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Building Thermal Performance Determination

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BUILDING THERMAL PERFORMANCE DETERMINATION

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Abstract

This research project investigated a method of calculating the thermal performance of two buildings using heating and temperature records measured during a survey of energy use. Temperature and heating records were measured over several years using data loggers in two domestic residences, near Wellington, New Zealand. Heating records were adjusted to equate to an indoor room temperature of 20°C when calculating the field measured building thermal performance. Sensitivity analyses were carried out, to determine the influence of the temperature corrections on the field-measured thermal performance, when the indoor temperature fluctuated above or below the required indoor temperature.

It was found that, using temperature corrections, a reasonably accurate measurement of the building's thermal performance from field measurements can be achieved. The field-measured thermal performance, even when monitored over only one winter month, was within ±16% of the measured value.

1.0 Background

This study uses data from a field survey of heat loss from slab floors[1] being carried out as part of an ongoing five-year analysis of the thermal performance of concrete slab-on-ground floors. Two houses were available for this study - both near Wellington. Both houses were required to maintain a steady indoor temperature of about 20°C in a pre-selected area of the house, for the entire duration of the project. The floor slab project measuring instruments included both ordinary thermocouples and purpose-built floor heat flux thermocouples. Continual automatic datalogging was carried out on a 54 channel data logger, recording hourly temperature averages.

It should be noted that although calculating the building thermal performance indices (BPIs) of a building is relatively easy, their measurement is more complicated. There are various reasons for the complications, but the main difficulty is that indoor temperatures always vary from the value (of 20°C) defined in the usual BPI definition. These variations may not be very large, but the effect on the heating energy requirements is.

2.0 Aims

The primary aims of this project were: to investigate a method of calculating the BPI from temperature and heating records measured during a survey of building energy use; to contribute to improvements in the thermal performance of residential buildings by determining the *accuracy* with which the thermal efficiency of existing buildings can be measured; and to attempt to find a *more accurate* way of assessing the thermal performance of residential buildings, and if possible, establish a procedure/formula for doing this.

3.0 Method

This study was mainly concerned with calculating field BPI values from data-logged information. The procedure for working out the field BPI of the two houses is as follows. Field data files containing energy-use figures and temperature readings were downloaded from the data logger onto EXCEL spreadsheets. The energy figures were then corrected to account for the heating appliance efficiencies and casual loads.

The mean indoor temperature was adjusted for any indoor under- or over-heating. The indoor adjustment operates so that if the indoor temperature **exceeds** the defined 20°C temperature, the degree day **increases** by that excess amount, and vice versa. In effect, this adjustment works by shifting the base temperature (of 16°C - below which indoor heating is required) and keeping the difference between it and the actual indoor temperature at a constant - in this case - 4°C. The field BPI was calculated by dividing the space heating energy use by the floor area, multiplied by the number of degree days. The resulting field BPI values were then compared with those calculated using the ALF[2,3] procedure.

4.0 Definitions

The following definitions are used to describe the various BPI terms and calculation methods:

Base Temperature: the outdoor temperature below which, by definition, indoor heating is required. In this case, the base temperature used is 16°C, as in Approved Document H1 Energy Efficiency[7].

Shading Coefficient (SC): a factor which accounts for the reduction in light transmission through a window, compared with a reference single sheet of 4mm glass. For example, an SC = 1 is the reference window condition, with no shading.

Field Values: *(empirically based BPI over the entire year which accounts for heater efficiency).*

- *Raw*: Basic, unmodified BPI data[#]
- *Heating Adjusted*: Adjusted BPI for under/over indoor heating
- *Winter Case*: Adjusted BPI for under/over indoor heating, for the four month heating season - May through August.

ALF Values: *(worksheet based BPI, for the May through August "heating season", using the ALF procedure).*

- $ALF_{W/S}$: calculations performed using the 4-page ALF worksheet method
- ALF_{PC}: calculations performed using PC ALF, with the degree day figure corresponding to that of Kelburn
- $ALF_{PC\text{-}dd}$: as for ALF_{PC}, but where the degree-day figure equates to the average field degree days, over the length of the assessment period
- ALF_{AV}: the average of $ALF_{PC\text{-}CURTAIN}$ and $ALF_{PC\text{-}dd}$.

5.0 Field Measurement

5.1 House Number One: Paraparaumu

5.1.1 General Statistics

House area: *142m²*, Year built: 1990, Number of occupants: *2*, Construction materials: *concrete slab floor, light timber frame construction, masonry veneer external walls and pressed metal tile roofing*, R-values: *Floor-1.8, Walls-1.5, Windows-0.18, Roof-2.5, (in* $m^{2o}C/W$*)*, Heater: *Principally direct flued gas heating*, Curtains: *not drawn at night.*

5.2 Procedure

The raw data, of averaged indoor and outdoor temperature readings taken approximately every 10 days, were converted into EXCEL files, edited and renamed. The original hourly average temperature records were converted into averages for each billing period of approximately one month.

The 10-day averaged temperatures and the monthly gas readings were then aligned to start and finish at the same time as the electrical billing period. The electrical billing period was picked arbitrarily as a reference.

5.3 Calculations and Graphical Work

5.3.1 Field Values

Electrical Energy Usage '91 - '93 (Paraparaumu)

The electrical energy usage is not significantly higher over the winter months, even though it is likely that some extra energy would have been needed for

[#] Strictly speaking, this is not a BPI, as the indoor temperature fluctuations have not been adjusted to 20°C. However, for this study, this has been noted with the use of the prefix *Raw*.

lighting and electric space heating. Also, the energy usage values are erratic over the non-heating season, leading to under/over estimates being made by the electrical authority during that period. The average monthly electrical energy usage for the three years was 650 kWh. Unfortunately, because of the aggregated nature of the data, it is impossible to tell if an electric booster heater was used to heat some rooms during particularly cold snaps. Thus, only the gas figures were used in the BPI calculations.

"Raw" Case BPI (Paraparaumu)

Figure 3 shows the building's thermal performance calculated on a monthly basis over the three years 1991 through 1993, where no corrections are made for indoor under/over heating. The calculated BPI is not constant, but is relatively stable for all the three years over the March through September period, compared to the "summer" (October through February) period. This instability during the "summer" period is a result of the denominator (Δ^oC) in the BPI equation becoming extremely small, resulting in minute errors in temperature measurement being amplified out of proportion.

It was calculated that the average raw BPI value over the three year period was 0.262 kWh/dd.m^2. Excluding the summer periods (October through February inclusive), the average raw BPI becomes 0.330 kWh/dd.m^2.

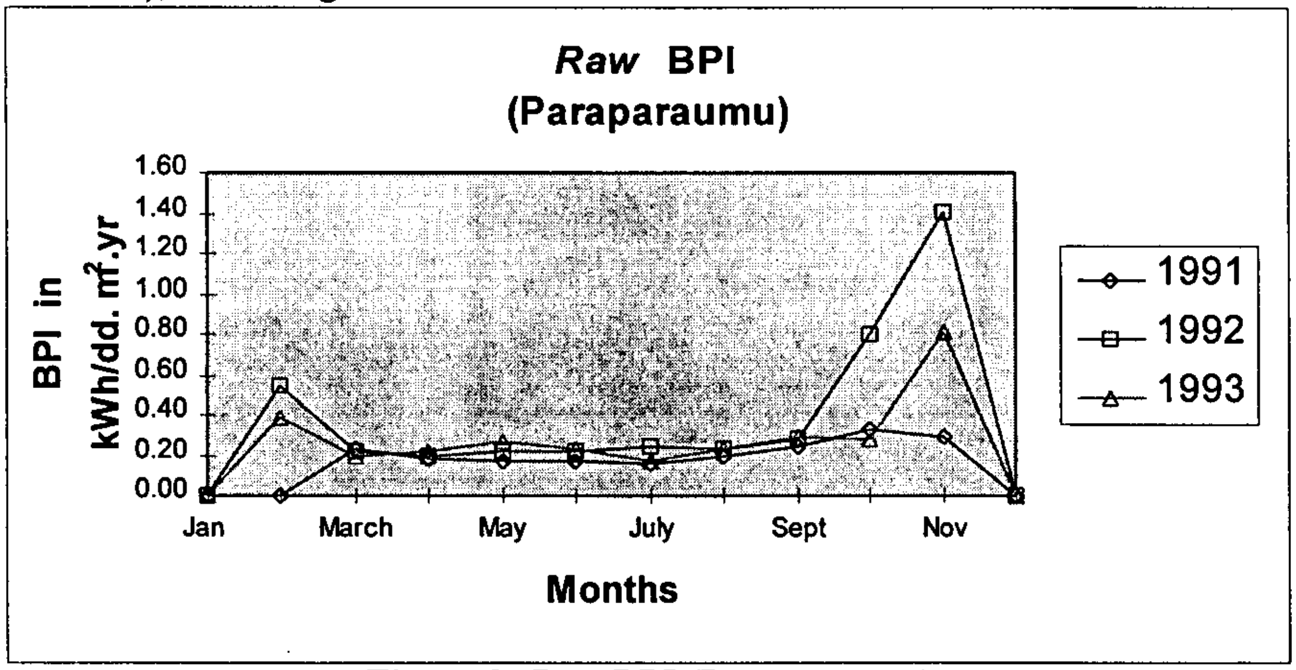

Figure 3: ***Raw BPI (Paraparaumu)***

Heating Adjusted BPI (Paraparaumu)

Figure 4 shows the building's thermal performance after adjustments for under/over heating. In comparison with the *Raw* BPI, the large summer fluctuations have been eliminated, reducing the range by a factor of six. This gives some support to the adjustment process. The new (*Heating Adjusted)* BPI over the whole year becomes 0.118 kWh/dd.m^2.

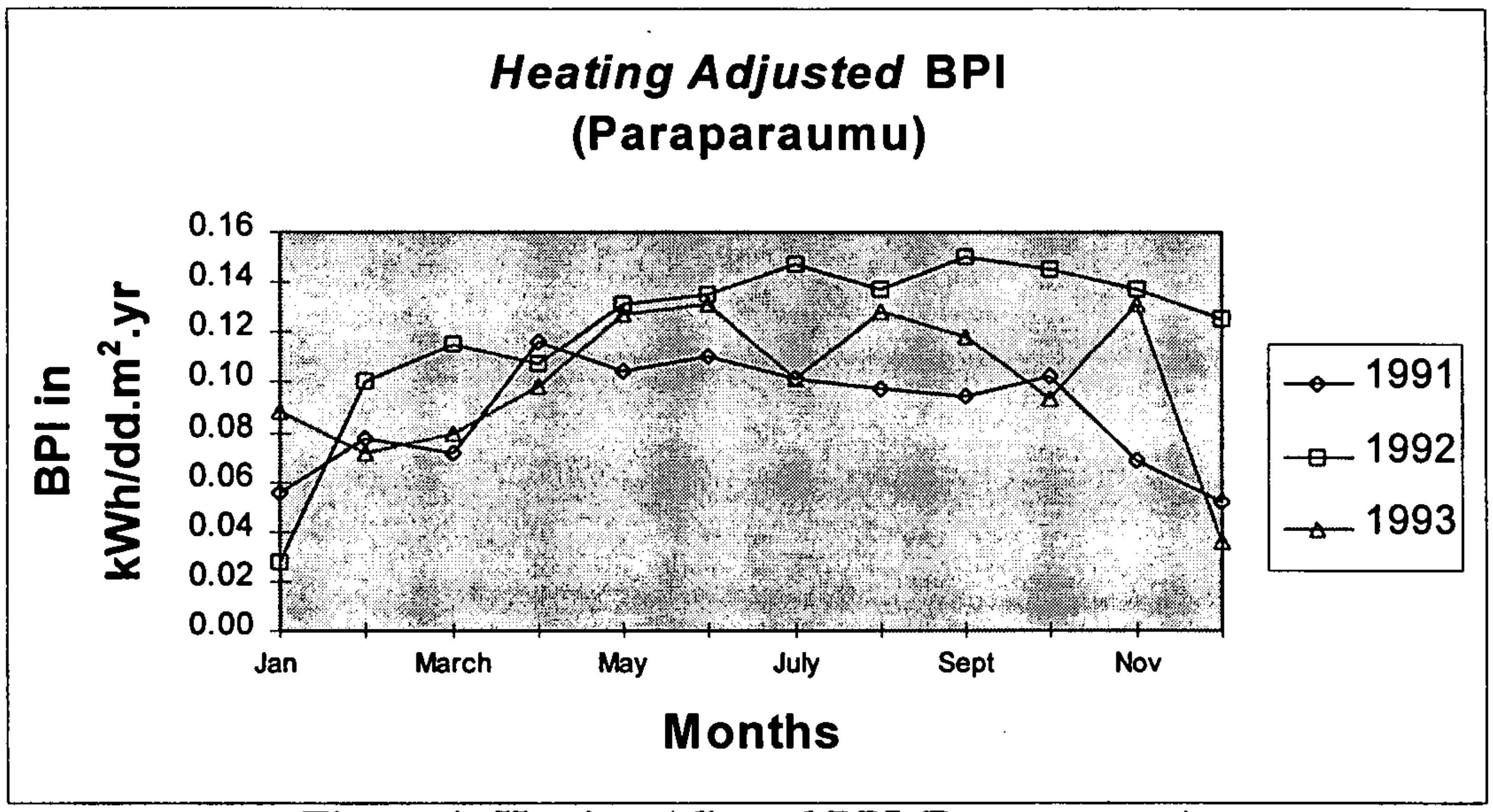

Figure 4: ***Heating Adjusted BPI (Paraparaumu)***

Table 1: "Winter Season" Length

Calculations were performed to assess the influence on the BPI of altering the length of the "winter season". Three "winter season time blocks" were used: July only, June through August, and finally May through September. The results were averaged over the data collection period 1991 - 1993.

Measured Building Thermal Performance (Paraparaumu)				
Period	July	June-August	May-September	All Year
Raw BPI (kWh/dd.m²)	*0.153*	*0.167*	*0.178*	-
Heating Adjusted BPI (kWh/dd.m²)	*0.126*	*0.121*	*0.118*	*0.103*

Table 1: ***Summary of Altering the "Winter Season" Length***

From Table 1, it can be seen that for the *Heating Adjusted* BPI figures:

- As the chosen winter time period is increased, there is a steady decline in the BPI figure
- Results obtained over only 1 month gives a BPI figure within ~ 7% of the 5 month figure
- Results obtained over 3 months give a BPI figure within ~ 3% of the 5 month figure
- The feild measured BPI value of the house is between 0.121 and 0.118 kWh/dd.m^2 over the heating season.

Given these results, it seems likely that a short monitoring period (in this case the same winter month for three years) of indoor temperature and energy use is at least sometimes capable of a close approximation of the building's thermal performance over the whole heating season.

5.3.2 ALF Values

5.3.2.1 Standard Calculations (ALF_{PC} and $ALF_{W/S}$)

A BPI comparison was calculated using both the PC ALF[3] programme (ie **ALF_{PC}**), in addition to the worksheet (ie **$ALF_{W/S}$**) method, to reduce the possibility of any simple arithmetic errors occurring. The **ALF_{PC}** version gave a BPI for the Paraparaumu house of 0.092 kWh/dd.m^2, and the **$ALF_{W/S}$** gave a similar BPI of 0.091 kWh/dd.m^2.

5.3.2.2 Degree Day Alignment ($ALF_{PC\text{-}dd}$)

The influence of differing field degree days (777 dd/y) from those gained through the ALF procedure (705 dd/y), was examined. For the Paraparaumu house, it was judged that the Kelburn figure as tabled in the ALF datasheets (of 705 degree days), would be a good approximation. However, over the period examined, the actual averaged number of degree days - using 16°C as a base temperature - equated to 777 dd/year. The result can be seen in the **$ALF_{PC\text{-}dd}$** (ie corrected for degree days) column in Table 2.

5.3.2.3 Influence of Curtains ($ALF_{PC\text{-}CURTAINS}$)

For the Paraparaumu house, it was assumed that the majority of fenestration would not have curtains drawn at night, thereby not achieving the possible reduction in R-value from the standard 0.18 m^{2}°C/W to a possible value of 0.23 m^{2}°C/W. This assumption was based on the premise that a large percentage of glazing (ie the kitchen, gallery and foyer area) did not have curtains to draw, and it was unlikely that the occupants would always draw the remaining curtains. The standard case is where the curtains are not drawn (ie **ALF_{PC}**), giving a BPI of 0.092 kWh/dd.m^2. If the curtains are drawn at night all of the time (ie **$ALF_{PC\text{-}CURTAINS}$**), assuming that all the windows have curtains, the BPI becomes 0.083 kWh/dd.m^2, effectively a 10% reduction in BPI.

Comparison of Various BPI Adjustments (Paraparaumu)

Figure 5 shows that, except for the non-heating months, the *Raw* BPI figures are significantly higher than the others. The peaks at the start and finish of the heating season are for the same reason as explained in Section 5.3.1. The ALF_{PC} figures correlate well with the field Heating Adjusted ones, but are always lower over the entire heating season.

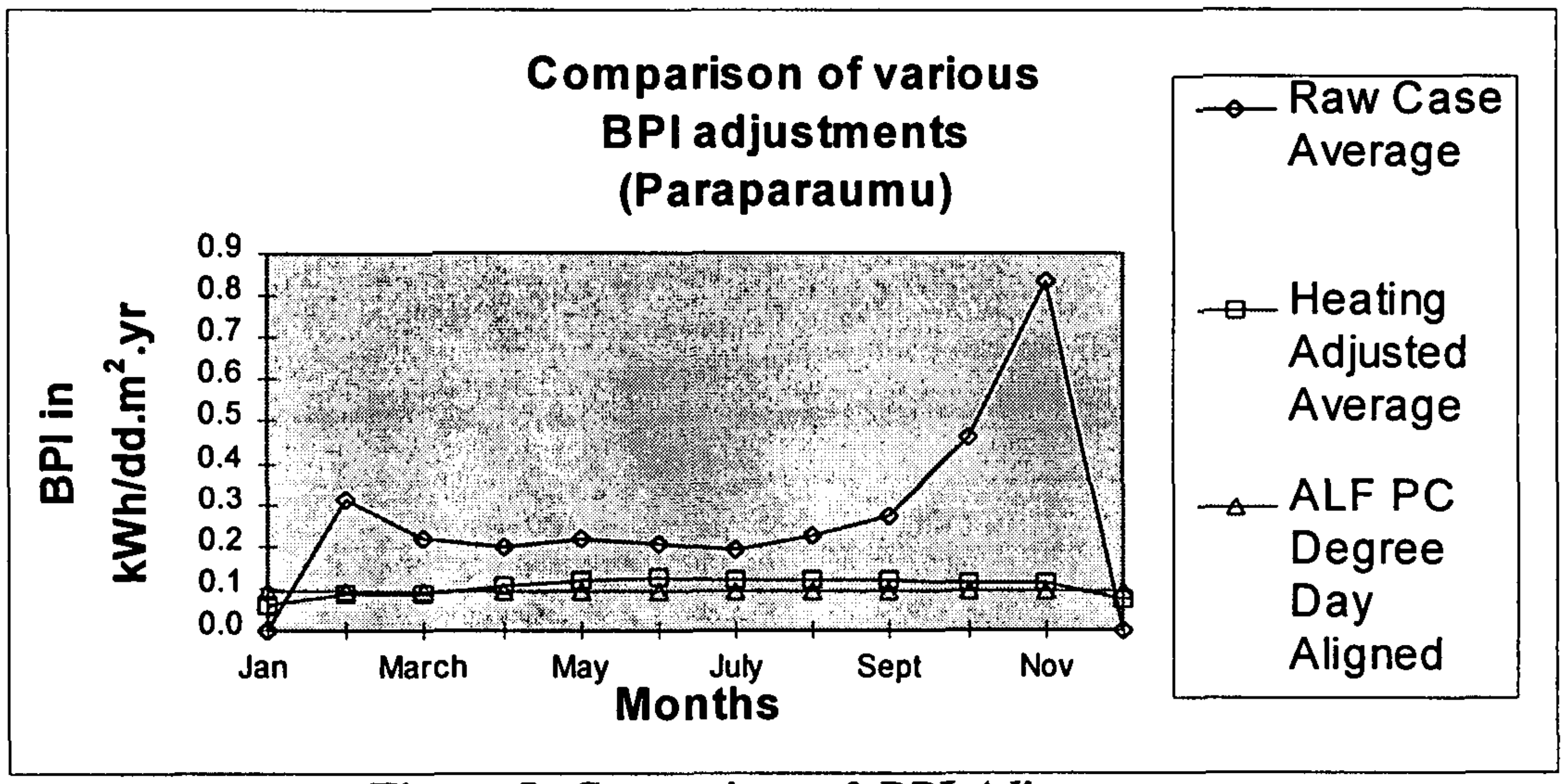

Figure 5: ***Comparison of BPI Adjustments***

A summary table of the various BPI calculations is produced below, in Table 3. The five month Heating Adjusted case will become the norm, and used as a basis for comparison.

Calculation Method	BPI Value ($kWh/dd.m^2$)	Percentage 'Error'
Raw Case	0.210	+78%
Heating Adjusted (1 month)	0.126	+7%
Heating Adjusted (3 months)	0.121	+3%
Heating Adjusted (5 months)	0.118	0%
Heating Adjusted (Full year)	0.118	0%
$ALF_{W/S}$	0.091	-23%
ALF_{PC}	0.092	-22%
$ALF_{PC\text{-}dd}$	0.094	-20%
$ALF_{CURTAINS}$	0.083	-30%
ALF_{AV}	0.089	-25%

Table 3: Comparative BPI Values for Paraparaumu

6.1 House Number Two: Whitby

6.1.1 General Statistics

House area: *39.6m^2 (only the kitchen/living room was recorded),* Year built: 1992, Number of occupants: *1,* Construction materials: *concrete slab floor, light timber frame construction, masonry veneer/plastered external walls and concrete tile roofing.*

R-values: *Floor-1.8, Walls-1.5, Windows-0.23, Roof-2.2, (in $m^{2o}C/W$)*

Heater: *Electric heating only,* Curtains: *drawn at night.*

6.2 Procedure

Electrical energy-usage readings were taken approximately every 14 days, with no segregation between differing end uses, excepting hot water usage. Indoor/outdoor temperature datalogging was recorded hourly. The hourly temperature figures were averaged over the electricity reading periods, by grouping the original data files into fortnightly blocks. Temperature readings were equally weighted.

As in the Paraparaumu house, the corrected degree day calculations accounted for when the indoor temperature was not the required 20°C (ie the excess/deficient temperature).

6.3 Calculations and Graphical Work

6.3.1 Field Values

Estimated Heating Energy Use (Whitby)

The Whitby house is entirely electrically heated, and using graphical methods it can be seen that the 'base load' (ie energy end-uses excluding space heating) is around 5 kWh/day when viewed over the whole year. This 5 kWh/day (ie 1820 kWh/year) baseload figure is subtracted from the daily energy figure over the whole year, to get a best representation of the space heating energy use only (as opposed to all end energy uses within the home), from the aggregated energy figures. It should be noted that, for the Whitby house, instead of the whole house being kept at 20°C, only the kitchen/living room was heated.

Raw BPI (Whitby)

This uncorrected graph shows little in the way of trends. There is however, a bottoming out during January and February, where the BPI remains at zero - as would be expected.

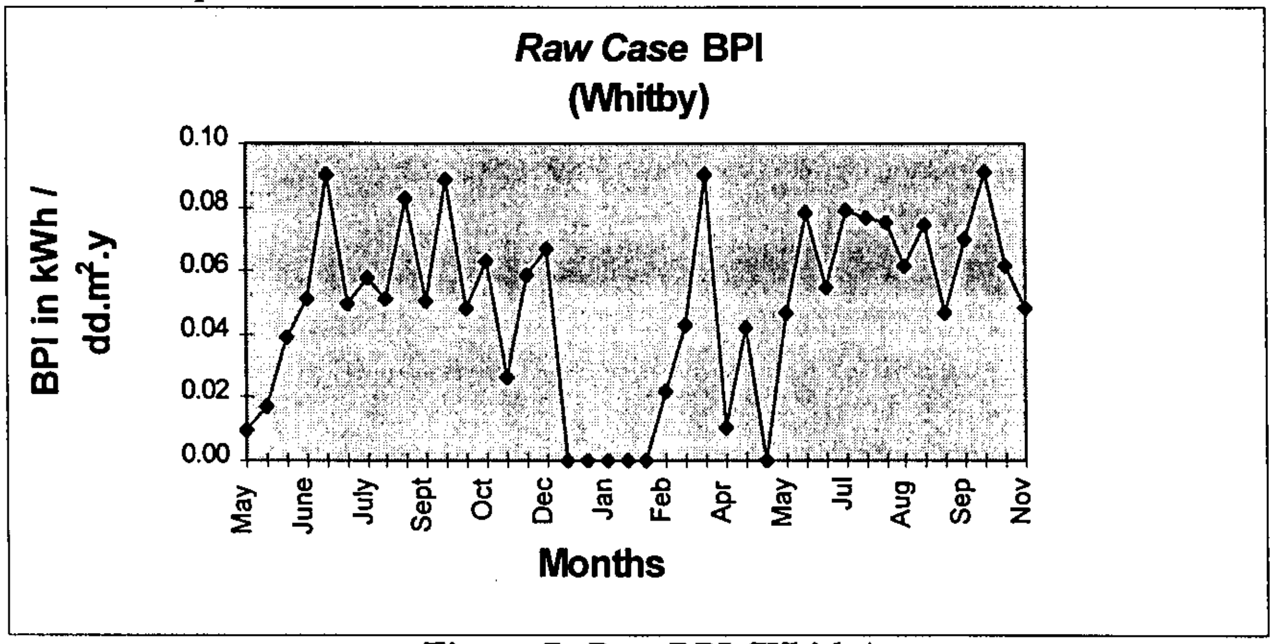

Figure 7: *Raw BPI (Whitby)*

Heating Adjusted Case (Whitby)

Compared to the *Raw* BPI, there is a marked reduction in the range of BPI - almost by a factor of three. There also appears to be a drop off in the BPI figures around the summer months. The cyclical nature of the graph is highlighted by a polynomial trendline which has been fitted.

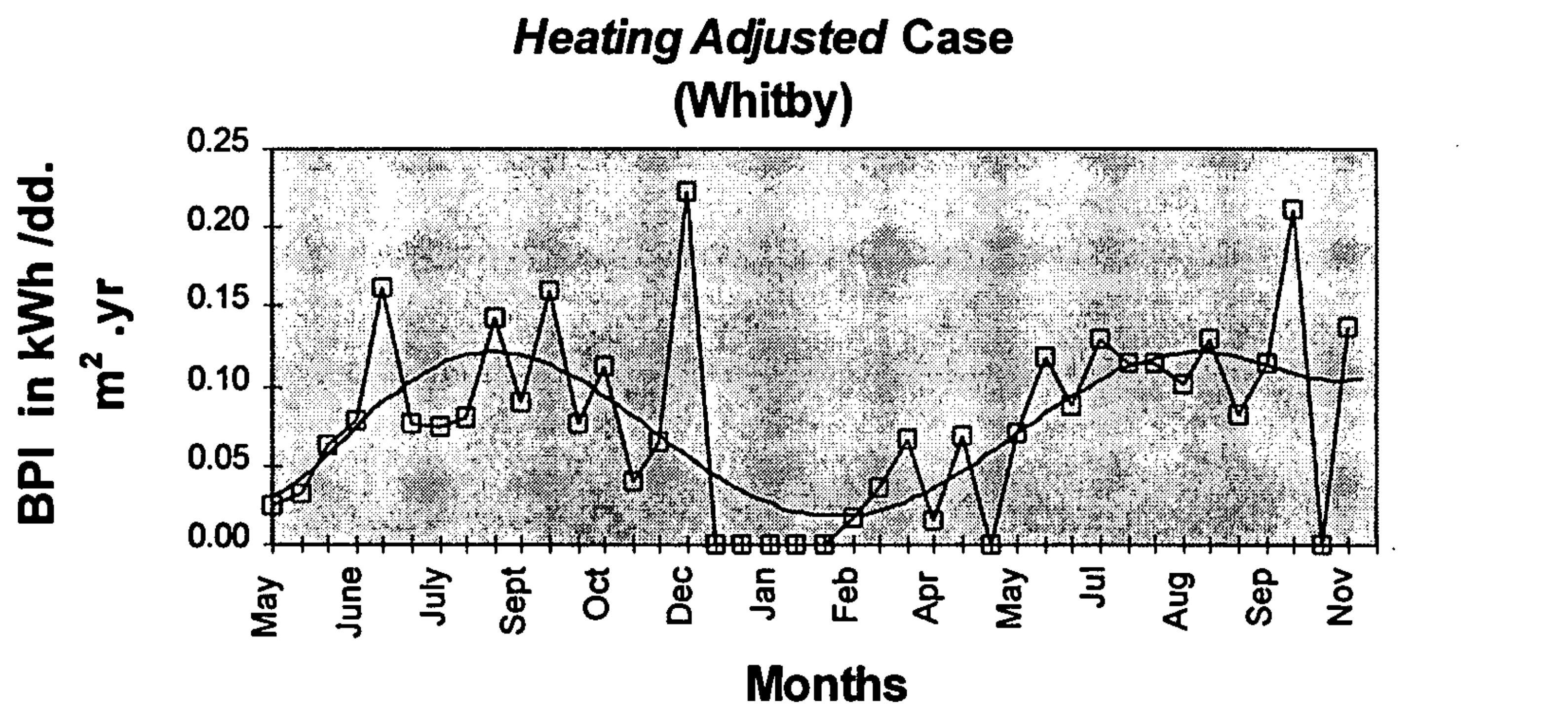

Figure 8: ***Heating Adjusted BPI (Whitby)***

"Winter" Season Length

As in the Paraparaumu house, the effect of altering the length of the winter season was investigated, with the same three time blocks. The results were averaged over the data collection period 1993 - 1994.

Measured Building Thermal Performance (Whitby)				
Period	July	June-August	May-September	All Year
Raw BPI (kWh/dd.m^2)	*0.072*	*0.061*	*0.057*	-
Heating Adjusted BPI (kWh/dd.m^2)	*0.108*	*0.098*	*0.091*	*0.078*

Table 4: ***Summary of Altering the "Winter Season" Length***

From Table 4, it can be seen that for the *Heating Adjusted* BPI figures:

- As the chosen winter time period is increased, there is a steady decline in the BPI figure
- The low *All Year* BPI figure is partially a result of the zero BPI values over the summer period
- Results obtained over only one month gives a BPI figure within ~16% of the five-month figure
- Results obtained over three months gives a BPI figure within ~7% of the five-month figure
- The house's BPI value as measured is between 0.098 and 0.091 kWh/dd.m^2 over the heating season.

6.3.2 ALF Values

6.3.2.1 Standard Calculations (ALF_{PC} and $ALF_{W/S}$)

The ALF_{PC} BPI for Whitby is 0.077 kWh/dd.m^2. $ALF_{W/S}$ gave a BPI of 0.080 kWh/dd.m^2. The small discrepancy of the two indexes is due to some minor simplifications in the ALF_{PC} version.

6.3.2.2 Degree Day Alignment ($ALF_{PC\text{-}dd}$)

There is a difference between the **ALF_{PC}** (BPI ~ 0.080 kWh/dd.m^2), and those experienced in the field (*Heating Adjusted* BPI ~ 0.089 kWh/dd.m^2). An investigation of the significance of the differing degree day figures (820 dd/year in the field, versus 705 dd/year in the ALF worksheets), was carried out. Another ALF calculation was performed, this time using 820 degree days. The effect of aligning the ALF degree days with those actually experienced in the field, as in the Paraparaumu house case, was to decrease the difference between the two BPI results. The difference between the field BPI value and the PC ALF calculation reduced the percentage "error" from 15% down to 10%. The **$ALF_{PC\text{-}dd}$** BPI value is 0.082 kWh/dd.m^2.

6.3.2.3 Influence of Curtains ($ALF_{PC\text{-}CURTAINS}$)

For the Whitby house, it was assumed that the curtains were drawn every night in the kitchen/living room during the heating season. The influence of not drawing the curtains and its effect on the **$ALF_{PC\text{-}CURTAINS}$** BPI was examined. Using the PC ALF version as a base, altering the window R-value to represent a single glazed curtain-less pane of glass resulted in a new BPI of 0.087 kWh/dd.m^2. This equates to a 13% rise in the BPI, and becomes very close to the *Heating Adjusted* field case figure of 0.089 kWh/dd.m^2.

Comparison of Various BPI Adjustments (Whitby)

The "damping" characteristics of adjusting the Raw figures for under/over heating, when compared to the Raw Case, can clearly be seen. Unlike the previous case, the adjusted BPI figures hover under the ALF_{PC} figures.

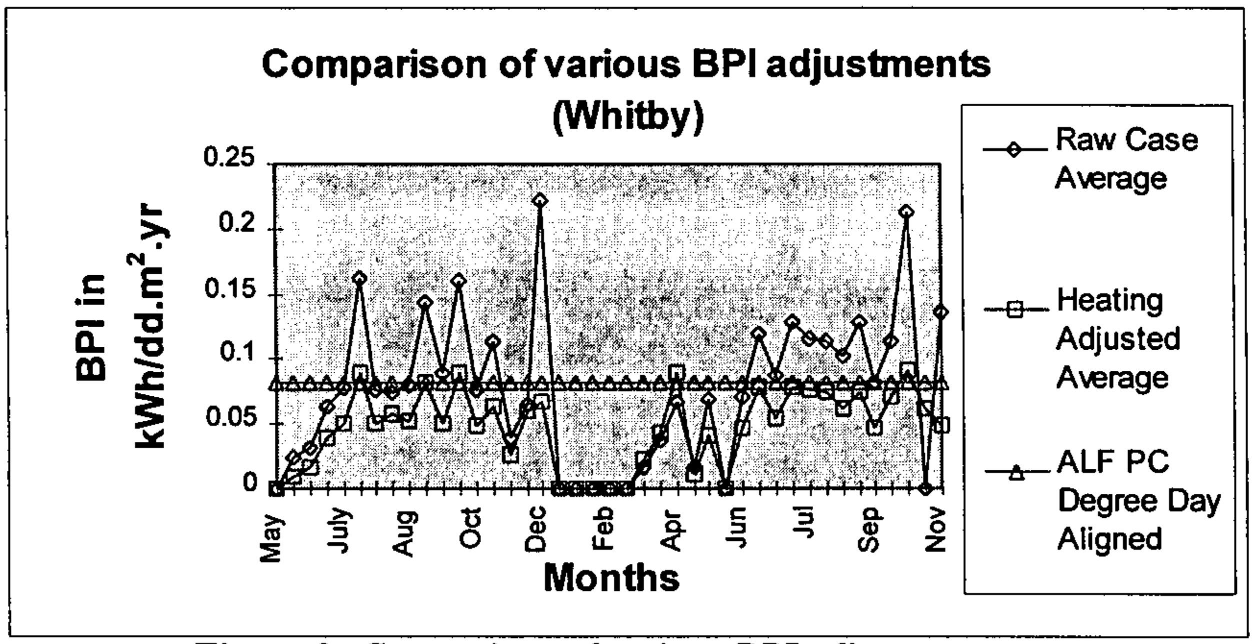

Figure 9: ***Comparison of various BPI adjustments***

A summary table of the various BPI calculations is produced below, in Table 6. The five-month Heating Adjusted case will become the norm, and is used as a basis for comparison.

Calculation Method	BPI Value ($kWh/dd.m^2$)	Percentage 'Error'
Raw Case	0.063	-31%
Heating Adjusted (1 month)	0.108	+16%
Heating Adjusted (3 months)	0.095	+7%
Heating Adjusted (5 months)	0.091	0%
Heating Adjusted (Full year)	0.078	-14%
$ALF_{W/S}$	0.080	-12%
ALF_{PC}	0.077	-15%
$ALF_{PC\text{-}dd}$	0.082	-10%
$ALF_{CURTAINS}$	0.087	-4%
ALF_{AV}	0.085	-7%

Table 6: ***Comparative BPI Values for Whitby***

7.0 Recommendations for Better BPI Predictions

In the calculation of a BPI figure from ALF, if the actual degree day number is known, this should be used. Naturally, the further the actual degree day number is away from the ALF one, the larger the discrepancy between the field and theoretical result. Energy use readings should be taken at small intervals, such as weekly, with the heating component separate from the other energy end uses, not just based on estimates. The indoor temperature adjustment method, which alters the number of degree days according to the amount of under or over heating, seems to be working well for this limited data set.

8.0 Conclusions

These conclusions must be regarded as tentative because of the small sample size.

- Although substantial corrections have had to be made from "raw" BPI values, it appears that a reasonably accurate measurement of BPI can be made from a short in-situ monitoring period, utilising proper corrections.
- A good indication of the field BPI appears obtainable by using just one winter month as a data logging period, which has been heat adjusted (ie ±16% of the field BPI figure). However, a three-month data logging period is a considerably better indicator.
- The field BPI is extremely sensitive to indoor room temperature fluctuations around the indoor base temperature (of 20°C).

- The PC ALF programme gives a good representation (ie <±30% of the measured figure) of the calculated BPI figure, no matter what assumption has been made regarding whether curtains are pulled at night or not.
- As access to the completed in-situ houses was feasible, a more accurate estimate of such variables as window shading by foliage, wall colouring etc., was possible. Thus, the ALF BPI calculations used are closer to reality than those obtained by utilising house plan information only.
- Parameter adjustments made in this study, including those made for degree day alignment, and fluctuating indoor room temperatures, account for sizeable corrections in the BPI. The largest influence on the resulting BPI can be attributed to fluctuating indoor temperatures.

9.0 References

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