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TABLE OF CONTENT

1 LIST OF ABBREVIATIONS, COMMON TERMS AND DEFINITIONS 4
2 INTRODUCTION/ BACKGROUND 5
3 HOW THIS DOCUMENT SHOULD BE USED 5
4 PROCEDURE/ ASSUMPTIONS PRIOR TO USE OF THE PROTOCOL 7
5 GENERAL CONSIDERATIONS FOR ANY TYPE OF INSTALLATION 9
6 PROTOCOL FOR THE INSTALLATION OF THE PERFORMER HUB 11
6.1 INTRODUCTION & BACKGROUND 11
7 METHODS FOR BUILDING FABRIC PERFORMANCE ASSESSMENT 12
7.1 AIR PRESSURE TESTING 12
7.2 ELEMENTAL/ FAÇADE HEAT LOSS / THERMAL FLUX MEASUREMENT 16
7.3 ENERGY SIGNATURE METHODS 18
7.4 WEATHER STATION FOR EXTERNAL ENVIRONMENTAL CONDITIONS 20
8 METHODS FOR MEASURING REAL-TIME ENERGY CONSUMPTION 23
8.1 ELECTRICITY METERS AND SUB-METERS – DATA FROM EXISTING METERS 23
8.2 ELECTRICITY METERS AND SUB-METERS – NEW METERS 25
8.3 ELECTRICITY GENERATION AND EXPORT METERS – DATA FROM EXISTING METERS 27
8.4 ELECTRICITY GENERATION AND EXPORT METERS – NEW METERS 30
8.5 LIQUID FLOW (FUEL) METERS AND SUB-METERS – DATA FROM EXISTING METERS 32
8.6 LIQUID FLOW (FUEL) METERS AND SUB-METERS – NEW METERS 34
8.7 HEAT METER (FOR HEAT SOURCE), I.E. FOR SOLID FUELS 35
8.8 HEAT FLOW AND RETURN METER (FOR WATER DISTRIBUTION SYSTEMS) 38
8.9 HEAT/ COOLING DELIVERY VIA AIR FLOW SYSTEMS FOR DUCTS/ VENTILATION 40
8.10 AIR FLOW RATE VERIFICATION/ CALIBRATION (PORTABLE EQUIPMENT) 42
8.11 PORTABLE/ NON-FIXED EQUIPMENT PLUG METERS/ LOGGERS 44
8.12 NON-INTRUSIVE APPLIANCE LOAD MONITORING SYSTEMS (NIALMS) 46
9 METHODS FOR MEASURING OCCUPANCY AND COMFORT PARAMETERS 47
9.1 INDOOR TEMP AND RH MEASUREMENT FOR COMFORT 47
9.2 CO_2 MEASUREMENT FOR AIR QUALITY 50
9.3 SITUATION ASSESSMENT USING PIR/ LIGHT SENSORS/ WINDOW SENSORS 51
10 CONCLUSION 54
ANNEXE A: PROACTIVE METHODS OF COMMISSIONING/ DATA VALIDATION 56
INITIAL/ SETUP CHECK OF SENSORS 56
SET UP OF MEASUREMENT UNITS 56
BOUNDARY SETTING 57

1 List of abbreviations, common terms and definitions

Abbreviation	Definition
BMS	Building Management System
CDD	Cooling Degree Days
CHP	Combined Heat & Power
CSV	Comma/ Character Separated Values
HDD	Heating Degree Days
HVAC	Heating, Ventilation & Air Conditioning
JSON	JavaScript Object Notation
KPI	Key Performance Indicator
PDW	PERFORMER Data Warehouse
Common terms	**Definition**
PERFORMER Client	Person (or group of people) leading the implementation of the PERFORMER solution, responsible for employing tradespeople/ contractors for any building works or equipment installation
Building/ Facilities Manager	Person (or group of people) responsible for building operation and meeting desired energy targets
PERFORMER Hub	A monitoring unit to which new sensors may be added, configured to transmit data to the PERFORMER Data Warehouse (also referred to as a PERFORMER box in other reports)

2 INTRODUCTION/ BACKGROUND

The PERFORMER solution is a holistic approach to monitoring and subsequently improving the energy performance of existing buildings. By collecting real-time data and in-situ measurements from a building it is possible to identify and correct deviations from the anticipated/ forecast energy performance. The PERFORMER solution essentially comprises two parts:

1. the physical equipment placed within the building, incorporating existing sensors and meters (potentially already linked to a Building Management System – BMS) along with any new supplementary equipment needed to capture the full range of data required
2. The PERFORMER Platform, which is a cloud-based data environment where the collected information is stored, analysed and recommendations are derived for building/ facilities managers to act upon to reduce energy consumption

All buildings are different, but the aim of this Monitoring Protocol document is to standardise the approach for installing and implementing a monitoring programme for any building. This Protocol covers:

- Methods for building fabric performance assessment
- Methods for measuring real-time energy consumption (of mechanical systems and energy using devices)
- Methods for measuring occupancy and comfort parameters, since energy savings should not be delivered at the expense of the occupants' comfort within a building

The Protocol will provide PERFORMER clients with an overarching concept of what will be monitored in their building and why, and give key criteria to be followed during installation to ensure it is consistent with the PERFORMER approach. It is not intended for this document to be a substitute for detailed, item-specific installation manuals that would be expected to accompany any new sensors or meters; instead this Protocol should complement such manuals by providing context to the PERFORMER solution for building owners and managers in readiness for the installation of any new equipment.

3 HOW THIS DOCUMENT SHOULD BE USED

Not all sensors/ meters detailed in this report will be required in every building using the PERFORMER solution – the bespoke sensor/ meter requirements for each building should be derived using the 'KPI → Sensor selection' tool and 'Cost Optimality' tool (discussed further in

Section 4). The output from the KPI → Sensor selection tool will indicate the types of sensors/ meters that will need to be present in the building to measure the KPIs chosen by the building owner/ manager. Each type of potential sensor/ meter has a corresponding section in this Protocol to explain how it will be used by PERFORMER and any key considerations for its installation. In particular, there will be different requirements depending on:

- whether the sensors/ meters are to be newly installed
- whether they are already present in the building and need additional counters/ loggers to collect the data and export it to the PERFORMER platform
- whether they are to be integrated into an existing BMS, the output of which may need to be configured in a particular format to be compatible with the PERFORMER Data Warehouse (PDW)

Since each section may be read in isolation depending on the needs of the test building, each section provides a self-contained summary of how the proposed equipment and its collected data will be used by PERFORMER. It also gives an indication of the likely skills that may be required to install the equipment (i.e. whether specialist trades such as an electrician or otherwise may be needed) so that Clients can make appropriate arrangements for the installation. Although it is expected that each piece of equipment would have its own detailed installation manual, the Protocol also provides high-level requirements that should be considered during the installation, such as the placement and location of sensors/ meters and any configuration/ formatting of outputs that may be necessary during their setup. The Protocol should, therefore, help chosen installers understand the overall requirements and supplement the fundamentals of the manufacturers' instructions.

Refer to the **Table of Contents** at the start of this document to readily identify the sections relevant to each type of chosen sensor. In addition, it is expected that some installations will require the installation of a PERFORMER hardware hub to facilitate the installation of new sensors/ meters and to interface with the virtual PERFORMER platform. Guidance relating to the installation of the hub itself is given in Section 6. (N.B: The PERFORMER hub may not be needed if *all* necessary sensor/ meter information is gathered and data can be exported via the building's BMS. In which case, follow guidance produced separately for the appropriate format and export of BMS data to the PERFORMER Data Warehouse.)

Furthermore, an overview of **general guidance relevant to any installation** is provided in Section 5 based on feedback from pilot partners. This considers the best practice approach to the implementation of new equipment for PERFORMER, which should help streamline the process and reduce the level of disruption experienced by building users.

4 PROCEDURE/ ASSUMPTIONS PRIOR TO USE OF THE PROTOCOL

This Protocol document is intended to be used to aid the installation of sensors/ meters required as a result of the KPIs chosen by clients. As such, it has a strong dependency on other tasks having already been carried out in readiness for the installation. The following steps outline the actions required for PERFORMER associated with this Protocol, with subsequent notes indicating the development stages/ outputs from PERFORMER that they are derived from.

Step 1: KPI → Sensor selection tool – KPIs are chosen by clients/ managers and corresponding sensor/meter requirements are output by the tool. [1] [2]

Step 2: Clients/ managers to assess whether the required sensors/ meters are already present in the building (e.g. as part of the BMS) and hence to determine whether existing sensors may be used or whether new sensors will need to be purchased and installed to fill gaps in the required data. [3] *(For existing sensors/ meters, the Monitoring Protocol will note whether additional counters/ equipment are likely to be needed to transfer the monitored data to the BMS or Performer hub.)*

Step 3: Cost optimisation tool – where it is decided that new sensors are needed, this tool will help establish the most cost optimal sensor/ meter choice (i.e. specification of unit(s) to be purchased), whether BMS integrated or stand alone. [4]

Step 4: The Monitoring Protocol then provides an overview of the monitoring solution chosen and highlights key skills and requirements that should be considered during the installation [5]

Step 5: Employ appropriate professionals for the installation and commissioning of the required equipment [6]

Step 6: Setup the data transfer from the BMS or other sources, such as a PERFORMER hub, in the required format to be received by the PERFORMER Data Warehouse [7]

[1] A global set of KPIs (i.e. theoretically relevant to any type of building) were derived under PERFORMER task 1.1. These were grouped as Primary KPIs (those to identify the magnitude of any performance gap) and Secondary KPIs (those to target the root cause of any performance gap). KPIs relating to intrinsic building fabric performance were more specifically elaborated in

task 1.2. It is accepted that not all KPIs may be relevant for every building type (particularly since building uses and services can be so different).

[2] The 'KPI → Sensor selection' tool was developed as part of Task 3.2 to help clients create bespoke KPI sub-sets from the global list according to their interests, ambitions and the nature of their building. When KPIs are chosen, the tool outputs the corresponding sensors/ meters needed to provide data for the KPI.

[3] A process for assessing the sensors/ meters present in an existing building was derived and detailed in PERFORMER task 3.3. This provided a template/ structure for assessing the equipment and the relevant communication protocols utilised so that a cross-comparison could be made with the required sensors/ meters from the KPI → Sensor selection tool.

[4] A 'cost optimisation tool' was developed as part of Task 1.3 to determine the best type of sensor/ meter specification for a building based on a number of practical parameters (e.g. BMS integrated, stand alone, level of disruption, anticipated cost, etc.) This gives a more detailed specification for the newly identified sensors/ meters for clients to take forward to purchase the necessary sensors.

[5] Users may wish to make reference to the report output for task 3.4 considering the challenges commonly experienced when measuring building parameters. This draws upon lessons learned when implementing monitoring solutions in the PERFORMER pilot buildings. It should help to ensure realistic expectations during the installation of new equipment via this Monitoring Protocol.

[6] A sensor/ meter commissioning plan was developed as part of Task 4.2 to advise building managers of the types of verification checks that should be carried out in all cases to ensure that sensors, meters and data transfer infrastructure are working correctly and producing accurate data. The proactive aspects of the commissioning/ data validation plan are included in Annexe A and it is recommended that clients/ building managers consider these steps with their installers during PERFORMER implementation.

[7] It will be necessary to set up the data export functionality from the BMS and/ or PERFORMER hub to make sure that it is correctly received and interpreted by the Data Warehouse, e.g. the units of measurement from each sensor/ meter must be correct, the fields identifying the type of data in each case should be correctly populated. This may be done by the client/ manager or installer (depending on the complexity of the system utilised, i.e. if BMS integrated, a suitable BMS specialist is likely to be required to ensure the information is correctly exported from the BMS to the PDW).

5 GENERAL CONSIDERATIONS FOR ANY TYPE OF INSTALLATION

A 'best practice' approach was derived when piloting the PERFORMER solution with typical buildings, which could apply to many equipment installations, irrespective of the actual sensors/ meters to be installed. These generally reflect the approach towards the installation, the pre-planning that has taken place and the overall management and overseeing of the process and contractors.

Minimum quantity and quality of data

PERFORMER uses smart analytics to help end users identify trends in energy consumption, forecast future energy use and make informed decisions regarding energy management. The system provides energy predictions that are compared to in-use measurements to identify gaps between actual and predicted values. Learning algorithms utilise historical data for training purposes. Although the amount of data required to train the solution for each observed building parameter varies, it is recommended that 1.5 years of data is provided to allow the models to learn and capture the relationships between input (e.g. weather conditions) and output (e.g. HVAC energy consumption) variables.

The analytics utilise hourly values and if data is sampled more frequently than this, PERFORMER will rationalise it to hourly intervals for this purpose. No compensation/ correction is made for the inherent accuracy of the sensors and meters used, since the pattern recognition programs are based on data correlations. Threshold values are then used to determine whether readings contribute to an energy gap or fault. The accuracy ranges of any commercially available meters and sensors are therefore deemed to be suitable for PERFORMER purposes.

Familiarity with systems

A key theme drawn from the pilots' experiences is that the installation of the PERFORMER solution has proceeded most smoothly when everyone involved (suppliers, installers/ contractors) have been familiar with the products, with the existing systems and with the circumstances of the building. Where pre-existing knowledge did not exist, making the time to gain familiarity made the actual installation run more smoothly. This can give an opportunity for installers to identify additional components that had not necessarily been foreseen and/ or to plan the work in such a way that it should take the shortest time possible, in order to minimise potential disruption for building users.

Multidisciplinary team

Ideally, planning the installation should take place in workshops with all relevant stakeholders together that are likely to have involvement (i.e. client, installers, BMS technicians, etc), so each has the opportunity to identify whether there are issues or considerations the others may not be aware of. This can eliminate the need for repeat, corrective visits if all parties know how things should be set up for the next person in the chain to complete their work.

Planning to minimise disruption

In many buildings, it is not practical to shut down services for long periods of time without disrupting the activities of the occupants. Hence consideration needs to be given to the necessary duration of the installation and whether there are 'better' times for this to take place than others. Allowing additional contingency time towards any installation (i.e. more time than is likely to be needed, but still manageable for the building and its occupants) can help to work around any unforeseen circumstances. Along with familiarising all parties with the systems (above) planning a suitable time for equipment shut down if necessary is an essential part of a good installation.

Pre-testing of additional communications networks

Many modern monitoring applications rely on wireless communications to transfer data. While a wireless solution can seem particularly convenient and non-intrusive, there will always be limits to the transmission distances via wireless. If wireless communications are to be relied on, particularly over relatively large areas or throughout whole buildings, signal transfer should be tested in advance of the installation to ensure that the correct number of repeater units, where required, can be purchased and suitable locations identified for them.

Discuss the context of installations with suppliers

Often it may seem easy to identify a suitable component from a catalogue and simply order it. However, it may be beneficial to verify with suppliers the compatibility with specific components beforehand to ensure units will operate as intended. In particular, if retrospectively installing new equipment onto an older system – even by the same manufacturers – back-compatibility should be verified to save wasted time due to inappropriate equipment. It will be good practice to provide as much contextual information as possible to suppliers when ordering equipment, in case they are able to identify compatibility issues that have not been foreseen by the project team. Alternatively, and more preferably, the installers should be involved during the equipment specification, as they will ultimately be required to fit the equipment.

6 PROTOCOL FOR THE INSTALLATION OF THE PERFORMER HUB

6.1 INTRODUCTION & BACKGROUND

Although the PERFORMER solution is intended to collect existing BMS data from buildings, it is recognised that there will be instances when the BMS does not include the required sensors or meters. Where it is not viable to connect new meters to the BMS, a PERFORMER Hub unit may instead be used as a data collector for new sensors. The Hub will allow sensors to be connected, collect and store the relevant data and then transmit the information in the correct format to the Performer Data Warehouse (PDW) for further processing.

The PERFORMER Hub can utilise wired or wireless sensor protocols and these will be pre-configured according to the needs of the building. The current version of the embedded framework supports various wired and wireless protocols, such as Modbus (not Mbus), NMEA, Zwave, 1wire and X2D/XXD from Delta Dore. An assortment of products from different makers are already supported, among them Fibaro, Delta Dore, Sirea/Solea, Kamstrup, LCJ, AdvanticSys, Fortrezz. Additional protocols and products can be configured and added as needed.

In addition, the PERFORMER hub can be used as a basic sensor/actuator network gateway, and local processing can be embedded and executed on the fly (i.e. for real time monitoring) and/or periodically (e.g. daily analysis, computation of aggregated indicators). There is no limit to the nature and complexity of this local processing, as long as the underlying physical platform provides the required resources (computation power, memory, etc). This includes ad-hoc document generation (PDF) and transmission.

Data can be uploaded to the PDW either in real time (in its basic gateway role) or in batch mode (e.g. every 24 hours). PDW interoperability is included by default in the PERFORMER hub.

The way devices are linked with the hub depends on the relevant communication protocols to be used. The hub provides a native browser based administration interface to provide hardware addresses or unit ID based associations (e.g. Modbus). The Delta-Dore proprietary discovery mechanism is also supported by the hub.

6.1.1 Specific skills required for the installation

The PERFORMER Hub comes pre-configured for a number of types of sensor and communication protocols that may be used. The software uses a Linux Debian packaging system. Technicians with experience of IT and electronic devices will be required, ideally with experience specifically in Linux administration and building monitoring applications.

6.1.2 Installation considerations/ requirements

The PERFORMER Hub will require a main power connection. This can be an external power supply plug or the hub can be set up to be compatible with DIN rail housings for ease of technical integration in such situations. This should be considered when identifying a suitable location to place the hub. The PERFORMER hub should be located in a safe place to prevent it from being damaged or tampered with. The method of sensor connection is also likely to influence where it can be installed, depending on whether it will use wireless or wired communication protocols. In the case of wireless data transmission, it would be advisable to test the radio frequency (RF) signal strengths between the intended location of sensors and the hub to determine if additional signal strength repeaters would be needed.

The level of disruption associated with installing the hub itself should be relatively minimal, although some sensor installations may be more disruptive depending on their nature – see the relative sections later in the report for such information. Since the PERFORMER hub is intended to be standalone from other systems (such as the BMS), its installation should not interfere with other building operations.

7 Methods for building fabric performance assessment

7.1 Air pressure testing

7.1.1 Introduction & background

Air infiltration rates are often estimated at the design stage and can be very inaccurate. For the purposes of modelling and other analysis methods discussed in this Protocol, estimates *could* be used but it must be understood that they could cause notable margins of error in the forecast of a building's energy use. It is therefore preferable to carry out an air pressure test for a building to provide more accurate forecasts for PERFORMER.

Air pressure testing is a physical test applied to a structure with the aim of establishing the air infiltration rate of a building's existing fabric. During the test, a building is either pressurised or depressurised (sometimes both, with an average of both results used) to a prescribed level.

The rate of air either entering or exiting the building as a result of the (de)pressurisation is then measured. This gives a figure that is comparable across buildings and allows the market to understand how robust a building's envelope is to air penetration through its construction. The air infiltration value is a useful intrinsic fabric performance indicator representing how 'leaky' a building is to heating or cooling loss, thus reflecting construction quality. It is a key parameter used in energy simulation models that will influence the forecast energy use of a building.

The building can be (de)pressurised through the use of a door or window-mounted fan blower system – where a fan or fans are fixed and sealed to a building using an open doorway or window – or using the building's existing ventilation system. For a typical building, a test should last approximately 30 minutes, with the blower door fan speed ramped up gradually to a maximum to achieve proper (de)pressurisation. The fan speed is then reduced, with sensor readings at the fan taken to determine the air tightness of the building.

Air permeability of the building fabric is often measured in $m^3/h{\cdot}m^2$ at a given pressurisation level e.g. 50 Pa, i.e. when a building is (de)pressurised, the volume amount of air of a building's conditioned areas that is lost/ gained per hour is measured per square meter of external envelope area, which includes the combined areas of the roof, the walls and the ground floor. Alternatively, in some tests the air change rate (ac/h) is given. This is calculated by dividing the volume of air required to keep a building (de)pressurised for an hour by the total conditioned volume of the building. To represent the air permeability at standard, daily pressure differences (as opposed to the artificial pressurisation level for testing), the test result obtained would need to be divided by a conversion factor. Local guidelines will often be provided in each country relative to the pressurisation level used in the national testing standards. It is also possible to derive an 'equivalent leakage area' (ELA), which converts the air permeability result to an equivalent opening/ void area (usually in m^2) in the building fabric according to the surface area of the building.

7.1.2 Specific skills required for the installation

The air pressure test should be conducted by a licenced air tightness tester so the building can receive an official document which declares the outcome of the test. Other personnel with relevant experience can conduct a test, provided their company is subject to third-party monitoring in line with ISO 17025:2005.

7.1.3 Installation considerations/ requirements

Many considerations are required depending on the size of the building to be tested. Particularly tall (over 15 stories) or large volume buildings (over 80,000 m³) will require multiple test fans, or may require testing floor-by-floor. Smaller portions of a building may be tested individually as required, to form a representation of a whole building, but at least 20% of the overall building's façade should be tested and this area must be representative of the overall building construction. Connections between the tested area and the non-tested area must be thoroughly sealed to prevent an erroneous test. Tests can be carried out at any time of year and any time of day with the building occupied or unoccupied. However, the external wind speed should be no greater than 6m/s (21.6 km/hr) throughout the duration of the test. Air pressure testing specialists should be able to determine appropriate testing requirements for any given building.

The 'conditioned' building space is the volume which is occupied; attics, storage spaces, cupboards, closets, etc. All are excluded from the conditioned volume and access doors to these spaces should be kept closed throughout the tests. No volume reductions are taken into account by existing furniture and fittings and the air pressure difference is slight enough that the building can remain occupied throughout the test (although building occupants will most likely find the noise of the equipment disturbing.) During the test, it is important all interior conditions remain constant should the building remain occupied, i.e. doors and windows shall remain in their fixed position as at the commencement of the test and trickle vents and other background ventilation should be fixed as per the normal operating conditions of the building. Uncontrolled natural ventilation openings, however, should be sealed prior to the commencement of the test.

Different countries have different standards by which air infiltration is measured. The variables typically include whether the building is pressurised or depressurised (or an average of both), the extent to which the building is (de)pressurised (typically from 4 Pa to 100Pa) and whether the result is expressed as m^3/hm^2 or ac/h. All test results can usually be converted to an air change rate (ac/h) for the building if its ventilated volume is known (if not already provided in those units) to normalise the result irrespective of the test methodology/ test pressure used. It is recommended that testing professionals are asked to present the results as an air change rate for PERFORMER in addition to any other units required by the national standard. Common air pressure test standards and units are given in

Table 1. As discussed above, the units would require conversion to the same air infiltration rate or air changes per hour given normal pressure differences for calculating heat loss/gain via infiltration in practice.

Table 1: Air pressure testing requirements across Europe[1]

Country	Results expressed as: (units)	Pressure difference of test (Pa)
Belgium Finland Germany Norway	ac/h	50
Sweden UK	$m^3/h \cdot m^2$	50
France Switzerland	$m^3/h \cdot m^2$	4
Italy	$m^3/h \cdot m^2$	98
Spain	$m^3/h \cdot m^2$	100
Netherlands	m^3/s	10

7.2 ELEMENTAL/ FAÇADE HEAT LOSS / THERMAL FLUX MEASUREMENT

7.2.1 Introduction & background

The thermal transmittance of a building element/ façade is represented by its 'U-value' in the units 'W/m^{2}K' and is essentially the heat flow rate between the internal and external environment. Elemental U-values are most commonly derived from calculations based on the laboratory-tested thermal conductivity of the comprising materials. However, the 'real' thermal properties of a building element could vary due to a number of factors, such as the quality of workmanship during construction, material substitutions, environmental conditions (moisture content, etc.), or they may simply be unknown in older buildings where the absolute construction make-up is uncertain.

Understanding the extent of the heat loss or gain through building elements is fundamental to making assumptions/ forecasts on the energy use of a building and hence is a key input for any energy simulation model and/ or for the PERFORMER solution. Although design U values may be available, it may be desirable to verify these in practice to ensure accurate energy forecasts or in particular where no construction information is available in older, existing buildings.

[1] ETHICS - Energy and Thermal Improvements for Construction in Steel, 2008

The U-value can be practically obtained by measuring the heat flow rate through an element with a heat flow meter or a calorimeter, together with the temperatures on both sides of the element. While ideally this should be done under constant environmental conditions, this is never achieved on a real site in practice. Instead, an approximation is assumed by using the average values of heat flow rate and temperature over sufficiently long periods of time to give a good estimate of 'steady state' conditions. Such testing is described in the standard ISO 9869-1:2014.

The equipment for such testing is temporary and relatively portable. Heat flux plates are attached to either side of the element to be measured (e.g. a wall). Additionally, temperature measurements need to be taken for the area on either side of the element (inside and outside). Data will be transmitted to the PERFORMER platform and sufficient 'average' conditions for deriving the U-value should be realised after approximately 3 to 7 days, depending on the consistency of the temperatures experienced.

This can be repeated at a number of points throughout the building to give an average value of thermal performance for major elements, which can be compared with predicted/ calculated values if available to validate the performance of the element(s).

7.2.2 Specific skills required for the installation

There is no specific trade or qualification required to carry out this testing. Any technician with a sufficient knowledge of building physics parameters can install the equipment, i.e.:

- With an understanding of how heat flows through the building envelope and of the phenomenon of thermal bridges, so heat flow meters can be suitably placed
- A basic understanding of electronics in order to link the heat flow meters to a PC either wired or wirelessly and set up the necessary software for the calculations

7.2.3 Installation considerations/ requirements

The solar irradiance should be kept as low as possible over the tested area. This may require testing to take place at specific times of the year (when the position of the sun places the area of consideration in the shade), or more readily on the most northerly orientated aspect of the element to be measured.

A minimum temperature difference of 10K should ideally be maintained between the inside and outside environment.

Internal temperature should be kept as constant as practicable within the zone adjacent to the tested element(s). **Temperature sensors** should be installed as described in section 9.1. In theory it should be possible to carry out the testing while the building is in use, assuming this does not impose any undesirable changes to the test conditions.

External temperature sensors should be shielded from direct sunlight and any other direct sources of heat/ cooling. This information may be collected via a thermometer/ weather station at the building as described in section 7.4.

Heat flux meters should be appropriately placed, away from any sources of heating, cooling or thermal bridging or any irregularities in the element's surface (e.g. cracks) (within an area approximately 1m^2 clear of any other influencing features). Thermal imaging/ thermography may be used to help ensure that the area(s) chosen to position sensors are not unduly influenced by other factors.

7.3 ENERGY SIGNATURE METHODS

7.3.1 Introduction & background

The energy signature method uses energy data gathered from a building while in use over a long period to estimate an overall building heat loss parameter (i.e. the energy that is lost via the building fabric). The test is usually run over a year or more, but at least during the heating season of a building – the longer the period of assessment the more reliable the output. This is useful for PERFORMER as it is a way of estimating the real 'as built', intrinsic performance of the thermal envelope to verify whether it is in line with the designed building parameters or where such building parameters are unknown (i.e. in older buildings). A correction could then be applied to amend the building's 'in use' energy forecast to be more realistic.

The method consists of plotting heating consumption data for the building as a function of the heating degree days (HDD) at the location, then fitting a straight line via linear regression. The slope of the line represents the Building Loss Coefficient (BLC), the y-intercept of the plot represents the 'free gains' to the building, e.g. solar gains, incidental internal gains, etc.). This is represented by the equation:

$$E_{heat,i} = 0.024 \times BLC \times HDD_i + TF$$

Where:

$E_{heat,i}$ Heat consumption of the building during the period i, in kWh

HDD_i Heating degree days during the period i, which should ideally be deduced from interior and exterior temperature measurements, in K.day (at the very least, internal temperature set points should otherwise be used with measured external temperature data)

BLC Building load coefficient, in W/K, including ventilation rate, heat transmission, and air infiltration rate through the envelope, identified by linear regression

TF Constant value, identified by linear regression, including all other heat fluxes such as internal loads, solar gain through windows, thermal radiation on the external side, in kWh

The value of 0.024 converts the term BLC x HDD_i, expressed as W/Day into kWh.

It is also assumed that the efficiency coefficient of the heating system, η, is 1.

The uncertainty of this measurement can be deduced from the linear regression parameters of the plotted data (i.e. point dispersion and R^2 coefficient).

An advantage of this method is that it utilises data from meters that are usually already in place within a building (i.e. meters for the building's overall heat demand and temperature measurements) and can take place while occupants are present. The temperature set points for the building should also be known in order to create bespoke heating degree day assumptions for the calculation. The BLC parameter also includes losses due to air infiltration and ventilation. Further measurements for air infiltration/ airtightness of the building and a calculation of the average losses from the ventilation system would be required to derive the 'Heat Loss by Transmission' (H_{tr}) for the fabric elements alone.

The method works best in buildings with relatively constant patterns of occupancy and usage. The building also needs to be in a semi-permanent state/ condition, i.e. the method will not work well in periods after the heating system has been off/ in set-back mode and is re-started – a relative equilibrium state (regular heating patterns) for the building will need to be reached. Irregular data (i.e. such as when the building is not experiencing steady-state conditions) will be removed from the dataset and subsequent calculations by the PERFORMER solution based on defined periods of occupancy set by the user.

7.3.2 Specific skills required for the installation

No specific skills are required to implement the energy signature method. The data will be collected/ utilised from other meters/ tests via the PERFORMER solution (see below), calculated and output via the PERFORMER Platform.

7.3.3 Installation considerations/ requirements

An energy meter or sub meter is required that can measure **only the energy used for heating** the building. See section 8.1 for further details on the use/ installation of such meters.

External temperature measurement is required in order to derive heating degree day (HDD) data for the given building location. This information may be collected via a thermometer/ weather station at the building as described in section 7.4. Alternatively (and less ideally) data may be utilised from a sensor/ weather station close to the building that will have essentially experienced the same climatic conditions. (Online sources of historic temperature data are often available from regional meteorological societies.)

Ideally, **internal temperature measurements** should be made to contribute to the HDD data, as described in section 9.1. Otherwise, internal temperature set points should be used.

In order to determine the Heat Loss by Transmission (H_{tr}) specific to the building fabric only from a Building Loss Coefficient (BLC), losses from ventilation and air infiltration need to be subtracted. An **air pressure test** is required to determine (and subsequently isolate) the air infiltration energy losses from a building. See section 7.1 for further details on carrying out an air pressure test. Average ventilation losses will also need to be calculated for the mechanical services using technical specifications and correlations between measured fan energy consumption and air flow rate.

7.4 WEATHER STATION FOR EXTERNAL ENVIRONMENTAL CONDITIONS

7.4.1 Introduction & background

Outdoor environmental conditions are major driving factors in estimating building energy consumption and evaluating its performance. The weather variables that are commonly monitored include outdoor air temperature, air humidity, wind speed and direction and solar radiation. Such information can be used by the Smart Analytics modules for prediction purposes. It can also be used to calibrate/ validate energy simulation models (where available) by running simulations with the 'real' weather data from the location and comparing the forecast energy demand with actual energy consumption. This can rule out weather variability as a potential cause of discrepancy during energy analysis.

Outdoor air temperature (°C, K) is the most commonly measured weather parameter. It is defined as the temperature of the outdoor air in a place otherwise sheltered from direct solar radiation. Temperature is measured by a thermometer or electronic thermocouple.

It is common for external temperature measurements to be used to create a 'Heating Degree Day' (HDD) profile for a given location. The HDD is a measurement intended to reflect the demand for energy required to heat a building. Conversely there are 'Cooling Degree Day' (CDD) figures that would be relevant in warm climates to indicate the cooling demand. HDDs and CDDs are defined relative to a base temperature; for HDD, days generally above 18ºC are considered to require no additional heating, while for CDD, days generally below 22ºC are deemed to require no cooling. Although more accurate methods may be used, they are often calculated simply by considering the average temperature for each day of the year, then subtracting this from the base temperature. If the value is less than or equal to zero the HDD is zero for that day. But if the value is positive, it represents the HDD for that day. The reverse is true for CDD, where the base temperature is subtracted from the average temperature and positive values contribute to the CDD. All the heating/ cooling days are then summed to provide a HDD/ CDD profile for a year/ heating/ cooling season. Amongst other potential analysis, such information is used to assess intrinsic building fabric performance via energy signature methods, as discussed in section 7.3.

Relative humidity (RH) is defined as the ratio of the vapour pressure to the saturation pressure relative to water at the same pressure and temperature. It is expressed as a ratio (%) and is measured using a hygrometer. Often sensors to determine RH are combined with temperature sensors in a single unit as the RH percentage is linked to the temperature, which also needs monitoring. *Wind speed and direction* is reported in m/sec and degrees respectively. Wind speed is measured by using an anemometer and direction can be estimated from a vane mounted on a pole with pointers. *Global, diffuse and reflected solar radiations* are normally measured by a pyranometer (W/m^2). Global irradiation (from the sky and the sun combined) is measured from an unshaded pyranometer and diffuse irradiation by a second shielded pyranometer. The diffuse reading can be deducted from the global reading to calculate direct irradiation from the sun.

7.4.2 Specific skills required for the installation

There are no specific skills required to install a weather station, although a basic understanding of electronics would be useful in order to link the weather station sensors to the PERFORMER hub, either wired or wirelessly and the ability to configure the PERFORMER solution to assign which parameters are being measured.

7.4.3 Installation considerations/ requirements

External air temperature and RH sensors need to be placed in locations that are ventilated but shaded. This is usually achieved using a 'Stevenson screen', which is a white louvered shelter that allows free air movement but protects the thermometer/ hygrometer inside from the warming effects of direct or indirect solar radiation and from rain, as shown in Figure 1. Such shielding apparatus should be considered a fundamental part of a 'weather station'.

Figure 1: Example of a wall-mounted Stevenson screen for temperature and RH sensors

It is also logical to place all weather sensors in relatively close proximity to each other to share power and/ or communications cabling as required. When locating the sensors/ weather station, consider the following:

- All sensors should be placed somewhere they are unlikely to be knocked, damaged, or vandalised. However, ongoing access may be required for any battery operated sensors/ loggers to allow the batteries to be periodically changed

- Temperature and RH sensors should be placed higher than 1.5m above the ground (to avoid any ground effects)
- For solar radiation sensors, ensure there are no surrounding objects (buildings, trees etc.) that will overshadow the sensors at any time of the day
- The standard height for wind measurements is 10m above ground level. The installation should make sure that there are no obstructions (tree, buildings, etc.) that can shield the wind. If there are obstructions in the vicinity (closer than 20m), the anemometer should be at least 2-3m above the height of the obstruction

8 METHODS FOR MEASURING REAL-TIME ENERGY CONSUMPTION

8.1 ELECTRICITY METERS AND SUB-METERS – DATA FROM EXISTING METERS

8.1.1 Introduction & background

Existing electricity meters in a building will usually be 'net analysers' or electronic counters. In order to use this information for PERFORMER, they have to be integrated through an open communication protocol (e.g. pulses, M-Bus or others) into the BMS or a PERFORMER hub. Where the power meters are already integrated with the BMS, this data will be received by the Performer Data Warehouse (PDW) along with data from any other meters or sensors. In cases where the power meters are not already integrated with the BMS, they need to be connected and included on it (if possible) or to a PERFORMER hub.

Electrical consumption is one of the most significant factors when assessing the overall energy consumption of a building and contributes to a significant number of PERFORMER KPIs. It is, therefore, essential to have detailed and accurate information on the amount, the origin (what system) and reason (what is the demand to cover) for that consumption. It is also important to gather information about the power 'quality'. If reactive power is very high, the building is considered a poor quality power consumer and Utilities often levy higher fees. The power quality will be different depending on the type of equipment installed in the building. It follows that not only the energy consumed must be measured, but other parameters such as reactive power, the periods and hours when the energy is consumed, etc. All these parameters strongly influence the energy costs and consumption and are therefore critical to the PERFORMER analysis.

Meters will usually give either a pulsed output or may be compatible with common communication protocols – compatibility with a potential BMS will need to be checked by a BMS technician, who should be able to recommend the required sensors or gateways that would need to be installed to transmit the meter data to the BMS.

A pulse counter may need to be installed on the meter to transmit the data to a PERFORMER hub if this is the option to be chosen. If the meter does not have a pulse output it will usually at least have an optical counter (usually a small blinking light on the meter) that represents a given energy usage, i.e. each blink = 1Wh. Other optical counters are available that can recognise and count the rotation of a specific number around an analogue dial. An optical sensor can be placed over the counter that will detect the blinking rate or number rotation, though it should be noted that there is generally a higher level of error associated with optical counters than with pulse counters. Whether using pulse outputs or optical sensors, it will be necessary to check that the recorded rate of energy use (i.e. what each pulse, blink or rotation represents) is transmitted correctly to the PDW. If there are no means of automatically reading and logging data from the meter on an ongoing basis (i.e. no pulse or optical counter or other communication method), it is likely that the existing meter will not be suitable for use by PERFORMER and a new meter will need to be installed (See section 8.2).

8.1.2 Specific skills required for the installation

If the meters are already integrated with the BMS, it will just be necessary to ensure that the data output from the BMS to the PDW includes the meter data. Depending on their level of knowledge of the BMS, this may be set up by the Building Manager or other appropriate building personnel. Otherwise, it may be necessary to employ a BMS technician to set up the appropriate data transfer. If meters are not currently integrated with the BMS but the intention is to do so, a BMS technician will inevitably be needed to assess the existing meters, recommend and install any necessary additional integrating equipment and, as above, to ensure the data is transmitted as part of the main data output from the BMS to the PDW.

If the intention is for the meters to send data to the PERFORMER hub rather than a BMS, no specific skills are needed to install pulse/ optical counters on the meters. However, a basic understanding of electronics would be useful in order to link the counters to the PERFORMER hub, either wired or wirelessly. Since the electrical circuits should not need to be disturbed in the case of existing meters, it should not generally be necessary to employ an electrician.

8.1.3 Installation considerations/ requirements

Electricity consumption is generally logged in kWh, but may be measured in MWh for larger energy consumers. The order of magnitude of the measurements should be checked when setting up the Performer solution for a specific meter to ensure the data received is correctly interpreted.

For existing electricity meters, the main consideration will be whether they could/ should be integrated into an existing BMS or instead just integrated via a PERFORMER hub. If the BMS can accept new meters and those being considered are compatible, connecting them to the BMS may be valuable. (It is actually quite likely that existing electricity meters will already be connected to a BMS if present, as they may form a key part of the reporting information for Building Managers.)

However, if the BMS cannot accept any new meters, either because it uses closed/ incompatible communication protocols or is at full capacity for example, counters/ sensors should be installed on the existing meters as necessary to instead transmit data to the PERFORMER hub, where it will then be transferred to the PDW for analysis.

8.2 ELECTRICITY METERS AND SUB-METERS – NEW METERS

8.2.1 Introduction & background

Although there will inevitably be one or more electricity meters (or sub meters) already in any building, the requirement to measure tailored KPIs applicable to key building zones and/ or systems for PERFORMER is likely to give rise to the requirement for additional sub-meters to be installed. This will provide additional granularity to the energy analysis that takes place. The building area(s) or system(s) that a meter is to measure should be established by PERFORMER clients and/ or Building Managers as part of the KPI and sensor selection process (described briefly in section 4).

Electrical consumption is one of the most significant factors when assessing the overall energy consumption of a building and contributes to a significant number of PERFORMER KPIs. It is, therefore, essential to have detailed and accurate information on the amount, the origin (what system) and reason (what is the demand to cover) for that consumption. It is also important to gather information about the power ‘quality’. If reactive power is very high, the building is considered a poor quality power consumer and Utilities often levy higher fees. The power quality will be different depending on the type of equipment installed in the building. It follows that not only the energy consumed must be measured, but other parameters such as reactive power, the periods and hours when the energy is consumed, etc. In order to be able to distinguish these different parameters it is necessary to use an electronic counter or a net analyser integrated with a data logger. These parameters strongly influence the energy costs and consumption in a building and are therefore critical to the PERFORMER analysis.

Meters will usually give either a pulsed output or may be compatible with common communication protocols. Compatibility with a potential BMS will need to be checked by a BMS technician, who should be able to recommend appropriate meters that would need to be installed to be compatible with the BMS. A pulse counter may need to be installed on the meter to transmit the data to a PERFORMER hub if this is the option to be chosen.

Alternatively, rather than using inline meters, it may be more practical to install Current Transformers (CTs) with their own separate counter. CT loops are placed around electric cables and determine energy use on an electrical circuit based on the measured current and a known or measured voltage. These will typically be less accurate than inline meters, but will generally be easier to install. CT loops may be solid, which will require the circuit do be disconnected in order to be placed through the loop prior to reconnection. Some CTs may use an openable clip connection, meaning they can be placed around the cable without disconnecting the electrical circuit. The latter may be more costly than solid CTs, but they may be useful and the only practical solution if it is difficult to find a suitable time to disconnect the relevant circuit(s) and systems.

8.2.2 Specific skills required for the installation

If new inline meters or solid CT loops are to be installed it will be necessary to employ an electrician. The electrician should also be able to help identify the most appropriate point(s) to install any new meters (see 'Installation Considerations' section below). If clip-on CTs are to be installed, no specific skills are required, but a familiarity with the building's electrical circuits will be necessary.

Once the meters are installed they can be integrated on the BMS or a PERFORMER hub:
If the intention is to integrate them into the existing BMS, a specific BMS technician will be required. The reason is not only technical (each BMS uses specific software and communication protocols and language) but may also be contractual. The current BMS manager/ installer may not allow any unauthorised technicians to integrate new component onto the BMS as it may

invalidate warranties or service agreements. The BMS technician will also need to ensure the new meter data is transmitted as part of the main data output from the BMS to the PDW.

If the intention is for the meters to send data to a PERFORMER hub rather than a BMS, no specific skills are needed to install pulse/ optical counters on the meters, although the electrician installing the new meters may also undertake this aspect. A basic understanding of electronics would be useful in order to link the counters to the PERFORMER hub.

8.2.3 *Installation considerations/ requirements*

Electricity consumption is generally logged in kWh, but may be measured in MWh for larger energy consumers. The order of magnitude of the measurements should be checked when setting up the Performer solution for a specific meter to ensure the data received is correctly interpreted.

In order to install new electricity (sub) meters, Building Managers must be aware that it will be necessary to temporarily disconnect the electrical supply to the part of the building or systems to be monitored. While the downtime may not be long, it can have an impact on the building's operation (e.g. lifts, lighting, HVAC, solar panels, etc.) so the timing of any shut down should be carefully considered. Some systems may need to be manually taken off-line rather than just allowing them to lose power. Alternatively, non-intrusive clip-on CT sensors may be used with a separate counter to avoid the need to disconnect equipment.

Theoretically, new meters or sub-meters can be installed anywhere within a dedicated circuit for the zone or system being considered. However, for practical purposes, it is logical to place a meter as close as possible to its unique junction point from other circuits, such as its branching point within a circuit box or distribution board. Its visibility should ensure that its purpose is readily understood by future Building Managers. The installing electrician should be able to help determine the appropriate point to install new meters, but they will need to discuss with the Building Manager to ensure they fully understand exactly what is intended to be measured so they install each new meter at an appropriate location in the circuit.

8.3 *Electricity generation and export meters – data from existing meters*

8.3.1 *Introduction & background*

Electricity generation and/ or export meters are used to measure the electricity contribution from renewable electricity sources, such as photovoltaic (PV) panels and/ or from co-generation/ combined heat and power (CHP) plant. Generation meters will measure the usable electricity created by the system, like a normal sub-meter. These will often already be in place, having been installed by the system installer or Utility Company. Export meters are similar to other meters but will measure 'up-stream' transfer of electricity back to the grid, rather than the more usual 'down-stream' draw of electricity from the grid. The difference between the two measurements (generation minus export) represents the 'offset grid electricity usage', i.e. that consumed directly by the building.

In situations where all electricity is exported to the grid (no use on site) a generation meter will effectively represent export. However, if the electricity is directly utilised by the building and only exported when there is an excess compared to the demand, it is valuable to also measure how much electricity is being exported to the grid and consequently to calculate how much is used by the building. Even though such electricity is often considered to be 'free of charge' it is useful for PERFORMER to understand how much offset usage has taken place to compare with energy use forecasts and to determine whether the energy use throughout the building is being optimised.

Existing electricity generation and/ or export meters in a building will usually be 'net analysers' or electronic counters. In order to use this information for PERFORMER, they have to be integrated through an open communication protocol (e.g. pulses, M-Bus or others) into the BMS or a PERFORMER hub. Where the generation/ export meters are already integrated with the BMS, this data will be received via the Performer Data Warehouse (PDW) along with data from any other meters or sensors. In cases where the meters are not already integrated with the BMS, they need to be connected and included on it (if possible) or to the PERFORMER hub.

Meters will usually give either a pulsed output or may be compatible with common communication protocols. Compatibility with a potential BMS will need to be checked by a BMS technician, who should be able to recommend the required sensors or gateways that would need to be installed to transmit the meter data to the BMS.

A pulse counter may need to be installed on the meter to transmit the data to the PERFORMER hub if this is the option to be chosen. If there is no means of automatically reading and logging data from the meter on an ongoing basis (i.e. no pulse counter or other communication method) it is likely that the existing meter will not be suitable for use by PERFORMER and a new meter will need to be installed (See section 8.4).

8.3.2 Specific skills required for the installation

If the meters are already integrated with the BMS, it will just be necessary to ensure that the data output from the BMS to the PDW includes the meter data. Depending on their level of knowledge of the BMS, this may be set up by the Building Manager or other appropriate building personnel. Otherwise, it may be necessary to employ a BMS technician to set up the appropriate data transfer. If meters are not currently integrated with the BMS but the intention is to do so, a BMS technician will inevitably be needed to assess the existing meters, recommend and install any necessary additional integrating equipment and, as above, to ensure the data is transmitted as part of the main data output from the BMS to the PDW.

If the intention is for the meters to send data to the PERFORMER hub rather than a BMS, no specific skills are needed to install pulse counters or other such sensors on the meters. However, a basic understanding of electronics would be useful in order to link the counters to the PERFORMER hub, either wired or wirelessly. Since the electrical circuits should not need to be disturbed in the case of existing meters, it should not generally be necessary to employ an electrician.

8.3.3 Installation considerations/ requirements

Electricity generation is generally logged in kWh, but may be measured in MWh for larger installations. The order of magnitude of the measurements should be correctly noted when setting up the Performer solution for a specific meter to ensure the data received is correctly interpreted.

For existing meters, the main consideration will be whether they could/ should be integrated into an existing BMS or instead just integrated via a PERFORMER hub. If the BMS can accept new meters and those being considered are compatible, connecting them to the BMS may be valuable. (It is actually quite likely that existing generation or export meters will already be connected to a BMS if present, as they may form a key part of the reporting information for Building Managers.)

However, if the BMS cannot accept any new meters, either because it uses closed/ incompatible communication protocols or is at full capacity for example, counters/ sensors should be installed on the existing meters as necessary to instead transmit data to the PERFORMER hub, where it will then be transferred to the PERFORMER platform for analysis.

8.4 ELECTRICITY GENERATION AND EXPORT METERS – NEW METERS

8.4.1 Introduction & background

Electricity generation and/ or export meters are used to measure the electricity contribution from renewable electricity sources, such as photovoltaic (PV) panels and/ or from co-generation/ combined heat and power (CHP) plant. Generation meters will measure the usable electricity created by the system, like a normal sub-meter. Export meters are similar to other meters but will measure 'up-stream' transfer of electricity back to the grid, rather than the more usual 'down-stream' draw of electricity from the grid. The difference between the two measurements (generation minus export) represents the 'offset grid electricity usage', i.e. that consumed directly by the building. The generation and export meters need to sample electricity at a small enough time scale to correlate with the incoming (grid) metering system so that the exact percentage of electricity which is exported and that used on site is known. For this reason small sample times (a few seconds) will be used by the meter with small data-logging intervals by the BMS or other management system.

In situations where all electricity is exported to the grid (no use on site) a generation meter will effectively represent export. However, if the electricity is directly utilised by the building and only exported when there is an excess compared to the demand, it is valuable to also measure how much electricity is being exported to the grid and consequently to calculate how much is used by the building. Even though such electricity is often considered to be 'free of charge' it is useful for PERFORMER to understand how much offset usage has taken place to compare with energy use forecasts and to determine whether the energy use throughout the building is being optimised.

Meters will usually give either a pulsed output or may be compatible with common communication protocols. Compatibility with a potential BMS will need to be checked by a BMS technician, who should be able to recommend appropriate meters that would need to be installed to be compatible with the BMS. A pulse counter may need to be installed on the meter to transmit the data to the PERFORMER hub if this is the option to be chosen.

8.4.2 Specific skills required for the installation

If new meters are to be installed it will be necessary to employ an electrician, preferably one specialising in the type of system being measured (i.e. PV, co-gen/ CHP). The electrician should also be able to help identify the most appropriate point(s) to install any new meters (see 'Installation Considerations' section below).

Once the meters are installed they can be integrated on the BMS or the PERFORMER hub:
If the intention is to integrate them into the existing BMS, a specific BMS technician will be required. The reason is not only technical (each BMS uses specific software and communication protocols and language) but may also be contractual. The current BMS manager/ installer may not allow any unauthorised technicians to integrate new component onto the BMS as it may invalidate warranties or service agreements. The BMS technician will also need to ensure the new meter data is transmitted as part of the main data output from the BMS to the PERFORMER platform.

If the intention is for the meters to send data to the PERFORMER hub rather than a BMS, no specific skills are needed to install pulse/ other counters on the meters, although the electrician installing the new meters may also undertake this aspect. A basic understanding of electronics would be useful in order to link the counters to the PERFORMER hub, either wired or wirelessly and the ability to configure the PERFORMER solution to assign which parameters are being measured.

8.4.3 *Installation considerations/ requirements*

Electricity generation is generally logged in kWh, but may be measured in MWh for larger installations. The order of magnitude of the measurements should be correctly noted when setting up the Performer solution for a specific meter to ensure the data received is correctly interpreted.

In order to install new generation or export meters, Building Managers must be aware that it will be necessary to temporarily disconnect the electrical supply to the generation system to be monitored. The installing electrician should be able to help determine the appropriate point to install new meters, but they will need to discuss with the Building Manager to ensure they fully understand exactly what is intended to be measured so they install each new meter at an appropriate location in the circuit.

8.5 Liquid flow (fuel) meters and sub-meters – data from existing meters

8.5.1 Introduction & background

In addition to electricity usage, the usage of all other fuels (solid, liquid or gas) will be important when assessing the overall energy consumption of a building. It is, therefore, essential to have detailed and accurate information about the real-time consumption of each different type of fuel present for PERFORMER to consider how a building's energy use may be optimised.

It is quite likely that existing liquid or gas fuel meters may be present in a building if it is served by a mains gas network, although such meters may also be in place to measure other liquid fuels used by the building. In order to use this information for PERFORMER, such meters have to be integrated through an open communication protocol (e.g. pulses, M-Bus or others) into the BMS or a PERFORMER hub. Where the meters are already integrated with the BMS, this data will be received via the Performer Data Warehouse (PDW) along with data from any other meters or sensors. In cases where the meters are not already integrated with the BMS, they need to be connected and included on it (if possible) or to a PERFORMER hub.

Meters may give a pulsed output or may be compatible with common communication protocols – compatibility with a potential BMS will need to be checked by a BMS technician, who should be able to recommend the required sensors or gateways that would need to be installed to transmit the meter data to the BMS.

A pulse counter may need to be installed on existing flow meters to transmit the data to the PERFORMER hub if this is the option to be chosen. If the meter does not have a pulse output it will usually at least be possible to use an optical counter (that may detect the rollover of a particular number on an analogue meter or the turning of an analogue dial) that represents a given energy usage, i.e. each rotation = 1 dm^3. It should be noted that there is generally a higher level of error associated with optical counters than with pulse counters. Whether using pulse outputs or optical sensors, it will be necessary to check that the recorded rate of energy use (i.e. what each pulse or rotation represents) is transmitted correctly to the PDW. This will be multiplied by the known calorific value/ energy content of the fuel source in order to provide measurements of kWh for comparison with energy simulation models. If there is no means of automatically reading and logging data from the meter on an ongoing basis (i.e. no pulse or optical counter can be employed or there is no other communication method) it is likely that the existing meter will not be suitable for use by PERFORMER and a new meter will need to be installed (See section 8.6).

8.5.2 *Specific skills required for the installation*

If the meters are already integrated with the BMS, it will just be necessary to ensure that the data output from the BMS to the PDW includes the meter data. Depending on their level of knowledge of the BMS, this may be set up by the Building Manager or other appropriate building personnel. Otherwise, it may be necessary to employ a BMS technician to set up the appropriate data transfer. If meters are not currently integrated with the BMS but the intention is to do so, a BMS technician will inevitably be needed to assess the existing meters, recommend and install any necessary additional integrating equipment and, as above, to ensure the data is transmitted as part of the main data output from the BMS to the PDW.

If the intention is for the meters to send data to the PERFORMER hub rather than a BMS, no specific skills are needed to install pulse counters or other such sensors on the meters. However, a basic understanding of electronics would be useful in order to link the counters to the PERFORMER hub, either wired or wirelessly. Since the flow meters should not need to be disturbed in the case of existing meters, it should not generally be necessary to employ a plumber.

8.5.3 *Installation considerations/ requirements*

Fluid/ gas meters may measure in a wide range of different units, such as kWh, m^3, BTUs and many others. The units and order of magnitude of the measurements should be correctly noted when setting up the Performer solution for a specific meter to ensure the data received is correctly interpreted.

For existing meters, the main consideration will be whether they could/ should be integrated into an existing BMS or instead just integrated via a PERFORMER hub. If the BMS can accept new meters and those being considered are compatible, connecting them to the BMS may be valuable.

However, if the BMS cannot accept any new meters, either because it uses closed/ incompatible communication protocols or is at full capacity for example, counters/ sensors should be installed on the existing meters as necessary to instead transmit data to the PERFORMER hub, where it will then be transferred to the PDW for analysis.

8.6 LIQUID FLOW (FUEL) METERS AND SUB-METERS – NEW METERS

8.6.1 Introduction & background

In addition to electricity usage, the use of all other fuels (solid, liquid or gas) will be important when assessing the overall energy consumption of a building. It is therefore essential to have detailed and accurate information about the real-time consumption of each different type of fuel present. Solid fuels will need to be measured by heat meters to provide sufficient data for PERFORMER (see section 8.7). Liquid and gas fuels will often utilise flow meters to quantify the amount of fuel consumed, particularly if this is being billed by a Utility supplier. However, for fuels that are physically delivered to a building, this may simply be billed based on the delivered quantity. In such cases, it is impossible to tell the real-time usage or carry out detailed analysis about the building's consumption patterns, so additional meters will need to be installed.

Liquid and gas meters are usually in-line installations placed in the pipework ahead of the fuel's point of combustion. Such meters may physically work in different ways and may be better suited to different mediums (liquid, gas), but will ultimately provide the same information about the volumetric flow. Since the volume of fuel flow will be measured, it will be necessary to multiply this by the known calorific value/ energy content of the fuel source in order to provide measurements of kWh for comparison with energy simulation models. (This calculation will be carried out by the PERFORMER platform.)

Flow meters may be 'positive displacement', taking the form of rotating pistons or oval gears within a measuring chamber, or 'turbine flow' where a turbine wheel spins around an axis. Both sit in the path of the fluid stream allowing the flow rate to be measured.

While it is technically possible to use ultrasonic flow meters (such as those discussed in section **Error! Reference source not found.** relating to measuring wet distribution systems), they will inevitably be less accurate than integral meters, hence integral meters are favoured for accuracy for measuring primary fuel sources within a building.

8.6.2 Specific skills required for the installation

Flow meters will need to be installed within the flow/ distribution pipework so will require the expertise of a plumber. For gas installations, they will also need to be accredited with any national gas safety register/ schemes. They should also be able to help identify the most appropriate point(s) to install any new meters (see 'Installation Considerations' section below).

Once the meters are installed they can be integrated on the BMS or the PERFORMER hub:
If the intention is to integrate them into the existing BMS, a specific BMS technician will be required. The BMS technician will also need to ensure the new meter data is transmitted as part of the main data output from the BMS to the PDW.

If the intention is for the meters to send data to the PERFORMER hub rather than a BMS, a basic understanding of electronics would be useful in order to link the counters to the PERFORMER hub, either wired or wirelessly.

8.6.3 *Installation considerations/ requirements*

Fluid/ gas meters should be selected that have a pulse or other suitable communication output so they are able to send data to a BMS or a PERFORMER hub. Meters may measure in a wide range of different units, such as kWh, m^3, BTUs and many others. The units and order of magnitude of the measurements should be correctly noted when setting up the Performer solution for a specific meter to ensure the data received is correctly interpreted.

Meters should be placed at the earliest practical point within pipework from the fuel supply/ store ahead of the point of use/ combustion. The installing plumber should be able to help determine the appropriate point to install new meters. It will be necessary to measure the specific pipe diameters where the meters are to be installed and ensure meters are chosen that will be the correct size for the pipe. Building Managers must be aware that it will be necessary to temporarily disconnect the fuel supply to the system to be monitored during the installation.

8.7 Heat meter (for heat source), i.e. for solid fuels

8.7.1 *Introduction & background*

The purpose of these heat meters is to measure thermal energy provided by a source, in this case from solid fuel heat generators such as co-generation plant or biomass boilers, which may otherwise be difficult to quantify. This is done by measuring the flow rate of the heat transfer fluid generated by the fuel and the change in its temperature (ΔT) between the outflow and return legs of the system. The amount of heat energy consumed over a defined period of time is proportional to the temperature differential between the flow and return legs of the system and the volume of liquid that has passed through.

It is imperative for PERFORMER to accurately measure all of the energy uses in a building to compare with the forecast energy use. Solid fuels are typically more difficult to measure; although they can be measured by hoppers/ weight based systems these will not determine the calorific value or 'heating potential' of the fuel and hence the final energy delivered (for instance, wood fuels with an elevated moisture content will not provide as high an energy output as dry fuels, due to the energy expended to first drive moisture from the fuel). In these cases heat meters must be used, though it may still be useful to measure the raw fuels using weight/ flow sensors to understand the quality of the fuel and the physical quantities used.

In some cases, users may wish to determine the renewable proportion of the fuels they use in a heat installation. Biomass boilers are frequently installed in conjunction with fossil fuel boilers. Because of this, the positioning of heat meters is crucial to ensure that the renewable heat is measured correctly. Where the biomass boiler can also use fossil fuel, it may be necessary to consider the installation of a fossil fuel supply meter (either a liquid flow meter as discussed in section 8.6 or a weight/ flow hopper mentioned above), which could be used to correct the heat meter reading so that only renewable heat is being measured, although this sort of 'subtraction method' may not be so ideal for solid fuels (as discussed above).

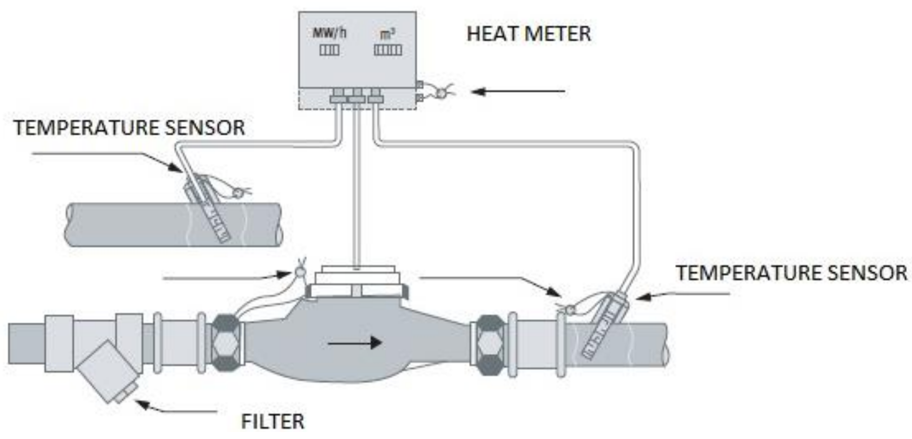
Heat used in a process that will deliver electricity or the re-use of condensate in a process to make the system more efficient will need to be deducted from the meter reading or the system will need to be configured in such a way that it is not recorded by the heat meter, to avoid double counting of the same unit of energy/ heat. For co-generation/ CHP plant, it will be necessary to install both a heat meter for the heat generation component of the generated energy and an electricity sub-meter for the electrical component of the energy (see section 8.4).

A heat meter has three components; a flow measuring device, a pair of temperature sensors (to measure the temperatures in the flow and return pipes) and a calculation or integrator unit. These may be sold as combined units where all three components have been matched by the manufacturer or as semi-combined where the components are separate but sold as a kit. Alternatively, individual components are sold that are matched and integrated on-site by the installer. One temperature sensor and the flow meter need to be installed in the flow pipe and another temperature sensor in the return pipe. These are connected to a central unit that has the electronics, which acquires the data from the probes/ sensors, a display to configure some parameters, some memory for data storage and ports for communication.

There are essentially two kinds of heat flow and return meters: thermal flow meters and ultrasonic flow meters. There will be implications for the practicality, accuracy and cost of these different approaches.

Thermal flow meters will be installed within pipework, using a device like a spinning wheel that will determine the flow rate of the fluid. Temperature sensors may then be embedded within the flow and return pipework as shown in **Error! Not a valid bookmark self-reference.**, or detected by platinum resistors placed at the pipe surface.

Figure 2: Diagram of the typical set up of a heat meter, detecting flow rate and flow and return temperatures



For ultrasonic flow meters, the water volume in the tube is measured by ultrasonic pulses that are transmitted in the direction of flow and against the direction of flow. Downstream, the time difference between the transmitter and receiver is reduced, upstream it is increased. The water volume is then calculated using the measured values of the time difference. The flow and return temperatures are subsequently acquired by non-intrusive platinum resistors placed at the pipe surfaces.

8.7.2 Specific skills required for the installation

For meters that will be integrated within the system, the installation needs to be done by an experienced plumber and it will also be necessary to close the valves of the flow/ return pipes during the installation works. This should be discussed with the Building Manager to ensure they understand the implications of the loss of use of certain systems during the installation. For non-intrusive meters, such specialist skills may not be necessary, although someone with a familiarity with the distribution system being considered and instrumentation is obviously needed. While it may not be necessary to break into the pipe network for non-intrusive equipment, it may still need to be switched off for a time so pipes are not too hot to work around (for safety reasons).

If the intention is to integrate the heat meters into the existing BMS, a specific BMS technician will be required. They will also need to ensure the new meter data is transmitted as part of the main data output from the BMS to the PDW.

If the meters will not be integrated with a BMS, it will be necessary to integrate them with the PERFORMER hub. A basic understanding of electronics would be useful in order to link the counters to the PERFORMER hub, either wired or wirelessly.

8.7.3 *Installation considerations/ requirements*

It is essential to install an intelligent flow meter, with communication capabilities. The temperature of the flow medium will be measured in ºC and the volume of liquid flow in m^3. The resulting energy generation will be output in kWh or MWh, depending on the scale of the systems considered. The order of magnitude of the measurements should be correctly noted when setting up the Performer solution for a specific meter to ensure the data received is correctly interpreted.

Pipe diameters will need to be known so appropriate meters/ sensors can be installed. Units should not be placed too close to pipe bends that may cause a pressure drop, which may influence the overall flow detected by the meter. Care should be taken to ensure that units are also correctly orientated for the intended direction of flow, according to manufacturer's instructions.

8.8 HEAT FLOW AND RETURN METER (FOR WATER DISTRIBUTION SYSTEMS)

8.8.1 *Introduction & background*

Many heat generators will often provide heat for a range of purposes, particularly for heating and hot water provision. It is also possible that heat generators will serve multiple building areas and it may be desirable to obtain data for only a specific area. Although the main generating source may be metered, in such cases it may be necessary to sub-meter wet distribution systems by employing heat flow and return meters. These meters measure the flow rate of the heat transfer fluid and the change in its temperature (ΔT) between the outflow and return legs of the system to be analysed. For PERFORMER, it will be necessary to be able to disaggregate the heat energy used for space heating from hot water systems and, depending on the 'zones' and 'systems' chosen for specific measurement via KPIs, various subsystems or areas may need to be measured in this way.

There are essentially two kinds of heat flow and return meters: thermal flow meters and non-intrusive ultrasonic flow meters. The amount of heat energy consumed over a defined period of time is proportional to the temperature differential between the flow and return legs of the system and the volume of water that has passed through. There will be implications for the practicality, accuracy and cost of these different approaches.

Thermal flow meters will be installed within pipework, using a device like a spinning wheel that will determine the flow rate of the fluid. Temperature sensors may then be embedded within the flow and return pipework, or detected by platinum resistors placed at the pipe surface.

For ultrasonic flow meters, the water volume in the tube is measured by ultrasonic pulses that are transmitted in the direction of flow and against the direction of flow. Downstream, the time difference between the transmitter and receiver is reduced, upstream it is increased. The water volume is then calculated using the measured values of the time difference. The flow and return temperatures are subsequently acquired by non-intrusive platinum resistors placed at the pipe surfaces.

8.8.2 Specific skills required for the installation

For meters that will be integrated within the system, the installation needs to be done by an experienced plumber and it will also be necessary to close the valves of the flow/ return pipes during the installation works. This should be discussed with the Building Manager to ensure they understand the implications of the loss of use of certain systems/ areas during the installation. For non-intrusive meters, such specialist skills may not be necessary, although someone with a familiarity with the distribution system being considered and instrumentation is obviously needed. While it may not be necessary to break into the pipe network for non-intrusive equipment, it may still need to be switched off for a time so pipes are not too hot to work around (for safety reasons).

If the intention is to integrate the heat meters into the existing BMS, a specific BMS technician will be required. They will also need to ensure the new meter data is transmitted as part of the main data output from the BMS to the PDW.

If the meters will not be integrated with a BMS, it will be necessary to integrate them with the PERFORMER hub. A basic understanding of electronics would be useful in order to link the counters to the PERFORMER hub, either wired or wirelessly.

8.8.3 Installation considerations/ requirements

It is essential to install an intelligent flow meter, with communication capabilities. The temperature of the flow medium will be measured in ºC and the volume of liquid flow in m^3. The resulting energy generation will be output in kWh or MWh, depending on the scale of the systems considered. The order of magnitude of the measurements should be correctly noted when setting up the Performer solution for a specific meter to ensure the data received is correctly interpreted.

Pipe diameters will need to be known so appropriate meters/ sensors can be installed. Units should not be placed too close to pipe bends that may cause a pressure drop, which may influence the overall flow detected by the meter. Care should be taken to ensure that units are also correctly orientated for the intended direction of flow, according to manufacturer's instructions.

8.9 Heat/ cooling delivery via air flow systems for ducts/ ventilation

8.9.1 Introduction & background

HVAC systems often represent one of the main energy uses of a building. In these systems air is generally heated (or cooled) using hot water, refrigerant coils or electric heaters, then the conditioned air is blown to the various zones of the building using fans and ducted distribution circuits. To determine the extent of the heating or cooling provided by the air requires the measurement of the air flow and the air temperature of the supply air and the return air.

Air flow can be measured using several types of device, either based on the measurement of differential pressure (e.g. a Pitot tube and Venturi principle) or by measurement of the air velocity multiplied by the area of the duct to give the value of the air flow. For the latter, the most common devices are a hot wire anemometer or a turbine anemometer. Air temperature can be easily measured using thermistors.

This method will be particularly useful for PERFORMER in instances where there is a desire to disaggregate the heating or cooling demand/ delivery in a particular zone of a building served by an HVAC system that also serves various other zones. This may be compared with forecast demand from energy simulation models to assess (and correct if necessary) the performance of the system.

8.9.2 Specific skills required for the installation

Air flow meters and temperature sensors are generally provided by manufacturers of ventilation units, though their use is often limited to the 'closed circuit' control of the HVAC system and not the reporting of delivered heat. Their installation (or adaptation for use by PERFORMER) is likely to require consultation with an HVAC engineer to make sure measurement instruments are properly installed and calibrated and the data correctly collected for the calculation of heat delivery.

If the intention is to report the heating/ cooling energy delivered via the air through an existing BMS, a specific BMS technician will be required. They will also need to ensure the new data is transmitted as part of the main data output from the BMS to the PDW.

If the sensors will not be integrated with a BMS, it will be necessary to integrate them with the PERFORMER hub. A basic understanding of electronics would be useful in order to link the meters/ sensors to the PERFORMER hub, either wired or wirelessly.

8.9.3 Installation considerations/ requirements

The temperature of the air flow will be measured in °C and the volume of air flow in m^3. The PERFORMER platform will carry out the necessary calculations for delivered heat, which should be reported in kWh. It is necessary to measure the air-flow and temperature of both the supply and return ducts of the zones of interest. Wherever possible the installer should seek to identify sensor points to capture as much of the zone as practical with a single set of sensors, i.e. at the first possible branching point that is unique to the zone in question. However, depending on how the heating/ cooling is transferred to the ventilation air (e.g. individual terminal unit/ VRV units in rooms), any selected 'zone' may require a number of 'sets' of sensors to capture all the delivered heat.

8.10 AIR FLOW RATE VERIFICATION/ CALIBRATION (PORTABLE EQUIPMENT)

8.10.1 Introduction & background

The flow rate of ventilation air can influence the comfort of the occupants within a space. For instance, if flow rates are too high it may manifest as localised draughts that occupants may find uncomfortable. Elevated flow rates can also lead to excessive drying of the air, which can cause dry throats and respiratory issues for sensitive occupants. Conversely, if localised flow rates are too low, it could prevent warm air from dispersing adequately and lead to localised overheating.

Although a building or zone may have a mechanical ventilation system intended to run at a specific air flow rate, minor adjustments may be possible at the room inlet points for calibration purposes or sometimes to offer localised user control. It follows that if inlet points are poorly adjusted this could lead to instances of discomfort.

In fixed flow rate ventilation systems (under consideration here, but the meters could in fact be used in many applications), the flow rates of inlets can be checked using hand held air flow sensors known as anemometers. These may utilise a 'hot wire' technique or a 'turbine' technique. Examples of each type of unit are given in Figure 3. The operation of turbine anemometers is relatively self explanatory, the speed of the turbine rotation representing the air flow speed. Hot wire anemometers detect the convective heat loss to the surrounding air from an electrically heated sensing element/ probe to infer the air flow rate. They are generally more reactive to low levels of air flow and are therefore likely to be most suitable for indoor occupied environments.

Figure 3: Example of hot wire (left - www.ecutool.com) and turbine anemometers (right - www.dwyer-inst.com)

The sensors of such units are placed in the proximity of each inlet to be measured. Since diffusers often have varied dispersion patterns, a number of readings should be taken in various locations within approximately a 1m radius of the inlet until the user is confident that a relatively consistent, average result is provided. If the inlet is found to be out of agreement with the intended flow rate the flow should be adjusted accordingly. This would generally only be considered a one-off verification or calibration exercise to rule out localised air flow as a source of discomfort during PERFORMER analysis of a zone/ building.

8.10.2 Specific skills required for the installation

No specific skills are required for using these anemometers. However, if it is suspected that any ventilation points require adjustment, this should be verified with a ventilation engineer that understands the full operation of the system, who can confirm the proposed changes are sensible (i.e. there are no other reasons the changes should not take place) and who can make the necessary adjustments.

8.10.3 Installation considerations/ requirements

Prior to carrying out such measurements, it may be advisable to carry out a brief survey (even if only informally) with building occupants to establish which parts of a building or zone are considered comfortable and which are not. In buildings or zones with potentially numerous inlet points, this should help focus the measurement in areas of interest and could significantly reduce the extent of the assessment required.

It will also be necessary to establish with Building Managers and/ or ventilation engineers/ designers for the installed system (as necessary) what the intended flow rates in the proposed area should be. Air flow rates should not simply be reduced on the grounds of localised discomfort if there is a need to maintain a particular flow rate across the building/ zone for overall health reasons. In such cases, alternative solutions should be considered with ventilation professionals.

8.11 PORTABLE/ NON-FIXED EQUIPMENT PLUG METERS/ LOGGERS

8.11.1 Introduction & background

Non-fixed loads or plug loads increasingly make up a very large proportion of electricity use in modern buildings. The issue for energy monitoring and management is that these loads can be made up of a wide range of different equipment and even with detailed sub-metering in place all electricity consumption by non-fixed loads is generally reported as 'small power' with no further disaggregation possible. Significantly, non-fixed loads are usually excluded from energy consumption estimates at building design stage, so where design stage calculations of electricity consumption are relied upon for future planning, this will lead to a significant difference between expected and actual electricity consumption.

Smart plug meters/ loggers offer an economical and easy to implement solution for the measurement of the electricity consumption of non-fixed equipment. The meters simply plug into an existing socket and devices are then plugged into the meter, which then measures the electricity use of the item. Wireless version of these plug meters can also send data to a remote logger for data storage and analysis.

It would not be economic to fit wireless plug meters to all items of non-fixed equipment in a building. After all, the usage profile for many specific items of equipment are likely to be relatively uniform, so once the profile is known, it will not need to be monitored indefinitely. Instead, it is recommended that a relatively small number of plug meters are employed to sample electricity use of common devices. The plug meters can easily be moved around a building to monitor different pieces of equipment for nominal periods of time.

The use of such plug meters will essentially stand alone from the main PERFORMER solution. However, they will be useful for Building Managers when 'trouble shooting' the energy uses that contribute to the small power electrical loads that are measured by PERFORMER, offering an insight into potential energy savings that could be made by better management of equipment. If a comprehensive assessment of the contribution of various small power loads is made using such meters, an overall 'usage profile' for small power may be derived for a theoretical year. This can then be added to energy forecasts for the building from simulation models that exclude such loads (where models are available) to give more accurate overall energy use estimates.

8.11.2 *Specific skills required for the installation*

No specialist skills are required for the installation of the plug meters. They are simply plugged into existing wall sockets and the devices then plugged in to the meters. Some IT skills or training may be needed to set up wireless connection and data recording from the plug meters if this route is chosen. Devices will often come with their own software for viewing and analysing the collected data.

8.11.3 *Installation considerations/ requirements*

Wireless smart plugs can be set up to record a range of data, most commonly consumption in kWh. It is important to select plug meters that will meet the user's needs and are practical to use. For instance, such units are available that only give a cumulative read out and duration the plug has been active on the plug itself, with no logging capability or power backup. Hence data will be lost if there is any power failure and they will need to be read manually at the meter. It is therefore preferable to use units that have a logging capability, a backup battery in case of power loss, and ideally a means of sending data to a PC (generally wirelessly) for ease of data download.

Prior to deployment of such plug meters, it will inevitably be valuable to carry out a walk-around audit of the non-fixed loads in the building and create a monitoring schedule to cover the items of interest. It is proposed that plug meters are used for at least a month on any given appliance (or whatever period is deemed to represent typical usage of the item, based on local knowledge).

Sensor location is naturally limited to the current location of existing plug sockets and equipment that is to be monitored. The devices are unobtrusive so should present few installation problems. The most significant issues are likely to be experienced where there is a need to install devices behind large pieces of equipment that are difficult to move, e.g. a catering fridge. Another issue that will need to be considered is the possibility of unauthorised removal or tampering with devices by building occupants.

8.12 NON-INTRUSIVE APPLIANCE LOAD MONITORING SYSTEMS (NIALMS)

8.12.1 Introduction & background

NIALMS (Non-intrusive Appliance Load Monitoring System) technology consists of a metering device that can be installed non-intrusively on an electricity supply cable that is able to disaggregate the electricity load profile of various end uses (lighting, small power, cooling, etc.) that the cable is supplying. It is therefore a very useful device to measure many energy uses simultaneously rather than relying on sub metering. For smaller scale, simple installations, the use of sub-meters may in fact be cheaper than NIALMS. However, the equipment needed for NIALMS does not particularly change depending on the size of the building, whereas in larger buildings many more sub-meters may be necessary. Hence, NIALMS is likely to become more cost competitive in larger buildings and those with poorly arranged electrical distribution networks (that would not facilitate sub metering). NIALMS offers a holistic way of collecting electrical energy consumption data by end use type for use by PERFORMER to identify energy performance discrepancies.

For NIALMS, electrical intensity and voltage are measured over time directly on the main electrical circuit of the building using clamp-on meters (hence 'non-intrusive'). Once data is gathered it is necessary to detect electrical events caused by appliance state transitions (i.e. on/ off). These events are detected by analysing changes in the power level. Each electrical load exhibits a unique energy consumption pattern, often termed as load or appliance 'signatures', which enables disaggregation algorithms to discern and recognise appliance operations from the aggregated load measurements. These variables are stored locally or remotely in a database and are compared to an existing database of appliances signatures. Although signature databases already exist covering a wide range of common appliances/ systems, such a database usually has to be updated when a NIALMS system is deployed to ensure it can recognise the systems in use in the specific building.

The database is usually created/ updated during a 'learning phase' after NIALMS installation. Energy signatures are gathered per appliance while the equipment is logging. There are two different approaches to this machine learning technique:

1) Manual setup (MS-NIALM) – this is accurate but intrusive and expensive because of the manual and systematic on-site collecting of appliance signatures (by manually switching items off and on to create signatures)

2) Automatic set up (AS-NIALM) – this is less accurate but more common due to lower costs and quicker installation. The signature database is generated remotely following data analysis to automatically identify signatures.

Non-domestic and commercial buildings usually have weekly cycles of energy consumption. Therefore, learning algorithms usually need a week to provide the first results. After this time, results can be delivered on a near real time or daily basis.

8.12.2 *Specific skills required for the installation*

The NIALMS instrumentation should be set up by a competent electrician. A technician competent with NIALMS (i.e. NIALMS suppliers) will need to integrate the data generated with the PERFORMER solution and/ or setup the NIALMS so data is exported in the necessary format to the PERFORMER platform.

8.12.3 *Installation considerations/ requirements*

NIALMS disaggregated data output is usually electrical power consumption measured in kW. The disaggregation process is usually performed in the cloud and most NIALMS suppliers offer a means of transferring collected data in CSV or JSON file formats. This will need to be configured for transfer of the data to the PERFORMER platform.

The current probes/ sensors must be installed on the main electrical panel. However, in some cases (like tower buildings) it might be useful to install current sensors in locations away from the main electrical panel. To address this, some NIALM providers utilise wireless current sensors that will transmit to a central data collection point. NIALMS experts/ suppliers should be able to advise on such needs.

9 METHODS FOR MEASURING OCCUPANCY AND COMFORT PARAMETERS

9.1 *INDOOR TEMP AND RH MEASUREMENT FOR COMFORT*

9.1.1 *Introduction & background*

The primary reason to monitor temperatures and relative humidity (RH) is to ensure that buildings are comfortable for the occupants, while taking into consideration the activities being carried out. While temperature and RH are not sole indicators of human comfort, temperature in particular is established as a major contributing factor to the perception of comfort. These will be important parameters to measure for PERFORMER to ensure that energy optimisation actions do not happen at the expense of occupant comfort.

Human comfort is often expressed as a 'Predicted Mean Vote' (PMV) and/ or the 'Predicted Percentage Dissatisfied' (PDD) index, for which ISO 7730:2005 provides a calculation method. The key components contributing to these comfort parameters are air temperature, radiant temperature, air velocity and air humidity (plus the level of physical activity and extent of clothing worn). Temperature (and to less an extent RH) are therefore key criteria for establishing comfort. Since other parameters that are used in the indicator can be standardised based on the activity occurring in a space (e.g. the type of activity and likely clothing) a temperature range can broadly represent the expected 'comfort zone' in a space. Indoor and outdoor temperature measurements are also used to predict the likely comfort zone temperatures for occupants according to the calculations in EN 15251. All of these indicators can be measured by the PERFORMER solution.

Temperature sensors may take a variety of forms, though they will all generally fundamentally rely on thermistors to digitally interpret the temperature. Most commonly, temperature sensors will be air temperature sensors, although this will generally underestimate the temperature actually experienced by building occupants. There are also radiative temperature sensors that will measure the radiative effects of heat; these are particularly important for buildings with radiative forms of heating and cooling, such as heated floors or chilled beams. Where the air speed in a space is negligible, an 'operative temperature' (i.e. that experienced by building occupants) is assumed to be an average of the air and radiative temperatures. It follows that it may be necessary to install two different types of temperature sensor (air and radiative) to calculate comfort parameters. It is also possible to measure a 'globe' temperature, (which consists of an air temperature sensor surrounded by a black globe, which represents a balance between air temperature and radiative temperature), which tends to closely represent occupant perception of temperature in a single sensor.

Sensors may be wired or wirelessly linked to a BMS, send data to a separate data logger (such as the Performer hub) or may be stand alone, relying on battery storage and with only limited data logging capacity. Standalone units will generally only be used for short-term investigation of temperature variations within a space, rather than longer-term control strategies. Temperature sensors are likely to already exist in a building. They may already be linked to a BMS, or they may be utilised in 'closed loop' systems, for example within the controls of a localised heating system that may not log or store data measurements. If they do not operate with communication protocols that can allow integration with a BMS or data transfer to the PERFORMER hub, it may unfortunately be necessary to install new compatible sensors and/ or to duplicate those already in place.

9.1.2 Specific skills required for the installation

If temperature and/ or RH sensors are already linked with a BMS, it will just be necessary to ensure that the data output from the BMS to the PDW includes the sensor data. Depending on their level of knowledge of the BMS, this may be set up by the Building Manager or other appropriate building personnel. If the intention is to integrate new temperature and/ or RH sensors into the existing BMS, a specific BMS technician will be required. They will also need to ensure the sensor data is transmitted as part of the main data output from the BMS to the PDW.

If the intention is for the sensors to send data to the PERFORMER hub rather than a BMS, no specific skills are needed to install the sensors, although a basic understanding of electronics would be useful in order to link them to the PERFORMER hub, either wired or wirelessly.

If standalone sensors are to be used, no specific skills are required for their installation.

9.1.3 Installation considerations/ requirements

For PERFORMER, temperature should be reported in units of °C for consistency. If the intention is to measure ambient temperatures, sensors should not be placed in the path of direct sunlight or too close to any heating or cooling emitters (such as radiators, etc.). However, this may explicitly be required if using short term, temporary sensors to measure conditions in close proximity to occupants/ areas experiencing discomfort.

When placing sensors, the height above the ground should be considered depending on the activity anticipated to take place in an area. For instance, sensors should be placed at heights between 0.6-1.1m above the ground if occupants will generally be seated and heights between 1.1-1.7m where occupants will generally be standing. Temperature sensors outside these respective ranges may give misleading information compared to the perspective of the occupants. Other comfort parameters such as relative humidity are less susceptible to positioning and sensors can reasonably be placed elsewhere in a space.

9.2 CO_2 MEASUREMENT FOR AIR QUALITY

9.2.1 Introduction & background

The main reasons to measure carbon dioxide (CO_2) concentration in a building are to check if the ventilation rate is adequate and to ensure indoor air quality for the occupants. CO_2 is produced by combustion and human metabolic activity (respiration). All air contains CO_2, with concentrations externally generally higher in highly urbanised zones than in rural areas. Levels in indoor environments are further elevated compared to outdoors because of the containment. However, CO_2 is not generally considered to be a health concern at the concentrations encountered indoors, although it can affect occupant's attention spans and concentration levels, which is why it is often a factor of interest in schools and offices etc.

Efficient ventilation will help reduce internal CO_2 concentrations and measurements can actually be used to check if the ventilation rate is adequate to ensure indoor air quality for occupants. EN 13779 defines the following CO_2 concentrations for air quality:

- Excellent quality < 400 ppm
- Average quality 400-600 ppm
- Acceptable quality 600-1000 ppm
- Low quality > 1000 ppm

As such, CO_2 sensors are often used to trigger a change in ventilation rate in mechanically ventilated buildings or the automated opening of windows in naturally ventilated buildings to prevent the build up of high concentrations of pollutants. For PERFORMER, CO_2 measurements may be used to estimate behavioural patterns within buildings, to verify adequate ventilation and/ or for active control recommendations for Building Managers to improve occupant comfort. CO_2 decay at the end of working periods, i.e. as the CO_2 rich air following occupation returns to average external concentrations overnight (due to the inherent air infiltration rate of the building), can be used to determine air infiltration rates. Repeated sampling of this decay rate can give a background infiltration rate by averaging the results and may be the only proxy measurement for an existing building where pressurisation testing is not possible.

9.2.2 Specific skills required for the installation

If CO_2 sensors are already linked with a BMS, it will just be necessary to ensure that the data output from the BMS to the PDW includes the sensor data. Depending on their level of knowledge of the BMS, this may be set up by the Building Manager or other appropriate building personnel. If the intention is to integrate new CO_2 sensors into the existing BMS, a specific BMS technician will be required. They will also need to ensure the sensor data is transmitted as part of the main data output from the BMS to the PDW.

If the intention is for the sensors to send data to the PERFORMER hub rather than a BMS, no specific skills are needed to install the sensors, although a basic understanding of electronics would be useful in order to link them to the PERFORMER hub, either wired or wirelessly.

If standalone sensors are to be used, no specific skills are required for their installation.

9.2.3 Installation considerations/ requirements

CO_2 data should be reported in parts per million (ppm). Since CO_2 concentrations will be mixed throughout the air, readings are not particularly susceptible to positioning and sensors can reasonably be placed anywhere in a space.

9.3 Situation assessment using PIR/ light sensors/ window sensors

9.3.1 Introduction & background

The situation assessment is intended to provide insight into occupant behaviours and how occupants perceive comfort relative to the energy performance of the building. User activities may have a significant impact on the energy performance of buildings. The influence is low when occupants have limited control of energy systems (HVAC), equipment and other energy-consuming devices, or envelope components like windows and shutters, but it may become much more significant in other cases. For instance, in residential and office buildings, occupants may have control on the temperature set-point of heating or cooling systems, may be able to open or close windows, open or close blinds, switch lights off or on, or use certain appliances, etc., in a manner specific to each occupant and not easily predictable. In such cases, user behaviour may be a critical influence on the building energy performance.

The PERFORMER solution can collect information that can be used to qualitatively appraise the role of occupants in building energy consumption. It should be noted that, depending on the situation, an action can be interpreted as a basic 'non-energy-efficient' behaviour (e.g. lights left on in a room when unoccupied), or a reaction to discomfort conditions (e.g. windows are open because indoor air quality is poor). It is therefore necessary to analyse various parameters in order to correctly interpret how a user behaves, especially to know if this behaviour can be corrected or improved (e.g. through measures meant to foster user awareness), or if it reflects a system malfunction or non-optimised operation of the BMS or building services.

The use of sensors such as those detailed here, occasionally in combination with other data collected elsewhere (i.e. whether the heating, ventilation or cooling systems are operating for example) can detect patterns that can help explain user comfort and/ or offer opportunities for energy savings compared to standard building operating assumptions. The following situation indicators may be determined by the PERFORMER solution:

- **Time that a space is occupied**: Uses **PIR sensors** with a 5 minute timing gate to calculate periods of time that a space is occupied versus unoccupied
- **Heating use in unoccupied rooms**: Uses combination of **PIR sensors** as above, plus recognition of heating valve positions to determine if heating is on
- **Occupant discomfort from over/ under heating**: The PERFORMER platform can be utilised to detect if a different temperature set point is actioned compared to the typical reference/ programmed value. This can indicate if users are not comfortable with the pre-set conditions
- **Windows left open when heating is on**: Uses a combination of **window sensors**, plus recognition of heating valve positions to determine if the heating is running while windows are open
- **Windows open due to poor internal air quality**: Uses a combination of **window sensors**, plus **CO_2 sensors** (see section 9.2) to determine ventilation inefficiency causing discomfort
- **Lights on but blinds are down**: Uses **light sensors** in various configurations to correlate daylighting levels with artificial lighting usage. This could signify either user inefficiency, faults with light controls or blind positioning, inappropriate room configuration (i.e. with glare from windows)
- **Workstation usage**: Uses a combination of **PIR sensors** for occupancy with **equipment plug meters** (see section 8.11) to determine if equipment is left operational with no user present (generally only worthwhile for equipment where absent usage (i.e. running with no user present) is not normal)

Some of the above indicators rely on basic parameters being available from an existing BMS, such as whether heating/ cooling systems are active within a space and temperature settings compared with temperature set points. Some may require additional sensors:

PIR sensors

Passive Infrared (PIR) sensors measure movement within the proximity of the sensor by detecting infrared light radiating from objects. They are commonly used in automatically activated lighting systems and in burglar alarms to detect the presence of people. The sensor converts changes in incoming infrared radiation into a change in output voltage and thus triggers the detection/ change in state. They cannot 'count' the number of people that may pass by during a single activation, nor can they determine a direction of travel, although placement of a number of sensors may be able to provide an indication of direction depending on the sequence with which sensors are triggered.

Light sensors

Light sensors are often used to help improve energy efficiency in spaces by detecting ambient light levels, thus allowing electric lights to be dimmed or turned off when adequate natural light is entering the space. Greater savings may be achieved when used in combination with PIR sensors to ensure that lights are not used at all unless the space is occupied; such sensors are often combined into single units to save on costs and installation effort.

Window sensors

Units are essentially circuit switches and are made up of a sensor and a magnet; the sensor is fixed to the door/ window surround and the magnet is attached to the door/ window itself. A simple circuit is created by the magnetic current. Opening the door/ window disrupts the current, giving an 'open' notification to a corresponding recording unit.

9.3.2 Specific skills required for the installation

If the sensors are already liked with a BMS, it will just be necessary to ensure that the data output from the BMS to the PDW includes the sensor data. Depending on their level of knowledge of the BMS, this may be set up by the Building Manager or other appropriate building personnel. If the intention is to integrate new sensors into the existing BMS, a specific BMS technician will be required. They will also need to ensure the sensor data is transmitted as part of the main data output from the BMS to the PDW.

If the intention is for the sensors to send data to the PERFORMER hub rather than a BMS, no specific skills are needed to install the sensors, although a basic understanding of electronics would be useful in order to link them to the PERFORMER hub, either wired or wirelessly.

9.3.3 Installation considerations/ requirements

Depending on the indicators being assessed, basic information such as heating/ cooling valve positions, temperature controls and set points will be required for the spaces to be assessed. It should be verified that any necessary complementary data will be available before new sensors are pursued for situation assessment.

All units will require a power source; mains power will be most reliable but may be more onerous and costly from an installation perspective. However, the inconvenience of having to check and replace batteries could be more burdensome in the long term. Building managers should discuss these implications with installers prior to selecting units.

Although PIRs are not too sensitive to false readings, they should not be placed so they could be false triggered by activities occurring outside the required space or by heating or ventilation activities.

Light sensor readings will be recorded in lux. Light sensors should be placed to avoid direct sunlight or artificial light entering the sensor (unless that is specifically the intention). If the aim is to determine the light level at a working surface, sensors should be placed so as to capture the light in the working area (i.e. with a narrow field of vision over the working space). Ensure the sensor is not obstructed by obstacles, such as pendant lights that will cast shadows. Sensors should also avoid viewing reflective surfaces, as this could interfere with correct readings.

Window sensors will report on an open or closed circuit so will report as durations of open and closing. Sensors may be fixed with adhesive or more permanently fixed with screws. The selection of sensor may depend on the likelihood of tampering and whether the solution will be short or long term.

10 CONCLUSION

This monitoring protocol offers advice about testing methodologies and the installation of monitoring equipment that may be adopted as part of the PERFORMER solution in order to close the performance gap between expected and actual building energy usage. The guidance is not intended to replace specific installation guidance from manufacturers, but is instead aimed at clients and building managers to ensure they employ appropriate professionals and understand the key considerations of any potential equipment or method. Carrying out tests and/ or installing equipment in keeping with these recommendations should ensure that high quality data can be collected that can be utilised by the PERFORMER solution to provide accurate guidance to building managers.

ANNEXE A: PROACTIVE METHODS OF COMMISSIONING/ DATA VALIDATION

INITIAL/ SETUP CHECK OF SENSORS

Any meters/ sensors (existing or newly installed) that will be relied upon for the generation of data for the proposed building should be checked for correct operation. For newly installed sensors/ meters, this is likely to be a routine part of the installation process. However, it is important that any existing sensors/ meters are checked and their correct operation verified.

This will require examination of the acquired data from the sensors/ meters in whichever local visualisation tool is available, e.g. BMS, other interfaces for logging equipment. Essentially, it should be checked that the sensor is reliably logging data and that the values are sensible. Some sensors may need to be physically tested by activating them to ensure they provided the required response, for example, checking that window opening sensors work in both open and closed states. Anything found to be performing incorrectly should be rectified by the installers.

Actions:

Installers to carry out a physical check of sensor/ meter data collection and correct operation:

- Primarily by examining output data (locally) from all sensors due to be uploaded to the PDW
- Some sensors may require activation/ forced change of state to confirm they are working correctly
- Manual cross checks of known values such as meter readings (visually checked) with collected data

SET UP OF MEASUREMENT UNITS

There are many variables that may carry different units of measurement. For example, gas fuel may be measured by its physical volume (e.g. m3), or by its energetic value (e.g. kWh, BTU). But even once this is standardised, it is still quite likely that variables may be measured with different orders of magnitude, i.e. kWh vs MWh.

This activity may form part of the previous task of ensuring that sensors and meters are measuring correctly. It should also be checked that data from the sensors is in the correct units and displaying the correct order of magnitude. The measurement units will be transmitted within the meta-data to the PDW and will then be used for any subsequent calculations. Hence it is essential that the units are set up correctly at the source. If the building manager requires the final measurements to be displayed in the visualisation tools in different units to those collected by the sensor/ meter, the installers/ technicians will need to arrange for the relevant conversion to take place within the data prior to it being uploaded to the PDW.

Actions:

- Installers will need to check that the data collected by the sensors/ meters is reported in the correct units and at the correct order of magnitude. This will primarily be done by examining output data (locally) from all sensors due to be uploaded to the PDW
- If the building manager requires the final KPI data to be displayed in different units to those used by the sensor/ meter, they will need to make their own arrangements for the relevant conversion to take place within the data before it is uploaded to the PDW

BOUNDARY SETTING

Building managers will need to set sensible boundary limits for relevant parameters; this is not only useful for fault detection and diagnosis but also a more fundamental check that the data is of the correct range and magnitude for its anticipated use. This then forms part of the meta-data that is associated with the variable(s) when uploaded to the PDW. A template has been separately produced which should be completed by the building manager uploaded for implementation on the PDW. This will only apply to sensors where conditions vary (e.g. temperature sensor, CO_2 sensor), rather than cumulative meters and counters (e.g. electricity meters), for which no limit should be set.

The aim of this activity is to set realistic boundaries that may be expected for each sensor during operation. If outside these boundaries, the data would be suspected as being erroneous. For example, in a room it may be expected that the temperature should not fall below 16ºC and not go above 28ºC if all services are operating correctly. Hence, if the sensor returns a reading of 10ºC or 40ºC it would be anticipated that the sensor is faulty or the heating/ cooling services are not operating correctly and require attention. Based on the set boundaries, the PDW would flag an error when there is an attempt to upload it and notify the building manager of the potentially erroneous sensor/ variable for them to investigate the fault.

Once this calibration exercise is carried out at the start of the monitoring process, it would not be anticipated to need repeating unless the activities within a space (and hence the expected conditions) are changed.

Actions:

- Building manager to complete the provided template for boundary limits they would consider sensible for relevant variables. Refer to CSTB if assistance is required for uploading this data to the PDW.
- This applies to existing sensors plus any new sensors.
- Users should pay particular attention to the expected location of each sensor – sensors of the same type will not all necessarily have the same boundaries, e.g. a conference room is likely to have different acceptable boundary limits to a spa/ leisure area.
- If it is not possible to estimate sensible ranges, seek support from PERFORMER technical partners who may be able to offer advice on suitable boundaries or help investigate the possibilities.