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Whole House Heat Loss Test Method (Coheating)

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Introduction

1 In the UK, as in most industrialised countries, the domestic sector contributes substantially to national energy use and CO_2 emissions. Currently, there are over 25 million dwellings in the UK accounting for just under 30% of the UK's total CO_2 emissions (DECC, 2011). This is a substantial figure given that the UK housing stock is categorised by long physical lifetimes and slow stock turnover. Therefore, if we are to mitigate the effects of climate change and achieve the Government's target of an 80% reduction in national CO_2 emissions by 2050 based on 1990 levels, then significant reductions in the carbon emissions from both new and existing dwellings will be required.

2 One factor that can have a significant impact on the energy use and CO_2 emissions attributable to dwellings is the performance of the building fabric. However, the performance of the building fabric is very rarely understood and is often taken for granted, particularly in in-use monitoring studies. Therefore, in the past, there has been a tendency for any discrepancies that are found between the monitored and predicted performance of the dwelling to be attributed to occupant behaviour. However, recent work undertaken by Leeds Metropolitan University (see Wingfield et al., 2009 and Zero Carbon Hub, 2010) has found that the performance of the building fabric can have a significant influence on overall energy and CO_2 emissions. Consequently, very few conclusions can be drawn from in-use monitoring studies unless the performance of the building fabric is understood. It should also be remembered that the domestic building fabric in the UK tends to have long physical lifetimes and slow replacement cycles. Therefore, it is crucial that we not only measure and analyse the performance of the building fabric as built, but in doing so, take the opportunities that arise to improve our understanding of fabric performance under real life conditions and the factors that influence this performance. Otherwise, there is a very real risk that we will leave a legacy of dwellings with poorly performing building fabric for generations to come.

3 A wide range of techniques are available that can be used to measure the performance of various aspects of the building fabric once constructed. These include pressurisation testing, leakage detection, tracer gas measurement, cavity temperature measurement, heat flux measurement, thermal imaging, partial deconstruction and air flow measurements. Central to all of these techniques is the co-heating test (see Figure 1).

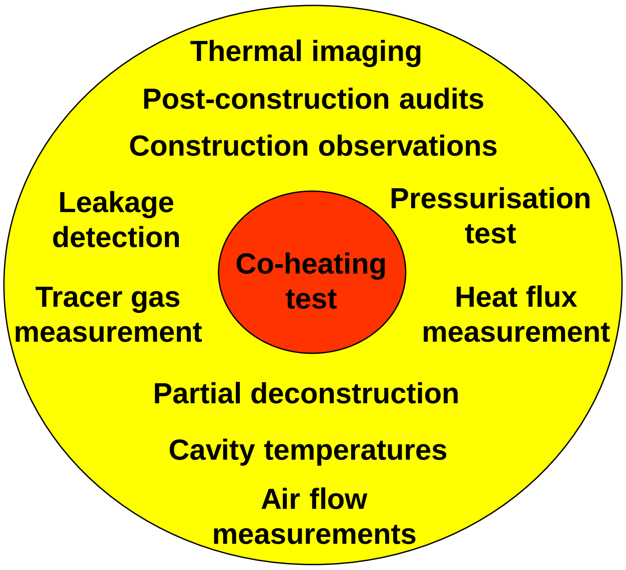

Figure 1 The relationship between the coheating test and other fabric measurement techniques.

Coheating test – what is it?

4 The coheating test is a quasi-steady state method that can be used to measure the whole dwelling heat loss (both fabric and background ventilation) attributable to an unoccupied dwelling. It is one of only a few methods (an alternative is the PSTAR method – see Subbararo et al., 1988) that are currently available to measure whole dwelling heat loss in the field. Although not a new concept (it has been around since the 1970's – see Sonderegger et al. 1979a and 1979b), the methodology is

very much in its infancy, and in the UK, is currently the subject of much research and debate. It involves heating the inside of an unoccupied dwelling electrically, usually using electric resistance point heaters, to a mean elevated internal temperature (typically 25 °C) over a number of days. The period of time taken to undertake the test can vary enormously, but typically ranges from 1 to 3 weeks once the dwelling has been heat saturated. Whilst heating the dwelling, a number of parameters are measured, namely total electrical energy input to the dwelling, internal temperatures and relative humidity, and various external climatic conditions. By measuring the total amount of electrical energy that is required to maintain the mean elevated internal temperature each day in response to the external conditions, the daily heat input (in Watts) to the dwelling can be determined. The heat loss coefficient for the dwelling can then be calculated by plotting the daily heat input against the daily difference in temperature between the inside and outside of the dwelling (ΔT). The resulting slope of the plot gives the raw uncorrected heat loss coefficient in W/K. An example of such a plot can be seen in Figure 2.

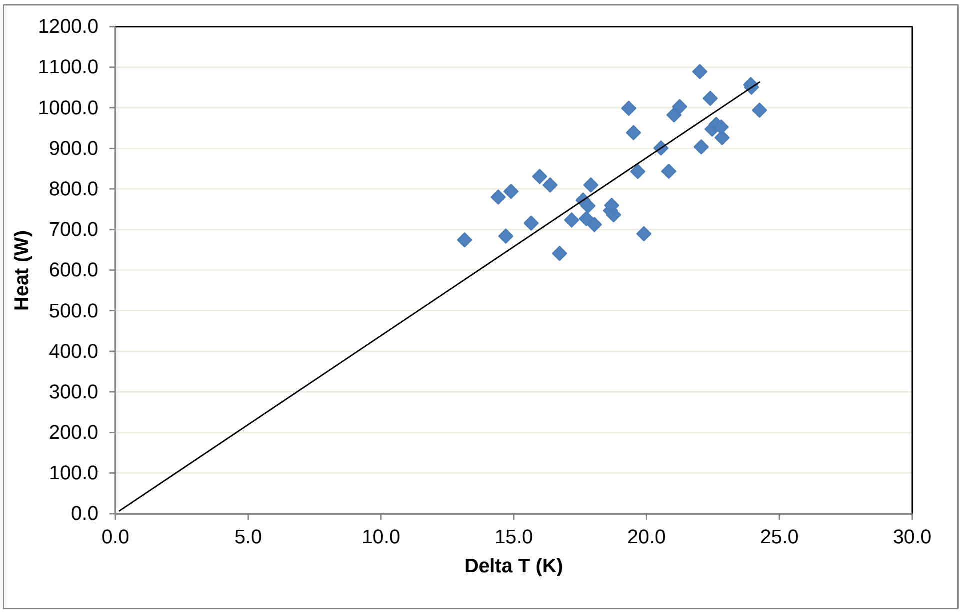

Figure 2 Example plot of the raw data obtained from a coheating test.

Issues to consider

5 Drawing on our experience of undertaking in excess of 40 coheating tests over the last 10 years or so, it is clear that a number of issues need to be carefully considered when planning to undertake a coheating test. These issues are as follows:

a) Testing period.
b) Duration of the test.
c) Building form.
d) Thermal mass.
e) Level of insulation.
f) Airtightness.
g) Drying out.
h) Proportion of glazing.
i) Adjacent dwellings.
j) Access to dwelling during coheating test.
k) Loading the domestic ring main.

Testing period

6 The period within the year in which testing should be undertaken is dictated by the requirement to obtain a sufficient value of ΔT (generally 10 K or more[*]). Consequently, the coheating test should be carried out in the winter months, usually between October/November and March/April. An added advantage of undertaking the tests during this period is that the effects of solar radiation are also minimised.

Duration of the test

7 The amount of time required to undertake a co-heating test can vary considerably and is dependent upon a range of factors. Such factors include: the thermal characteristics of the dwelling, the amount of residual moisture contained within the dwelling, external environmental conditions, the time taken for the dwelling to be heat saturated and the objectives of the test. Ideally, the test should be undertaken for a sufficient period of time to enable there to be a number of data points plotted on the power versus ΔT graph, at as wide a range of ΔT's as possible, such that an appropriate correlation coefficient can be obtained for the data. However, in some cases this will not be possible, as access to the dwelling will either be time constrained or external environmental conditions are such that a wide range of ΔT's are not possible. It should also be remembered that time will have to be built into the test to account for setting up and removing the coheating test equipment, undertaking the pre-and post coheating test pressurisation tests, and the time taken to heat the dwelling and its fabric to the chosen mean elevated temperature (at this point the dwelling is said to be heat saturated).

8 Our experience suggests that as a minimum, the test should be undertaken for one week after heat saturation of the dwelling has occurred. In most cases a test should be able to be undertaken in 2 to 4 weeks.

9 Coheating test data should be collected 24 hours a day during the length of the test. Only measuring night-time data, say from 6pm to 6am, is not advised, as it tends to ignore mass effects. This can be particularly problematic in heavyweight dwellings.

Building form

10 Careful consideration has to be given to the type, the form and the method of construction used on the dwelling that is to be tested. In dwellings that have a large number of relatively small rooms, additional equipment may need to be installed (fan heaters and/or air circulation fans) to ensure that the mean elevated temperature is achieved within all of the rooms within the dwelling.

11 In dwellings that comprise two or more storeys, difficulties can be encountered maintaining the mean elevated temperature throughout the dwelling, due to stack effects. Additional air circulation fans may need to be positioned within the dwelling to blow any warm air that is naturally rising back down to the lower floors to enable adequate mixing of the internal air.

Thermal mass

12 Lightweight dwellings will heat up quickly but may be prone to overheating in certain areas, particularly if the dwelling is well insulated and airtight and there is a large amount of South-facing glazing. If this is the case, additional air circulation fans may need to be installed to remove any excess heat from those areas of the dwelling that are prone to overheating.

13 Heavyweight dwellings, on the other hand, will take much longer to become heat saturated, but may be susceptible to mass effects that have a considerable time delay. For instance, the solar radiation absorbed on one day may not be re-emitted to the space until the next day. This needs to be taken into consideration when analysing any results.

14 The amount of thermal mass within the dwelling will also determine how quickly the dwelling will respond to internal and external temperature fluctuations and heat inputs[†]. The greater the thermal mass, the longer the time that it will take for the dwelling to respond to these effects, whilst the more lightweight the dwelling is, the quicker it will take to respond to these effects.

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[*] The figure of 10 K has been commonly referred to as it ensures that the majority of the heat flow that occurs through the dwelling during the test is from the inside to the outside.

[†] It should be remembered that solar gain can occur through opaque as well as transparent elements of the building fabric.

15 It is possible to average out the time dependent thermal effects by increasing the amount of time taken to undertake the test – the longer the test, the more these effects are averaged out.

Level of insulation

16 In dwellings that are very well insulated, only a small amount of heat input may be required at one or two strategic points within the dwelling. Air circulation fans can then be used to distribute this heat evenly throughout the dwelling. The converse is also true of dwellings that are poorly insulated. In poorly insulated dwellings, additional heat input and/or air circulation fans may be required in order to achieve the desired mean elevated internal temperature. In extreme cases, it may even be necessary to reduce the mean elevated internal temperature in very poorly insulated dwellings, to reduce the potential for overloading the domestic ring main circuit.

Airtightness

17 In very airtight dwellings, such as those constructed to Passivhaus standards, the background ventilation rate may be so low that it takes 2 to 3 days for all of the air within the dwelling to be removed and replaced with ‘fresh’ air from outside. In such dwellings, it may not be possible to use a CO_2 dispersal system to disperse CO_2 into the dwelling and then measure the CO_2 decay over time.

Drying out

18 It is important that the dwelling is sufficiently dried out prior to the commencement of the coheating test. If the dwelling is not sufficiently dry, then some of the heat input will be used to evaporate any residual moisture within the structure rather than heat the dwelling to the required mean elevated internal temperature. This will result in a higher heat input that would otherwise be required. In addition, in very airtight dwellings, any excess moisture generated during the heat-up phase may not be adequately ventilated during the test, resulting in surface condensation and mould growth within the dwelling.

19 It is also important to realise that any residual moisture that is present within the structure will also have an impact on the thermal conductivity and heat loss attributable to various elements of the dwelling. The greater the amount of residual moisture present, the greater the thermal conductivity of the materials and the greater the corresponding heat loss.

Proportion of glazing

20 Dwellings that incorporate a large proportion of South-facing glazing may have rooms that are susceptible to overheating. Care needs to be taken to ensure that any excess heat in these rooms is adequately distributed around the rest of the dwelling. Alternatively, attempts should be made to ensure that the dwelling is tested at a time when there is expected to be the least amount of solar radiation (typically, around the winter solstice).

Adjacent dwellings

21 If the dwelling to be tested is semi-detached, terraced or an apartment, then consideration will have to be given to any heat loss that may occur through any party elements of construction (such as party walls, party floors, etc.) or to any unoccupied spaces (such as stairwells, communal areas, etc.). If access to adjacent dwellings or spaces can be obtained, then the ideal solution would be to maintain these spaces at the same mean elevated internal temperature as the test dwelling. This can be achieved by installing additional fan heaters, air circulation fans, thermostatic controllers and temperature and humidity sensors in these spaces. In doing so, any heat loss through the party elements of construction that would have occurred due to differences in temperature between the test dwelling and the adjacent spaces, will be eliminated. However, it should be remembered that this will not necessary eliminate all of the heat losses through the party elements of construction, as heat loss will still occur if any thermal bypasses in the construction exist.

22 If access to any adjacent dwellings or spaces cannot be achieved then an alternative approach would be to measure the internal temperature and relative humidity in all of the adjacent spaces and install heat flux sensors on the internal surface of the test dwelling to measure the heat flux through the elements of construction concerned. However, this approach has a number of important limitations. These are as follows:

a) The heat flux measured will relate to a particular point on the construction and may not be representative of that construction as a whole. It is therefore imperative that attempts are made to position the heat flux sensors such that they are likely to give as representative a value for that particular element of construction as possible. For instance, if the construction comprises a timber-frame stud wall, heat flux sensors should be positioned on both the studded and non-studded portion of the wall, so that the effects of thermal bridging through the timber stud can be taken into consideration.

b) If a thermal bypass is present in the construction, such as at the party wall, then the amount of heat flux measured by the heat flux sensors will be a function of the thermal bypass, rather than any temperature difference between the adjacent dwellings.

c) The heat flux measured by the heat flux sensors will relate only to the ΔT monitored. It may be that the heat flux will vary depending on the value of ΔT.

d) The heat flux measured by the heat flux sensors

Access to the dwelling during the coheating test

23 Throughout the test, entry to the dwelling should be kept to a minimum and limited to those times when adjustments are required to be made to equipment. If entry to the dwelling is required, it should be for as short a time as possible and the use of any electrical equipment within the dwelling, such as lights, should be minimised where possible. Any dates of entry to the dwelling should be recorded and referred to when analysing the coheating data, as entry to the dwelling may have an important impact on the result.

24 It is also important to realise that a coheating test may not always be a ‘fit and forget’ test. Access to the dwelling may be required during the test, particularly if additional measurement techniques, such as heat flux measurements, are been conducted at the same time as the coheating test.

Loading the domestic ring main

25 Care needs to be taken to ensure that if power is to be taken off the domestic socket ring main, it is not overloaded. In new multi-floor dwellings, one ring circuit is normally installed per floor and at least two ring circuits are normally installed in apartments. In the UK, the ring circuit is likely to be rated at 30 amps (7200 Watts) and will be protected by a 32 amp RCD connected to the consumer unit. In addition, each socket on the ring circuit will be rated at 13 amps. This will limit the number of items of equipment that can be connected to each ring main, particularly fan heaters which may be rated at 3kW each.

Equipment required

26 A number of items of equipment are required in order to be able to undertake a coheating test on a dwelling. The main items of equipment required within the dwelling to be tested (the test dwelling) are as follows:

a) **Temperature and relative humidity sensors** – These are used to measure internal temperature and relative humidity within the dwelling. As a minimum, only the temperature sensors are required. However, the addition of the relative humidity sensors can be advantageous when analyzing the data obtained from the coheating test, as they can give an indication of whether the dwelling has been drying out during the test.

b) **Fan heaters** – These are used to heat the air inside the dwelling. A variable output model is preferred as it enables a degree of adjustment to be undertaken if required.

c) **Air circulation fans** – These are used to mix the internal air within the dwelling. A variable speed fan with an adjustable tilt is preferred as it enables a degree of adjustment to be undertaken if required.

d) **Thermostatic controller** – These will be pre-set to the mean elevated internal temperature and are used to control the heat output from the fan heaters.

e) **kWh meters** – These are used to measure the electrical energy consumption of all of the electrical equipment installed within the dwelling, such as fan heaters, the air circulation fans and the datalogger (if mains powered). The kWh meters are required to have a pulsed output that can be read by a datalogger. A transmitter may be required to transmit the pulsed output to the datalogger.

f) **Datalogger** – This is used to record the data obtained from all of the sensors installed inside the dwelling. Careful consideration should be given to the choice of datalogger used to ensure that it is capable of recording all of the data that needs to be obtained from the dwelling. This data will include: temperature and humidity data from the temperature and humidity sensors and kWh data from the fan heaters and air circulation fans.

g) **Extension leads** – These are used to supply mains power to the fan heaters and air circulation fans, as well as any other items of electrical equipment installed within the dwelling, such as thermostatic controllers or dataloggers that require mains power.

27 A wireless battery powered monitoring system with a mains-powered datalogger is the preferred option within the dwelling as it removes the need for wiring between the various sensors and the datalogger. This enables unrestricted layout and flexibility in the placement of the sensors and the various items of equipment within the dwelling.

28 A photograph illustrating the main items of coheating test equipment installed within a test dwelling can be seen in Figure 3.

Figure 3 Main items of test equipment installed within a test dwelling.

29 It is important to note that additional items of equipment, such as transmitters, modems, etc. may also be required within the test dwelling depending upon the type of monitoring equipment used.

30 In addition to the above items of equipment, additional equipment is also required to be installed externally in order to collect external weather data. The amount of weather data that can be collected for the coheating test can vary, but generally consists of measurements of external temperature and relative humidity, vertical South facing solar radiation, wind speed and wind direction, barometric pressure and rainfall. In order to obtain this data, the following items of equipment are required:

a) **Weather station** – This is used to measure the external temperature, relative humidity, wind speed, wind direction, rainfall and barometric pressure. As a minimum, only the external temperature and relative humidity sensors are required. However, the addition of the other sensors, particularly the wind speed and direction sensor, can give invaluable insights when analyzing the data obtained from the coheating test.

b) **Pyranometer** – This is used to measure the vertical South facing solar radiation flux density in W/m^2.

c) **Datalogger** – A separate dedicated datalogger for the weather station (including the pyranometer) may be required. This will be dependent upon whether the datalogger installed within the dwelling is capable of recording all of the inputs from the weather station in addition to all of the inputs from the sensors located within the dwelling. If a wireless system is used, it may also be dependent upon the proximity of the weather station to the dwelling.

31 A photograph illustrating the weather station can be seen in Figure 4.

Figure 4 **Coheating test weather station installed on a gable wall.**

Location and numbers of equipment

32 The location and number of items of equipment required to undertake a coheating test will vary and will be dependent upon a number of factors. These include the size, the form, the internal layout and the thermal performance of the dwelling. The location and numbers of equipment that are likely to be required in a typical detached dwelling are as follows:

a) **Temperature and relative humidity sensors** – Ideally a temperature and relative humidity sensor should be installed in all of the habitable areas within the dwelling (living room, dining room, kitchen, bedrooms, toilets, bathrooms, en-suites, hallways, etc.). However, this is not always practical, particularly in large dwellings. In this instance, an appropriate number of sensors should be installed to ensure that a realistic measure of mean elevated internal temperature is obtained. They should be distributed throughout the dwelling in such a manner that they are capable of giving an indication of whether the mean elevated internal temperature is being achieved throughout the dwelling or not. Typically, they would be located in the living room, kitchen, hall, master bedroom and bathroom. The sensors also need to be strategically positioned within each room to avoid direct sunlight and to minimise direct heating from the fan heaters.

b) **Fan heaters** – . The number and positioning of fan heaters will depend upon the size and form of the dwelling. It may be necessary to reduce or increase the number of fan heaters during the warm up period in order to maintain a stable mean elevated internal temperature. The fan heaters should be connected to the extension lead output of the kWh meter and positioned in such a way as to provide as much heating to the zone as possible. Care should be taken when selecting and installing the fan heaters to ensure that they do not overload the ring circuit that they are connect to and trip out the consumer unit if all the fan heaters and air circulation fans were switched on at once.

c) **Air circulation fans** – Enough air circulation fans should be installed per dwelling to ensure a consistent mean elevated internal temperature and to avoid heat stratification. The air circulation fans should be connected to the extension lead output of the kWh meter and located to provide good mixing of the air within the dwelling. Additional air circulation fans may be required if adequate mixing of the air throughout the dwelling cannot be achieved.

d) **Thermostatic controllers** – One thermostatic controller is required per fan heater. The thermostat should be located at working plane height (approximately 0.85m above ground level) and be installed in-line with the fan heater. The thermostat should also be strategically positioned to avoid direct sunlight and to minimise direct heating from the fan heaters.

e) **kWh meters** – One kWh meter should be installed per fan heater. It should be installed in-line with any extension lead that supplies power to the fan heaters, air circulation fans and datalogger. If less fan heaters are required to maintain the mean elevated temperature within the dwelling, then the number of kWh meters can be reduced accordingly.

f) **Datalogger** – At least one datalogger will be required per dwelling. If mains powered, it should be connected to the extension lead output of one of the kWh meters.

g) **Extension leads** – At least one extension lead will be required per kWh meter. Additional extension leads may be required depending upon the numbers of equipment installed that require mains power. If additional extension leads are required, a kWh meter will have to be installed in-line to measure the electrical energy consumption of any appliances connected to the lead.

h) **Weather station** – One weather station will be required which should be mounted horizontally above ground level on a mast. It should be positioned to avoid any possible overshading or sheltering.

i) **Pyranometer** – One pyranometer will be required to be mounted vertically above ground level on a mast. It must be South-facing and positioned to avoid any possible overshading.

33 It should be noted that the location of the equipment within the rooms is not an exact science and is likely to involve a degree of trial and error. It is not uncommon to have to move equipment around or adjust equipment during the early stages of a test to achieve even temperatures throughout the dwelling.

Test procedure

34 Prior to undertaking the coheating test, a pressurisation test should be performed on the dwelling. The pressurisation test should be carried out in accordance with ATTMA Technical Standard L1 (ATTMA, 2010).

35 Following the pressurisation test, a number of measures are required to be put in place in order to minimise the contributions from other heat gain and heat loss mechanisms during the test. These measures are as follows:

a) All heating and electrical systems within the dwelling that are not used during the test need to be turned off. This should be done at the consumer unit where applicable. For instance, the space and hot water heating system (including the hot water cylinder), lights, fridge, freezer, oven, hob and any mechanical extract fans.

b) All trickle vents, acoustic vents and mechanical supply/extract vents need to be adjusted to the closed position or temporarily sealed.

c) All flues and fire places need to be temporarily sealed.

d) All water traps and U-bends in kitchens, bathrooms, en-suites and toilets need to be filled with water. These will need to be topped-up throughout the test period due to evaporation.

e) All external doors and windows should be inspected to ensure that they are tightly closed.

f) All internal doors (including wardrobe and built-in cupboard doors) need to be temporarily wedged open to allow free movement of air around the dwelling.

36 Once the above measures are in place, the test can commence. The test procedure is as follows:

a) Adjust all of the thermostatic controllers to the mean elevated internal temperature setpoint, say 25°C.

b) Switch on all of the fan heaters and adjust them such that they are operating on an appropriate heat and fan speed setting.

c) Switch on all of the air circulation fans and adjust to an appropriate angle .

d) Switch on the CO_2 gas dispensing system.

e) Activate all of the dataloggers to record the internal and external data at an appropriate interval, say 10 minutes.

f) Observe the CO_2 concentrations for the first couple of days to ensure that the gas dispensing system is capable of producing a relatively constant concentration of CO_2 gas throughout the dwelling each day before the dispensing system is switched off and the decay of the gas is monitored.

g) Observe the internal temperatures obtained from the temperature sensors for the first couple of days to ensure that they are increasing towards the setpoint on the thermostatic controllers (say 25°C).

h) Once the setpoint temperature has been reached, observe all of the internal temperatures obtained from the temperature sensors to determine whether there is a relatively uniform mean internal temperature throughout the dwelling.

i) If the mean internal temperature observed throughout the dwelling is not uniform, increase the heat input from the fan heaters as necessary to obtain a uniform mean internal temperature. If a uniform mean internal temperature can still not be achieved, it may be necessary to change the position of the fan heaters and air circulation fans. It may also be necessary to adjust the speed of the air circulation fans, alter the angle of the air circulation fans or add additional air circulation fans and fan heaters.

j) If a relatively uniform mean internal temperature is observed throughout the dwelling, but it is marginally different to the setpoint temperature on the thermostats, then the test should be allowed to continue at the different mean elevated internal temperature.

k) Once a relatively uniform mean internal temperature is achieved, continue to log all of the data for a sufficient period of time such that a range of internal to external temperature differences (ΔT's) are recorded. As a minimum, this should be for at least one week, but preferably two or three.

l) Download the data from the datalogger/s daily and analyse the data.

37 After completion of the coheating a test, a second pressurisation test should be undertaken on the dwelling once the dwelling has been allowed to cool down. The result from this test should be combined with the pressurisation test result obtained immediately prior to the undertaking the coheating test, to determine the average air leakage rate for the dwelling over the period of the test. This figure can then be used to give an estimate of the background ventilation rate for the dwelling using the n/20 ‘rule of thumb’.

Combining techniques

38 Although the coheating test is a very important tool for measuring whole dwelling heat loss, the results obtained by undertaking the test in isolation have limited value on their own. The result can be used to make comparisons between the as-built measured heat loss and the designed heat loss, but if any discrepancy in performance is identified, it is not possible to be able to identify the reasons why such a discrepancy occurs.

39 It is possible to gain a much richer insight and understanding of the principal heat loss mechanisms that are occurring within a particular dwelling, if the co-heating test is combined with other fabric measurement techniques. In fact, the mean elevated internal temperatures experienced during a co-heating test give favourable conditions for undertaking specific diagnostic techniques, such as a survey of the dwelling using an infrared thermal imaging camera. Other measurements techniques that may be used during a coheating test include: pressurisation tests, leakage detection, tracer gas measurement, cavity temperature measurement, heat flux measurement, thermal imaging, partial deconstruction, air flow measurements, design assessment and site observations. By combining these techniques with the coheating test, a ‘forensic’ style investigation of the dwelling can be undertaken.

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