dwelling over the course of the monitoring period. As the resident was clearly able to perceive the discomfort associated with these sustained high temperatures, to the extent that window opening illustrated by fig 4.6.8 was required, the question remains as to why such high temperatures are allowed to prevail. With the resident also identifying the limitation of the thermostatic control this seemed presented a possible cause of the problem.

In Dwelling 5 on arrival to carry out the installation of monitoring equipment the living room window was found to be open to the extent shown in fig. 4.6.8. – evidently with the occupant feeling the flat was overly warm, yet the thermostat was already at its lowest setting. At this lowest setting, under-floor heating surface temperatures of approximately 27ºC were recorded (ref fig 4.6.3 and 4.6.4 below).

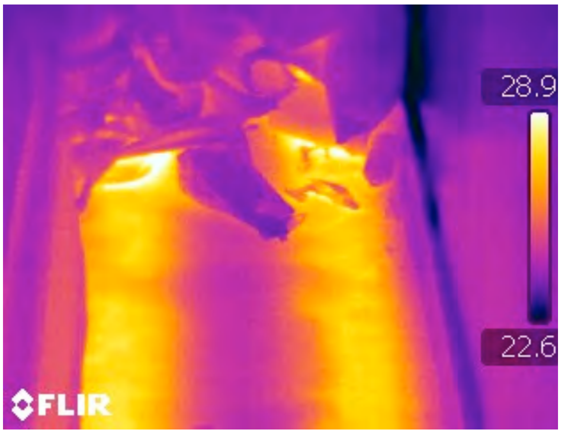


Fig 4.6.3 Bedroom floor surface temps 'before'

Fig 4.6.4 Kitchen floor surface temps 'before'

The high readings achieved when the system should have been off were unexpected and as such further testing of the thermostat response was undertaken.

The thermostat unit was turned from its lowest to highest setting and left for one hour. After this time the same series of thermographic images were taken with significant results shown below in figures 4.6.5 and 4.6.6.

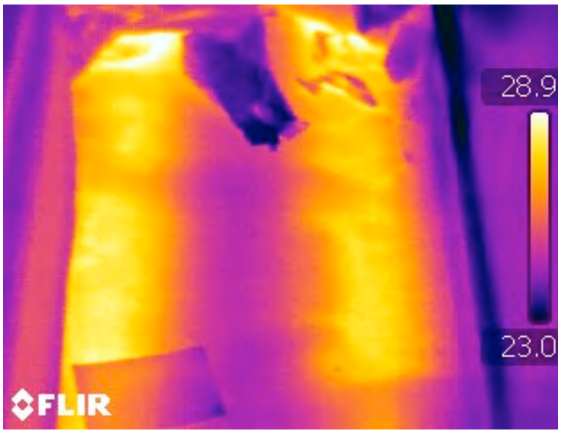


Fig 4.6.5 Bedroom floor surface temps ‘after’

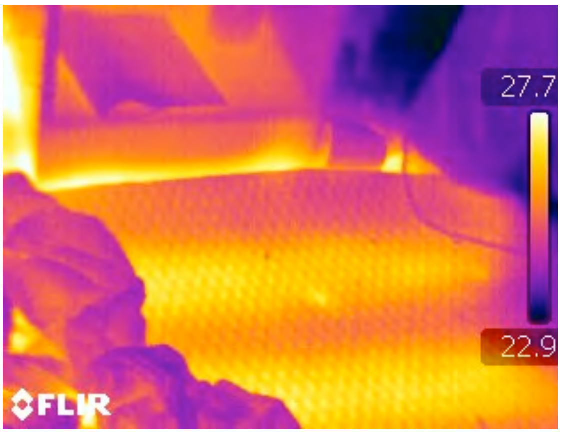


Fig 4.6.6 Kitchen floor surface temps ‘after’

These images and their respective maxima and minima temperature values show that there is very little difference in surface temperature despite the changes made to the thermostat settings and the time given to allow the system to respond. This clearly shows that either the thermostat is ineffective/ not working or that the system has a very slow response which is inappropriate for the building fabric. As the installed system is one which provides a quick thermal response then the main issue appears to be with the thermostat itself.

The ineffective nature of this thermostat could be limited to this one dwelling, and further testing would be required to ascertain whether this is the case, but if this problem does exist throughout the development then it could provide a further explanation to the identified issue of overheating which is evident in some dwellings.

Not withstanding the mechanical limitations of this thermal control system, there are also apparent limitations with the user/ control interface, which appears to require further action.


Fig 4.6.7 Typical dwelling thermostat

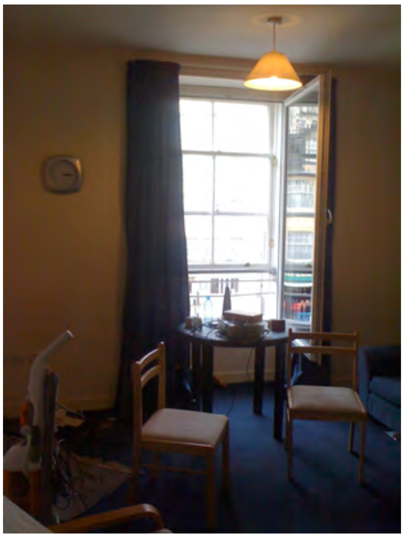


Fig 4.6.8 Living room ventilation

Fig 4.6.7, above, shows an image of one of the installed thermostats along with it’s very simple approach to temperature control. Whilst there is recognition that an overly complex system of dwelling controls would be inappropriate for supported housing, the installed thermostats do not offer the occupant enough information to allow them to effectively control the internal environment.

With no information on what the maximum or minimum values are, or indeed the value of each increment, it is obviously very difficult for any user to make an informed judgement on where the thermostat should be set. This type of control inevitably leads to a reactive, rather than proactive, use of a heating system with occupants moving controls from maximum to minimum values in response to temperature fluctuations. In a thermally fast responsive building envelope this cycle is likely to be exacerbated, leading to poor thermal comfort, characterised by peaks and troughs in temperature and inefficient use of energy.

With the type and tenure of the housing at Gilmour's Close and the quick turn around of tenants, which is often experienced, consideration should be given to the installation of a more accessible controls for the heating system; ones which can be operated by those with limited experience of the dwelling in order to achieve relative thermal stability.

OFFICE SPACE

4.7 Office

Description;
Care management office arranged over two levels as follows;
Ground floor comprising;

- Managers office, visiting staff office, meeting room and accessible WC off the ground floor hall.

First floor comprising;

- Staff kitchen, staff office and WC off first floor hall.

Office is populated by differing numbers of staff during the working week and after hours but general occupation is between two and four staff during normal weekly working hours of 08.00 to 17.00, no occupation between 17.00 and 21.00 daily and one occupant between 21.00 and 08.15.

3 week monitoring period (refer appendix G)

Office Overall;

	Temperature (°C)	Relative Humidity (%)	CO_2 Concentration (ppm)	Vapour Pressure (haPa)
Max’	31.60	84.10	2408.00	19.05
Min’	15.70	24.40	445.00	6.22
Mean	20.58	41.37	760.39	10.01

The mean temperature of the office during the monitoring period is above that which would be desirable for an office environment (20°C).
RH and CO_2 concentration are at acceptable levels and suggest reasonable air quality.

Specific rooms;

Ground Floor
MANAGER’S OFFICE (quiet room)
Temperature;
The mean temperature of this room over the duration of the project, recorded as 19.09ºC, is only slightly below the optimum for an office space and was generally very stable throughout.

This space was the one noted by the Gowrie Care manager as being particularly cold and uncomfortable and goes some way to explaining the stability of the temperature as the room is seldom used. When the room is used (significant peaks in CO_2 concentration) the temperature can be seen to rise sharply by approximately 3ºC with a similarly sharp fall after the room is vacated. This is, as with the dwellings, a good illustration of the high thermal response of the construction and the potential issues that can arise because of this. Whether the increase in temperature is due to just metabolic gains or the use of a small electric heater is unclear.

Not withstanding the rapidity of heat gain and loss the more pertinent question appears to be why this space is perceived to be uncomfortably cold when the temperature profile tends to suggest otherwise. Possible explanations are that, while its temperature is acceptable, it appears cold relative to the higher temperature on the first floor (see below) or that it feels cold due to the limited light infiltration caused by just one small east facing window, looking onto a shaded external close with 100% window covering (as recorded at time of visits).

CO_2 Concentration;

The space had a very good air quality, during monitoring, commensurate with the limited periods of occupation. When the room was occupied, however, the air quality very quickly became poor with CO_2 concentrations reaching levels greater than 2000ppm. This may have occurred as this very small volume had its trickle vent closed at the time of survey and, from the results, it could be presumed this situation remained for the duration of the experiment.

Vapour Pressure;

The vapour pressure values remained low and relatively steady throughout the project with only small peak values during the limited periods of occupation.

MEETING ROOM (store)

Temperature;

Despite being termed the 'meeting room' this space is effectively a store and filing space. At the start of the monitoring period the temperature was a relative low of just over 16ºC but over the course of this experiment this steadily rose to an acceptable maximum of 19.70ºC and a mean of 18.11ºC. While this value is below what would be desirable this is not surprising as there was very limited visible floor space from which the under floor heating could emit heat to the room. In addition the 2 small windows were fully obscured preventing any useful heat gains.

The conditions in this room lend themselves to an air of being cold and inhospitable, as seems to be the case across the ground floor generally, but this is perhaps due more to the way they are used than as a symptom of the limitations of the heating system.

CO_2 Concentration;

During weekdays there is a regular pattern of gradual CO_2 concentration increase over the course of the working day with levels rapidly decreasing over the course of the night. From daily minimum to maximum a range of around 1000ppm only was recorded and with a mean value of 741ppm it can be seen that the air quality in this infrequently occupied room is good.

Vapour Pressure;

The vapour pressure profile is very similar to that of the manager's office with no significant peaks or troughs.

VISITING STAFF OFFICE

Temperature;

Over the course of the project this office maintained a fairly steady temperature despite it being slightly below the ideal, at 19.16ºC.

CO_2 Concentration;

As with other rooms on this level, the anecdotal evidence suggests that the space is used sparingly. This assertion appears to be supported by the very good air quality of the room with its mean value of 495ppm. There are daily peaks in the CO_2 concentration which are similar to those seen in the meeting room and appear to be the result of air infiltration from elsewhere in the office where concentration are higher due to occupant activity.

Vapour Pressure;

The vapour pressure profile is very similar to that of the manager's office with no significant peaks or troughs.

GROUND FLOOR HALL

Temperature;

During he first 7 days of the project the ground floor hall maintains a fairly steady temperature of 23.72ºC up to 13.15 on 24th March. Over the course of the next 18 hours, or thereby, the temperature drops by around 4ºC and then maintains a fairly steady mean temperature of 19.40ºC for the remainder of the project.

The profile strongly suggests that the temperature during the first week was too high and this has been adjusted by the occupants to a more comfortable level which is subsequently well maintained.

The figures identified in this area again seem to disprove the anecdotal evidence regarding the comfort levels of the ground floor area in general.

CO_2 Concentration;

Not monitored in hall.

Vapour Pressure;

Generally the VP profile matches that of the other ground floor volumes but with an increased frequency of small peaks and troughs as would be expected from a space that is so frequently opened to the exterior and to the adjacent WC.

First Floor
1ST FLOOR HALL
Temperature;
As described by the staff, the first floor has a higher temperature with the hall space over 1.5ºC higher than the corresponding ground floor space, with a mean temperature of 22.07ºC. The relative stability of the ground floor profile is also something which is noticeably different on the first floor with a series of significant peaks occurring above a base temperature of approximately 20ºC. In the most extreme case a temperature of 27.60ºC is reached at 03.35 on the 29th March.

CO_2 Concentration;
Not monitored in hall.

Vapour Pressure;
The mean vapour pressure value of 10.54haPa is the highest recorded in the office but it is not at a level which is of concern. The peaks in the profile closely match the temperature profile and suggest that temperature is a main contributory factor in the variation as opposed to an increase in the actual mass of moisture in the air.

STAFF KITCHEN
Temperature;
At 22.15ºC, the mean temperature is slightly higher than would be desirable. This value may be acceptable, however, given the intensity of occupation the space can come under and the nature of the heat producing activity, cooking, that takes place within.

CO_2 Concentration;
The mean value of 939ppm points towards a lesser quality of internal air and this is confirmed by the profile which highlights that daily maxima greater than 1500ppm are frequently achieved. As above this confirms the intensity of occupation but also points to the requirement for improved ventilation in this space.

Vapour Pressure;
The recorded mean of 10.35haPa is not one which provides a cause for concern, given the nature of the space. The profile illustrates expected sharp peaks reflective of periods of occupation and moisture producing activity.

STAFF OFFICE
Temperature;
The mean temperature of 22.91ºC is one which is overly warm for a suitable working environment. While a minimum temperature of 20.20ºC is recorded there are several intense peaks in temperature up to a maximum value of 31.60ºC. At this level the space can be seen to be overly hot, unsuitable for office work and confirms the note made by the staff that the space is indeed

too hot. The rate of temperature increase is of particular note as it is representative of the high thermal response of the construction.

Separate electric heaters and cooling units were recorded in this space and their presence alone is indicative of the problems that the occupant experience on a daily basis. They are, however, perhaps not suitable for a construction with such a high thermal response and may, in fact, be exacerbating the problem. Even if this is not the case, in terms of comfort, they will certainly be contributing to a high energy use in this relatively small space.

Not withstanding the above, it is worth considering where such significant heat gains are coming from to allow the peak temperatures to be reached. With reference to figure 4.7.6, it is hard to image that from an already overly warm base temperature of 23ºC the occupants have chosen to use a separate heat source. This would therefore suggest that the heat gain is coming from the central heating system, office equipment or simply from metabolic heat gains from the workers confined in the small office.

CO_2 Concentration;

The mean value of 939ppm points towards a lesser quality of internal air and this is confirmed by the profile which highlights that daily maxima greater than 1500ppm are frequently achieved. As above this confirms the intensity of occupation but also points to the requirement for improved ventilation in this space.

It is possible that the poor ventilation in this space has a relationship with the temperature increase.

Vapour Pressure;

The vapour pressure in this part of the office is more unstable than recorded elsewhere. This appears to be caused by both the sharp increases in temperature and by moisture vapour output from the occupants, as there is a correlation between the VP profile and those for CO_2 concentration and temperature

Conclusions

The main criticism of the Office users was very clearly the distinction existing between the high temperatures and stuffy nature of the 1st floor area compared to the overly cold zones on the ground floor. Analysis of the ground floor data certainly supports the assertion that the ground floor is at a lower temperature than the upper zones but not necessarily that this is uncomfortable.

Fig 4.7.1 and 4.7.2 below show daily profiles that are achieved in two of the ground floor rooms.

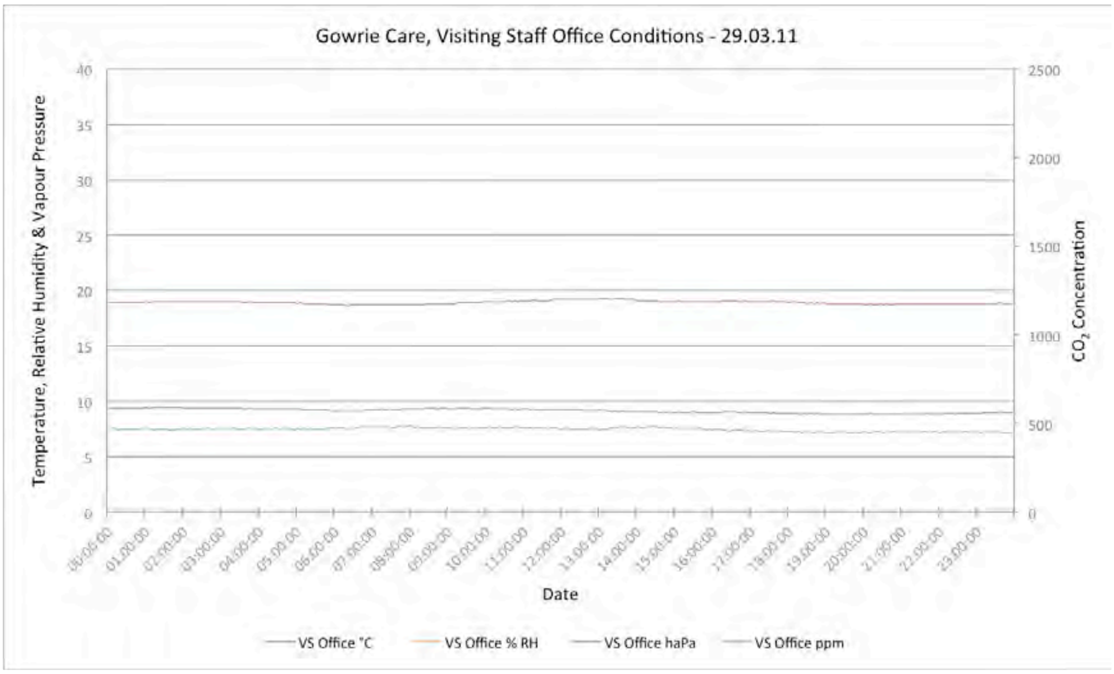


Fig 4.7.1 – Visiting staff office recorded data for 29.03.11

Fig 4.6.2 – Manager's office recorded data for 02.04.11

While these temperatures are minimally below what would be desirable for a working environment the spaces do exhibit a high degree of stability. The stability of the temperature profile here is due in no small part to the limited use of these spaces – in fact, on the days illustrated it is questionable whether these spaces were used at all. While this goes no way to showing us how the spaces respond to periods of occupation it does show that, in the case of the Manager's office, the under-floor heating is capable of providing a suitable working temperature and in the case of the visiting staff office, if the floor

space was freed from clutter (refer fig 4.7.5, below) then the heating may also be able to perform adequately.
In either case, heating would not seem to be a major problem in these areas – noting that during the period of data acquisition, the severely low temperatures experienced over the preceding two winters did not occur.

If absolute temperature is not the main problem with this area then it appears that the cold perception of this space may be due to;

1. The slightly ‘dingy’ ambience created by limited natural light availability
2. Direct comparison to the overly warm upper level

In terms of natural light, this is perceptibly poor as noted by the staff survey respondent. In the office the extent of natural light available is largely constrained by the historic fenestration arrangement yet there do appear to be improvements which could be made very simply by reducing the extent of window covering and by removing clutter around windows.

Fig 4.7.3 to 4.7.5, below, show window conditions from the time of survey and illustrate the simple moves which could be made to improve the quality of natural light within the ground floor volumes.

Any improvements made here will also have an impact on the extent of artificial lighting required and, therefore, reduce the electrical energy consumption of the office.

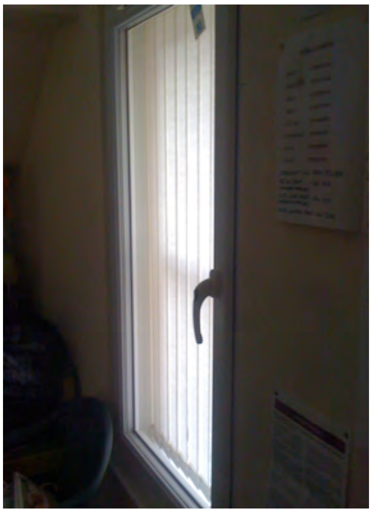


Fig 4.7.3 Visiting Staff Office window coverings


Fig 4.7.4 Manager’s Office window coverings


Fig 4.7.5 Meeting room clutter

Recorded data supported the anecdotal view in confirming that the first floor spaces are markedly warmer than the ground floor spaces. If efforts are made to reduce the mean temperature in this area, to a more comfortable level, then it is likely that the ground floor spaces will feel comparatively warmer and may promote increased occupation and use.

In investigating the overly warm temperatures of the first floor it was evident that the most problematic space on this level was the Staff Office. The large scale data set, for the full 3 weeks, pointed towards daily peaks in temperatures and it was initially assumed that these were largely caused by peak levels in occupation and associated gains from staff and the use of office equipment. There also appeared to be a great deal of fluctuation of the temperature profile over the course of each day – problems which would not be unexpected for an intensely populated work space but which may be difficult to resolve.

Investigation of the daily profiles, however provided a very different picture.

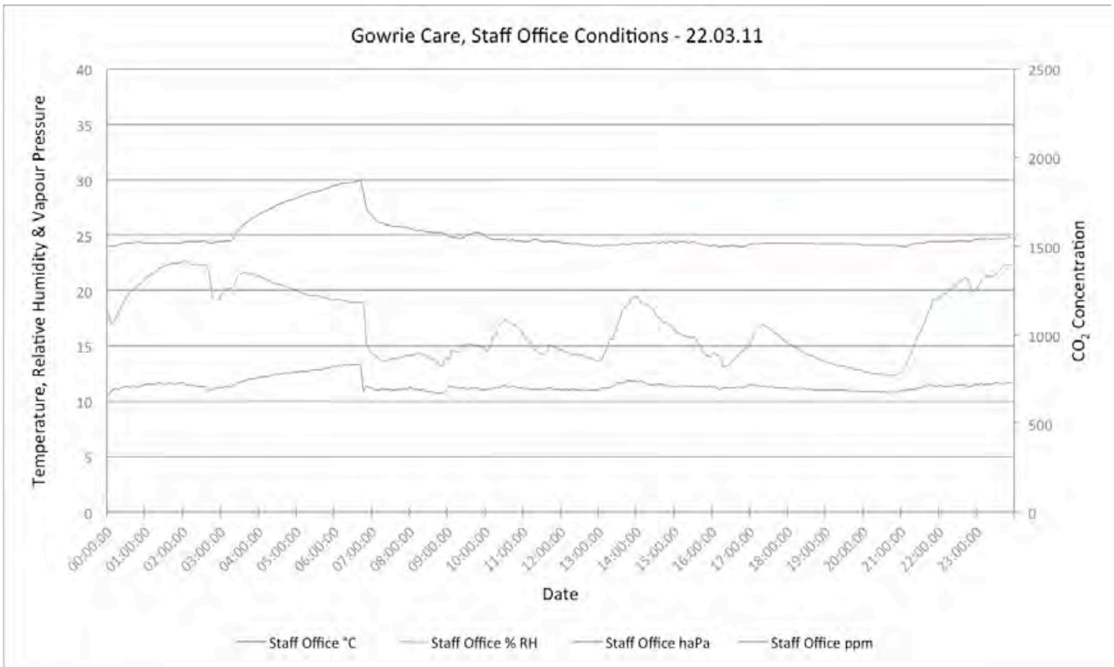


Fig 4.7.6 – Staff office recorded data for 22.03.11

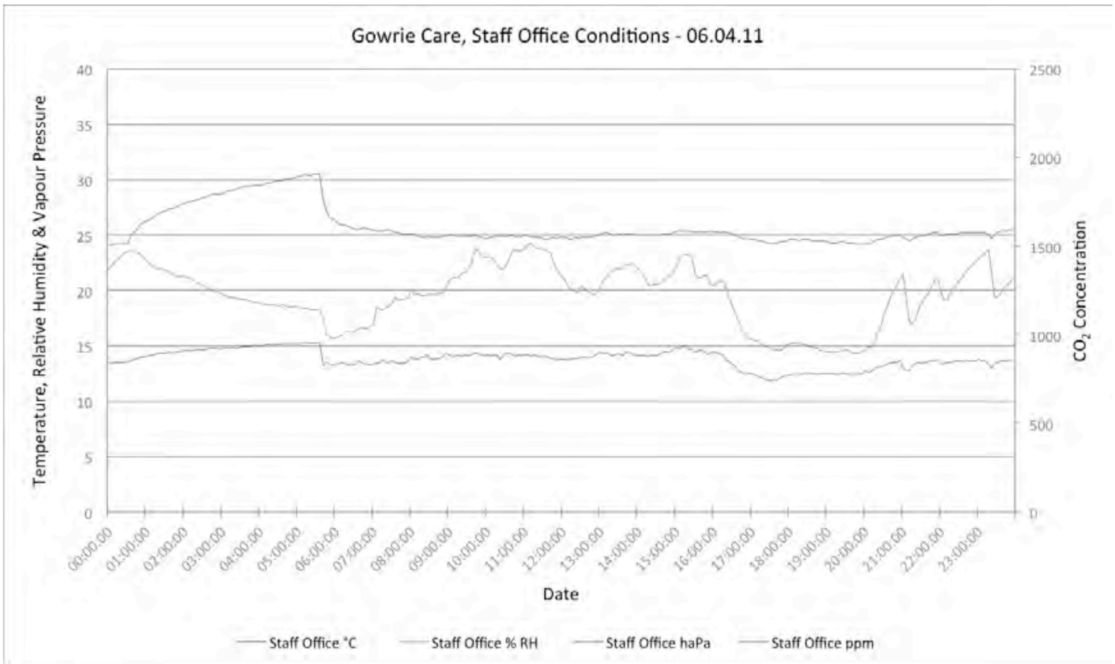


Fig 4.7.7 – Staff office recorded data for 07.04.11

Fig 4.7.6 and 4.7.7, above, illustrate 2 recorded profiles for the staff office during the working week.

As expected these both show a temperature which is constantly above that which would be desirable for an office environment. What they unexpectedly show, however, is that even during working hours, the temperature retains a remarkable degree of stability even under periods of high occupancy. Where the problem appears to lie is simply that the temperature is starting from too high a base point and so the space is perpetually too warm.

If the base temperature of this zone were lowered then it is feasible that the stability would be retained and the space would function more effectively as an office. This could be achieved, in the first instance, by reducing the intensity of, or omitting all together, the early morning heating boost which is evident in both illustrations. As noted above, this would also aid the perception for the ground floor temperature.

5.0 Appendices

A - Sample Occupant Questionnaire
B - Dwelling 1 - 3 week duration room specific data
C - Dwelling 2 - 3 week duration room specific data
D - Dwelling 3 - 3 week duration room specific data
E - Dwelling 4 - 3 week duration room specific data
F - Dwelling 5 - 3 week duration room specific data
G - Gowrie Care Office 3 week duration room specific data

Appendix A

Sample Occupant Questionnaire

7-11 Gilmour’s Close

Post Occupancy Evaluation

DWELLING X

Gilmour's Close Data Collection

Surveyor observation checklist.

Heating

1 Note thermostat setting, take thermographic images of floors, and note air temperature, RH and CO_2.

2 If any setting above 0, turn to zero. At end of survey and installation, take thermographic images of floors and return thermostat to original setting.

3 If setting is at 0, turn to highest setting. At end of survey and installation, take thermographic images of floors and return thermostat to original setting.

Observations:

4 Photograph all rooms to show disposition of furniture

5 Identify main appliances and heat producing equipment

6 Casual observations- smokers, damp smell, pets?

Ventilation

7 What condition is the MVHR Filter?

8 Window ventilation - tick

	Wide Open	Partially Open	Closed	Trickle Vent Open
Support				
Meeting				
Managers				
Bathroom				
Staff Office				
Staff Break				
Hall				

9 Window Coverings - tick

	Closed	<50 obscured	>50% obscured	Open
Support				
Meeting				
Managers				
Bathroom				
Staff Office				
Staff Break				
Hall				

10 Is there evidence of other moisture producing activity?

Occupant Questions

1 Which room do you use most during the day?

2 What time(s) do you go leave the office?

3 What time(s) do you enter the office?

4 How do you find the temperature in the office

Too Cold 5 4 3 2 1 Too warm

5 Which rooms are most affected?

6 If you were too hot, what would you do?

7 If you were too cold, what would you do?

8 How do you find the stuffiness of the office?

Very Stuffy 5 4 3 2 1 Not Stuffy at all

9 Do you think its easy to open the windows?

10 How often do you open the windows?

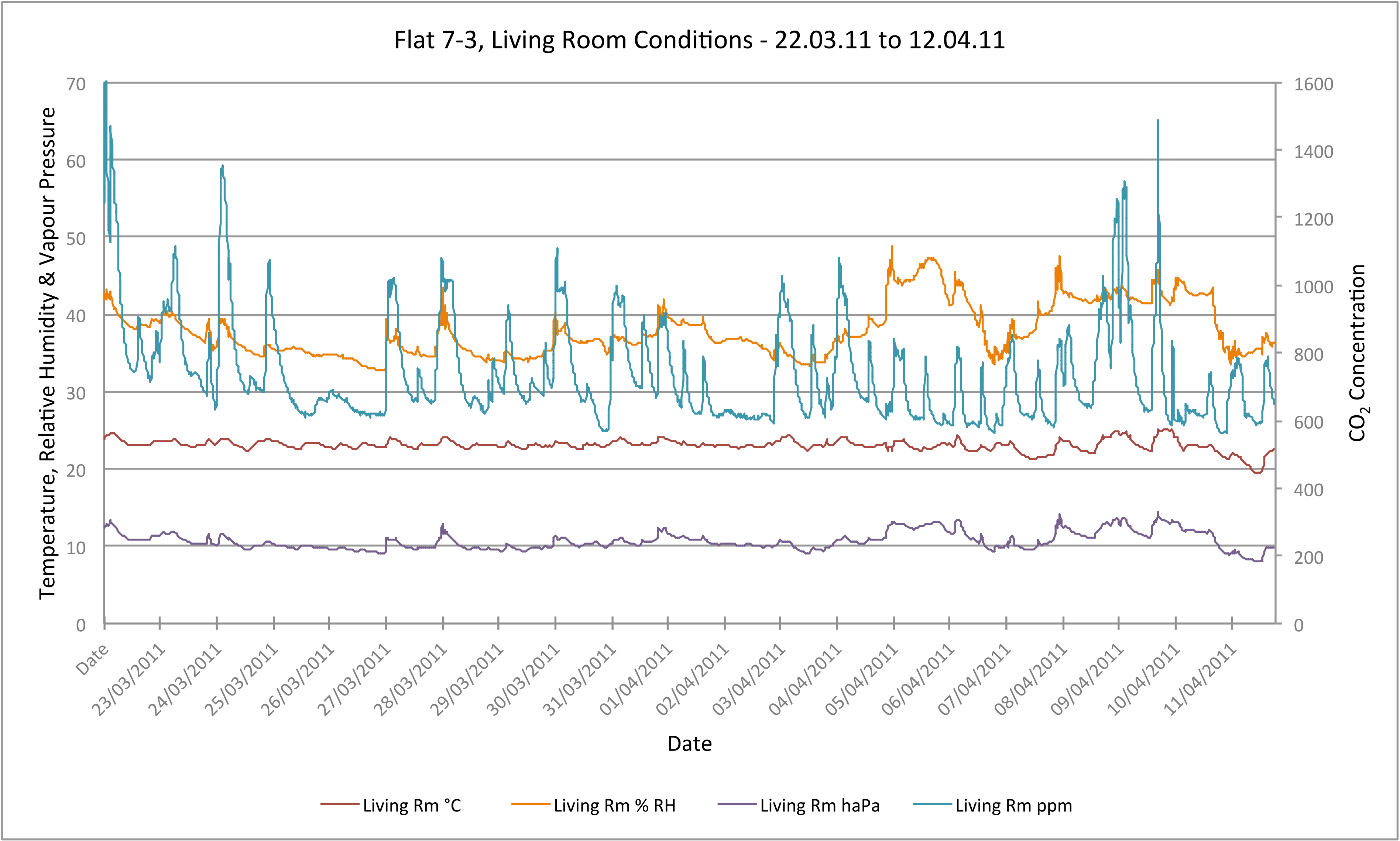
11 Are you happy with the size of the windows and the amount of light?

12 How much does it cost you to heat the office?

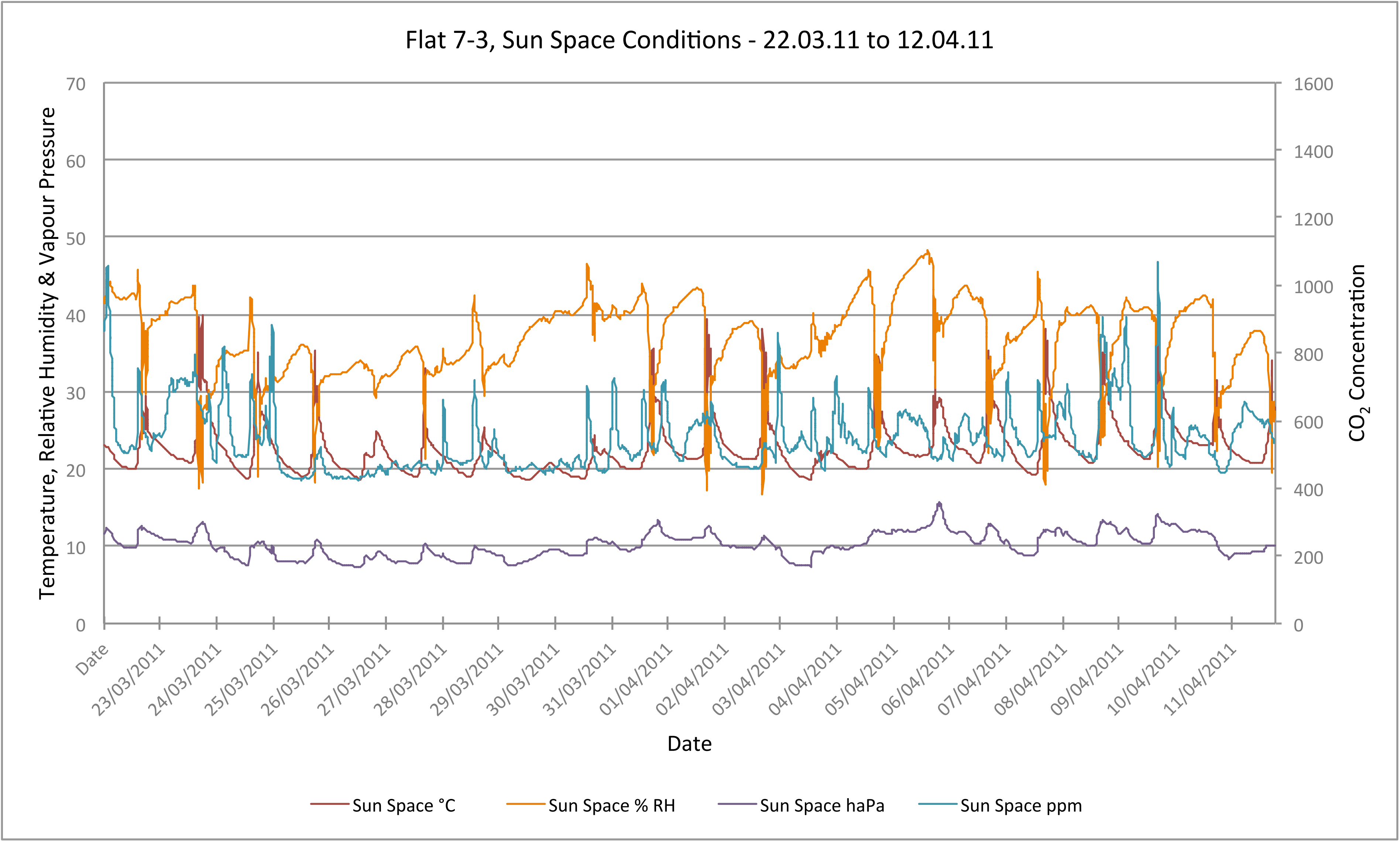
13 Have you had any problems in the office?

Appendix B

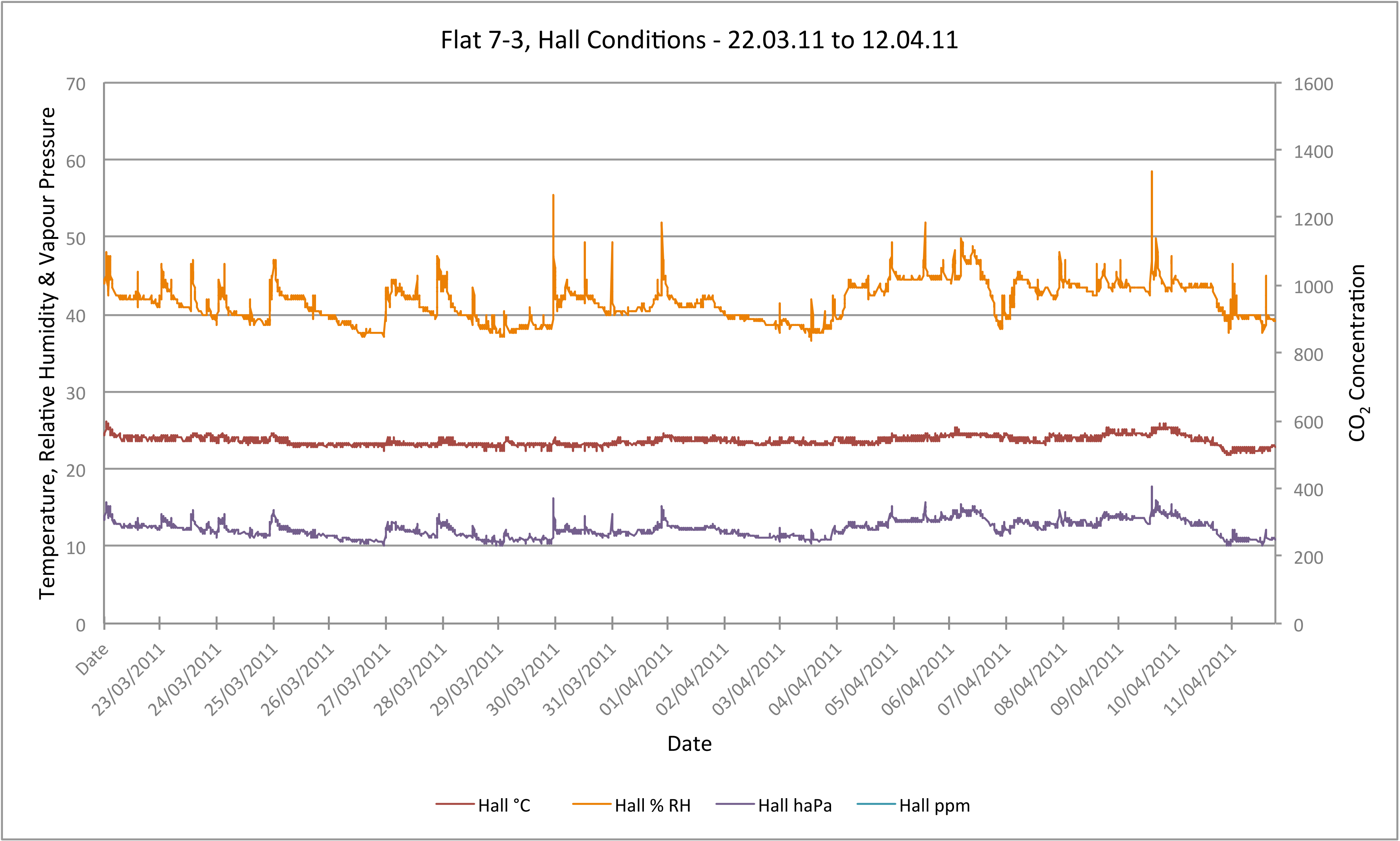
Dwelling 1;
3 week duration, room specific data



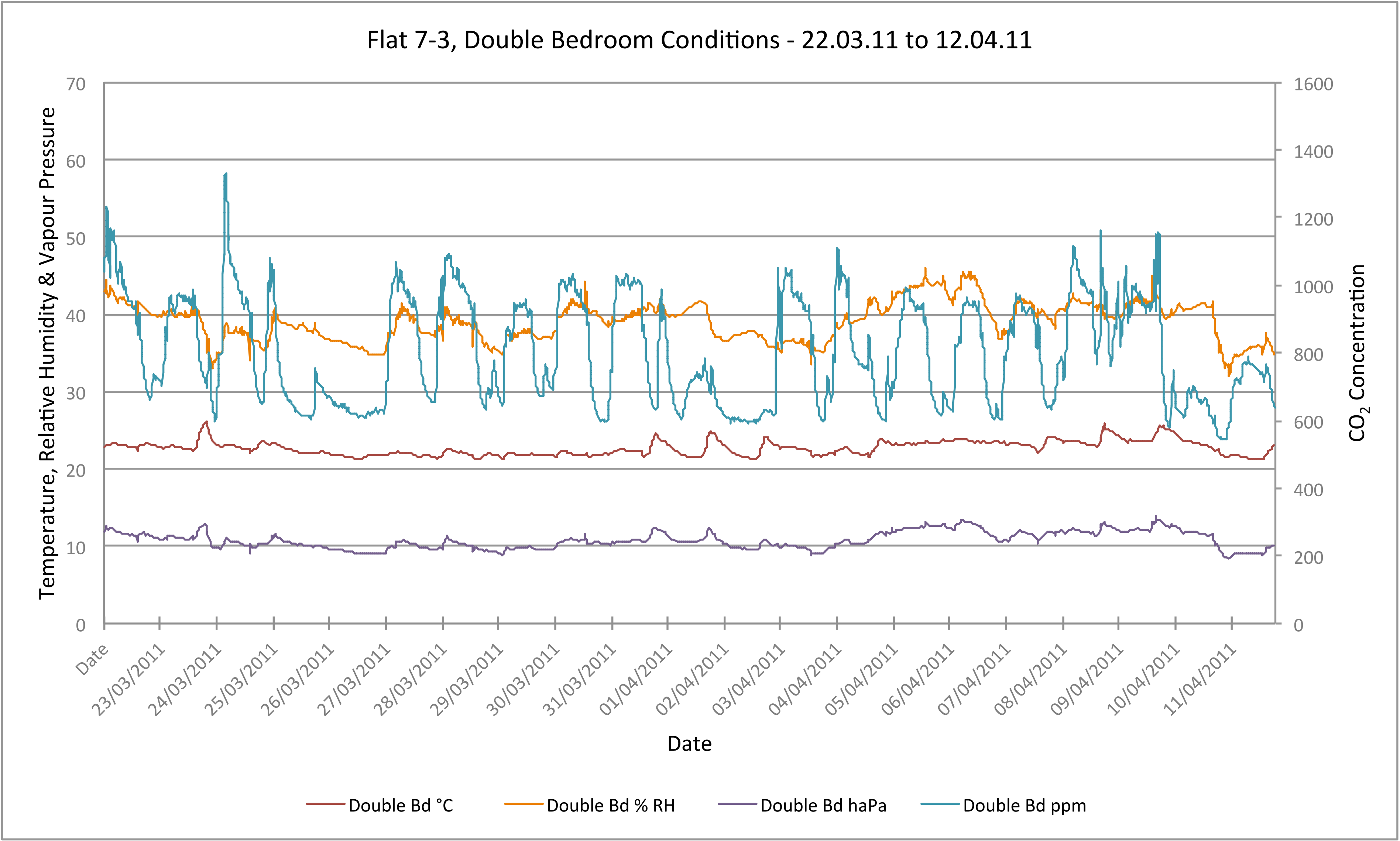
Flat 7-3, Living Room Conditions - 22.03.11 to 12.04.11
Temperature, Relative Humidity & Vapour Pressure
CO_2 Concentration
0
10
20
30
40
50
60
70
0
200
400
600
800
1000
1200
1400
1600
Date
23/03/2011
24/03/2011
25/03/2011
26/03/2011
27/03/2011
28/03/2011
29/03/2011
30/03/2011
31/03/2011
01/04/2011
02/04/2011
03/04/2011
04/04/2011
05/04/2011
06/04/2011
07/04/2011
08/04/2011
09/04/2011
10/04/2011
11/04/2011
Date
Living Rm °C
Living Rm % RH
Living Rm haPa
Living Rm ppm



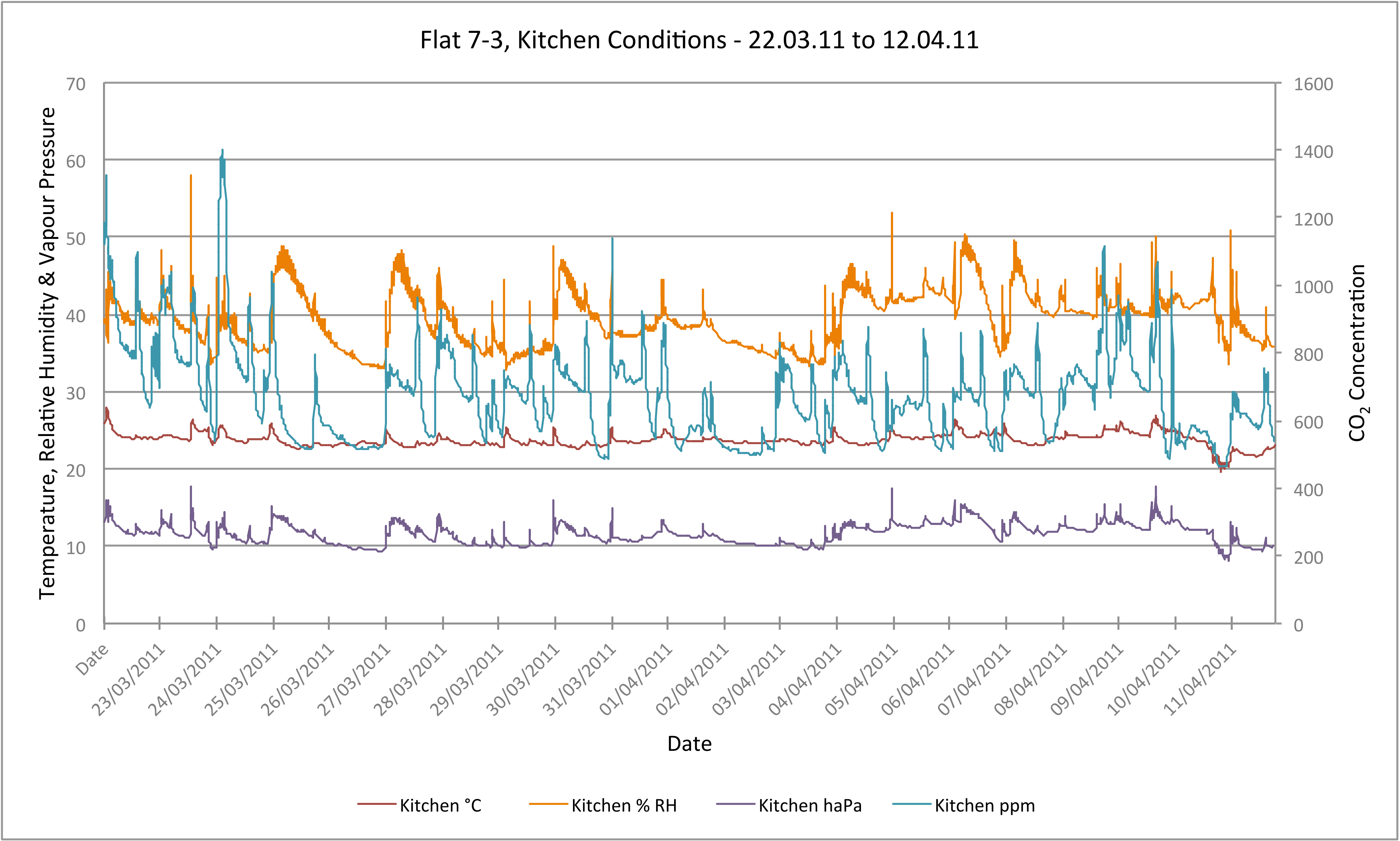
Flat 7-3, Sun Space Conditions - 22.03.11 to 12.04.11
Temperature, Relative Humidity & Vapour Pressure
CO_2 Concentration
70
60
50
40
30
20
10
0
1600
1400
1200
1000
800
600
400
200
0
Date
23/03/2011
24/03/2011
25/03/2011
26/03/2011
27/03/2011
28/03/2011
29/03/2011
30/03/2011
31/03/2011
01/04/2011
02/04/2011
03/04/2011
04/04/2011
05/04/2011
06/04/2011
07/04/2011
08/04/2011
09/04/2011
10/04/2011
11/04/2011
Date
Sun Space °C
Sun Space % RH
Sun Space haPa
Sun Space ppm



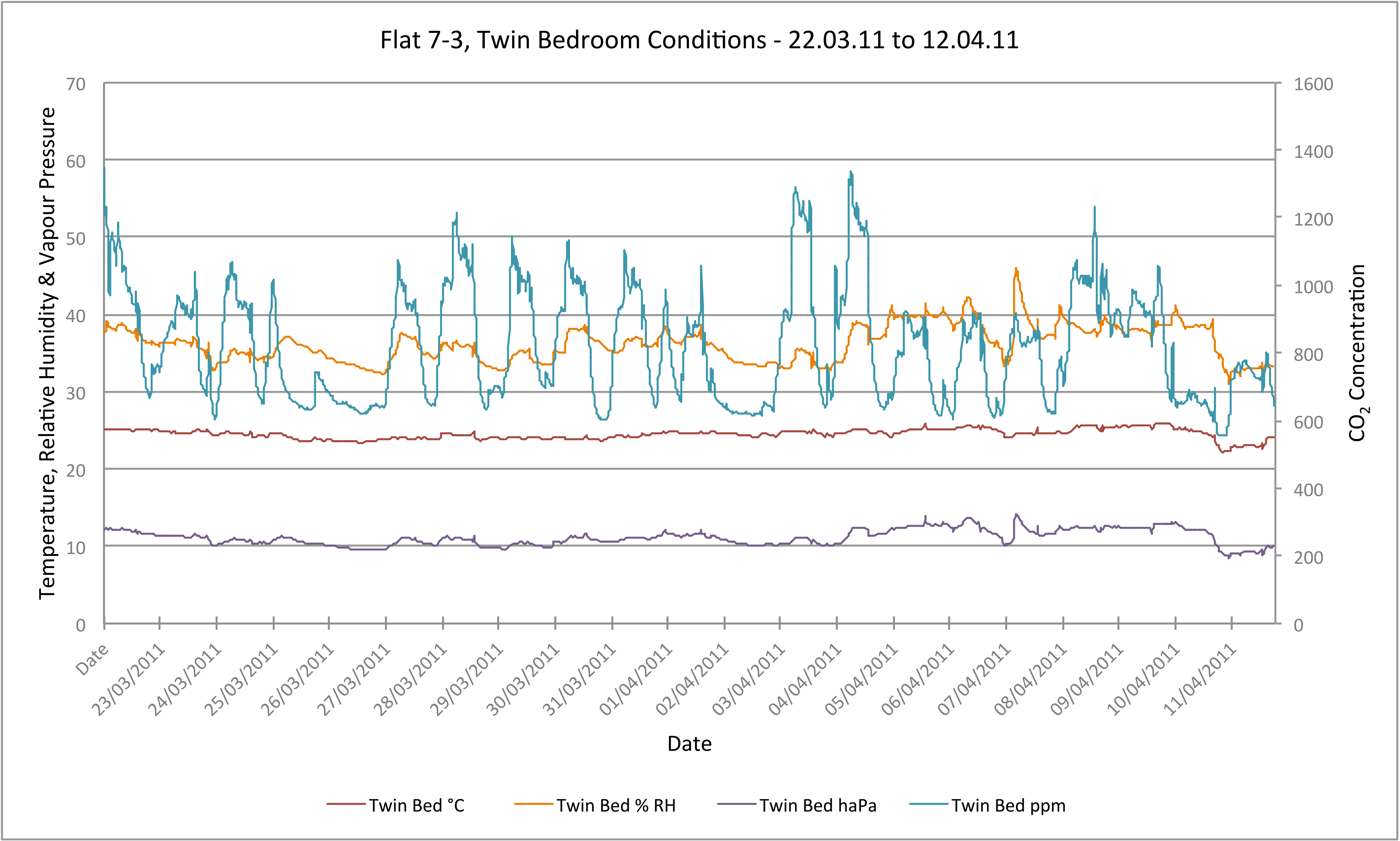
Flat 7-3, Hall Conditions - 22.03.11 to 12.04.11
Temperature, Relative Humidity & Vapour Pressure
CO_2 Concentration
70
60
50
40
30
20
10
0
1600
1400
1200
1000
800
600
400
200
0
Date
23/03/2011
24/03/2011
25/03/2011
26/03/2011
27/03/2011
28/03/2011
29/03/2011
30/03/2011
31/03/2011
01/04/2011
02/04/2011
03/04/2011
04/04/2011
05/04/2011
06/04/2011
07/04/2011
08/04/2011
09/04/2011
10/04/2011
11/04/2011
Date
Hall °C
Hall % RH
Hall haPa
Hall ppm



Flat 7-3, Double Bedroom Conditions - 22.03.11 to 12.04.11
Temperature, Relative Humidity & Vapour Pressure
CO_2 Concentration
70
60
50
40
30
20
10
0
1600
1400
1200
1000
800
600
400
200
0
Date
23/03/2011
24/03/2011
25/03/2011
26/03/2011
27/03/2011
28/03/2011
29/03/2011
30/03/2011
31/03/2011
01/04/2011
02/04/2011
03/04/2011
04/04/2011
05/04/2011
06/04/2011
07/04/2011
08/04/2011
09/04/2011
10/04/2011
11/04/2011
Date
Double Bd °C
Double Bd % RH
Double Bd haPa
Double Bd ppm



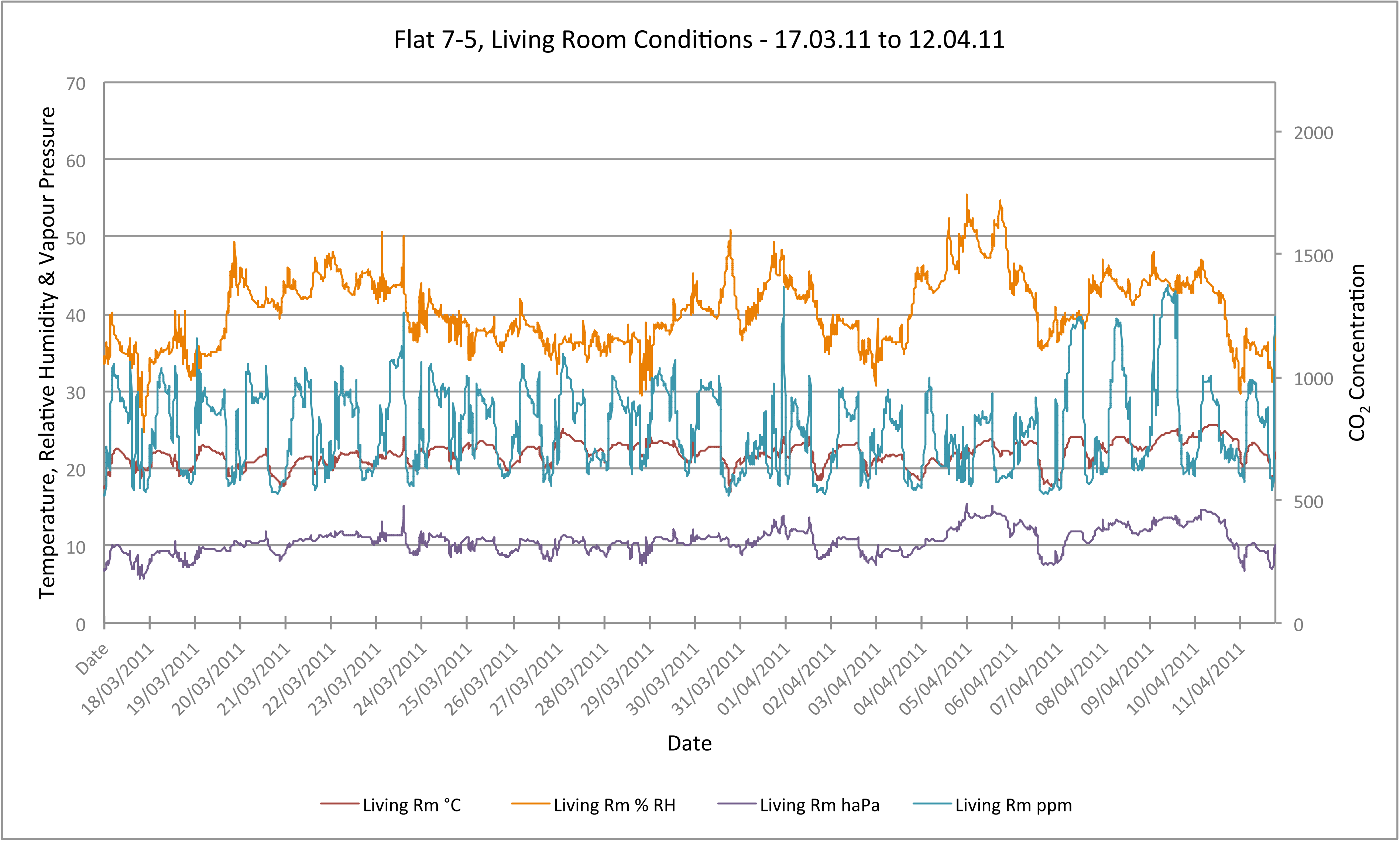
Flat 7-3, Kitchen Conditions - 22.03.11 to 12.04.11
Temperature, Relative Humidity & Vapour Pressure
CO2 Concentration
70
60
50
40
30
20
10
0
1600
1400
1200
1000
800
600
400
200
0
Date
23/03/2011
24/03/2011
25/03/2011
26/03/2011
27/03/2011
28/03/2011
29/03/2011
30/03/2011
31/03/2011
01/04/2011
02/04/2011
03/04/2011
04/04/2011
05/04/2011
06/04/2011
07/04/2011
08/04/2011
09/04/2011
10/04/2011
11/04/2011
Date
Kitchen °C
Kitchen % RH
Kitchen haPa
Kitchen ppm

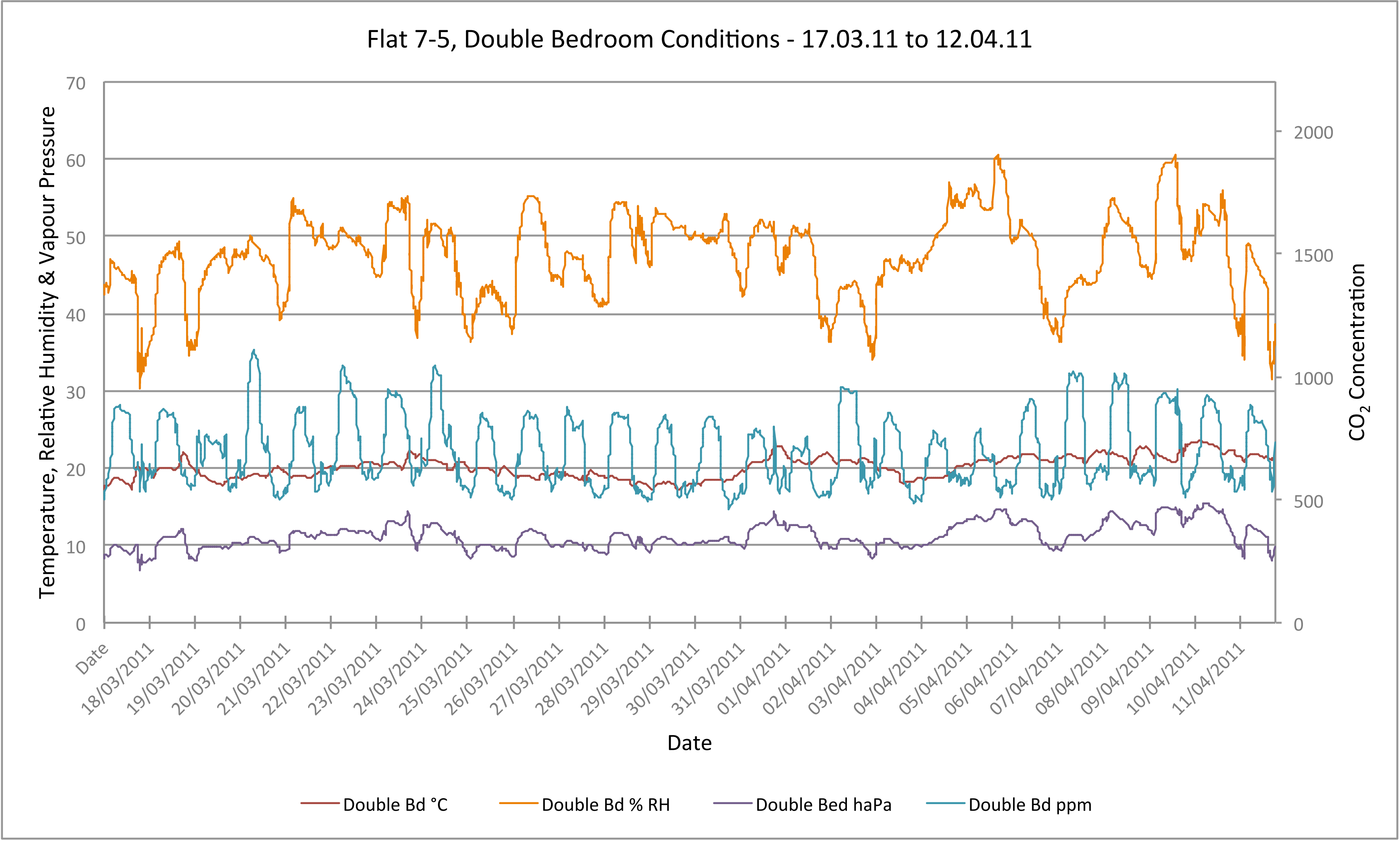


Flat 7-3, Twin Bedroom Conditions - 22.03.11 to 12.04.11
Temperature, Relative Humidity & Vapour Pressure
CO2 Concentration
0
10
20
30
40
50
60
70
0
200
400
600
800
1000
1200
1400
1600
Date
23/03/2011
24/03/2011
25/03/2011
26/03/2011
27/03/2011
28/03/2011
29/03/2011
30/03/2011
31/03/2011
01/04/2011
02/04/2011
03/04/2011
04/04/2011
05/04/2011
06/04/2011
07/04/2011
08/04/2011
09/04/2011
10/04/2011
11/04/2011
Date
Twin Bed °C
Twin Bed % RH
Twin Bed haPa
Twin Bed ppm

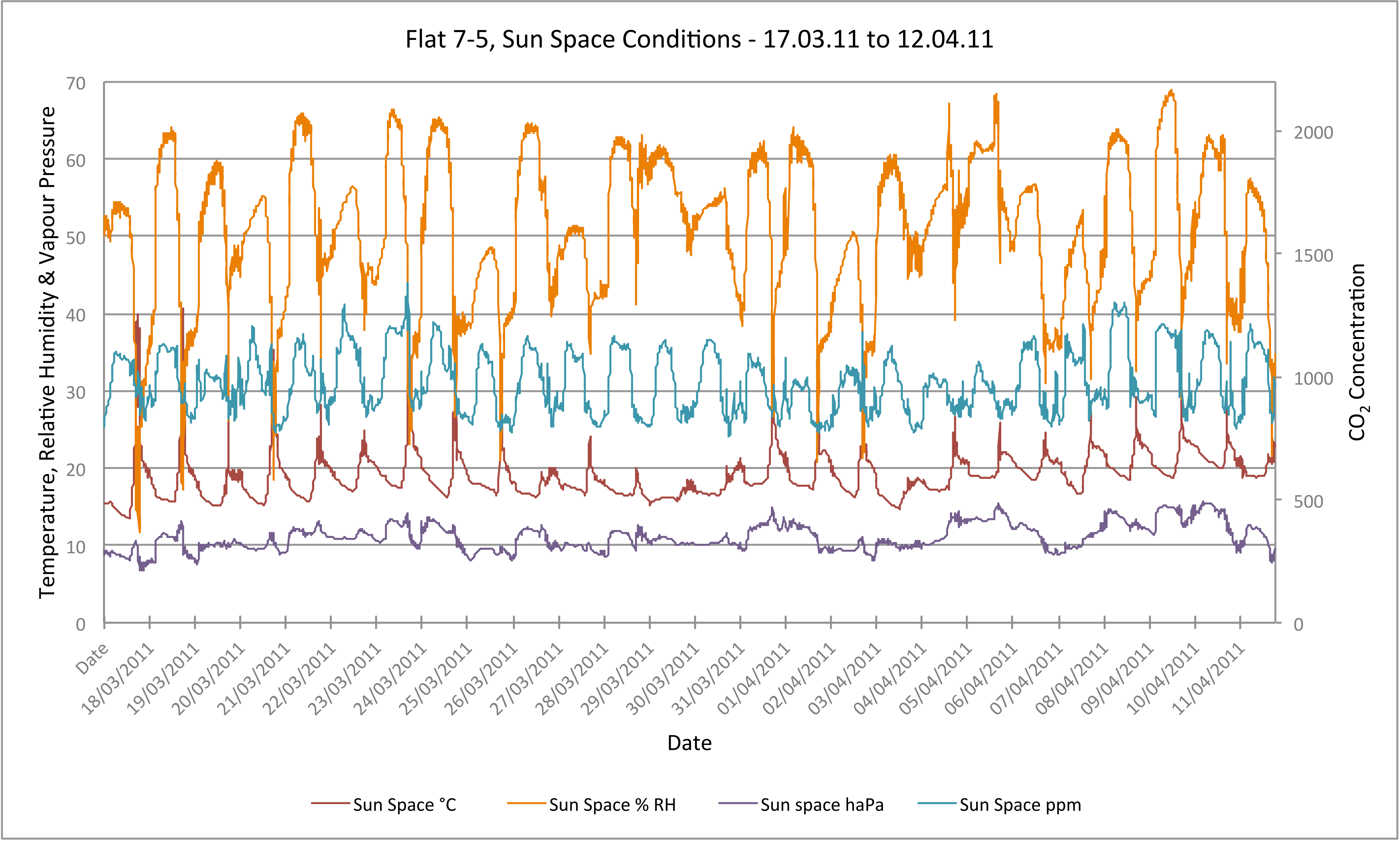
Appendix C

Dwelling 2;
3 week duration, room specific data

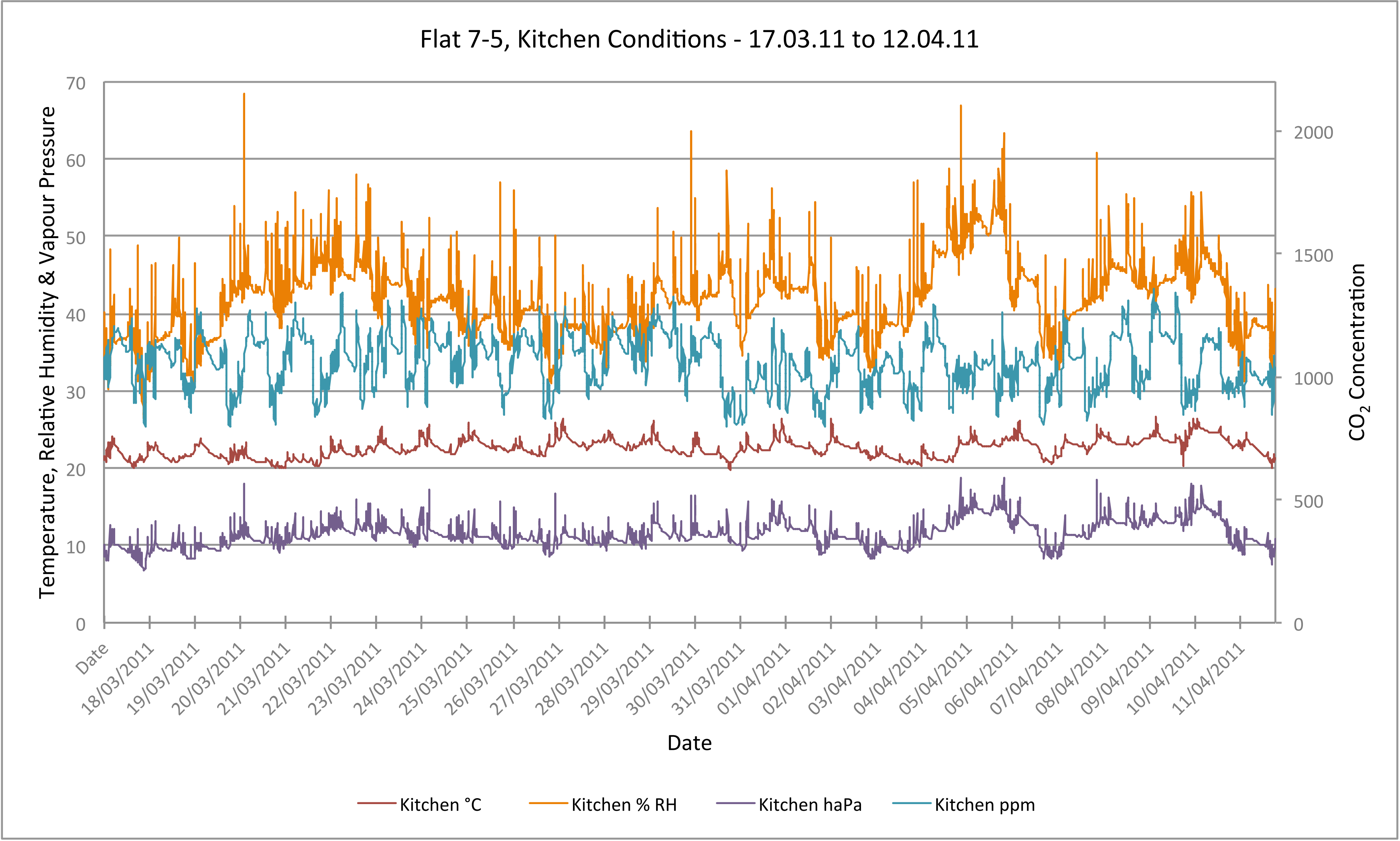

Flat 7-5, Living Room Conditions - 17.03.11 to 12.04.11
Temperature, Relative Humidity & Vapour Pressure
CO_2 Concentration
70
60
50
40
30
20
10
0
2000
1500
1000
500
0
Date
18/03/2011
19/03/2011
20/03/2011
21/03/2011
22/03/2011
23/03/2011
24/03/2011
25/03/2011
26/03/2011
27/03/2011
28/03/2011
29/03/2011
30/03/2011
31/03/2011
01/04/2011
02/04/2011
03/04/2011
04/04/2011
05/04/2011
06/04/2011
07/04/2011
08/04/2011
09/04/2011
10/04/2011
11/04/2011
Date
Living Rm °C
Living Rm % RH
Living Rm haPa
Living Rm ppm



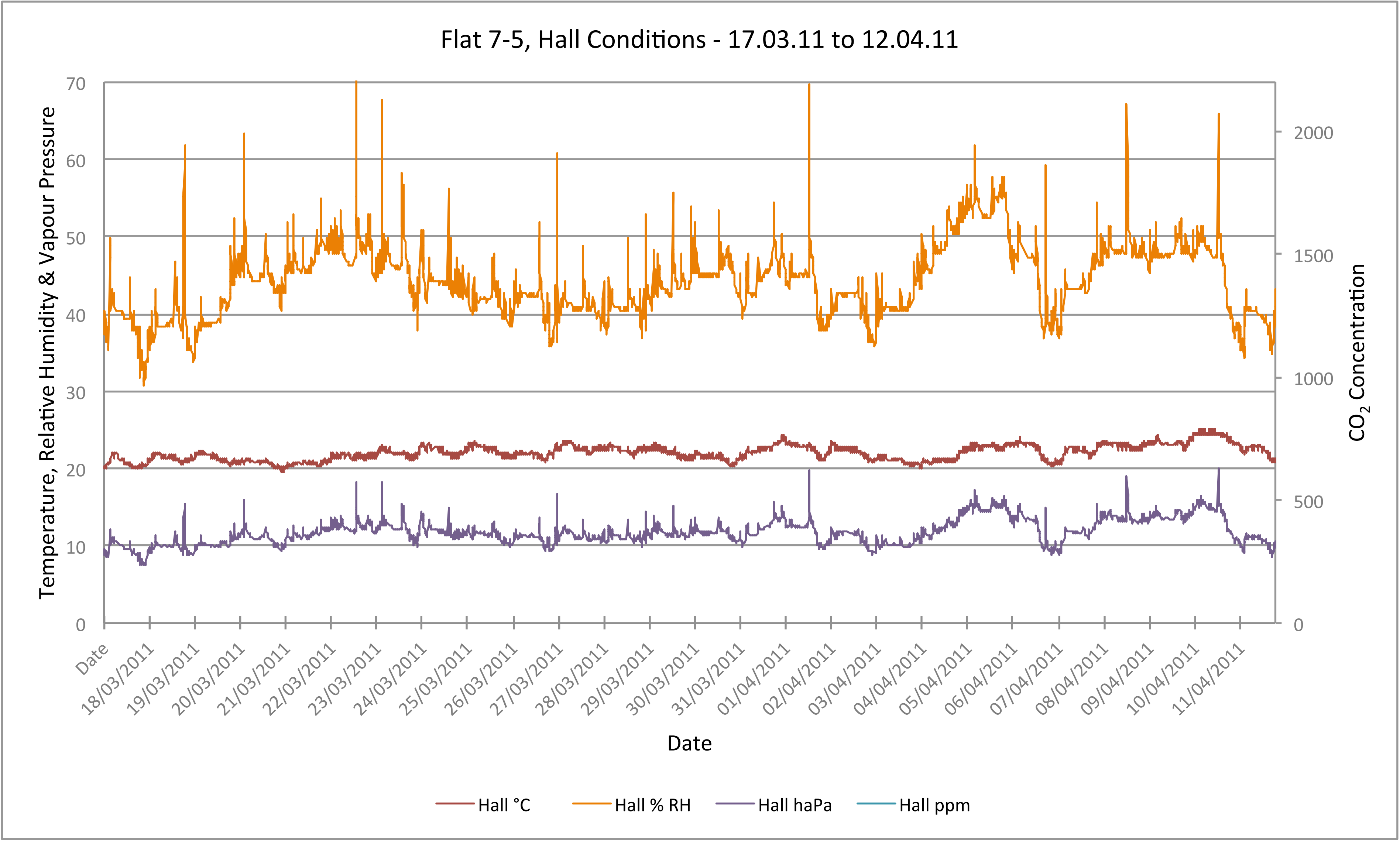
Flat 7-5, Double Bedroom Conditions - 17.03.11 to 12.04.11
Temperature, Relative Humidity & Vapour Pressure
CO_2 Concentration
70
60
50
40
30
20
10
0
2000
1500
1000
500
0
Date
18/03/2011
19/03/2011
20/03/2011
21/03/2011
22/03/2011
23/03/2011
24/03/2011
25/03/2011
26/03/2011
27/03/2011
28/03/2011
29/03/2011
30/03/2011
31/03/2011
01/04/2011
02/04/2011
03/04/2011
04/04/2011
05/04/2011
06/04/2011
07/04/2011
08/04/2011
09/04/2011
10/04/2011
11/04/2011
Date
Double Bd °C
Double Bd % RH
Double Bed haPa
Double Bd ppm



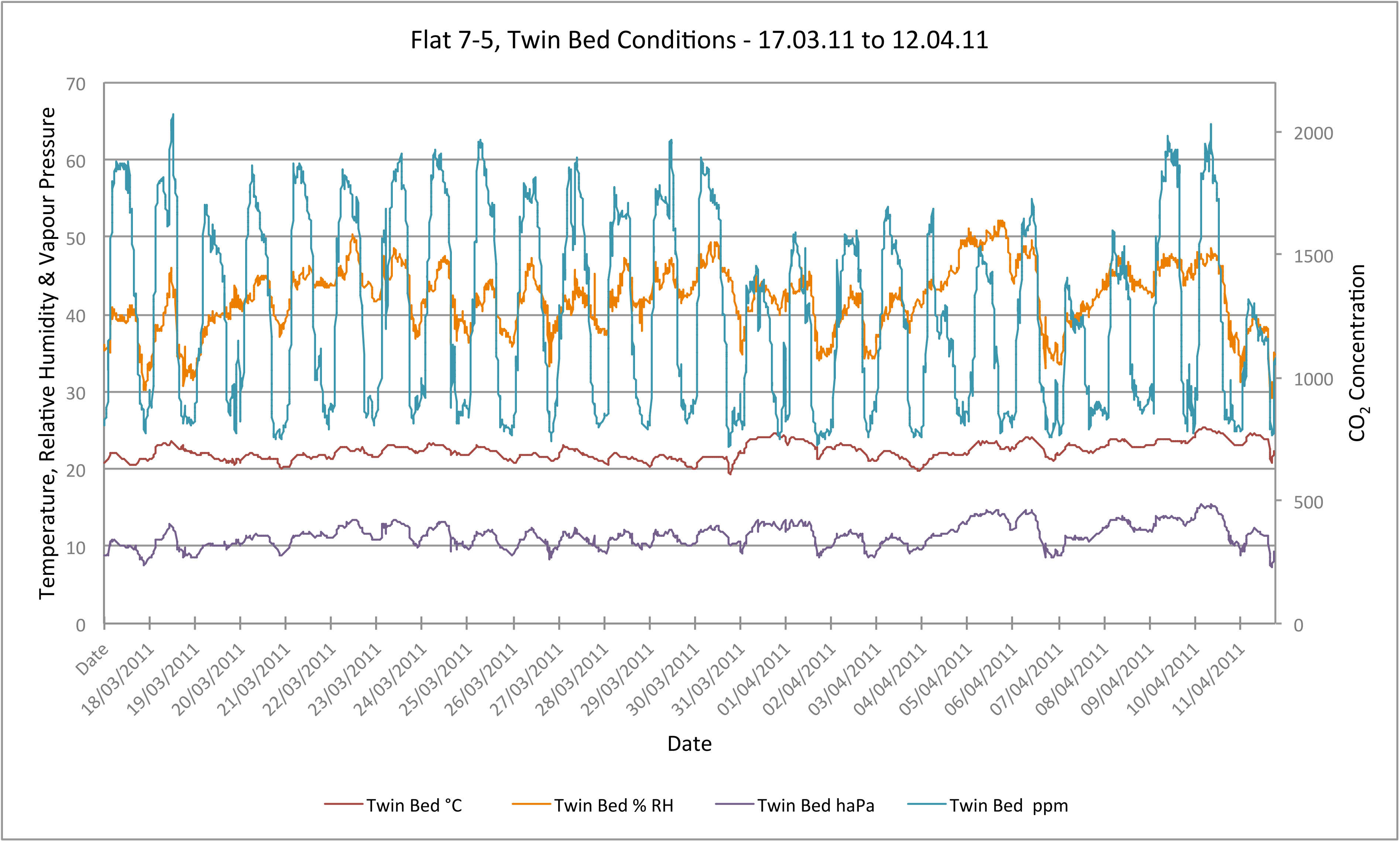
Flat 7-5, Sun Space Conditions - 17.03.11 to 12.04.11
Temperature, Relative Humidity & Vapour Pressure
CO_2 Concentration
70
60
50
40
30
20
10
0
2000
1500
1000
500
0
Date
18/03/2011
19/03/2011
20/03/2011
21/03/2011
22/03/2011
23/03/2011
24/03/2011
25/03/2011
26/03/2011
27/03/2011
28/03/2011
29/03/2011
30/03/2011
31/03/2011
01/04/2011
02/04/2011
03/04/2011
04/04/2011
05/04/2011
06/04/2011
07/04/2011
08/04/2011
09/04/2011
10/04/2011
11/04/2011
Date
Sun Space °C
Sun Space % RH
Sun space haPa
Sun Space ppm



Flat 7-5, Kitchen Conditions - 17.03.11 to 12.04.11
Temperature, Relative Humidity & Vapour Pressure
CO_2 Concentration
0
10
20
30
40
50
60
70
0
500
1000
1500
2000
Date
18/03/2011
19/03/2011
20/03/2011
21/03/2011
22/03/2011
23/03/2011
24/03/2011
25/03/2011
26/03/2011
27/03/2011
28/03/2011
29/03/2011
30/03/2011
31/03/2011
01/04/2011
02/04/2011
03/04/2011
04/04/2011
05/04/2011
06/04/2011
07/04/2011
08/04/2011
09/04/2011
10/04/2011
11/04/2011
Date
Kitchen °C
Kitchen % RH
Kitchen haPa
Kitchen ppm



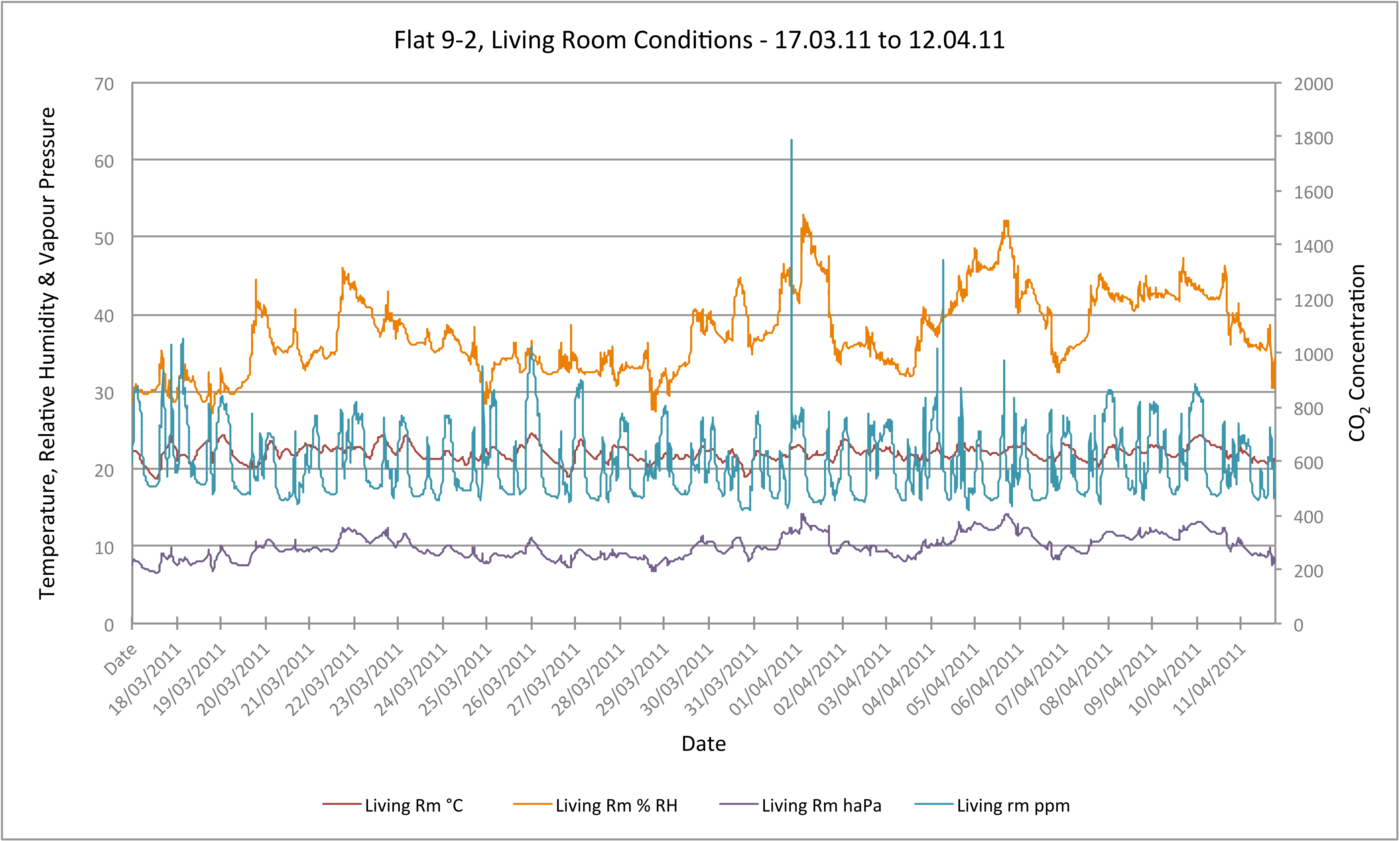
Flat 7-5, Hall Conditions - 17.03.11 to 12.04.11
Temperature, Relative Humidity & Vapour Pressure
CO2 Concentration
70
60
50
40
30
20
10
0
2000
1500
1000
500
0
Date
18/03/2011
19/03/2011
20/03/2011
21/03/2011
22/03/2011
23/03/2011
24/03/2011
25/03/2011
26/03/2011
27/03/2011
28/03/2011
29/03/2011
30/03/2011
31/03/2011
01/04/2011
02/04/2011
03/04/2011
04/04/2011
05/04/2011
06/04/2011
07/04/2011
08/04/2011
09/04/2011
10/04/2011
11/04/2011
Date
Hall °C
Hall % RH
Hall haPa
Hall ppm



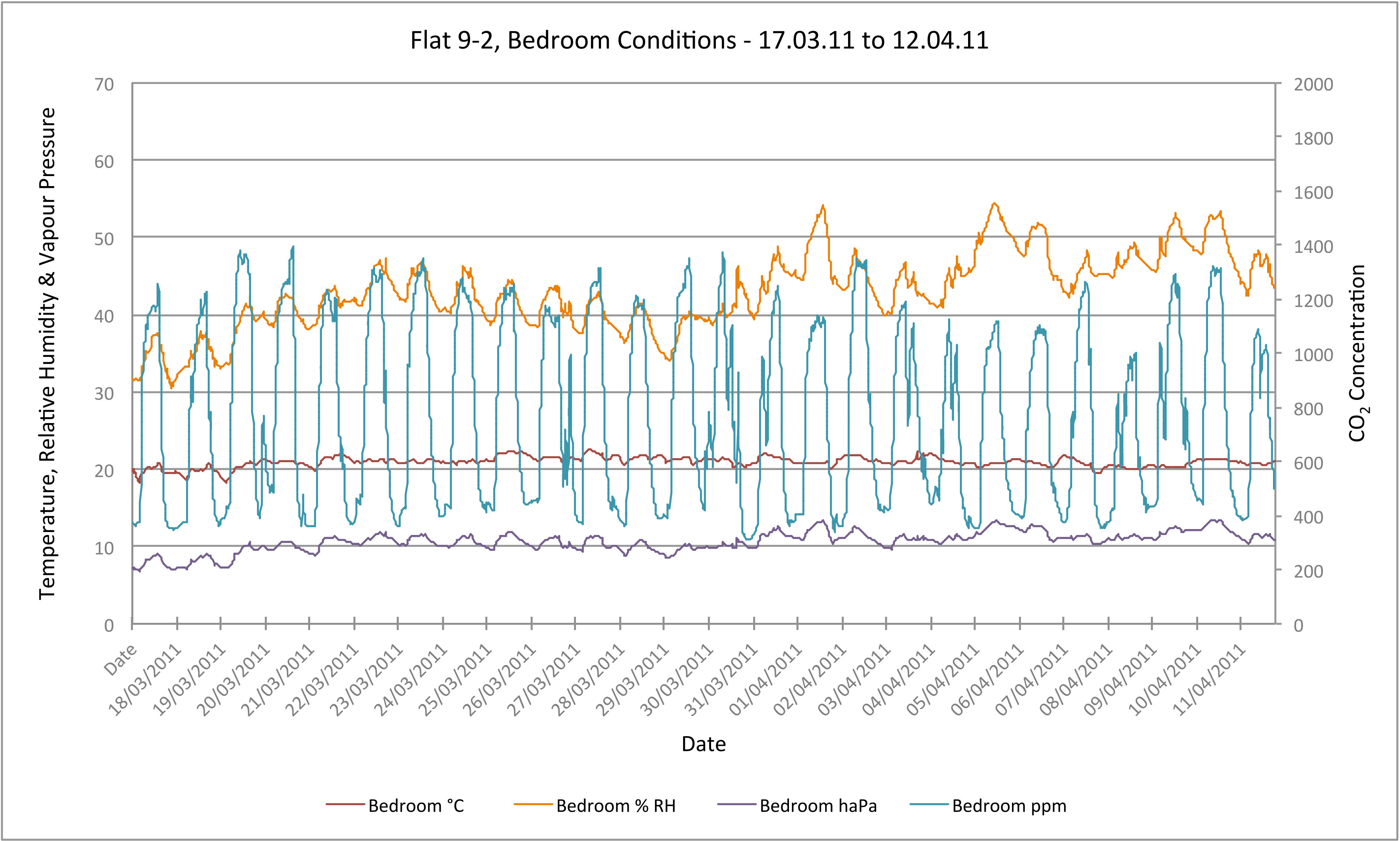
Flat 7-5, Twin Bed Conditions - 17.03.11 to 12.04.11
Temperature, Relative Humidity & Vapour Pressure
CO_2 Concentration
70
60
50
40
30
20
10
0
2000
1500
1000
500
0
Date
18/03/2011
19/03/2011
20/03/2011
21/03/2011
22/03/2011
23/03/2011
24/03/2011
25/03/2011
26/03/2011
27/03/2011
28/03/2011
29/03/2011
30/03/2011
31/03/2011
01/04/2011
02/04/2011
03/04/2011
04/04/2011
05/04/2011
06/04/2011
07/04/2011
08/04/2011
09/04/2011
10/04/2011
11/04/2011
Date
Twin Bed °C
Twin Bed % RH
Twin Bed haPa
Twin Bed ppm

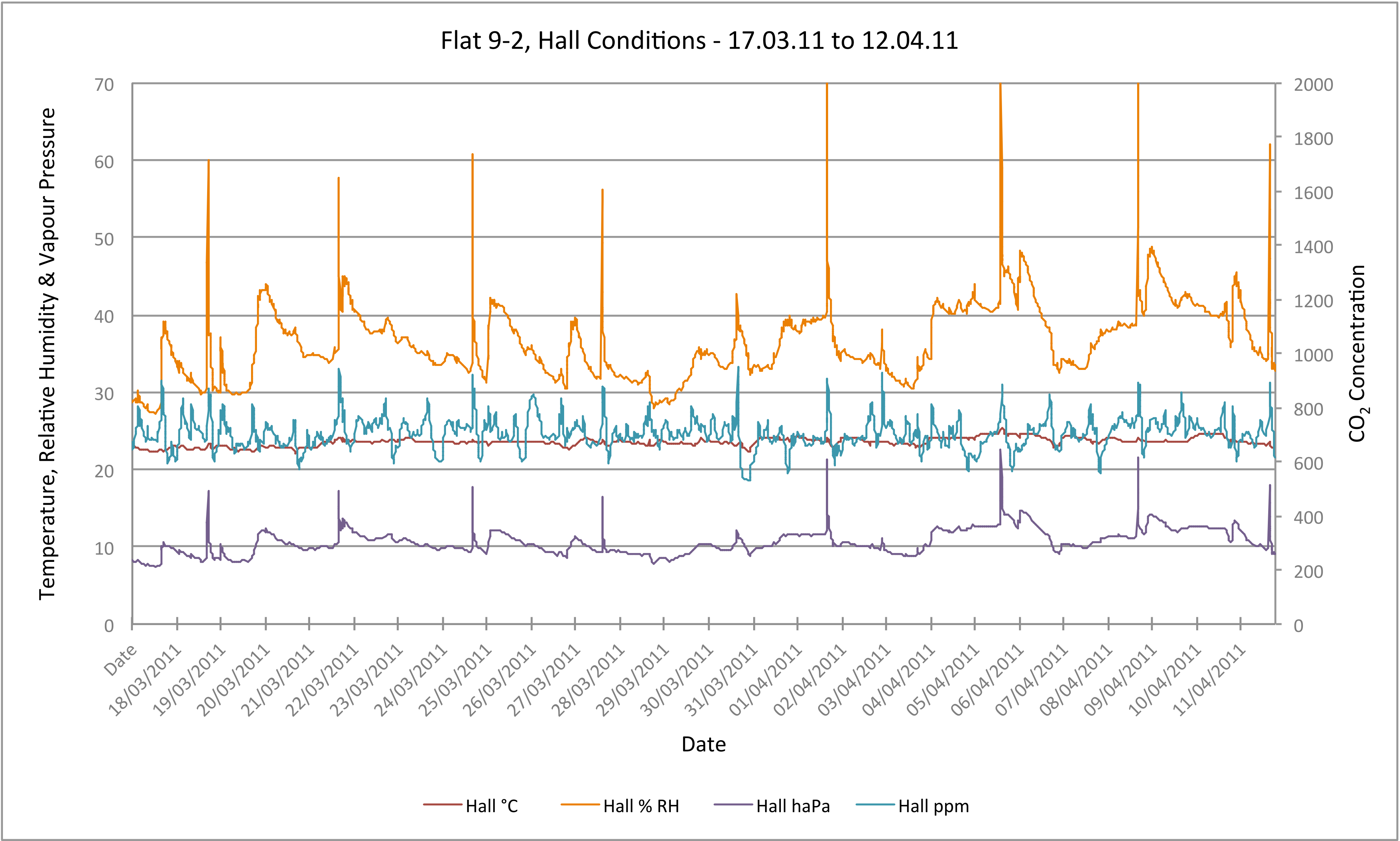
Appendix D

Dwelling 3;
3 week duration, room specific data



Flat 9-2, Living Room Conditions - 17.03.11 to 12.04.11
Temperature, Relative Humidity & Vapour Pressure
CO_2 Concentration
Date
Living Rm °C
Living Rm % RH
Living Rm haPa
Living rm ppm

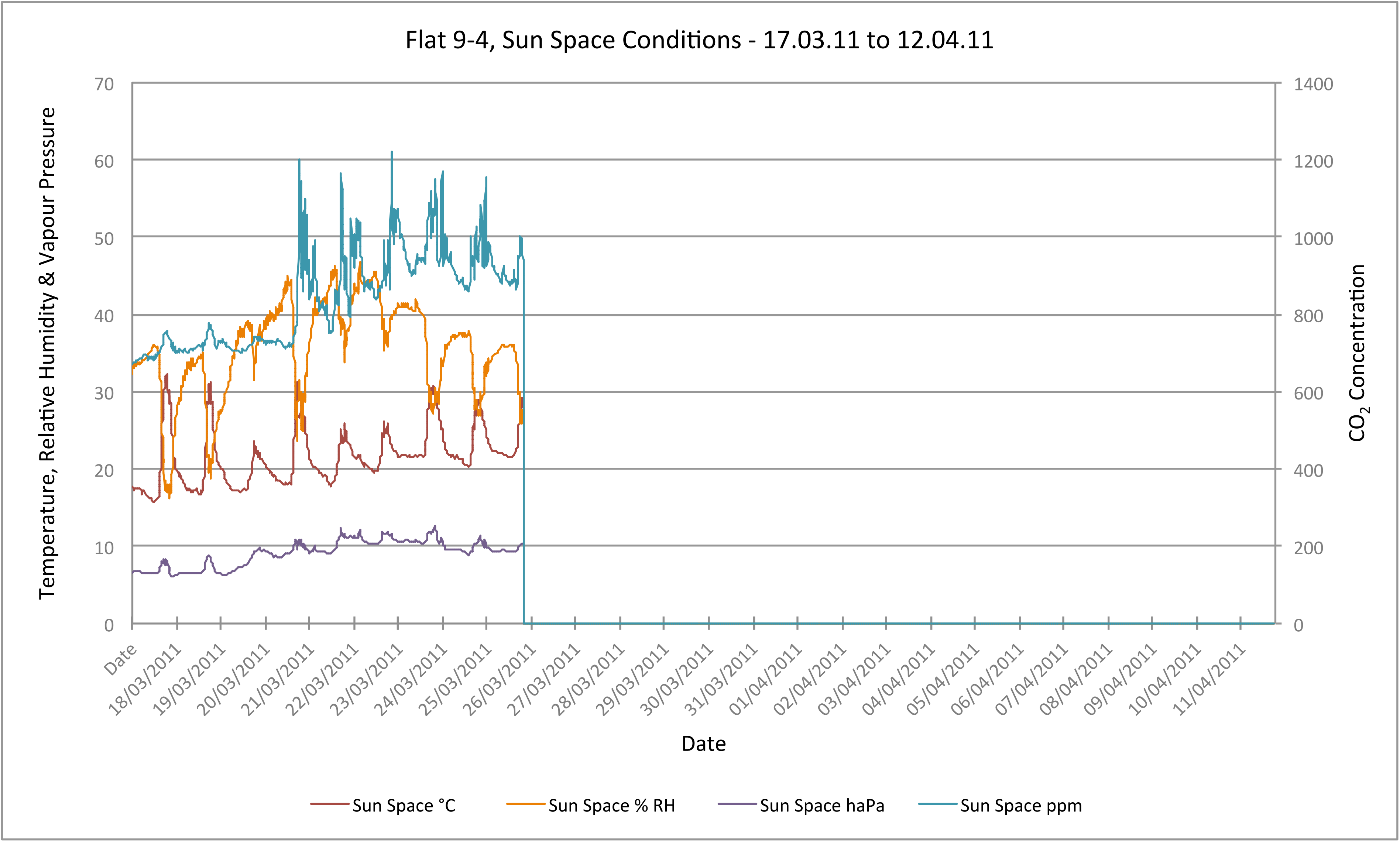

Flat 9-2, Bedroom Conditions - 17.03.11 to 12.04.11
Temperature, Relative Humidity & Vapour Pressure
CO2 Concentration
70
60
50
40
30
20
10
0
2000
1800
1600
1400
1200
1000
800
600
400
200
0
Date
18/03/2011
19/03/2011
20/03/2011
21/03/2011
22/03/2011
23/03/2011
24/03/2011
25/03/2011
26/03/2011
27/03/2011
28/03/2011
29/03/2011
30/03/2011
31/03/2011
01/04/2011
02/04/2011
03/04/2011
04/04/2011
05/04/2011
06/04/2011
07/04/2011
08/04/2011
09/04/2011
10/04/2011
11/04/2011
Date
Bedroom °C
Bedroom % RH
Bedroom haPa
Bedroom ppm

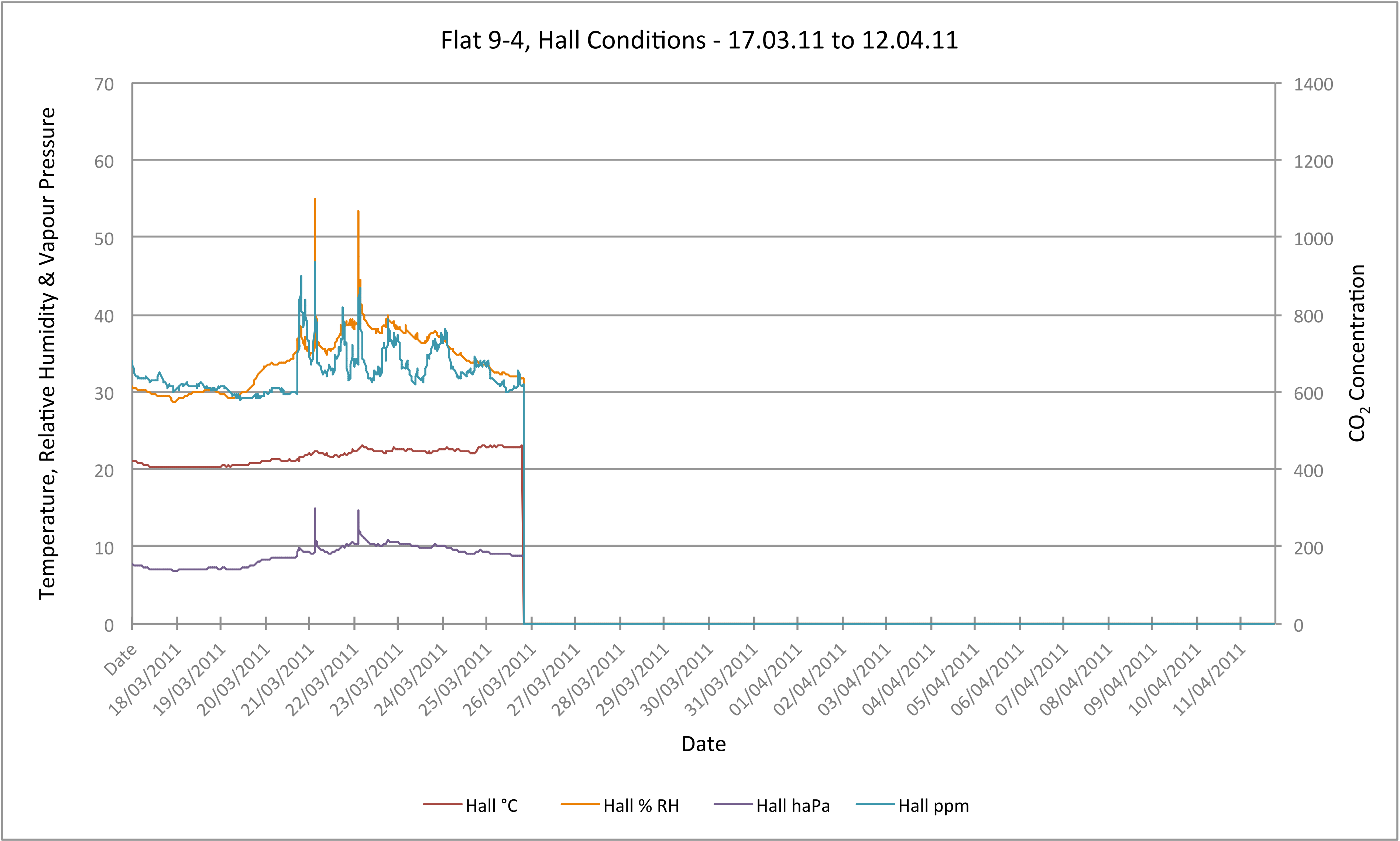


Flat 9-2, Hall Conditions - 17.03.11 to 12.04.11
Temperature, Relative Humidity & Vapour Pressure
CO_2 Concentration
0
10
20
30
40
50
60
70
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Date
18/03/2011
19/03/2011
20/03/2011
21/03/2011
22/03/2011
23/03/2011
24/03/2011
25/03/2011
26/03/2011
27/03/2011
28/03/2011
29/03/2011
30/03/2011
31/03/2011
01/04/2011
02/04/2011
03/04/2011
04/04/2011
05/04/2011
06/04/2011
07/04/2011
08/04/2011
09/04/2011
10/04/2011
11/04/2011
Date
Hall °C
Hall % RH
Hall haPa
Hall ppm

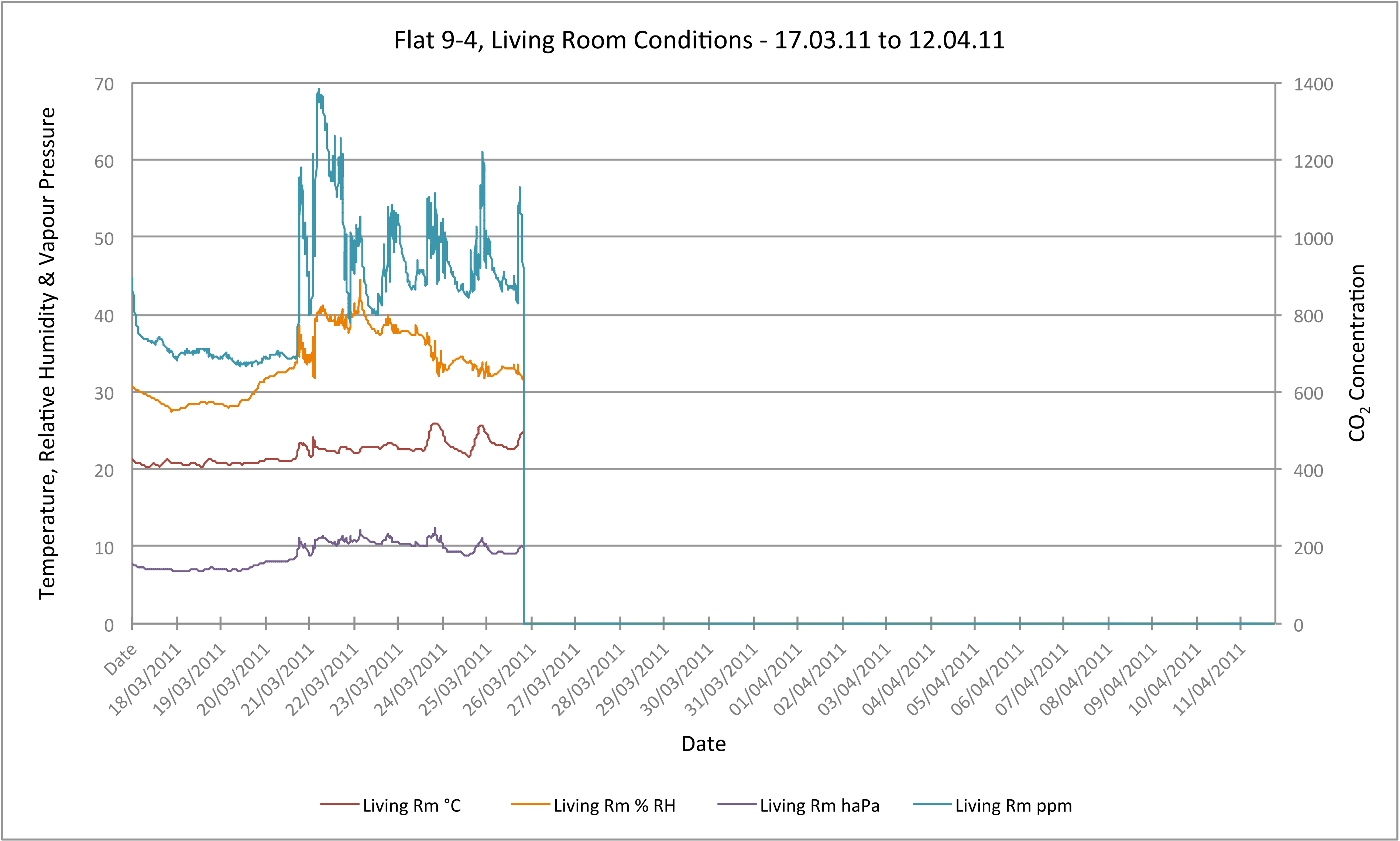
Appendix E

Dwelling 4;
3 week duration, room specific data

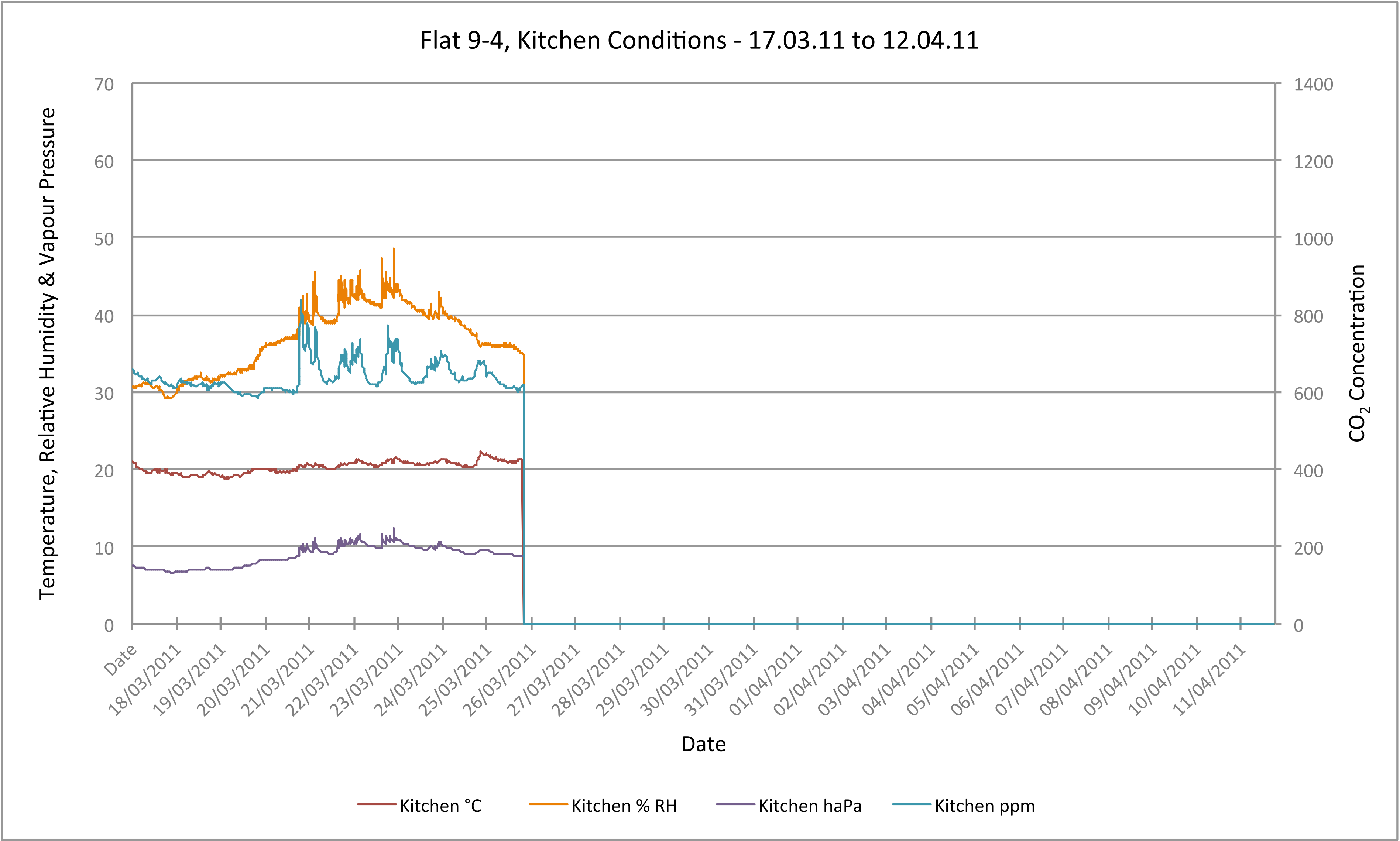

Flat 9-4, Sun Space Conditions - 17.03.11 to 12.04.11
Temperature, Relative Humidity & Vapour Pressure
CO2 Concentration
70
60
50
40
30
20
10
0
1400
1200
1000
800
600
400
200
0
Date
18/03/2011
19/03/2011
20/03/2011
21/03/2011
22/03/2011
23/03/2011
24/03/2011
25/03/2011
26/03/2011
27/03/2011
28/03/2011
29/03/2011
30/03/2011
31/03/2011
01/04/2011
02/04/2011
03/04/2011
04/04/2011
05/04/2011
06/04/2011
07/04/2011
08/04/2011
09/04/2011
10/04/2011
11/04/2011
Date
Sun Space °C
Sun Space % RH
Sun Space haPa
Sun Space ppm



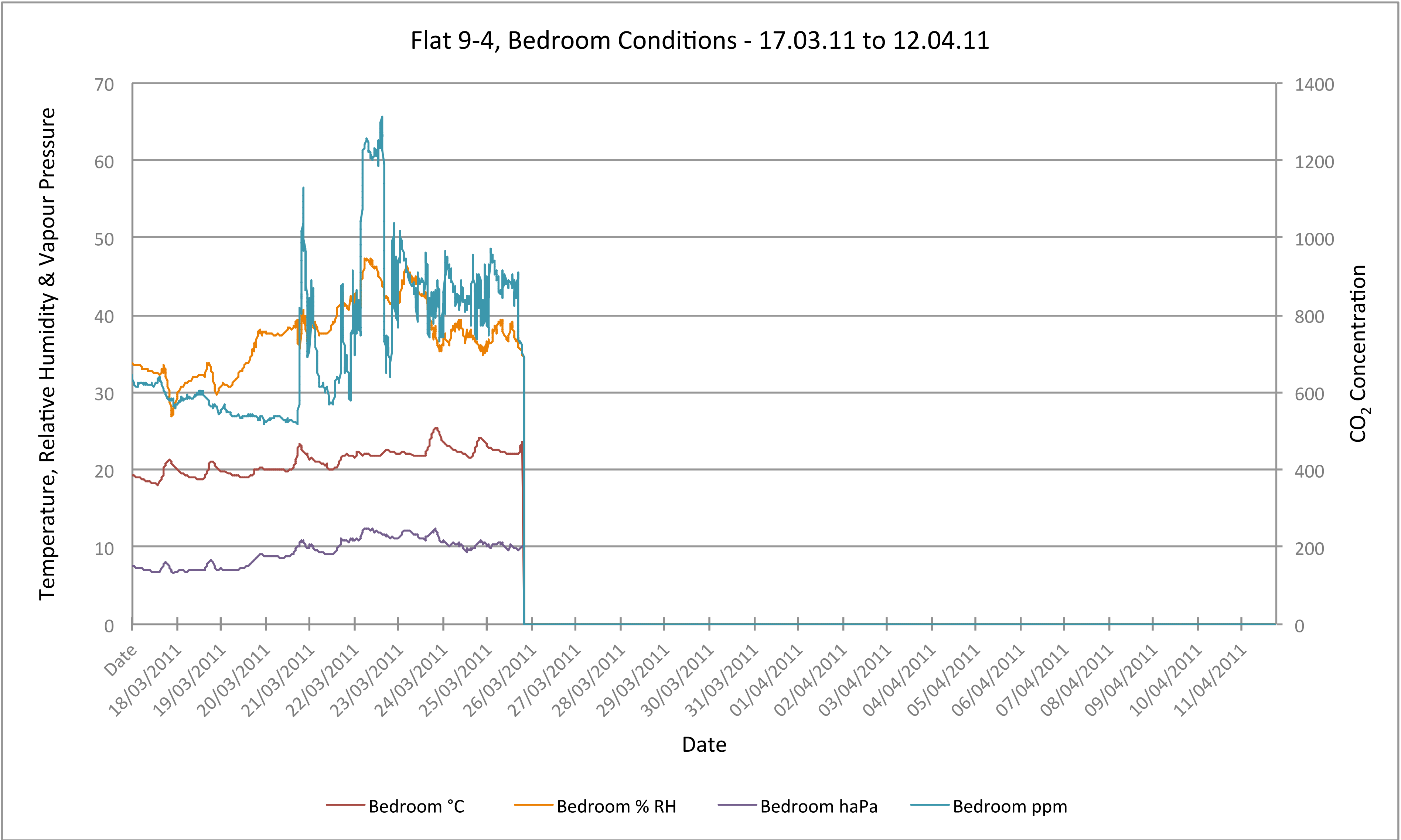
Flat 9-4, Hall Conditions - 17.03.11 to 12.04.11
Temperature, Relative Humidity & Vapour Pressure
CO_2 Concentration
70
60
50
40
30
20
10
0
1400
1200
1000
800
600
400
200
0
Date
18/03/2011
19/03/2011
20/03/2011
21/03/2011
22/03/2011
23/03/2011
24/03/2011
25/03/2011
26/03/2011
27/03/2011
28/03/2011
29/03/2011
30/03/2011
31/03/2011
01/04/2011
02/04/2011
03/04/2011
04/04/2011
05/04/2011
06/04/2011
07/04/2011
08/04/2011
09/04/2011
10/04/2011
11/04/2011
Date
Hall °C
Hall % RH
Hall haPa
Hall ppm



Flat 9-4, Living Room Conditions - 17.03.11 to 12.04.11
Temperature, Relative Humidity & Vapour Pressure
CO_2 Concentration
70
60
50
40
30
20
10
0
1400
1200
1000
800
600
400
200
0
Date
18/03/2011
19/03/2011
20/03/2011
21/03/2011
22/03/2011
23/03/2011
24/03/2011
25/03/2011
26/03/2011
27/03/2011
28/03/2011
29/03/2011
30/03/2011
31/03/2011
01/04/2011
02/04/2011
03/04/2011
04/04/2011
05/04/2011
06/04/2011
07/04/2011
08/04/2011
09/04/2011
10/04/2011
11/04/2011
Date
Living Rm °C
Living Rm % RH
Living Rm haPa
Living Rm ppm

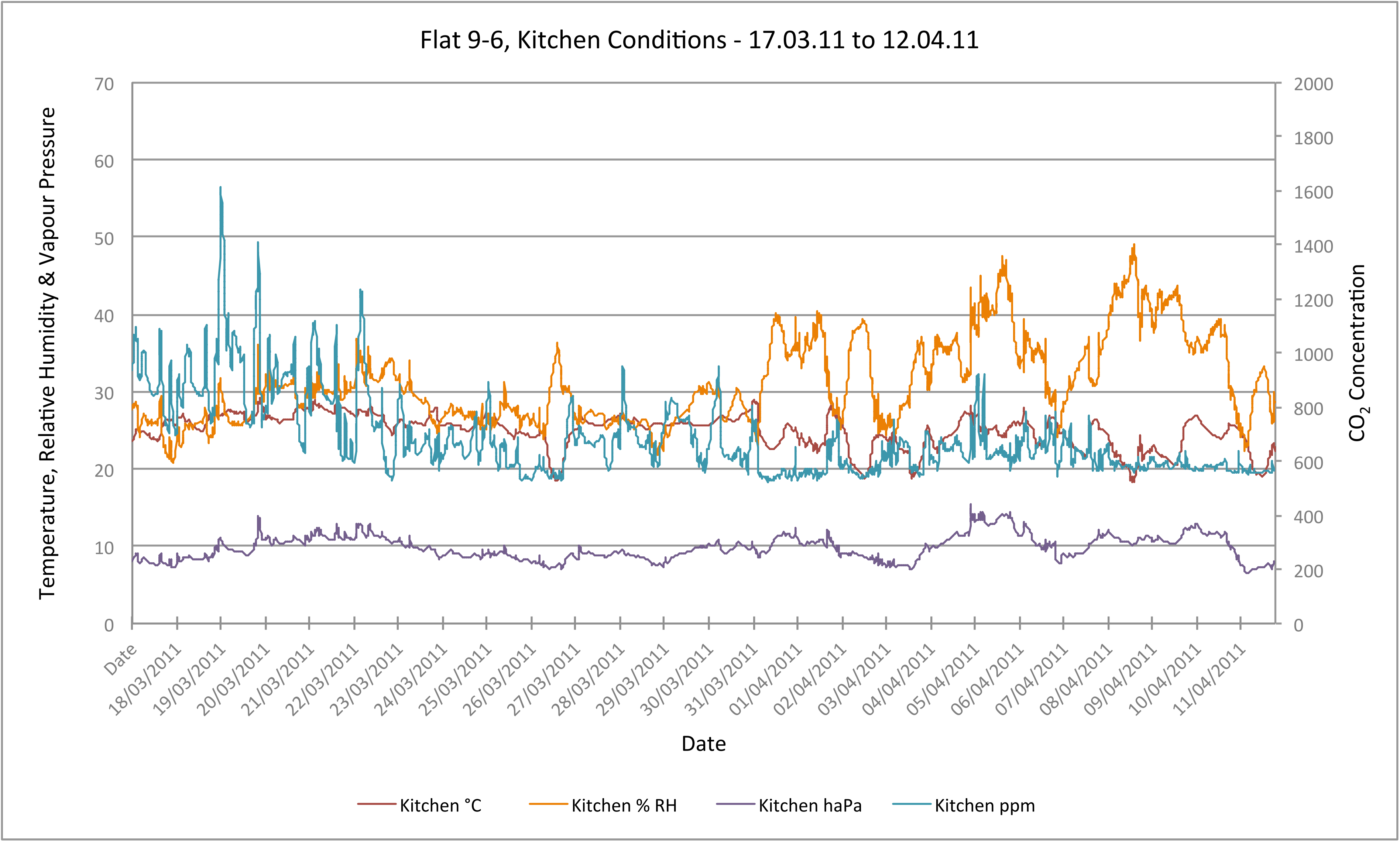


Flat 9-4, Kitchen Conditions - 17.03.11 to 12.04.11
Temperature, Relative Humidity & Vapour Pressure
CO_2 Concentration
70
60
50
40
30
20
10
0
1400
1200
1000
800
600
400
200
0
Date
18/03/2011
19/03/2011
20/03/2011
21/03/2011
22/03/2011
23/03/2011
24/03/2011
25/03/2011
26/03/2011
27/03/2011
28/03/2011
29/03/2011
30/03/2011
31/03/2011
01/04/2011
02/04/2011
03/04/2011
04/04/2011
05/04/2011
06/04/2011
07/04/2011
08/04/2011
09/04/2011
10/04/2011
11/04/2011
Date
Kitchen °C
Kitchen % RH
Kitchen haPa
Kitchen ppm

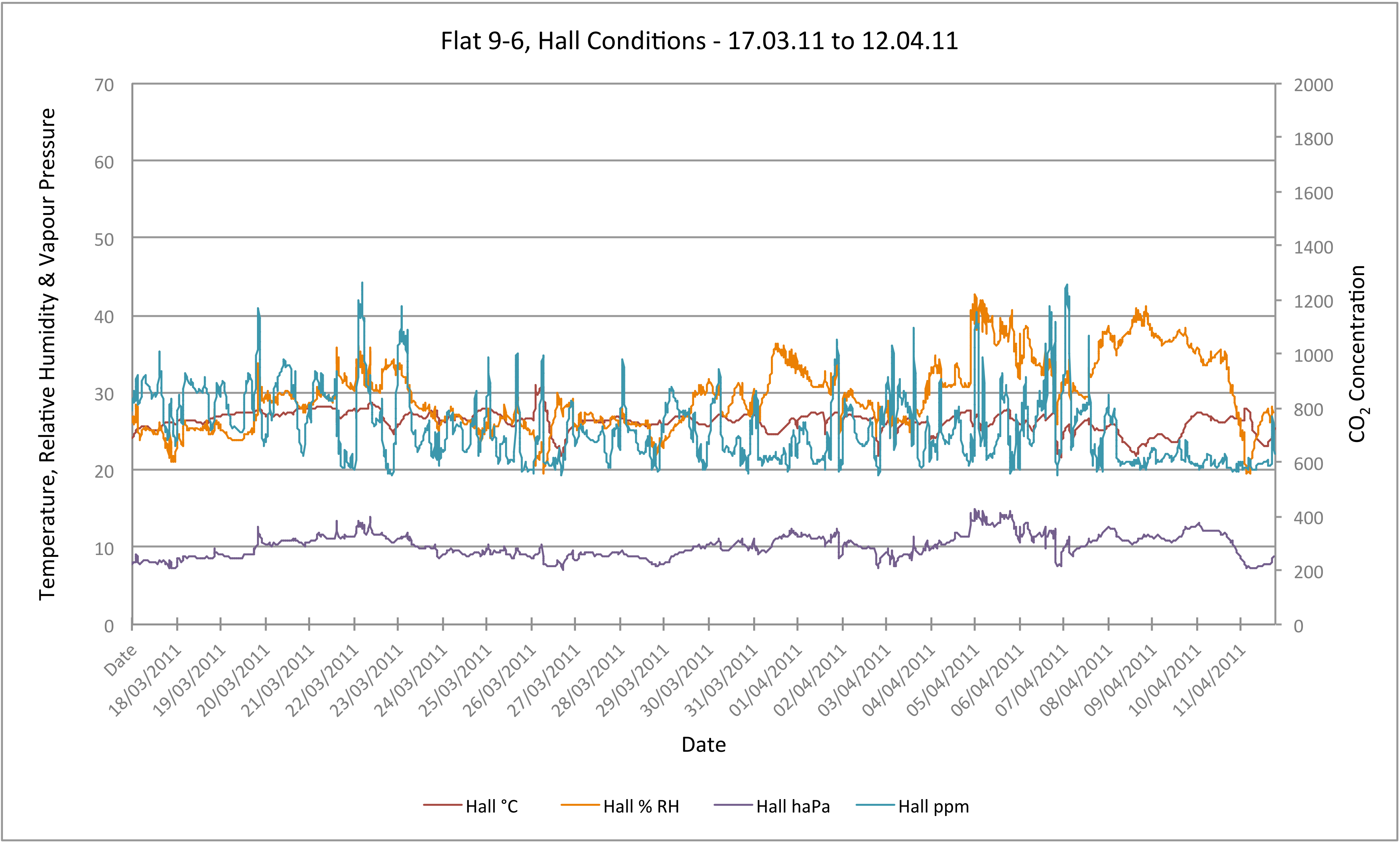

Flat 9-4, Bedroom Conditions - 17.03.11 to 12.04.11
Temperature, Relative Humidity & Vapour Pressure
CO_2 Concentration
70
60
50
40
30
20
10
0
1400
1200
1000
800
600
400
200
0
Date
18/03/2011
19/03/2011
20/03/2011
21/03/2011
22/03/2011
23/03/2011
24/03/2011
25/03/2011
26/03/2011
27/03/2011
28/03/2011
29/03/2011
30/03/2011
31/03/2011
01/04/2011
02/04/2011
03/04/2011
04/04/2011
05/04/2011
06/04/2011
07/04/2011
08/04/2011
09/04/2011
10/04/2011
11/04/2011
Date
Bedroom °C
Bedroom % RH
Bedroom haPa
Bedroom ppm

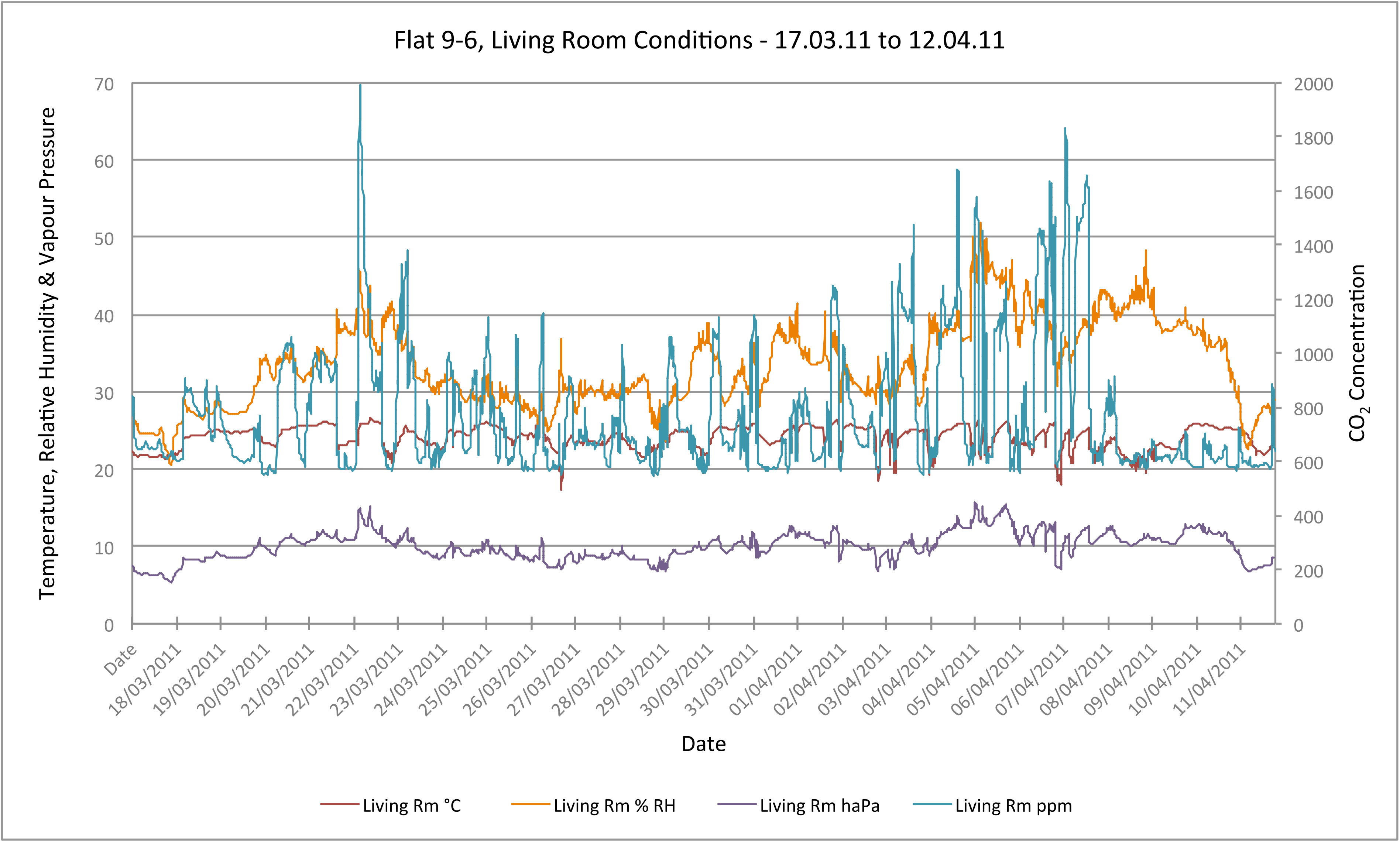
Appendix F

Dwelling 5;
3 week duration, room specific data

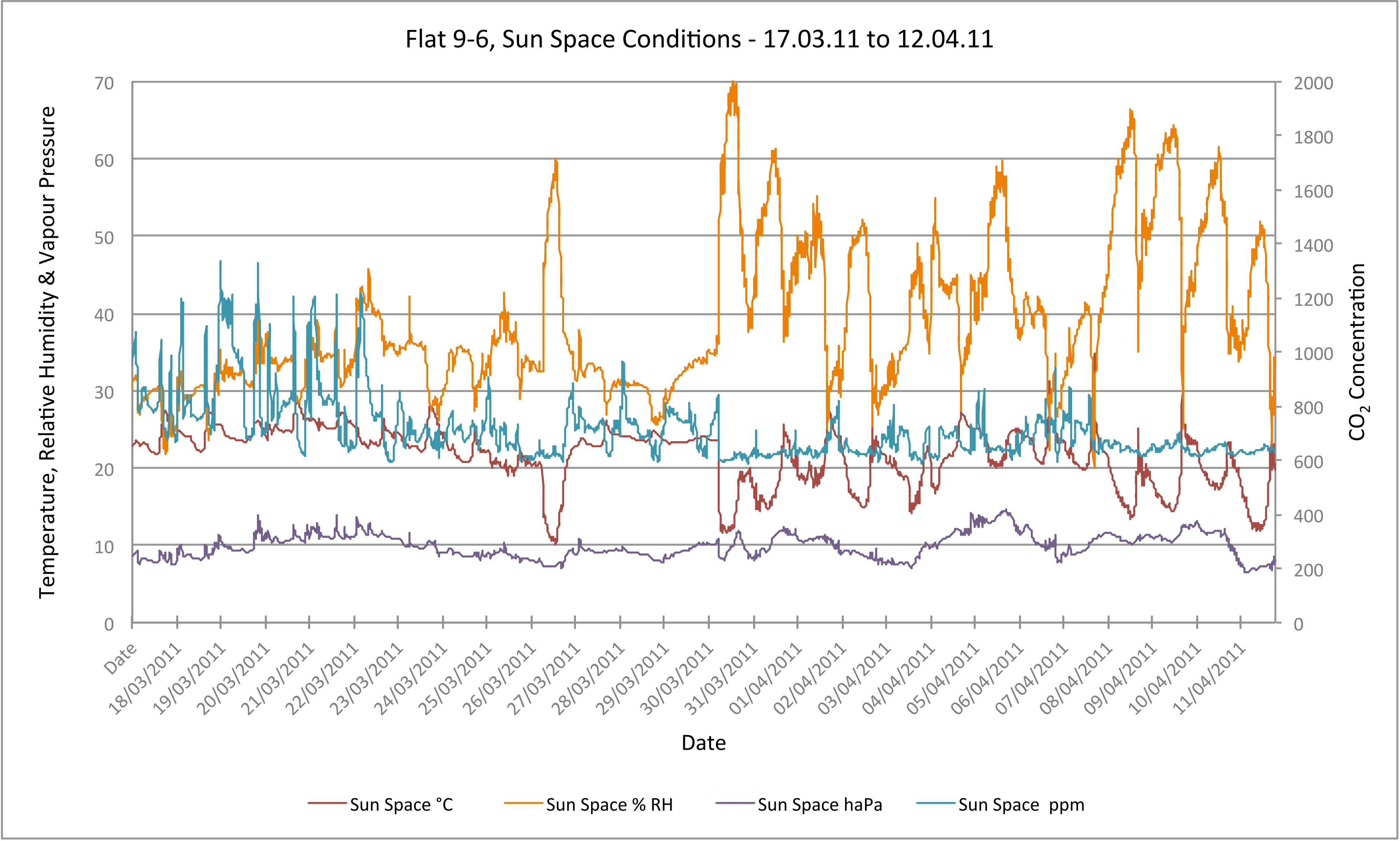


Flat 9-6, Kitchen Conditions - 17.03.11 to 12.04.11
Temperature, Relative Humidity & Vapour Pressure
CO_2 Concentration
70
60
50
40
30
20
10
0
2000
1800
1600
1400
1200
1000
800
600
400
200
0
Date
18/03/2011
19/03/2011
20/03/2011
21/03/2011
22/03/2011
23/03/2011
24/03/2011
25/03/2011
26/03/2011
27/03/2011
28/03/2011
29/03/2011
30/03/2011
31/03/2011
01/04/2011
02/04/2011
03/04/2011
04/04/2011
05/04/2011
06/04/2011
07/04/2011
08/04/2011
09/04/2011
10/04/2011
11/04/2011
Date
Kitchen °C
Kitchen % RH
Kitchen haPa
Kitchen ppm

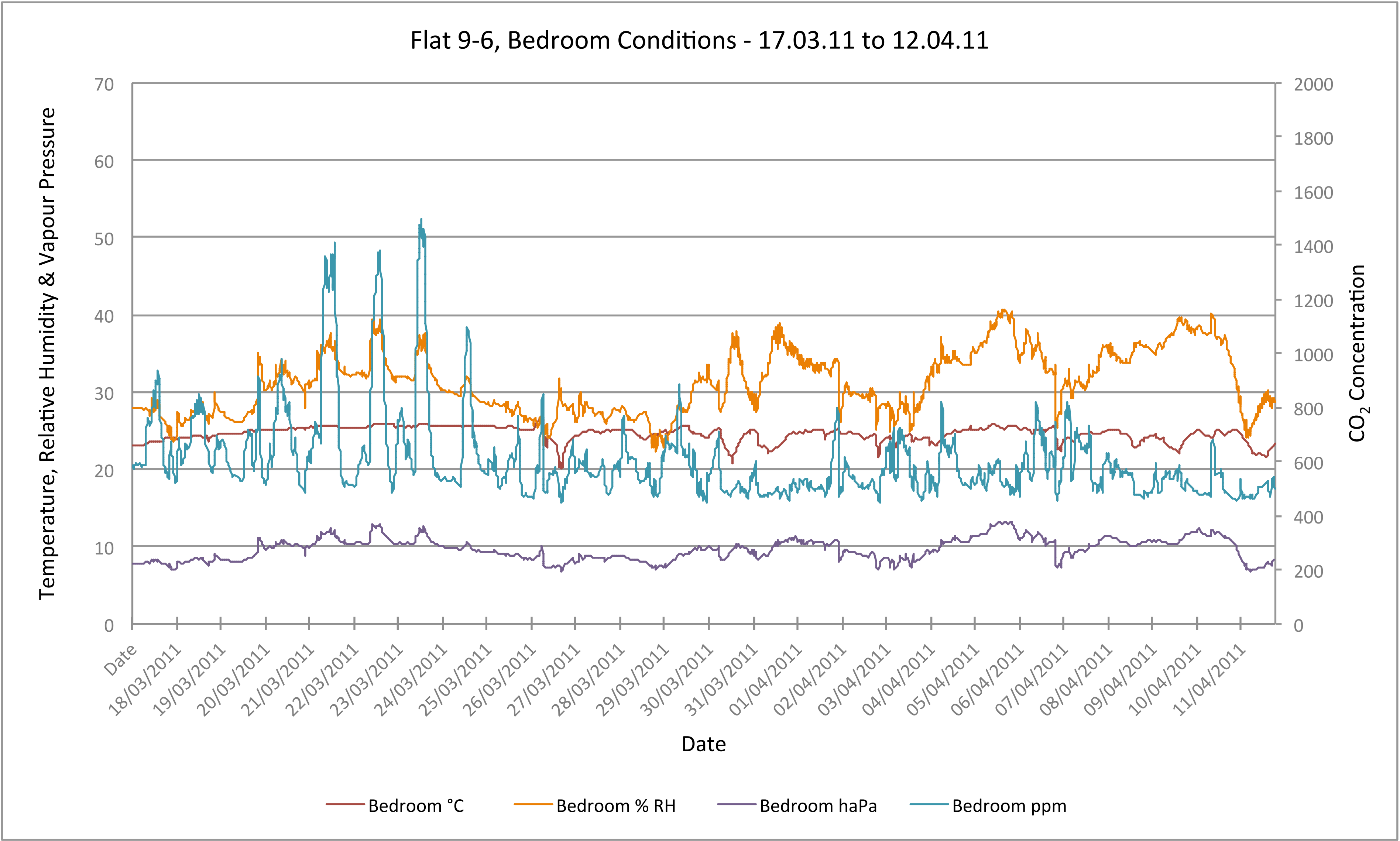

Flat 9-6, Hall Conditions - 17.03.11 to 12.04.11
Temperature, Relative Humidity & Vapour Pressure
CO_2 Concentration
70
60
50
40
30
20
10
0
2000
1800
1600
1400
1200
1000
800
600
400
200
0
Date
18/03/2011
19/03/2011
20/03/2011
21/03/2011
22/03/2011
23/03/2011
24/03/2011
25/03/2011
26/03/2011
27/03/2011
28/03/2011
29/03/2011
30/03/2011
31/03/2011
01/04/2011
02/04/2011
03/04/2011
04/04/2011
05/04/2011
06/04/2011
07/04/2011
08/04/2011
09/04/2011
10/04/2011
11/04/2011
Date
Hall °C
Hall % RH
Hall haPa
Hall ppm



Flat 9-6, Living Room Conditions - 17.03.11 to 12.04.11
Temperature, Relative Humidity & Vapour Pressure
0
10
20
30
40
50
60
70
CO_2 Concentration
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Date
18/03/2011
19/03/2011
20/03/2011
21/03/2011
22/03/2011
23/03/2011
24/03/2011
25/03/2011
26/03/2011
27/03/2011
28/03/2011
29/03/2011
30/03/2011
31/03/2011
01/04/2011
02/04/2011
03/04/2011
04/04/2011
05/04/2011
06/04/2011
07/04/2011
08/04/2011
09/04/2011
10/04/2011
11/04/2011
Date
Living Rm °C
Living Rm % RH
Living Rm haPa
Living Rm ppm



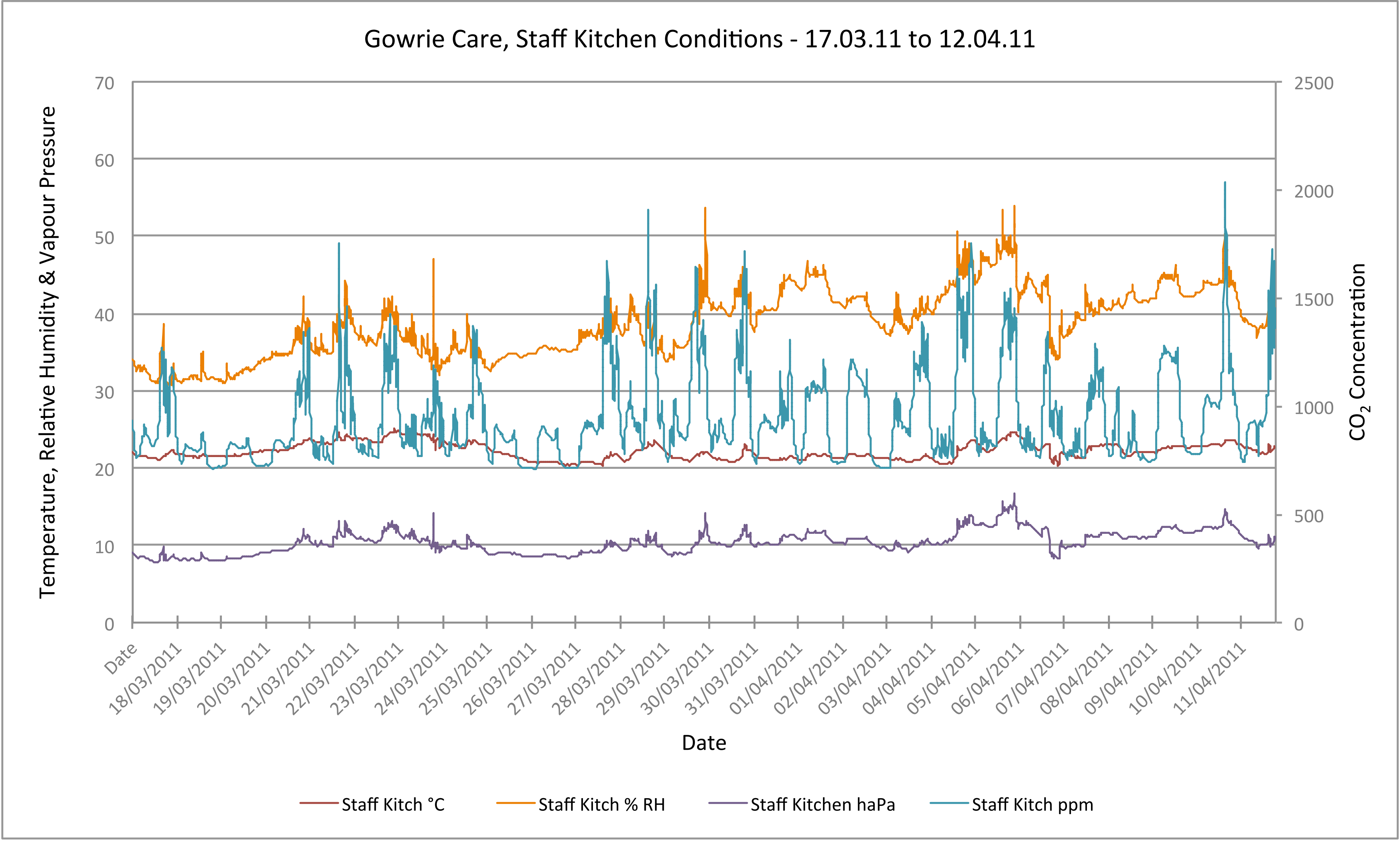
Flat 9-6, Sun Space Conditions - 17.03.11 to 12.04.11
Temperature, Relative Humidity & Vapour Pressure
CO2 Concentration
0
10
20
30
40
50
60
70
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Date
18/03/2011
19/03/2011
20/03/2011
21/03/2011
22/03/2011
23/03/2011
24/03/2011
25/03/2011
26/03/2011
27/03/2011
28/03/2011
29/03/2011
30/03/2011
31/03/2011
01/04/2011
02/04/2011
03/04/2011
04/04/2011
05/04/2011
06/04/2011
07/04/2011
08/04/2011
09/04/2011
10/04/2011
11/04/2011
Date
Sun Space °C
Sun Space % RH
Sun Space haPa
Sun Space ppm



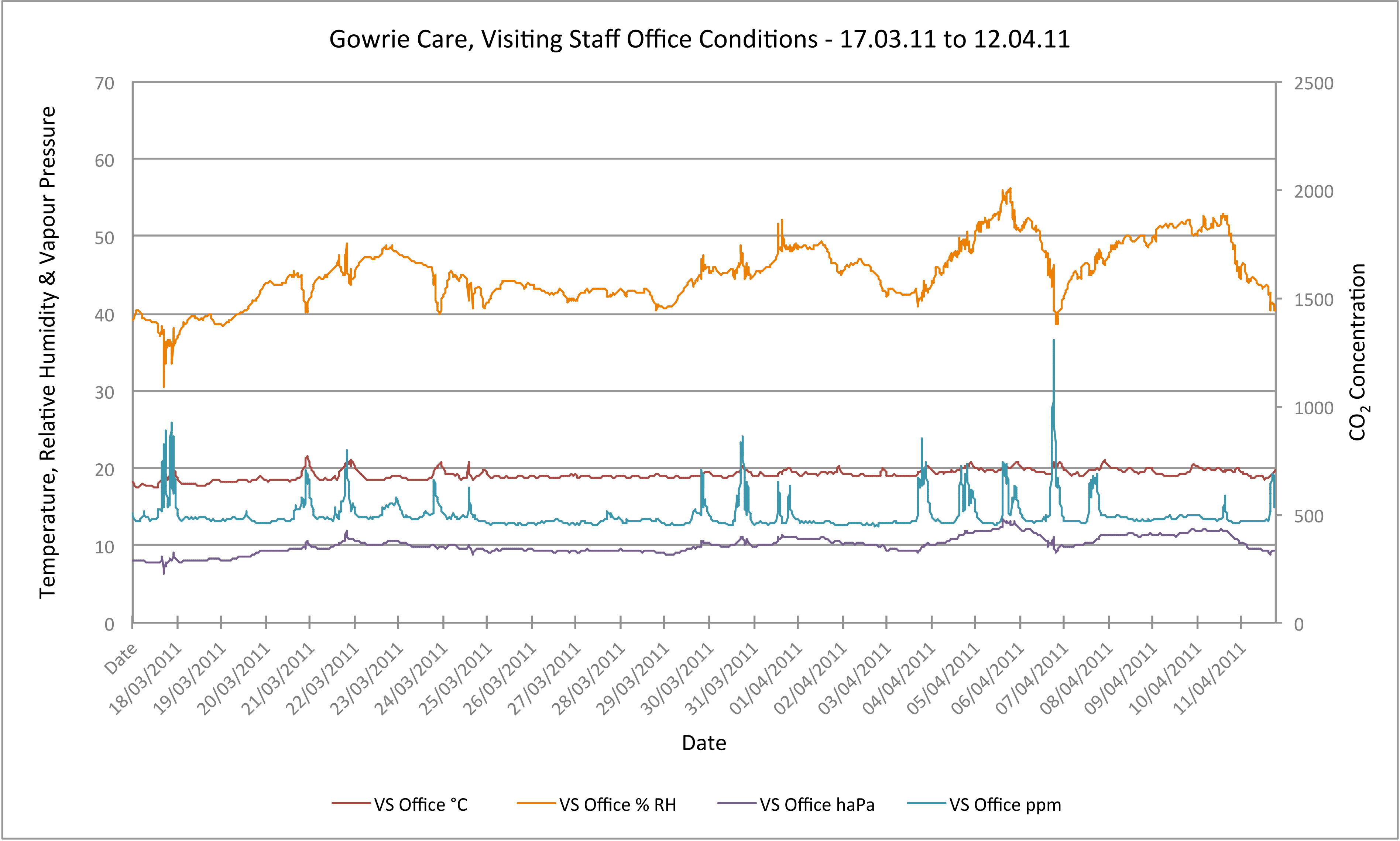
Flat 9-6, Bedroom Conditions - 17.03.11 to 12.04.11
Temperature, Relative Humidity & Vapour Pressure
CO2 Concentration
70
60
50
40
30
20
10
0
2000
1800
1600
1400
1200
1000
800
600
400
200
0
Date
18/03/2011
19/03/2011
20/03/2011
21/03/2011
22/03/2011
23/03/2011
24/03/2011
25/03/2011
26/03/2011
27/03/2011
28/03/2011
29/03/2011
30/03/2011
31/03/2011
01/04/2011
02/04/2011
03/04/2011
04/04/2011
05/04/2011
06/04/2011
07/04/2011
08/04/2011
09/04/2011
10/04/2011
11/04/2011
Date
Bedroom °C
Bedroom % RH
Bedroom haPa
Bedroom ppm

Appendix G

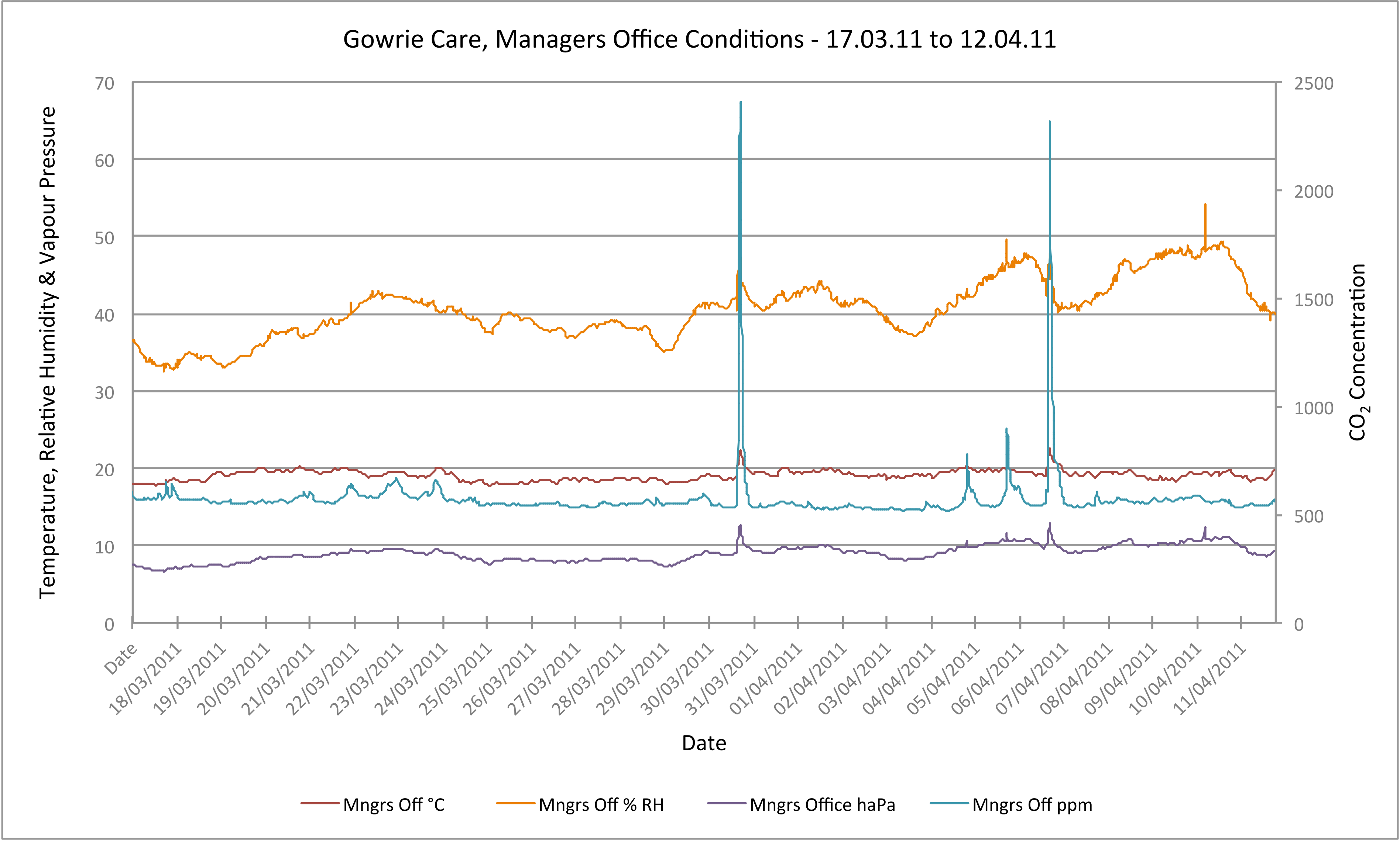
Gowrie Care Office;
3 week duration, room specific data



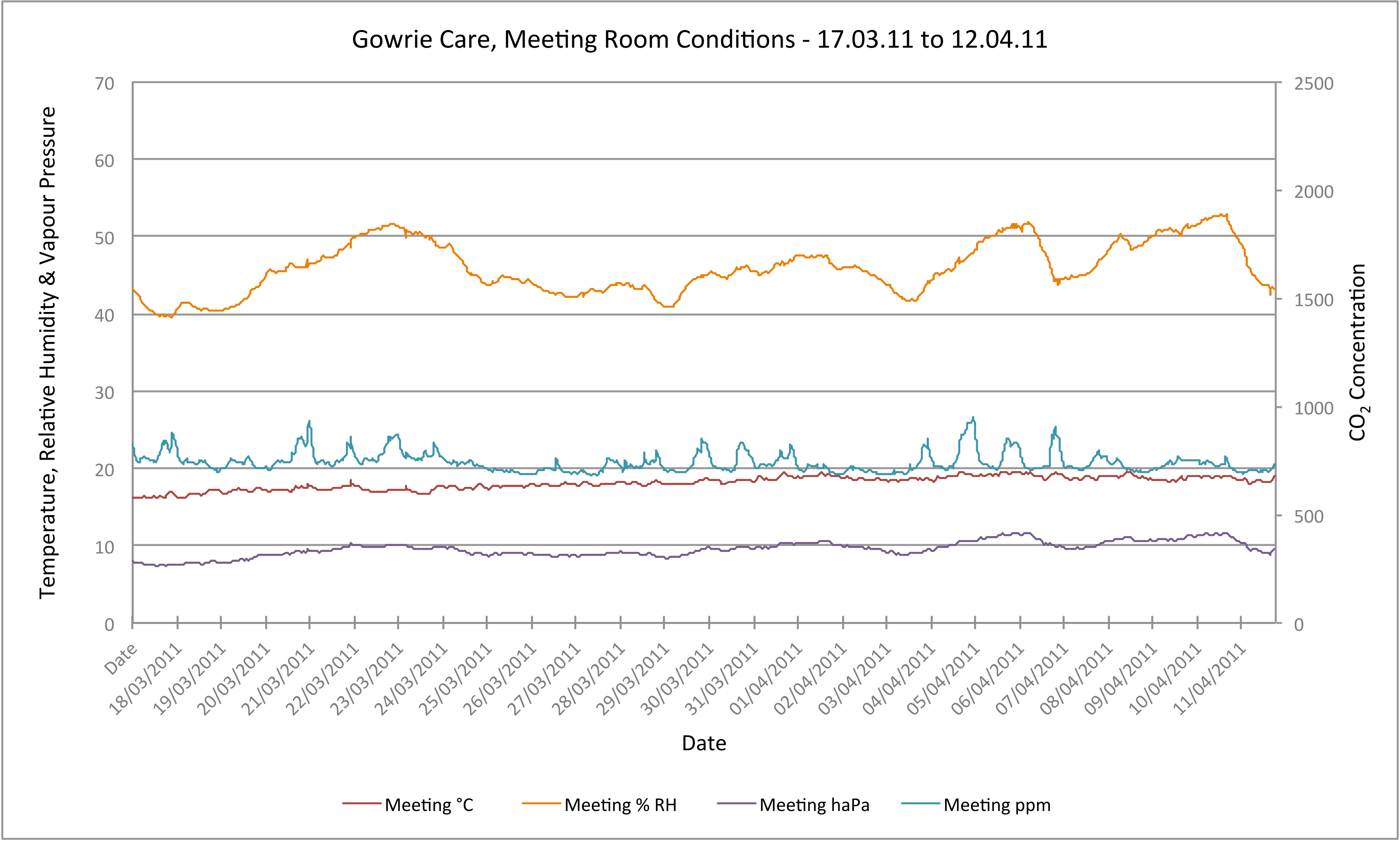
Gowrie Care, Staff Kitchen Conditions - 17.03.11 to 12.04.11
Temperature, Relative Humidity & Vapour Pressure
CO2 Concentration
70
60
50
40
30
20
10
0
2500
2000
1500
1000
500
0
Date
18/03/2011
19/03/2011
20/03/2011
21/03/2011
22/03/2011
23/03/2011
24/03/2011
25/03/2011
26/03/2011
27/03/2011
28/03/2011
29/03/2011
30/03/2011
31/03/2011
01/04/2011
02/04/2011
03/04/2011
04/04/2011
05/04/2011
06/04/2011
07/04/2011
08/04/2011
09/04/2011
10/04/2011
11/04/2011
Date
Staff Kitch °C
Staff Kitch % RH
Staff Kitchen haPa
Staff Kitch ppm



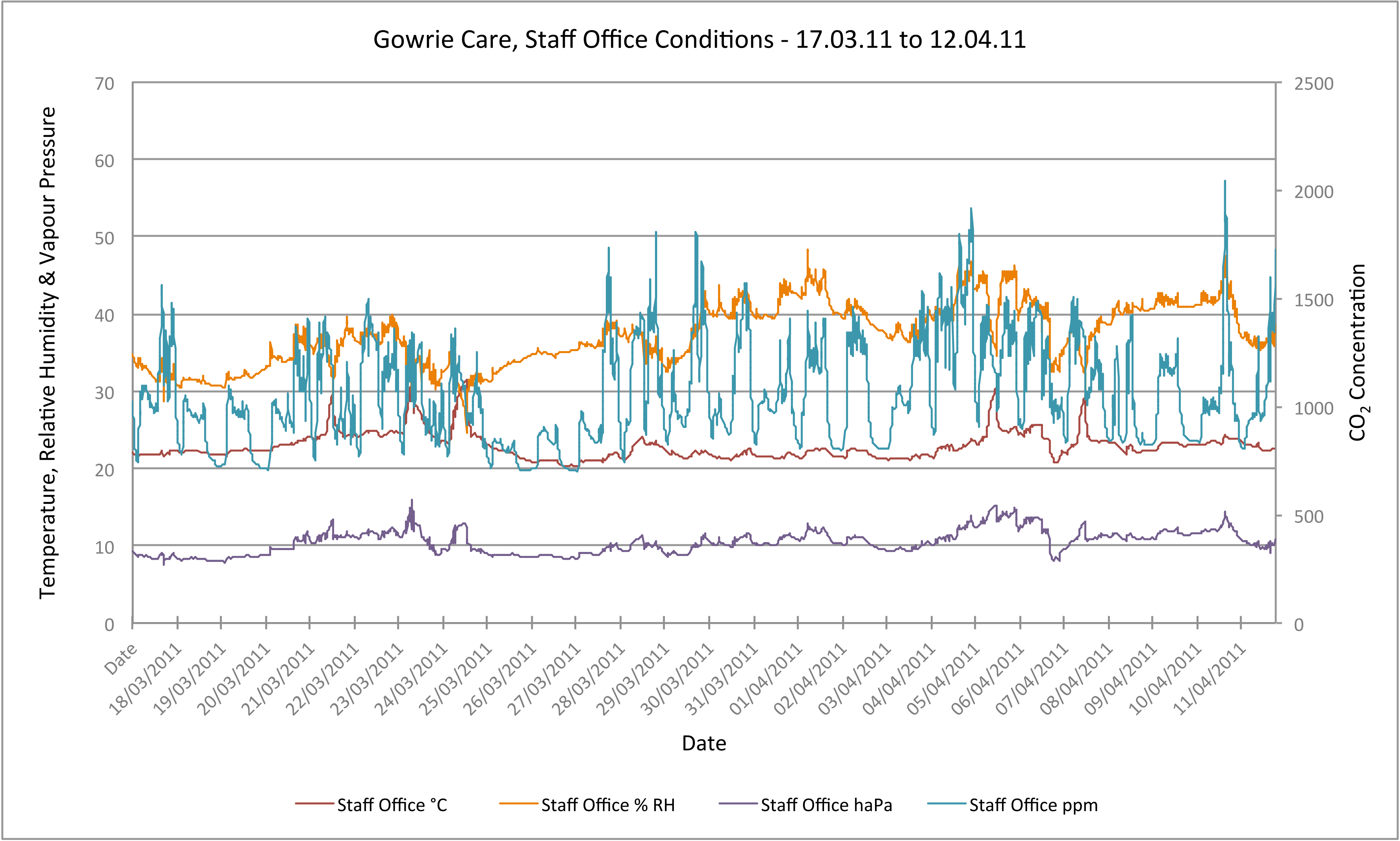
Gowrie Care, Visiting Staff Office Conditions - 17.03.11 to 12.04.11
Temperature, Relative Humidity & Vapour Pressure
CO2 Concentration
70
60
50
40
30
20
10
0
2500
2000
1500
1000
500
0
Date
18/03/2011
19/03/2011
20/03/2011
21/03/2011
22/03/2011
23/03/2011
24/03/2011
25/03/2011
26/03/2011
27/03/2011
28/03/2011
29/03/2011
30/03/2011
31/03/2011
01/04/2011
02/04/2011
03/04/2011
04/04/2011
05/04/2011
06/04/2011
07/04/2011
08/04/2011
09/04/2011
10/04/2011
11/04/2011
Date
VS Office °C
VS Office % RH
VS Office haPa
VS Office ppm

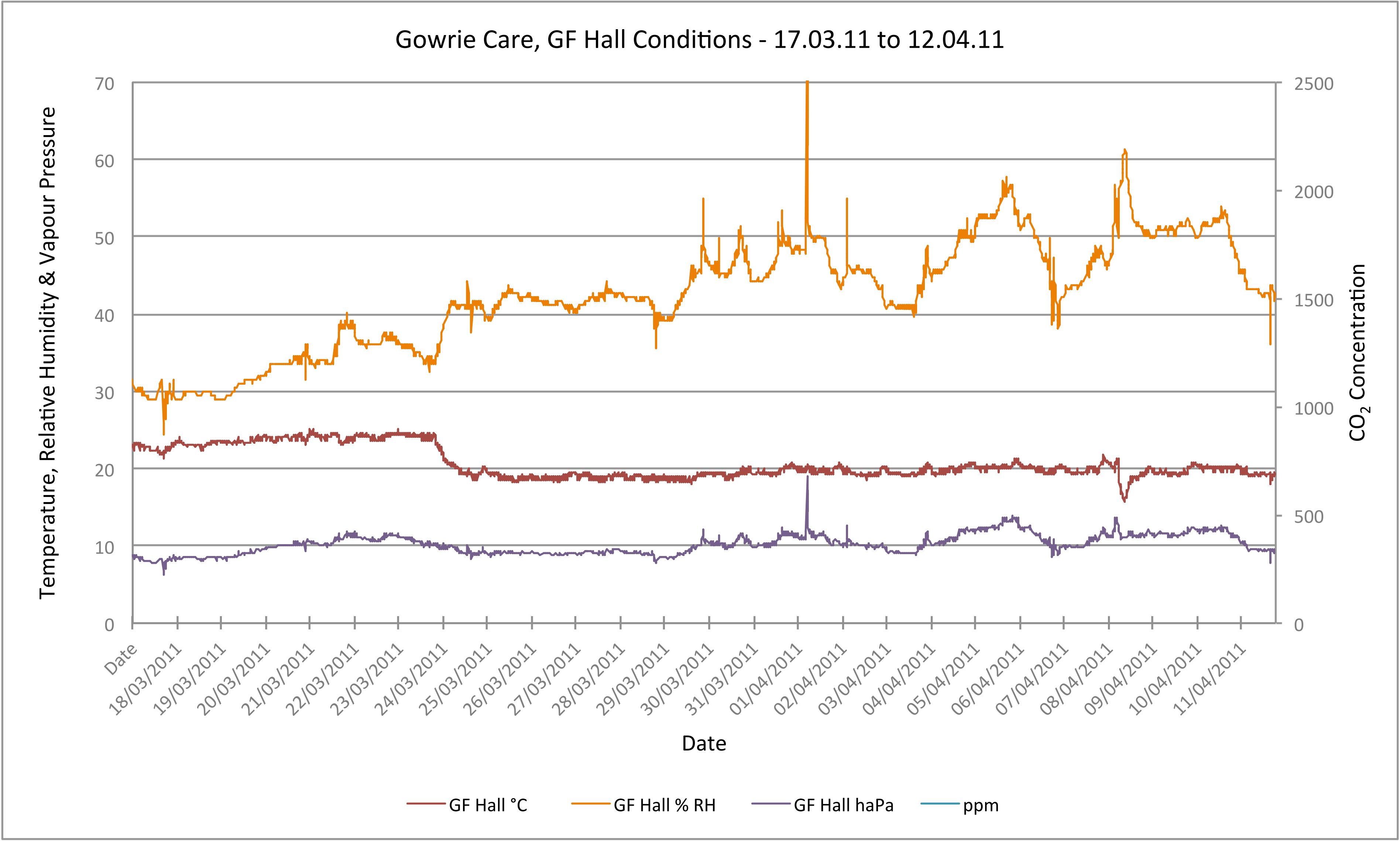


Gowrie Care, Managers Office Conditions - 17.03.11 to 12.04.11
Temperature, Relative Humidity & Vapour Pressure
70
60
50
40
30
20
10
0
2500
2000
1500
1000
500
0
CO_2 Concentration
Date
18/03/2011
19/03/2011
20/03/2011
21/03/2011
22/03/2011
23/03/2011
24/03/2011
25/03/2011
26/03/2011
27/03/2011
28/03/2011
29/03/2011
30/03/2011
31/03/2011
01/04/2011
02/04/2011
03/04/2011
04/04/2011
05/04/2011
06/04/2011
07/04/2011
08/04/2011
09/04/2011
10/04/2011
11/04/2011
Date
Mngrs Off °C
Mngrs Off % RH
Mngrs Office haPa
Mngrs Off ppm

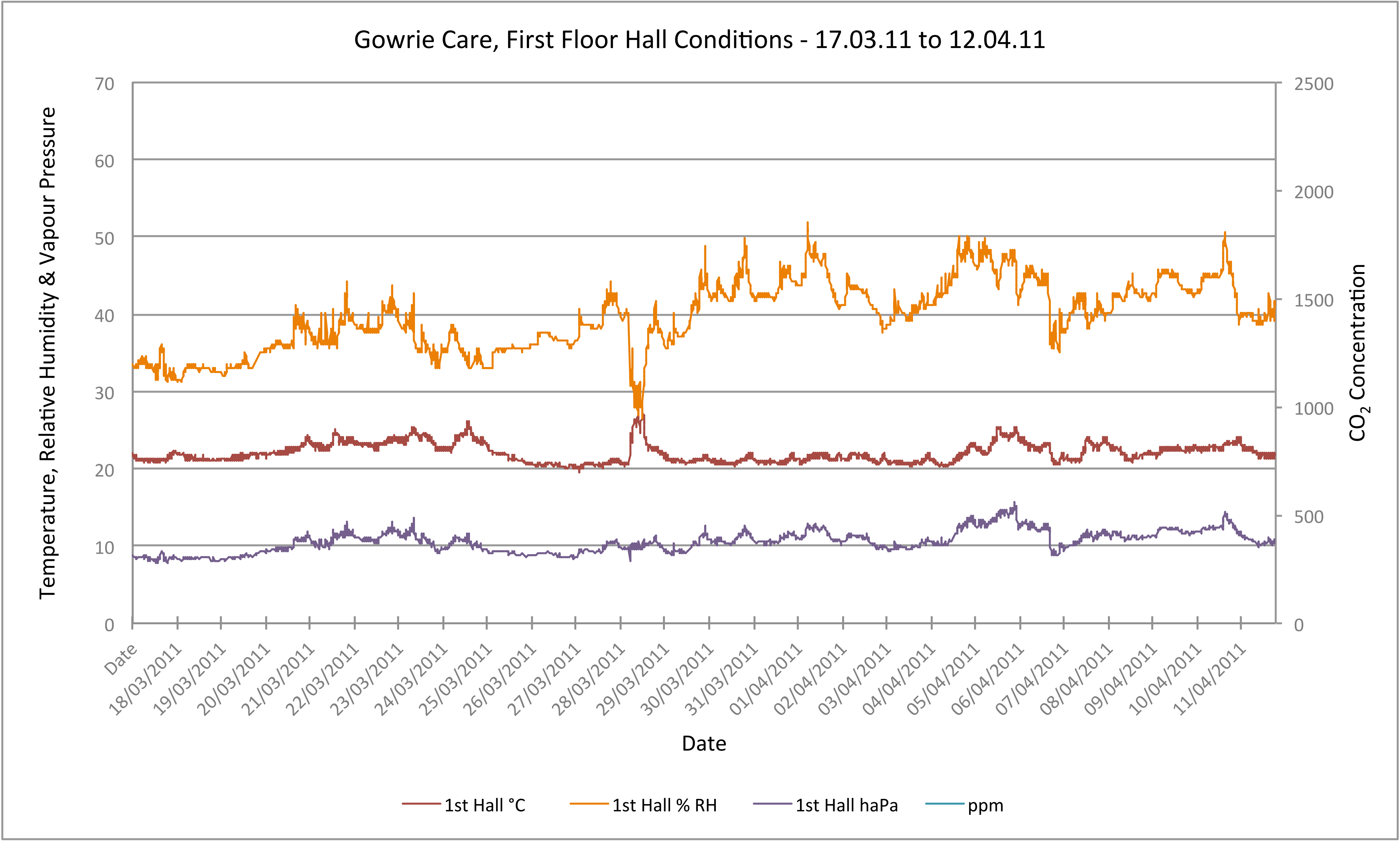


Gowrie Care, Meeting Room Conditions - 17.03.11 to 12.04.11
Temperature, Relative Humidity & Vapour Pressure
CO_2 Concentration
70
60
50
40
30
20
10
0
2500
2000
1500
1000
500
0
Date
18/03/2011
19/03/2011
20/03/2011
21/03/2011
22/03/2011
23/03/2011
24/03/2011
25/03/2011
26/03/2011
27/03/2011
28/03/2011
29/03/2011
30/03/2011
31/03/2011
01/04/2011
02/04/2011
03/04/2011
04/04/2011
05/04/2011
06/04/2011
07/04/2011
08/04/2011
09/04/2011
10/04/2011
11/04/2011
Date
Meeting °C
Meeting % RH
Meeting haPa
Meeting ppm


Gowrie Care, Staff Office Conditions - 17.03.11 to 12.04.11
Temperature, Relative Humidity & Vapour Pressure
CO2 Concentration
70
60
50
40
30
20
10
0
2500
2000
1500
1000
500
0
Date
18/03/2011
19/03/2011
20/03/2011
21/03/2011
22/03/2011
23/03/2011
24/03/2011
25/03/2011
26/03/2011
27/03/2011
28/03/2011
29/03/2011
30/03/2011
31/03/2011
01/04/2011
02/04/2011
03/04/2011
04/04/2011
05/04/2011
06/04/2011
07/04/2011
08/04/2011
09/04/2011
10/04/2011
11/04/2011
Date
Staff Office °C
Staff Office % RH
Staff Office haPa
Staff Office ppm



Gowrie Care, GF Hall Conditions - 17.03.11 to 12.04.11
Temperature, Relative Humidity & Vapour Pressure
CO_2 Concentration
70
60
50
40
30
20
10
0
2500
2000
1500
1000
500
0
Date
18/03/2011
19/03/2011
20/03/2011
21/03/2011
22/03/2011
23/03/2011
24/03/2011
25/03/2011
26/03/2011
27/03/2011
28/03/2011
29/03/2011
30/03/2011
31/03/2011
01/04/2011
02/04/2011
03/04/2011
04/04/2011
05/04/2011
06/04/2011
07/04/2011
08/04/2011
09/04/2011
10/04/2011
11/04/2011
Date
GF Hall °C
GF Hall % RH
GF Hall haPa
ppm


Gowrie Care, First Floor Hall Conditions - 17.03.11 to 12.04.11
Temperature, Relative Humidity & Vapour Pressure
CO2 Concentration
70
60
50
40
30
20
10
0
2500
2000
1500
1000
500
0
Date
18/03/2011
19/03/2011
20/03/2011
21/03/2011
22/03/2011
23/03/2011
24/03/2011
25/03/2011
26/03/2011
27/03/2011
28/03/2011
29/03/2011
30/03/2011
31/03/2011
01/04/2011
02/04/2011
03/04/2011
04/04/2011
05/04/2011
06/04/2011
07/04/2011
08/04/2011
09/04/2011
10/04/2011
11/04/2011
Date
1st Hall °C
1st Hall % RH
1st Hall haPa
ppm