Coheating test
Future Works, Ebbw Vale
v. 0.1

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16th may, 2011

1. Introduction

The Larch and Lime Passivhaus projects in Ebbw Vale were monitored for the Post Construction and Initial Occupation study for TSB. Under the TSB guidelines for reporting the study, the Welsh School of Architecture carried out coheating and gas tracer tests in both houses. The tests were carried out in the first months of 2011.

The coheating test is used to determine the heat loss of an unoccupied building by means of background ventilation and fabric. The results should be delivered in the form of a graph to derive a static value in W/K. these data can be useful to compare buildings in order to determine best practices or benchmarks.

This report consists of 5 sections. Section 2 contains the methodology of the study, including explanations on the test procedure, the equipment used and its locations. Section 3 presents the results of the coheating tests. Section 4 introduces the results of the tracer gas tests. Last, section 5 shows initial conclusions in relation to the tests presented in this report.

2. Methodology

Coheating testing is a means to determine a ‘real life’ whole-house heat loss rate: this rate is linked to thermal losses through the fabric, plus losses from air-leakage, again through the fabric. It is a method to compare the thermal performance of unoccupied dwelling’s fabric. During the testing period, internal space of selected property is heated by electrical resistance fans and maintained at desired temperature (25˚C) by sensitive temperature controller. Each test lasts 3 weeks; begin with the Larch House at the end of January 2011. Electricity used for maintaining the elevated temperature is measured in order to determine the heat input (W). The heat loss coefficient (W/K) is then calculated by comparing the heat input against the difference of internal and external temperature (K) of the property. The temperature difference is ideally greater than 10 degree or more for sufficient value so we selected eight consecutive weeks from 31 Jan 2011.

2.1 Equipment

The following equipment has been used in the testing houses.

	Description
Fan Heaters 	900 Watt electric resistance fan heaters are used to elevate the internal temperature gently.
Thermostats 	Measures temperature and regulates the fan heater output. The fan heater will be shut down instantly once temperature reaches required level then re-power the fan heater once temperature drops 0.5 Celsius degrees in order to prevent rapid ON-and-OFFs. Each fan heater is controlled by a thermostat individually.
Circulation fans 	Create active airflows within the property to ensure the inter air well mixed and balanced hot air distribution. Fan speed is adjusted to suit the room size location.
Electricity meters 	Two accurate electricity meters are in charge of measuring electricity consumptions for two zones: ground floor and first floor. Within each zone, energy consumption of all the fan heaters and circulation fans are measured.
Air temperature and relative humidity sensors 	Internal temperature and RH are measured. The RH also indicates the how the internal space dries out throughout the testing period. Each room has a set of sensors that has been placed away from fan heater and circulation fan.
Weather station  	Three types of sensor are installed externally and they record air temperature, relative humidity and solar radiation. Air temperature and RH probe are hosted in a shield that is place at the north in order to avoid direct sunlight. The pyranometer is installed on the south façade.

	Description
Data loggers 	Stores all the test readings via wired and wireless communications
Tripods 	Lift the thermostat in order to pick up the mean internal air temperature which gives more accurate fan heat control.
CO_2 decay measurement system 	Including CO_2 dispensing system and sensors. CO_2 is injected into the property as a tracer gas. Once the CO_2 concentration reaches desired level, the dispensing system is switched off and decay rate is measured.

2.2 Test Procedure

This is a measurement of heat loss through the fabric of the building. Therefore, all intended points of ventilation are temporarily sealed prior to commencement of the testing. In this test, the inlet and outlet of the Mechanical Ventilation Heat Recovery (MVHR) have been sealed (Figure 2.1). A pressurisation test has been done in each house prior to undertaking the coheating test (not by WSA).

Figure 2.1 Sealed MVHR inlet & outlet (the Larch House)

The equipment deployed within the tested building includes fan heaters connected to thermostats, axial fans to agitate the air (Figure 2.2 and 2.3), and temperature and relative humidity sensors, which are all spaced evenly throughout the property; all of which are connected to a wireless data logger (Figure 2.4). Their electricity consumption has been recorded by pulse/kWh meters (Figure 2.5).

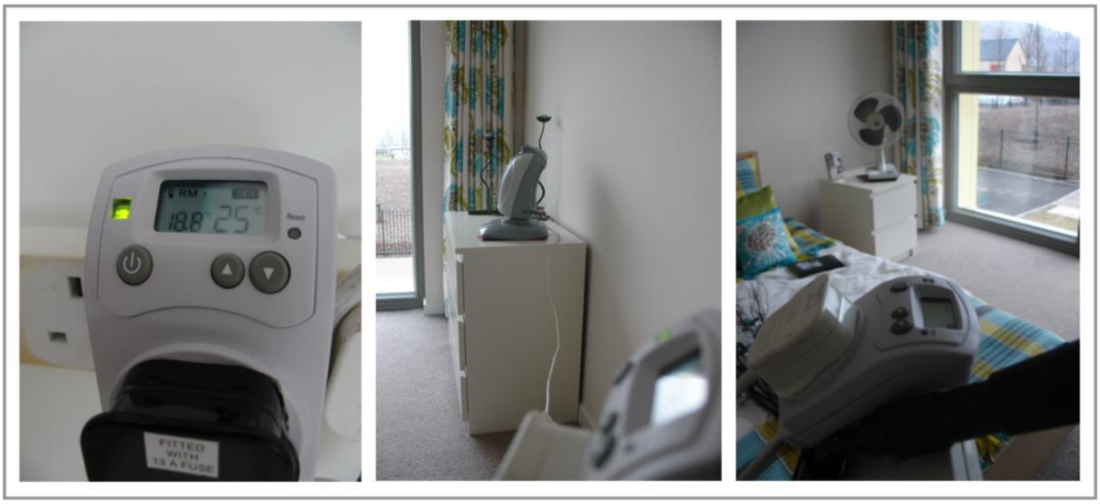


Figure 2.2 Thermostat plug, fan heater and circulation fan

Figure 2.3 testing equipment installed in the kitchen and dining area (the Larch House).

Figure 2.4 Pulse KWh electricity meter and data logger

Weather conditions have been monitored by an external temperature and relative humidity sensor, and pyranometer that are installed outside. The temperature and RH shield was mounted at the northeast corner for minimum solar gain. The pyranometer measures solar radiation was mounted on the south facade at the height of 2.5 meters with no overshadowing.

Figure 2.5 Outdoor temperature, relative humidity and solar radiation measurement

With equipment installed and operating, the thermostats are all set to a desired temperature (nominally 25°C). The equipment continually records all the readings for temperature (internal/external), energy use, and solar irradiance. The period of monitoring is 3 weeks, which requires an initial 3 days of set up and time for internal temperature to stabilise.

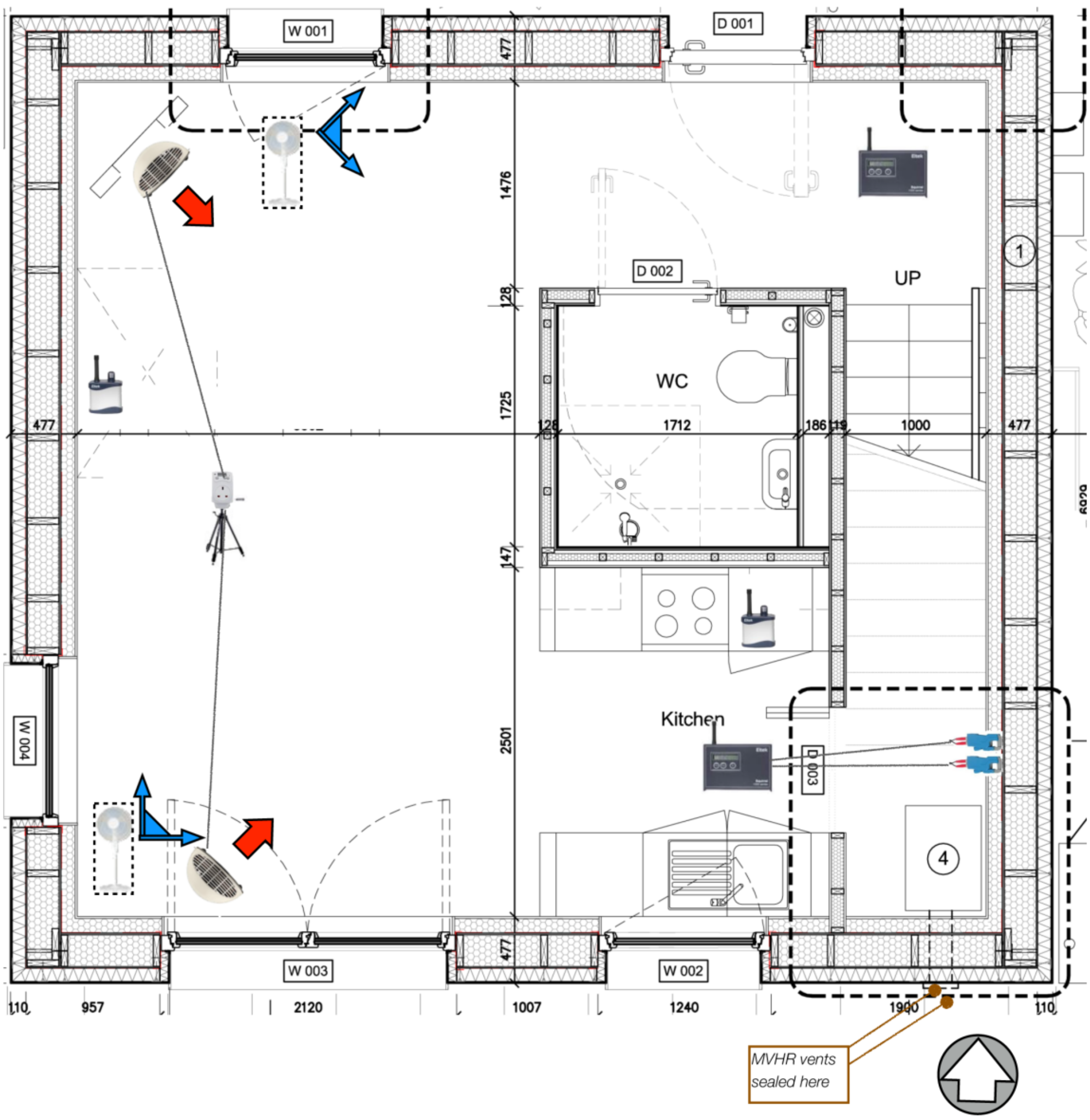
The data collected is used to calculate the thermal coefficient of the building, which encompasses all envelope elements including roof construction, wall construction (incorporating doors and windows), floor construction, etc. The results can be used to prove actual fabric performance and used as a basis to compare dwellings.

CO_2 decay method was used in order to estimate background ventilation rate. The CO_2 dispensing and measure system elevates CO_2 concentration up to 1000ppm and measures the decay rate. The CO_2 tracer gas result indicates the air leakage rate which can also be used to estimate background ventilation rate.

All the sensors report their readings at 5 minutes interval to the data loggers.

2.3 Testing equipment locations

Testing equipment arrangements are shown in plan views.



3. Ground floor testing equipment arrangement, the Lime House

Figure 2.6 Ground floor testing equipment arrangements, the Lime House

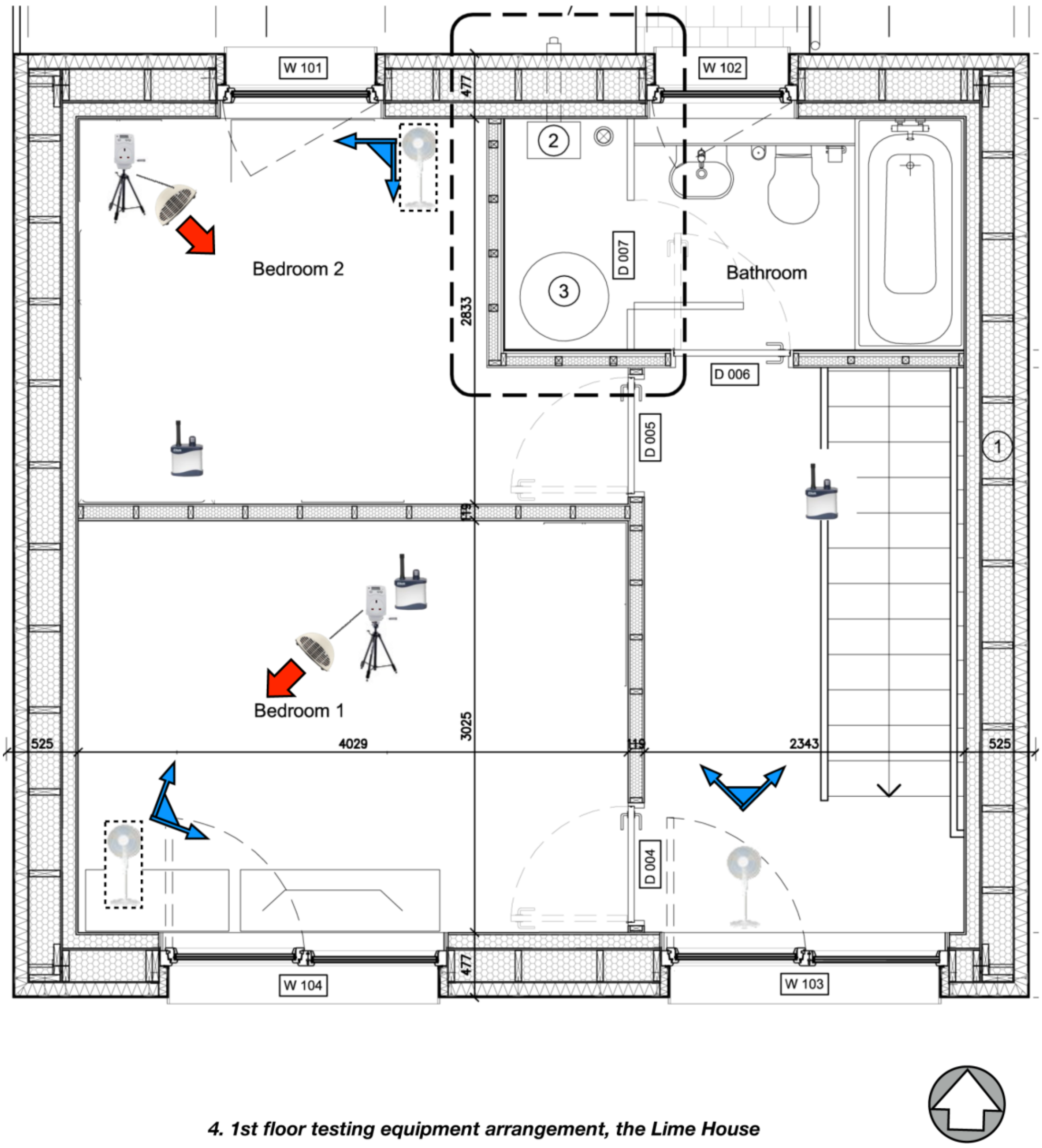


Figure 2.7 1st floor testing equipment arrangements, the Lime House

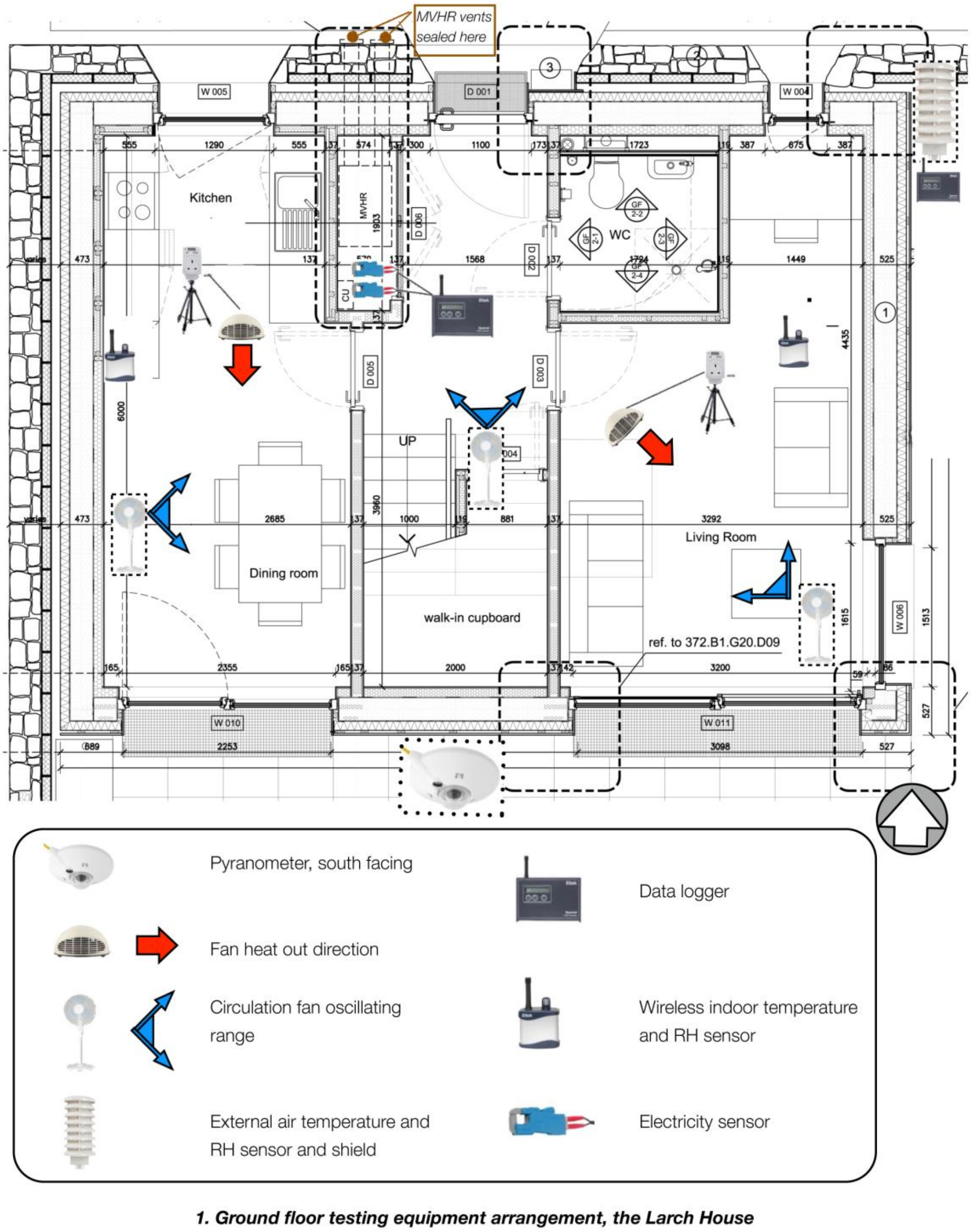
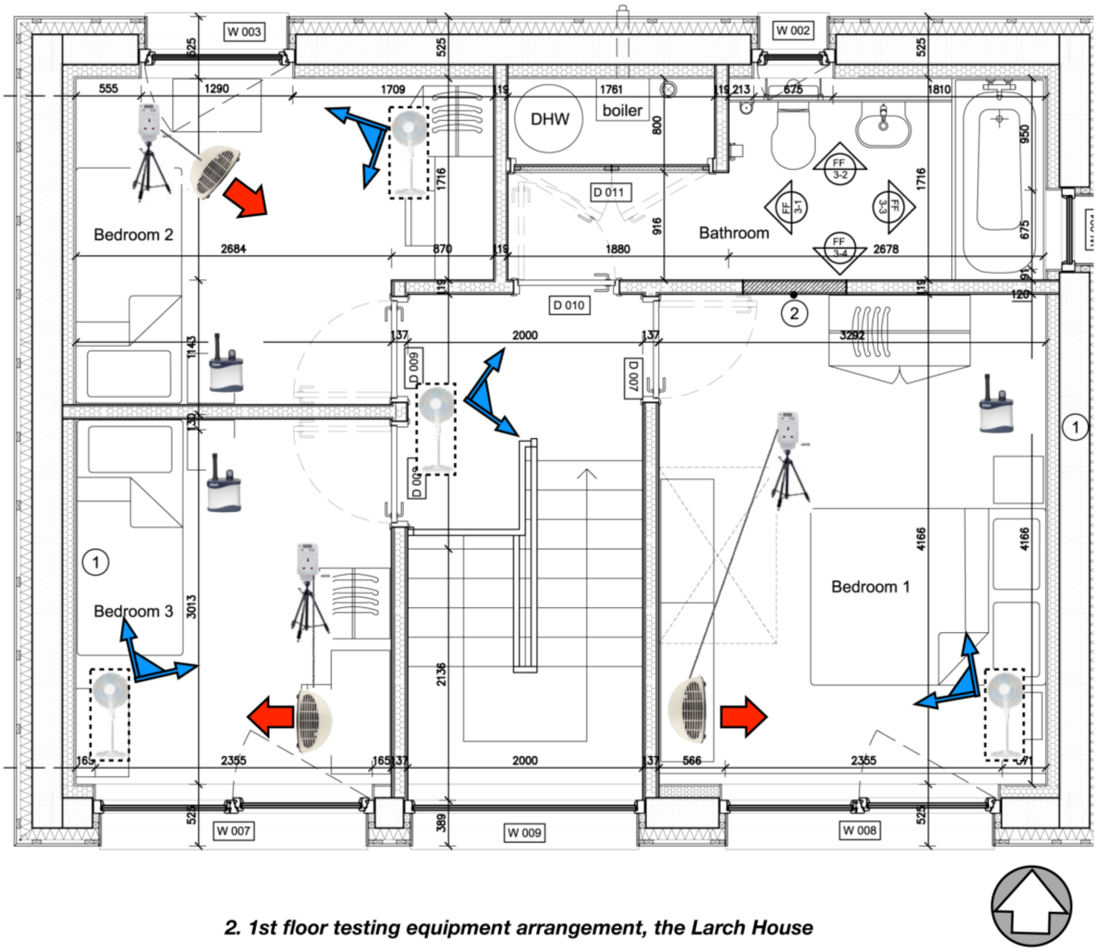


Figure 2.8 Ground floor testing equipment arrangements, the Larch House



2. 1st floor testing equipment arrangement, the Larch House

Figure 2.9 1st floor testing equipment arrangements, the Larch House

3. Coheating Results

Coheating analysis was made on "total energy" and simple average (e.g. not volume or HLC weighted) of internal temperatures. Daily totals are determined from midnight to midnight.

The simplistic calculations of hourly total energy divided by hourly average temperature difference (E/ΔT) are plotted against time of day. Those values occurring just before dawn indicated the most appropriate value for the heat loss parameter, as the impact of solar gains will be diminished.

However both houses are heavily insulated, so it is entirely possible that "beneficial" solar gains may be carried over to the following day. For this reason a Siviour type analysis was also applied to the data. This method establishes a relationship between the degree of solar gain and its impact on the energy required to maintain the internal/external temperature difference (ΔT) parameter. This relationship can then be used to estimate the heat loss parameter under a zero solar condition. The slope of the relationship also provides an estimate of the effective solar aperture of the building

3.1 Lime house

From the start of the tests, it took about 3 days to approach stability. These three days were excluded from the analysis. There are several periods where solar gains appear to displace heating for several hours (Fig. 3.1).

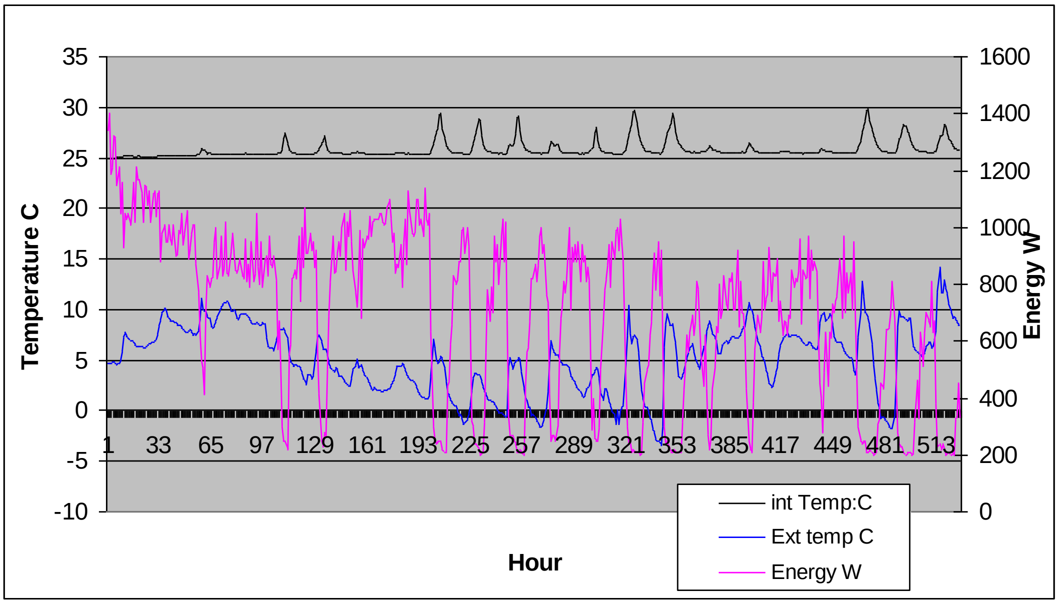


Figure 3.1 Energy [W], internal and external temperatures [C] per hour of the testing period for the Lime house

The simplistic calculation of HLC is shown in Figure 3.2. The hourly total energy is divided by hourly average temperature difference (E/ ΔT). The calculation showed that HLC overnight approaches 41± 8 W/C.

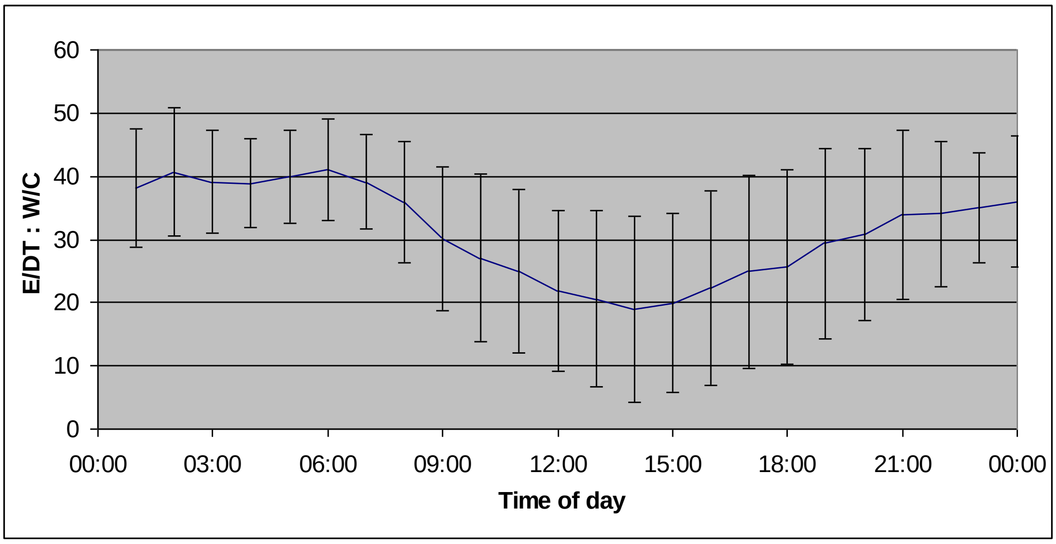


Figure 3.2 Simplistic calculation HLC [W/C] for the Lime house

Siviour style analysis (E/ ΔT vs. S/ ΔT) using the relationship between the degree of solar gain and its impact on the energy required is shown in Figure 3.3. The analysis on all data provides a HLC of 45 ± 2 W/C.

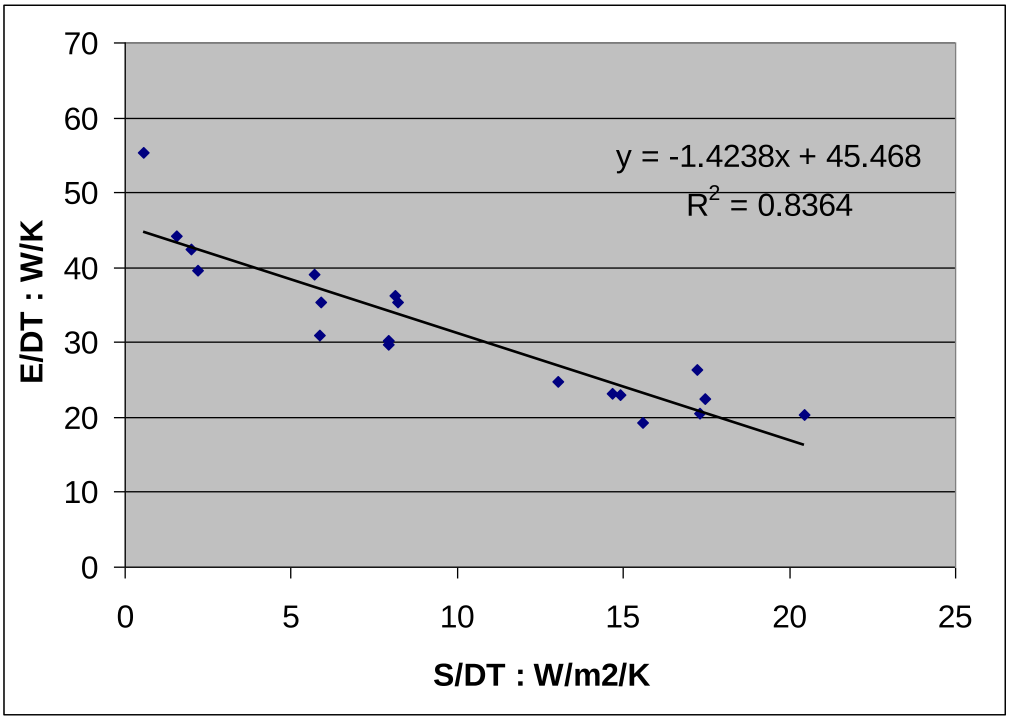


Figure 3.3 Siviour style analysis HLC [W/C] for the Lime house

There is some discrepancy between the heat loss parameter derived from the simplistic E/ ΔT analysis when compared with that obtained from the Siviour analysis (41±8 W/C and 45±W/C respectively). However the Siviour analysis approach is more sensitive to the impact that solar gain has on the heat loss parameter therefore it is probably more appropriate to use this figure.

3.2 Larch house

The coheating analysis was made on “total energy” and simple average (e.g. not volume or HLC weighted) of internal temperatures. Daily totals are determined from midnight to midnight.

From the start of the tests, it took about 5 days to approach stability. These five days were excluded from the analysis. There are several periods where solar gains appear to displace heating for several hours (Figure 3.4).

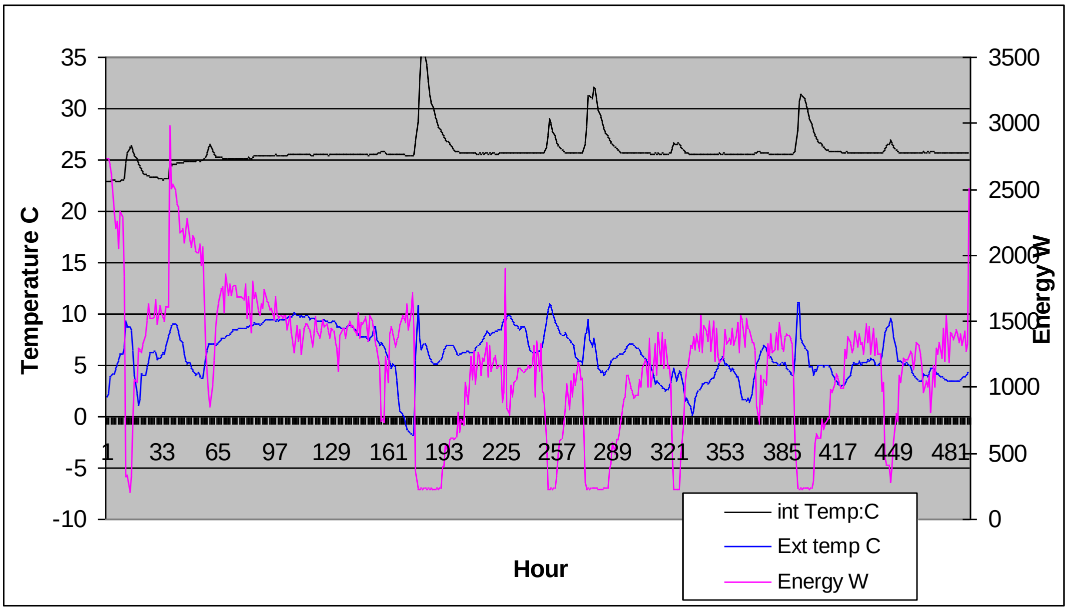


Figure 3.4 Energy [W], internal and external temperatures [C] per hour of the testing period for the Larch house

Figure 3.5 shows the results from the simplistic calculation of HLC: hourly total energy divided by hourly average temperature difference (E/ ΔT). The highest HLC reached overnight approaches 60± 14 W/C.

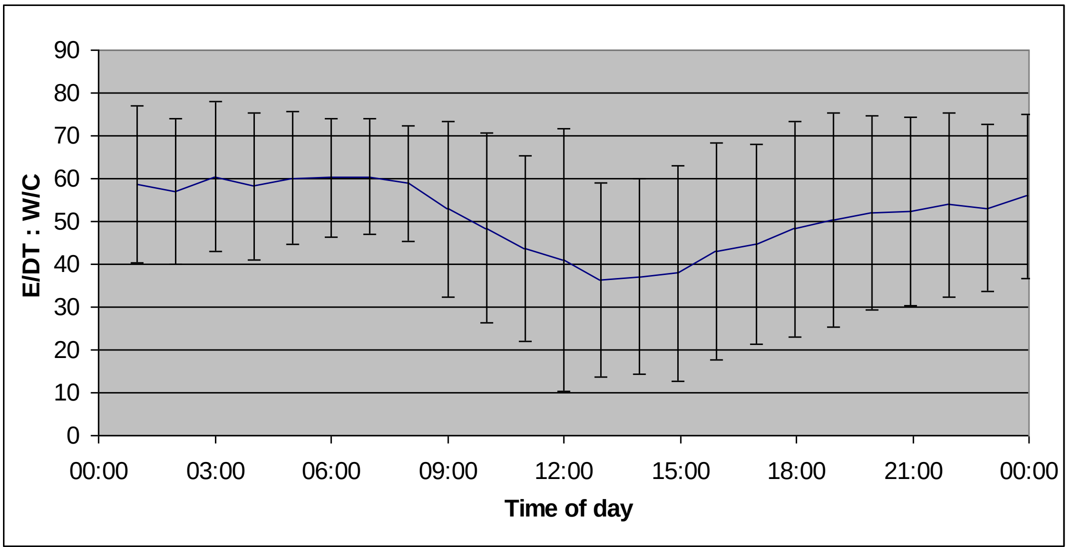


Figure 3.5 Simplistic calculation HLC [W/C] for the Larch house

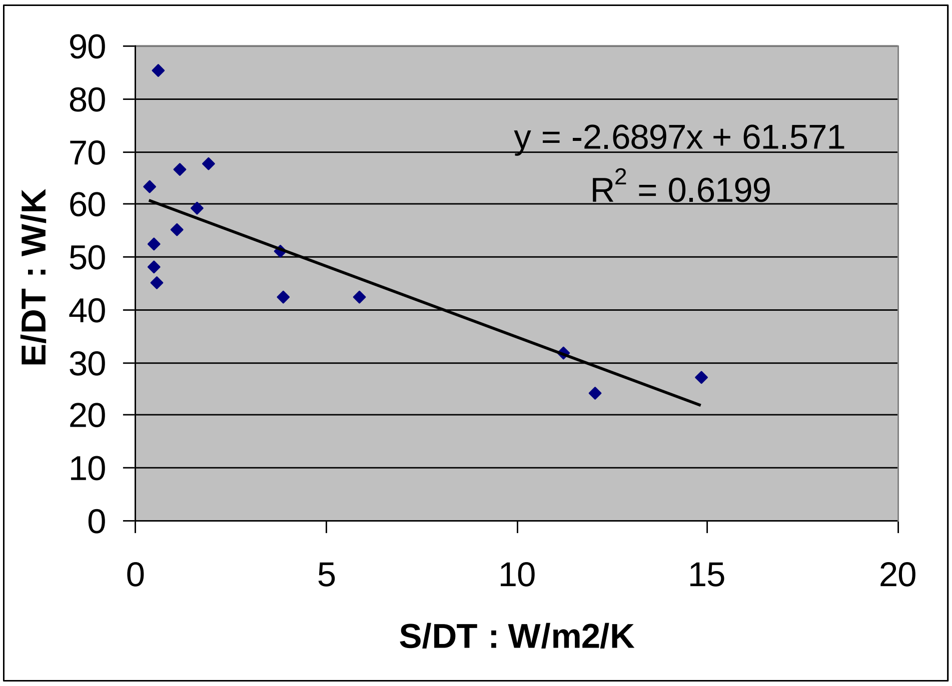


Figure 3.6 Siviour style analysis HLC [W/C] for the Larch house

Siviour style analysis (E/ ΔT vs. S/ ΔT) is shown in Figure 3.6. The analysis on all data provides a HLC of 62 ± 4 W/C. There is considerable scatter around low S/ ΔT days. Inspection shows some low S/ ΔT days follow high S/ ΔT days; if there is considerable thermal mass the solar gains of a preceding day could affect the results. In order to reduce the influence of a previous warm day, the same analysis was carried out using two-day averages (Fig 3.7). Sivior style analysis (E/ ΔT vs. S/ ΔT) on two-day data smoothes out the appearance but provides a similar HLC of 62 ± 4 W/C.

There is little discrepancy between the heat loss parameter derived from the simplistic E/ ΔT analysis when compared with that obtained from the two Siviour analyses. The results for Larch house are therefore reasonably consistent, with HLC = 62 W/C a reasonable conclusion.

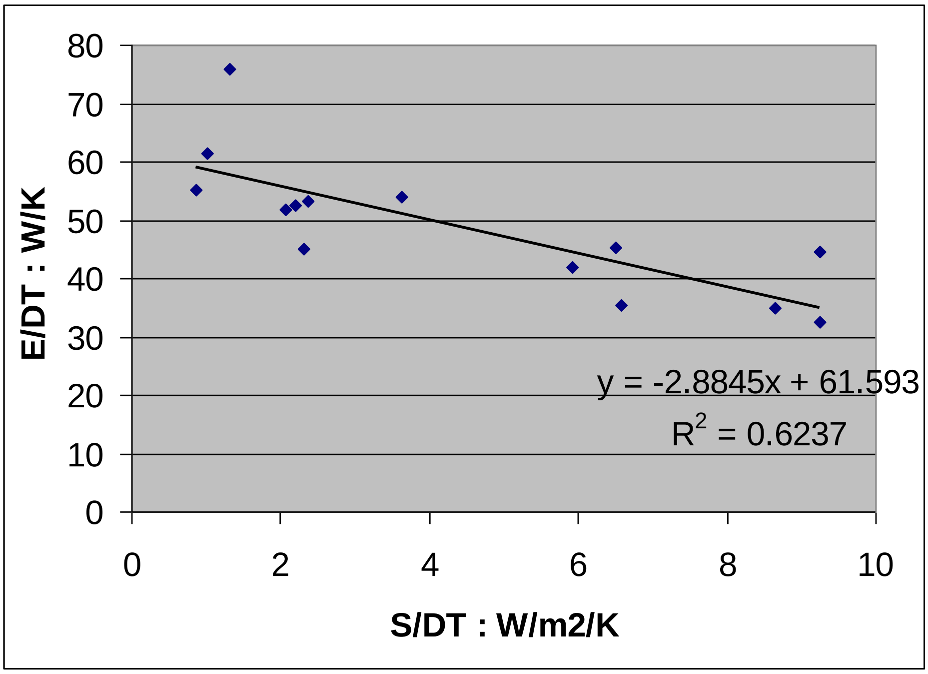


Figure 3.7 Siviour style analysis HLC [W/C] for the Larch house using two-day averages

4 Tracer Gas Decay

4.1 Lime House

The tracer gas concentration was measured and recorded every minute for a period of 70 hours. The resulting graph of the decay shown in figure 4.1 shows that even after 3 days the internal CO_2 concentration had still not dropped to external levels (approximately 450 parts per million) indicating an exceptionally good envelope air tightness.

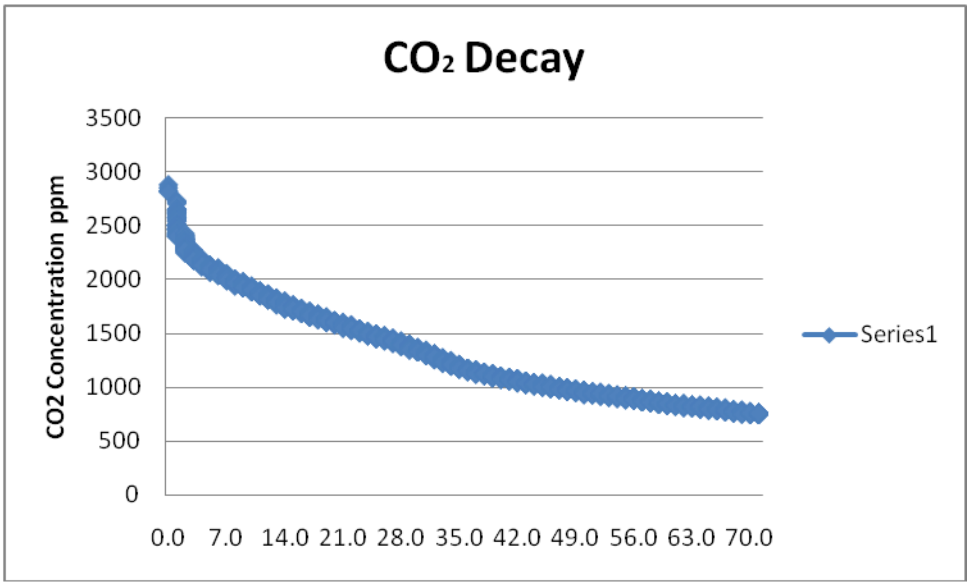


Figure 4.1 Tracer gas decay against time (raw data)

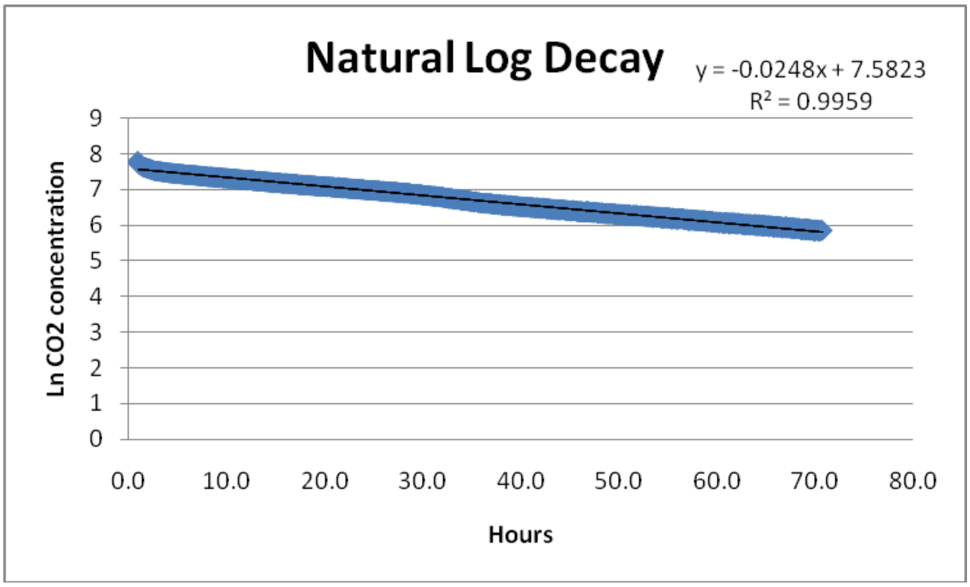


Figure 4.2 Natural logarithm of CO2 concentration vs. time

To determine the air changed rate, the external CO_2 concentration value in parts per million (determined by measurement both before and after the experiment) is subtracted from the internal value and the natural log of the resultant figure is plotted against time in hours (Figure 4.2). A best fit linear regression of this natural log decay is then calculated and the resultant equation is shown in figure 4.2.

The slope of the natural log decay line vs. time provides an estimate of the infiltration rate and in this instance, the slope of the regression line has a value of 0.0248. This is somewhat better than the value used in the PHPP spreadsheet of 0.043.

4.2 Larch House

The tracer gas concentration was measured and recorded every minute for a period of 70 hours. The resulting graph of the decay shown in Figure 4.3 shows that even after 3 days the internal CO_2 concentration had still not dropped to external levels (approximately 450 parts per million) indicating an exceptionally good envelope air tightness.

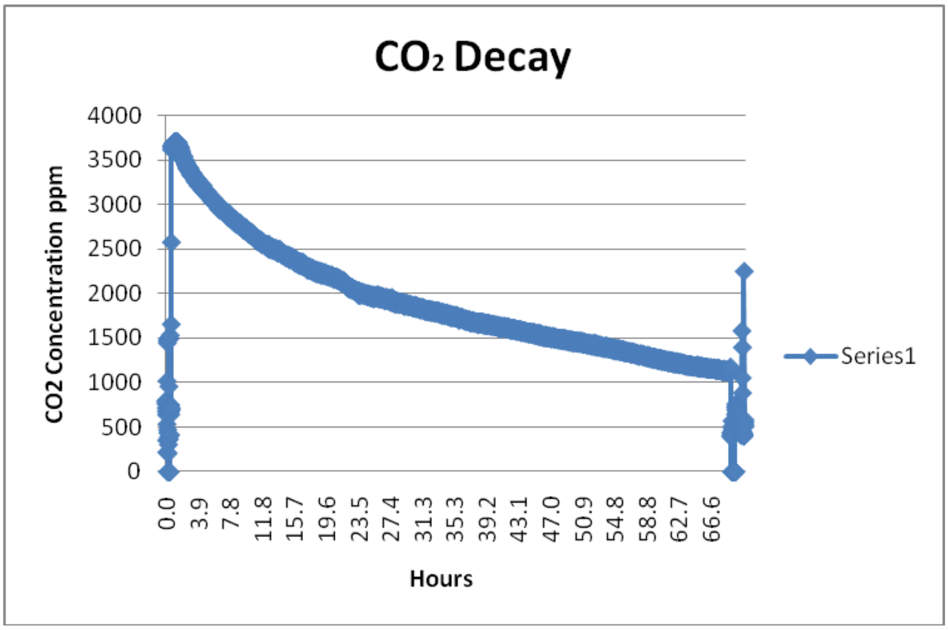


Figure 4.3 Tracer gas decay against time (raw data)

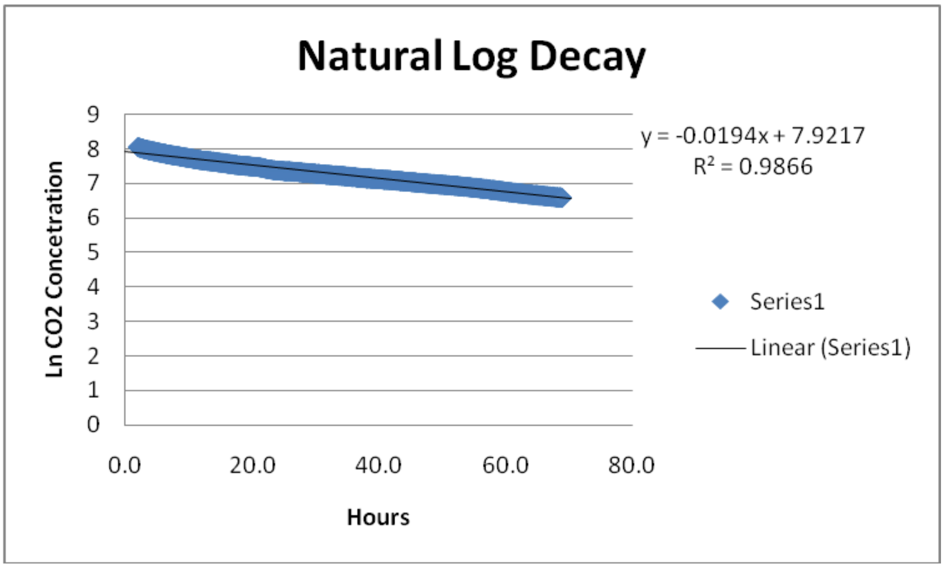


Figure 4.4 Natural logarithm of CO_2 concentration vs. time

To determine the air changed rate the external CO_2 concentration value in parts per million (determined by measurement both before and after the experiment,) is subtracted from the internal value and the natural log of the resultant figure is plotted against time in hours. (Figure 4.4)

A best fit linear regression of this natural log decay is then calculated and the resultant equation is shown in Figure 4.4. The slope of the natural log decay line vs. time provides an estimate of the infiltration rate and in this instance, the slope of the regression line has a value of 0.0194. This gives a good agreement with the value stated in the PHPP of 0.021.

5 Conclusions

In this section, the results from the coheating and tracer gas analysis are compared with the design parameters. The design parameters were derived from the data provided in the PHPP software for Passivhaus certification.

The design heat loss coefficient was calculated to be 37.2 W/K for the Lime house and 57.6 W/K for the Larch house. This figure includes both the heat loss through fabric and through air leakage. However, concerns exist about the effect of the inclusion of the thermal bridges in the calculation. Therefore, more investigation should be done on this issue.

The heat loss parameter figure of 37.2 W/^{o}K derived for the Lime house can be compared with 41± 8 W/ ^{o}K from the simple analysis and 45 ± 2 W/ ^{o}K from the Siviour analysis. The heat loss parameter figure of 57.6 W/^{o}K derived for the Larch house can be compared with 60± 14 W/ ^{o}K from the simple analysis and 62 ± 4 W/ ^{o}K from the Siviour analyses. It seems that the real performance of the Lime house is less accurate than the performance of the Larch house.

The results from the tracer gas decay test (0.0194) showed that there is a good agreement between the calculated values in the PHPP calculation (0.021), and the actual air change rate. From this result, next to the results from the coheating test for the Larch house showing also a relatively good agreement between the design value and the actual value, we can conclude that the parameters of the Larch house closely reflect the design parameters.

The results of the tracer gas decay measurement in the Lime house showed a lower air change rate (0.0248), than the one showed in PHPP calculations (0.043). In addition, the results from the coheating test showed a higher heat loss parameter than the figure calculated during the design on the building. These results indicate that the actual parameters of the Lime house are slightly different to those specified in the design.