Final report documenting the final version's algorithms and methodology

By

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Project websites:

Main website: http://www.iservcmb.info
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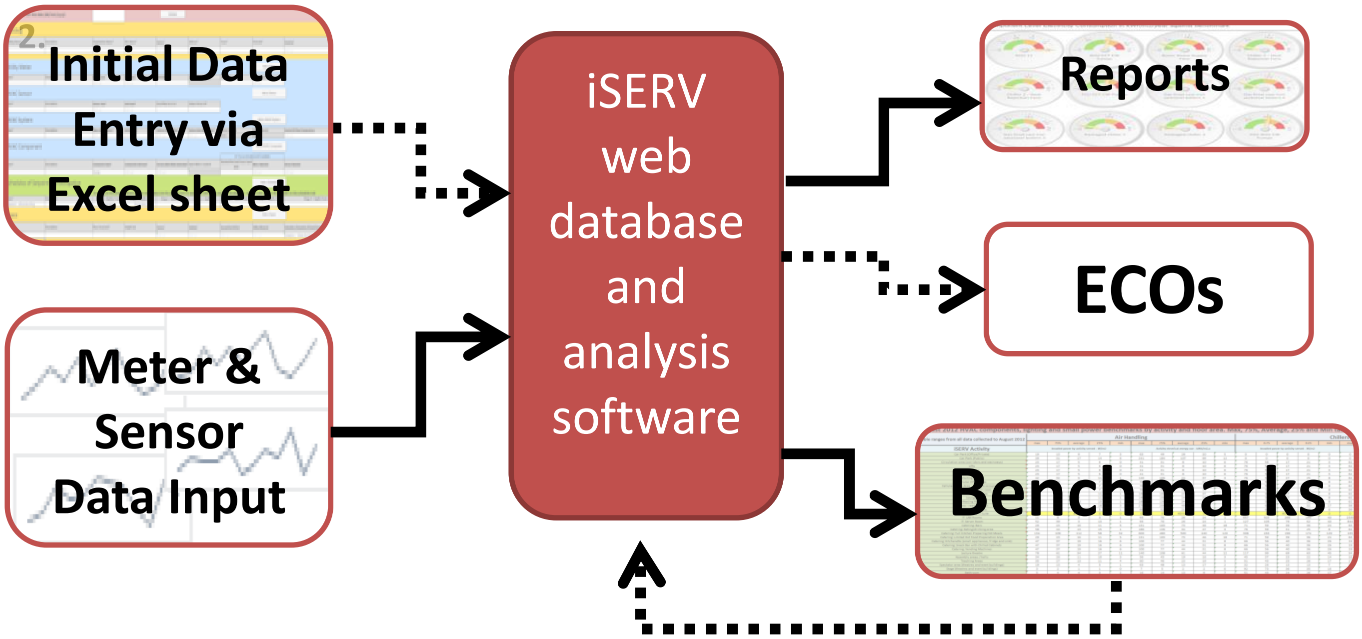
1. iSERV Application Overview

The main iSERV applications physical processes are shown below:



2.1 Data Entry via Excel Sheet

The iSERV application has been designed to allow a HVAC system to be configured so that it is connected to its Building, Components, Sub-Components, Spaces, Activities and Meters. This configuration takes place in the iSERV Configuration Excel spreadsheet and on completion is loaded into the iSERV database.

2.2 Meter & Sensor Data Input

Once a configured HVAC system is available in the database its meter and sensor data can be loaded into the system. This is done via .csv and .txt files which are emailed to the system via a unique email address.

2.3 Reports

The iSERV system will produce standard Building, HVAC and Component reports for a HVAC system based on:

- the configuration of the Building and HVAC system
- the uploaded meter and sensor readings

- the component level benchmarking for the HVAC Components

2.4 Energy Conservation Opportunities (ECOs)

The iSERV system will produce ECOS for HVAC Systems. The outputs will be produced using the Reporting framework. These ECOs will depend on:

- the configuration of the Building and HVAC system
- the uploaded meter and sensor readings
- The ability of the Liege and Ljubljana algorithms to identify and then quantify the savings to be made at the Building, HVAC System and Component level

The number of ECOs that can be produced will depend on:

- the configuration of the building, HVAC systems, components and corresponding schedules;
- the availability of sub-hourly meter data at the building, HVAC system and components level;
- the availability of sub-hourly sensor data at the building, HVAC system and components level;

2.5 Benchmarks

Benchmarks are central to the iSERV project:

- benchmarks are currently produced at an annual consumption level and are recorded in units of kWh per m2 per annum;
- there is a benchmark for each combination of utility, component sub-type and activity;
- for each utility, component sub-type, activity combination the following benchmark values are commonly used:
  - min = the minimum value possible (excluding erroneous outliers by the use of Least Squares Fitting),
  - max = the maximum value possible (excluding erroneous outliers by the use of Least Squares Fitting),
  - 25PC = min + (max – min) * 0.25,
  - 75PC = min + (max – min) * 0.75,
  - Average = the average value,
- benchmarks have been drawn from a wide variety of sources and can vary over time. They have been produced by Cardiff University and Politecnico di Torino. These benchmarks have been loaded by K2n into the HERO system so that bespoke benchmarks can be produced at the HVAC System level.

- there are over 15,000 benchmarks combinations for: utility, component sub-type and activity
- they are used as the basis for apportioning data between components and spaces where detailed sub-metering is not available,
- benchmarks are used as the yardstick against which rolling annual consumption per m2, at the system and component level, is compared.

3. iSERV Application Entities

The following tables show the main entities of the iSERV database. All of the tables will, in this version, hold the minimum fields the K2n application expects to store for a HVAC system process. The number of fields will increase as the project progresses.

3.1 Building

Buildings must be divided up into spaces. A building must have at least one space.

Building
Building_Id
Building_Name
Building_Description
BaseTemp_Id
Building_Floor_Area_m2
Governed_By_HVAC_Schedule_Id
Control_Of_HVAC_Temperature_Type_Id
Construction_Month
Address1
Address2
Address3
Town
Postcode
Property_Reference_Code
Country_Id
UPRN
GPS_Lat
GPS_Long

Notes on the fields:

- The UPRN is a Unique Property Reference Number used in the UK – it is included here to align with Member States who also use a UPRN type system;
- The GPS coordinate field is for use in the whole of the EU to enable identification of location. It may end up as more than one field. The GPS coordinates will be used to show the general location of the Building within a radius that does not allow identification of the specific location, unless the owner agrees to this identification;
- The Governed_By_HVAC_Schedule_Id defines which HVAC schedule the building is using;
- Control_Of_HVAC_Temperature_Type_Id allows for users of the building to see the temperature
- The town and country are visible so that it is possible to easily identify the location of any buildings registered on the system so that the distribution of buildings across geographical areas can be established;

3.2 Space

A building must be described in terms of its constituent spaces. Each space must have a name, a start month, an activity and its gross internal area in m^2 as a minimum. If a HVAC system exists for this space it must be attached to that specific HVAC system process. The activity type, area and the space's link to a HVAC system are key parameters in setting benchmarks for HVAC systems.

Space
Space_Id Building_Id Space_Name Space_Description Space_Id Space_Floor_Area_m2 Activity_Id Governed_By_HVAC_Schedule_Id Control_Of_HVAC_Temperature_Type_Id Space_Height_m

Notes on the fields:

- An activity is used to help produce a benchmark on a utility basis. Office would be an example of an activity; it also allows a space to link to multiple Process Types as the iSERV application can support multiple processes per space – to allow for lighting for example – but for the iSERV project only HVAC processes will be configured;
- The link table *SpaceLocationOfHVACComponentLink* allows a set of process component to be physically located in the space;
- The link table *SpaceLocationOfMeterLink* allows for meters to be also physically located in the space;
- A composite activity is automatically selected, when a space is attached to an HVAC system process and its components. A benchmark for all relevant utilities is selected based on the activity of the space, the utility and the attached HVAC component and sub component types;
- The Floor Area (m^2) is the Gross internal floor area (GIA) for each space in m^2. It is defined as the area measured from the internal face of any external walls to the centre line of any internal separating walls which define the space;
- HVAC Schedule can be specified at the space level to over-ride the setting at the building level;
- Schedule of setpoints can be specified at the space level to over-ride the settings at the building level;
- Where there are numerous spaces with the same characteristics (activity) served by the same HVAC system it will be possible to create one space in the system with the total area.

3.3 HVAC System

The iSERV application has been designed to handle HVAC systems as a process. A HVAC system is made up of components and meters and is attached to specific spaces, and hence activities, within the building.

The HVAC system must be able to clearly account for ALL the electrical energy consumption used to meet the requirements for ventilation and air conditioning to the spaces it serve.

The three areas of functionality; components, meters and spaces, are dealt with in detail in the sections below this.

HVAC System
HVAC_System_Id
HVAC_System_Name
HVAC_System_Description
System_Type_Id
System_Classification_Id
System_Sub_Classification_Id
Main_HVAC_System
Control_Of_Flow_Temperature_Type_Id

Notes on the fields:

- The process name is the building owner's name for the HVAC system;
- For iSERV the process type will always be "HVAC". The K2n application supports multiple process types – lighting, small power are examples of other process types;
- HVAC System Type. HVAC systems are further defined in terms of their System Classification and System Sub-Classification. The table below holds a list of these HVAC system process types from which the end user can choose. A HVAC system process type when linked to a space's activity will produce a composite activity for that space;

System Types
Cooling and Mechanical Ventilation
Cooling and Mechanical Ventilation plus local Heating
Cooling and Natural Ventilation
Cooling and Natural Ventilation plus local Heating
Full Air Conditioning (heat/cool/vent and RH)
Full Air Conditioning (no RH control)
Heating and Mechanical Ventilation
Heating and Mechanical Ventilation plus local A/C
Heating and Natural Ventilation
Heating and Natural Ventilation plus local A/C
Heating, Cooling and Natural Ventilation
Mixed-mode with Mechanical Ventilation
Mixed-mode with Mechanical Ventilation plus local A/C
Mixed-mode with Natural Ventilation
Mixed-mode with Natural Ventilation plus local A/C
Domestic Hot Water System

- *Full air conditioning is heating, cooling and ventilation, with no humidification/ dehumidification, whereas mixed mode is the use of heating, mechanical vent and cooling only when the external conditions are not favourable for natural ventilation and passive heating/cooling;
- System Classification. The system classification is derived from the HARMONAC categorisation of HVAC systems using elements from the CEN, ASHRAE and CIBSE classification systems. The main HVAC system classification will be Centralised or Non-Centralised. Beneath this there will be the sub-classification with choices from five non-centralised and eleven centralised HVAC process systems. Six of the centralised options will be Air-Based derivatives. The table below shows the Centralised or Non-Centralised HVAC process system names:

Centralised Systems	Non-Centralised Systems
All Air Single Duct CV	**Single Packaged Unit**
All Air Single Duct VAV	**Singled Duct Unit**
All Air Dual Duct CV	**Split Packaged Unit**
All Air Dual Duct VAV	**Multi-Split Packaged Unit***
All Air Displacement Ventilation	**Water Loop Heat Pump**
All Air Low Temperature System	
Water Based	
Air & Water	
Water Source Heat Pump	
Ground Source Heat Pump	
Air Source Heat Pump (ASHP)	

- *A centralised system usually means a system supplying all or the majority of a building with the associated plant room space, etc. Multi-Split Packaged Units are normally seen as supplying small areas of a building as opposed to whole buildings. They can however supply the whole of a small building. For the iSERV project they are considered to be non-centralised systems;
- Schedule of Setpoints governs the temperatures to which the HVAC system's cooling and heating will be applied. If the schedule is set at the process level then all of the spaces served by the process inherit this schedule. If required the schedule can then be over-ridden at the space level. The schedule is specified as follows:
  - Day of week (1-7);
  - Start Time;
  - End Time;
  - Heating setpoint;
  - Cooling setpoint;
  - Notes.
- Heating Set. The room temperature setpoint which an HVAC system would be trying to maintain when heating is required. A setpoint will have a 'dead band' around it so when the heating setpoint plus say 1.5 °C is reached then the heating will turn off. When it drops 1.5°C below the setpoint then the heating will come back on;
- Cooling Set. The room temperature setpoint which an HVAC system would be trying to maintain when cooling is required.

*The schedule can be set in the HVAC & Building Excel Spreadsheet.

It should be noted that the types of components used by a HVAC system will be used to further categorise a system at the reporting level. Common HVAC systems that might need more detail of how to categorise them would be:

- VRF/VRV – Non-centralised split packaged unit if just one indoor unit, or non-centralised multi-split packaged unit if more than one indoor unit;

- Rooftop units – these are considered as non-centralised single packaged units, even if they supply the whole of a small building

- AHU's containing DX coils – Description depends on how the AHU fits into the larger system type.

3.4 HVAC Components and sub-components

A component or sub-component is the generic description of any item of equipment that might comprise an HVAC System process. An HVAC process, as already described in 2.3, consists of

HVAC components and sub-components. A component or sub-component can belong to one or more HVAC System processes. Examples of this would be a chiller or air handling unit. Each HVAC component (categorised by its component type) represents one or more HVAC sub-components.

Examples of component types would be: cold generators, heat generators, humidifiers, hot and cold water pumps, Air Handling Units (AHU's) and fan coil units. Examples of sub-components would be: fans, pumps, heat exchangers, etc e.g. the components of an AHU.

HVAC Components
HVAC_Component_Id
HVAC_Component_Name
HVAC_Component_Description
Component_Type_Id
Component_Sub_Type_Id
Nominal_Electrical_Power
Parent_HVAC_Component_Id
Nominal_Heat_Rejection_Capacity
Coefficient_Of_Performance
Energy_Efficiency_Rating
Seasonal_Energy_Efficiency_Rating
European_Seasonal_Energy_Efficiency_Rating
Equipment_Serial_Number
Year_Of_Manufacture
Nominal_Cooling_Capacity
Nominal_Heating_Capacity
Nominal_Heating_Power_Input
Maintenance_Contract
Date_Of_Last_Maintenance_Visit
Date_Of_Next_Maintenance_Visit
Equipment_Manufacturer
Equipment_Range
Equipment_Model
HVAC_Component_Notes
Maintenance_Trigger

Notes on the fields:

- The component or sub-component name is the building owner's name for the HVAC component e.g. North AHU;
- The component is connected to the HVAC process via the link table
- The component type and sub-type is used to give the component or sub-component a generic component type that can be used for analysis.
- Nominal Power a fixed value which can be used to calculate the power being used by a component if a meter is not attached. Unmetered components are assumed to use energy on a worst case basis. Data is stored as kW but can be entered as Watts;

- A component can be connected directly to a Meter via the link table *HVACComponentMeterLink*,. This meter will automatically become a sub-meter of the main incoming HVAC system meter. If a meter is not provided then a nominal power rating MUST be provided;
- The Parent Component field allows for a hierarchy of components to be defined e.g. an AHU might have a supply fan, an extract fan, a plate heat exchanger, heating coils and cooling coils as sub-components;
- Space Where Located is an optional field, which can be used to identify the space in which the component is physically located. This is different to the spaces that the component serves which is handled by the *SpaceHVACSystemLink* table relationship which attaches components to spaces at the HVAC systems level

The table below shows the Component and Sub-component Types available:

Heat Generator with Sub-types
Water Source Heat Pump (WSHP)
Ground Source Heat Pump (GSHP)
Air Source Heat Pump (ASHP)
Fuel Fired Boilers
Electric Boilers
Biomass boiler
Co-generation
CHP (Combined heat and power)
District Heating
Solar collectors (to evaluate)
Solar Hot Water Panels
All in One System with Sub-types
ASHP Heating Only
ASHP Cooling Only
ASHP Reverse Cycle - Heating Optimised
ASHP Reverse Cycle - Cooling Optimised
GSHP Heating Only
GSHP Cooling Only
GSHP Reverse Cycle - Heating Optimised
GSHP Reverse Cycle - Cooling Optimised
WSHP Heating Only
WSHP Cooling Only
WSHP Reverse Cycle - Heating Optimised
WSHP Reverse Cycle - Cooling Optimised

Cold Generator with Sub-types
Reciprocating Liquid Chillers Centrifugal Liquid Chillers Screw Liquid Chillers Scroll Liquid Chillers Absorption Chillers Direct evaporative cooler Indirect evaporative cooler Dry Coolers & Cooling Tower
Humidifier Component with Sub-types
Electric Steam Waste heat Gas Water Spray Vaporizing Air Washer
Dehumidifier with Sub-types
Dessicant wheel dehumidifier*
Air Handling Unit (AHU) with Sub-types
Supply only Extract only Supply and extract Supply with heating and cooling variants Supply and extract with heating and cooling variants, etc Fresh air only or Mixed air
Pump with Sub-types
Hot water primary pumps Hot water secondary pumps Chilled water primary pumps Chilled water secondary pumps DHW primary pumps DHW secondary (circulation) pumps Condenser water pumps
Terminal Units with Sub-types

Electric radiators Water radiators Underfloor heating Heated ceiling panels Passive heated beams Active heated beams Chilled ceiling panels Passive chilled beams Active chilled beams Chilled pipes in fabric : - 2or 4 tubes Fan Coils – 2 or 4 tubes Induction units – 2 or 4 tubes VRV/VRF indoor unit DX indoor unit
Storage systems with Sub-types
Cold water buffer tank Hot water buffer tank Ice storage tank PCM (phase change material)
Heat rejection with Sub-types
Air condensers Dry cooler Evaporation cooler Forced air condensers Natural Draft Towers Mechanical Draft Towers Closed Circuit Cooling Towers Open Circuit Cooling Towers
Heat recovery with Sub-types
Run-around-coil Heat Recovery (Air/Water) Plate Heat Exchanger (Air/Air) with/without by-pass Rotary Wheel Heat Exchanger sensible/sensible + latent Recuperator Heat Recovery Heat pipe (DX heat recovery)
Heat Pump with Sub-types
Air source reverse cycle - heating optimised Air source reverse cycle - cooling optimised Ground source reverse cycle - heating optimised Ground source reverse cycle - cooling optimised Water source reverse cycle - heating optimised Water source reverse cycle - cooling optimised
Flow Control with Sub-types

Motorised Damper
Motorised Valve
Direct Variable Speed Drive
Magnetic/Viscous/Slip Coupling Variable Speed Drive

* We are only concerned here about additional equipment installed that is specifically designed to dehumidify in addition to that possible through the normal cooling coils.

3.5 Meters

Meters monitor the consumption of energy and water. Their consumption data can be in the format of meter readings or consumption values. Both will be stored a Meter Reading table with a meter reading, a date and time stamp and a native and calculated consumption.

In order to fully measure the energy consumption of a HVAC system we need the following meter configuration:

- One or more main incomer kWh meters connect to the HVAC System
- A set of sub-meters which have the main incomer as a parent and can be connected directly to one or more components such as Chillers and AHUs.

Meters
Meter_Id
Meter_Name
Meter_Type
Meter_Description
Meter_Point_Ref_No
Meter_Parent_Id
Unit_Id

Notes on the fields:

- The Meter Type categorises a meter with a standard type. For example: Gas, Electricity, Water, Temperature, etc.;
- The Parent Meter field allows for sub-metering;
- The Unit categorises a meter with a standard unit type. For example cubic metres, litres, and kWh

For the iSERV project the following meter types will be enterable into the system:

Meter	Unit	Precision (dp)
Fixed Schedule (Fixed energy inputs)	kWh	2
Coal	tonnes	2
Electricity	kWh	2
Gas	m^3, 100s cu ft, litres	2

Gas/Diesel Oil	m^3, 100s cu ft, litres	2
Heat Meter	kWh	2
Heat Meter - Cooling	kWh	2
Heat Meter - Heating	kWh	2
LPG	m^3, 100s cu ft, litres	2
Oil	m^3, 100s cu ft, litres	2
Water	m^3, 100s cu ft, litres	2

Notes on the meter types:

- The Fixed Schedule Meter Type allows for an energy input to be entered against a schedule. For example, short term readings might have collected the average energy use for a particular HVAC component over time. This average energy use can be provided to complement the nominal power calculation that will be used for the 'official' consumption where dedicated meters are not available. This will allow the end user to get a better idea of the potential benchmark improvement they can expect by metering this component.
- A special Fixed Schedule meter is used where no dedicated meter is attached to a component. At present this meter will assume the component operates at its nominal power rating for 24 hours a day. This will automatically be calculated from the nominal power rating of the component.

3.6 Meter Readings

The Meter Reading table holds meter reading data. Readings can be held in time intervals from sub-hourly up to monthly data. The energy consumption for the meters serving the HVAC systems must be in a format that can be uploaded into iSERV via a standard set of file formats. An example of a file format can be seen in Appendix A.

This table forms the basis of the main consumption table. Information is held by a unique combination of Meter Id and Date and Time

Meter Reading
Meter_Id
Read_Date_Time
Month_Year
Meter_Reading
Native_Consumption
Native_Unit_Id

Notes on the fields:

- The Native Unit Id allows the iSERV system to standardise consumption within the system. For example Wh will be rounded up to kWh as will cubic metres of Gas.

3.7 Sensors

Sensors are used to record non-consumption type values; for example temperature. These readings will be used in the standard set of Reports as well as the identification and implementation of Energy Conservation Opportunities (ECOS).

Sensor
HVAC_Sensor_Id
Sensor_Unit_Type_Id
Unique_Sensor_Identifier
Installation_Date
Duct_Pipe_Area

Notes on the fields:

- The Sensor_Unit_Type_Id categorises a sensor with a standard type and unit. For example: Temperature in degrees centigrade, % of relative humidity, etc.
- The Unique_Sensor_Identifier is used to link the data file sensor identity to the internal iSERV sensor id field HVAC_Sensor_Id.

For the iSERV project the following sensor types will be enterable into the system:

Sensor	Unit	Precision (dp)
Temperature	Centigrade	1
Relative Humidity	%	0
Fluid Flow	Cubic m/hour or l/sec	2
CO2	PPM	0
Specific Fan Power (W/l/s)	SFP	2
Specific Pump Power (W/l/s)	SPP	2
Energy Efficiency Ratios (EER)	EER	2
On/Off Sensor	On/Off	0
Pressure	Pascal	0
Pressure Drop	Pascal	0
VOC	PPM	0

3.8 Sensor Readings

The Sensor Reading table holds sensors data. Readings can be held in time intervals from sub-hourly up to monthly data. The sensor data values for the HVAC system must be in a format that can be uploaded into iSERV via a standard set of file formats. An example of a file format can be seen in Appendix A.

This table forms the basis of the main consumption table. Information is held by a unique combination of Sensor and Date/Time:

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Sensor Readings
HVAC_Sensor_Id
Read_Date_Time
Month_Year
Sensor_Reading
Native_Value
Native_Unit_Type_Id

Notes on the fields:

- The Native Unit Id allows the iSERV system to standardise values within the system. For example Fahrenheit will be converted to Celsius.

The sensors have non-cumulative values. For example a temperature sensor which records an oscillating range of temperatures during the day. The table will have the same fields as the existing Sensor Reading table.

All the sensor meters default to assuming they are spot values. A flag will allow them to be 'average' reading meters if required.

The sensor values for the HVAC system must be in a format that can be uploaded into iSERV on a monthly or more frequent basis. The iSERV application will be able to import a standard set of file formats. An example of a file format can be seen in Appendix A.

3.9 Activity

All spaces in the building must have a mandatory activity. This activity in conjunction with the HVAC system and its components provide the benchmark which will provide the weighting for the apportionment of energy to the space.

Activity
Activity_Id
Activity_Name

3.10 Activity Weightings

An activity weighting is automatically selected, when a space and its designated activity is attached to an HVAC system process and its components. The benchmark selected is based on the activity of the space, the utility and the attached HVAC component and sub component types. The benchmark will be represented as a range of energy consumption and power. The boundaries will be in the range of 25%, 50% and 75% .

ActivityWeighting
Activity_Id
Utility_Id
Process_Component_Type_Id
Process_Component_Sub_Type_Id

ActTargetMin_kWhm2yr_PerUtility
ActTarget25PC_kWhm2yr_PerUtility
ActTarget50PC_kWhm2yr_PerUtility
ActTarget75PC_kWhm2yr_PerUtility
ActTargetMax_kWhm2yr_PerUtility
Installed_PowerMin_Wm2_PerUtility
Installed_Power25PC_Wm2_PerUtility
Installed_Power50PC_Wm2_PerUtility
Installed_Power75PC_Wm2_PerUtility
Installed_PowerMax_Wm2_PerUtility
Level_Of_Certainty

Notes on the fields:

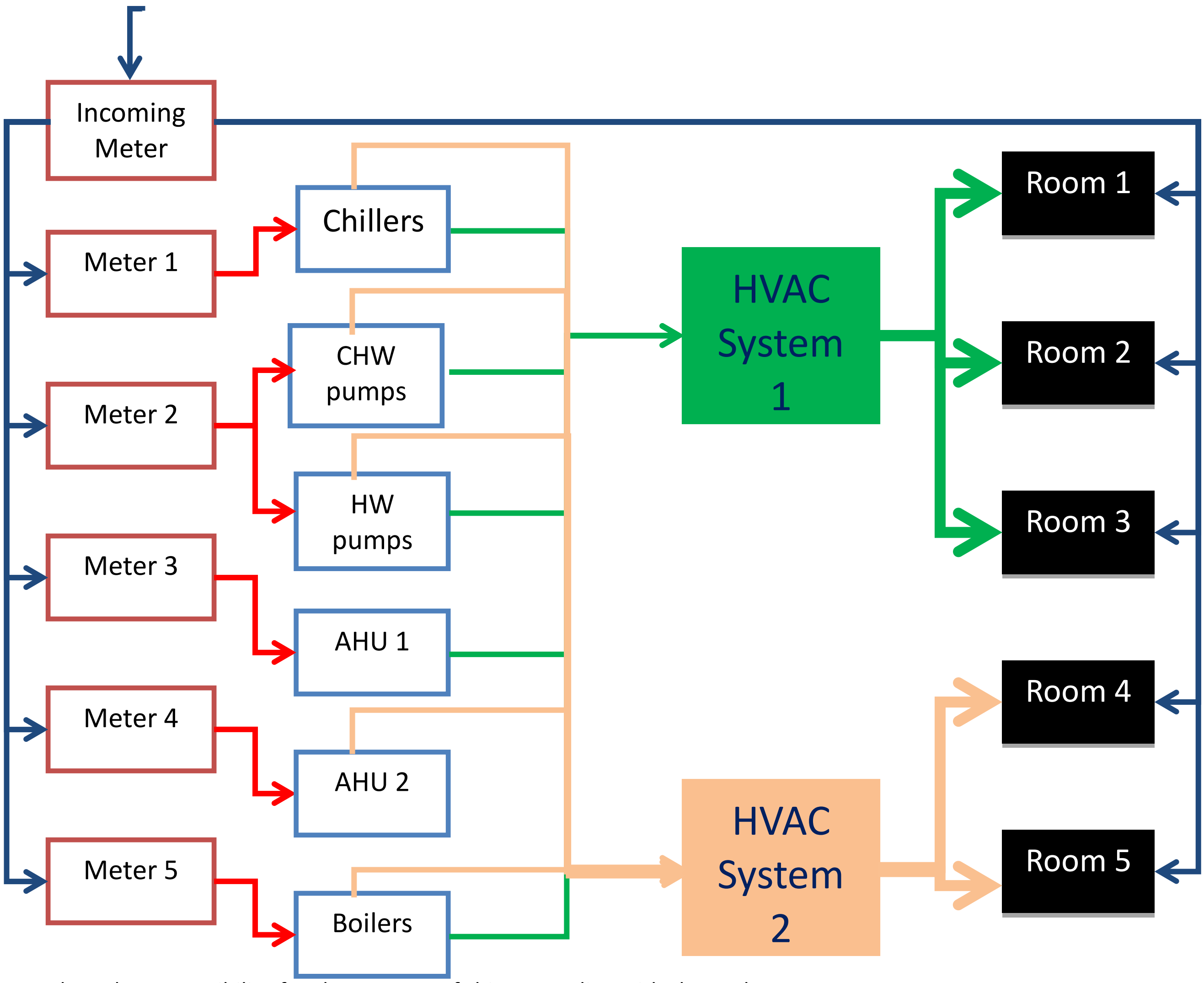
- The Target kWh per m^2 values will be based on rolling annual kilowatts per hour per m^2
- The Installed Power Wm^2 values will be based on watts per m^2
- The Level_of_Certainty field will represent the confidence the application places in the range of values. A reading of 100 would provide total confidence in the benchmark.

4. iSERV Application Processes & Algorithms

4.1 HVAC Configuration

The configuration below shows a common scenario in a building. The incoming meter has sub-meters Meter 1-5. These sub-meters are attached to one or more HVAC Components. The Boiler, Chiller and Pump components serve both HVAC System 1 and 2. The Air Handling Units 1 and 2 serve their corresponding HVAC Systems separately. These components are combined to create the two HVAC systems which are then attached to their required spaces. The Main incomer will also attach to other processes such as Small Power and Lighting. They are represented as a direct link to the spaces as they are not part of the iSERV system.

The manual configuration of this building will take place in the Data Entry Excel Sheet. The sheet and its data is automatically loaded into the iSERV application and stored in the SQL Server configuration tables. These tables are represented in Section 3.



4.2 Data Loaders & Unique Ids

Once the Data Entry Excel Sheet is loaded the elements that make up the configuration as described in 4.1 are loaded into the database. At this point the end user or partner should have also collected Meter/Sensor data for the Building and HVAC system. The user should check:

- The data files are in a .csv or .txt format only;
- The HVAC Unique Meter Ids match the iSERV Unique Meter Ids in the data files;
- The Unique Meter Ids are unique to the building or organisation (if the meters for multiple building are in the same file);
- That the data is computer readable in a repeatable format and does not contain; random comments, sub-totals or totals.

4.3 Consumption Apportionment at a Space Level

HERO calculates the consumption for each: meter, component and connected space combination (MCCS). This MCCS consumption is aggregated up to produce reports at component, system and system type levels. Given that not all MCCS combinations are sub-metered it is necessary to apportion consumption using a weighting algorithm.

The weighting algorithm works as follows:

- each MCCS combination gets a weighting that is calculated by multiplying the space's area in m2 by the average benchmark for the component sub-type and the meter utility type and then dividing it by the sum of all of the weightings for the meter,
- the meter's consumption is then multiplied by this weighting factor to apportion the consumption to the MCCS combination.

4.4 Main Incoming Meters, Sub-Meters and Unallocated Consumption

In HERO meters cannot be connected directly to a space or a system. The meters are connected to components, which are connected to systems and the systems are then connected to spaces.

Meters need to be attached to all the end uses they supply; otherwise their consumption will not be properly apportioned. This includes connecting them to uses other than HVAC components; for example lighting and small power components.

The main incomer is the meter that measures the consumption of the whole building. If a main incomer is specified and has sufficient consumption data then it is possible to report on the whole buildings consumption. If there is no main incomer then it is only possible to report at the level of specific systems within the building: small power for example.

Sub-meters are meters that are connected between the main incomer and any components that consume energy – air handling units for example. If a building has sub-metering then it is possible to get a better understand the consumption of the systems within the building than would be possible with only a main incoming meter.

Sub-meters are connected in a hierarchy with a top level parent meter (usually the main incomer) along with the child sub-meters. It is possible to have many levels in the hierarchy with a parent meter being both a parent and a child meter. A child meter can only have one parent meter.

The consumption from sub-meters is subtracted from the parent meter and any remaining consumption is apportioned across any components that the parent meter is directly connected to. If the parent meter is not directly connected to any components then this remaining consumption is "unallocated". If the sum of the sub-meters is larger than the parent meter then there is an issue with either the accuracy of the parent meter, the accuracy of one or more of the child meters or the discrepancy has been introduced by missing/corrupt meter data.

4.5 Sub-Hourly Data

Sub Hourly Data, in the form of Meter and Sensor data is required for detailed reporting and for the production of the majority of the iSERV ECOs

4.5.1 Meter Data

Meter data is used to measure and aggregate consumption via meter readings or actual consumption figures.

4.5.2 Sensor Data

Sensor data is used to measure spot values over time. Sensor data cannot be aggregated.

4.6 Data Aggregation

The iSERV system aggregates up sub-hourly data to a monthly reading. This allows the iSERV system to show trends in consumption over long periods of time.

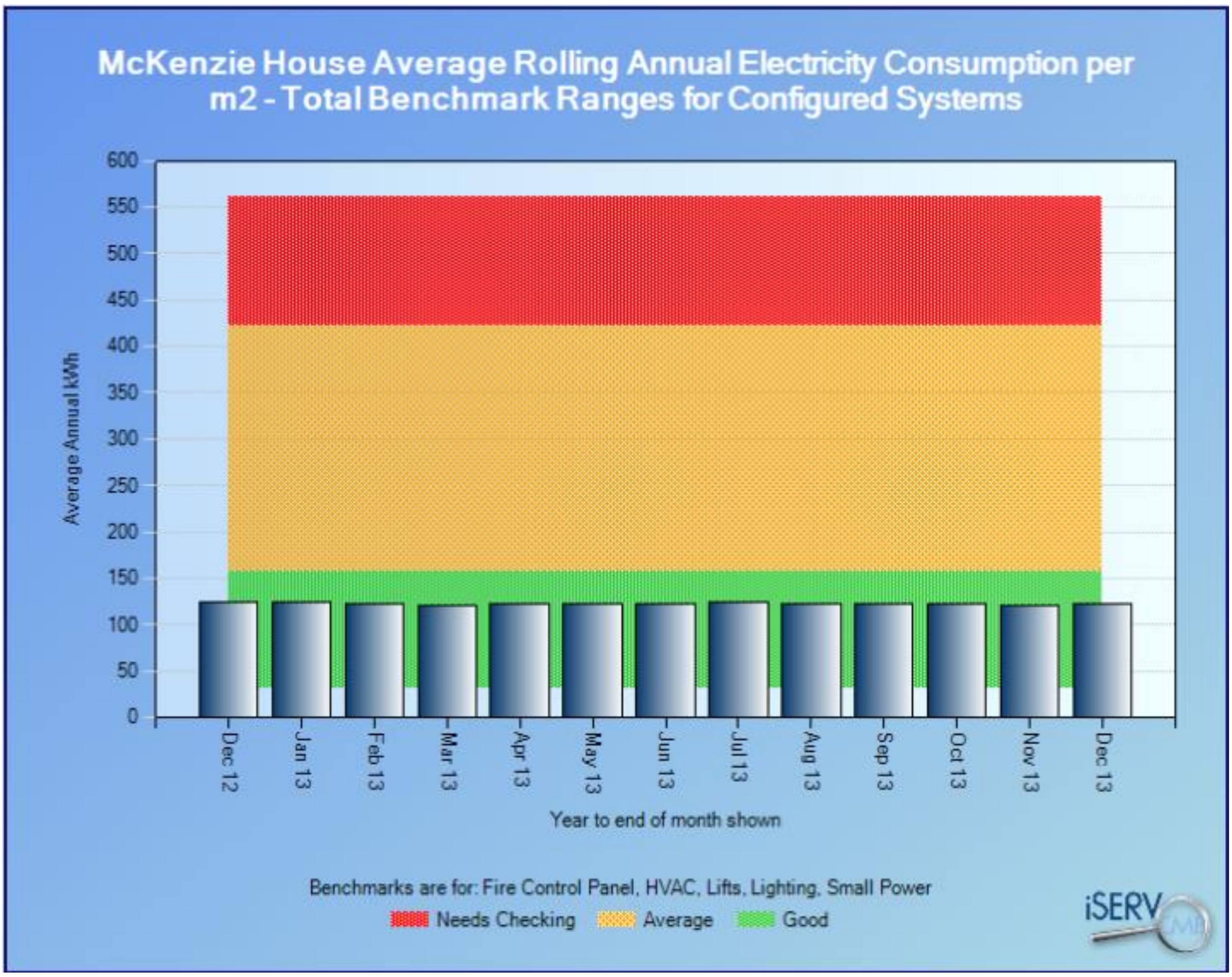
5. BENCHMARKS

Benchmarks can be calculated at the: organisation, site, building, system, component and space level. The algorithm that is used to calculate the benchmark is basically the same for each level with a variation depending on the level of aggregation that is required. Benchmarks are calculated at the min, 25PC, 75PC and max levels. To calculate the 25PC electricity benchmark for a system for example the following algorithm is used:

- For each space that the system serves: sum up the 25PC benchmarks for each component type in the system;

- Multiply this by the space's area in m2 to give the space's system benchmark;
- Sum up the space system benchmarks and divide this by the sum of the area of all of the spaces to give the system's 25PC benchmark.

The benchmark indicates the expected consumption for the system per m2 per year. The benchmark ranges are charted in a RAG format with red being between 75PC and max, amber being between 25PC and 75PC and green being between min and 25PC. An example benchmark report for McKenzie House – which is categorised as good - is shown below:



5.1 Rolling Annual Consumption per m2

Benchmarks are produced at the component, utility and activity level and are measured using Rolling Annual Consumption per m^2 where consumption is based on the standard units for the utility.

Rolling Annual Consumption is measured in monthly intervals. Each monthly interval is the sum of the current month's consumption plus the previous 11 months. This equates to one year's consumption per interval. The equation below show a sequence of 6 months' worth of rolling annual consumption:

$$\sum_{-11mnth}^{1mnth} cons^{1}, \quad \sum_{-11mnth}^{1mnth} cons^{2}, \quad \sum_{-11mnth}^{1mnth} cons^{3}, \quad \sum_{-11mnth}^{1mnth} cons^{4}, \quad \sum_{-11mnth}^{1mnth} cons^{5}, \quad \sum_{-11mnth}^{1mnth} cons^{6},$$

mnth = Month,
cons = consumption for a given area

Rolling Annual Consumption per m2 is simply Rolling Annual Consumption divided by the area of the space or spaces consuming the energy:

$$\sum_{-11mnth}^{1mnth} \frac{consumption}{area\ served}$$

5.2 Benchmark Generation

The benchmarks were compiled by Cardiff University from a number of sources and then loaded into HERO. A set of trusted benchmarks will be derived by Cardiff University.

6. Reporting

There are 200+ chart and tabular reports that can be generated by HERO. There are reports at the organisation, site, building, system, and component level. Groups of charts and tables can be combined into pre-configured report sets. HERO auto-generates a standard report set per building which contains a number of charts that show the detailed consumption of the building and the systems within it. Report sets can be run on demand or in batch mode based on a schedule of daily, weekly or monthly frequency. Report sets run in batch mode are delivered as attachments in emails. Reports can be output in Word, Excel, PDF or XML format.

7. ECOs

The ECOs and HARMONAC Tools are a set of equations based on the research undertaken in the AUDITAC and HARMONAC EU projects. The equations will be available under ECOs and Modelling Tools.

The equations detect Energy Conservation Opportunities. Not all of them apply to the HVAC System and Components. The ECOs are listed in section 7.3.

ECOs & Harmonac Tools use the same iSERV report module as the reports to produce the reports after they have gone through a custom pre-report process.

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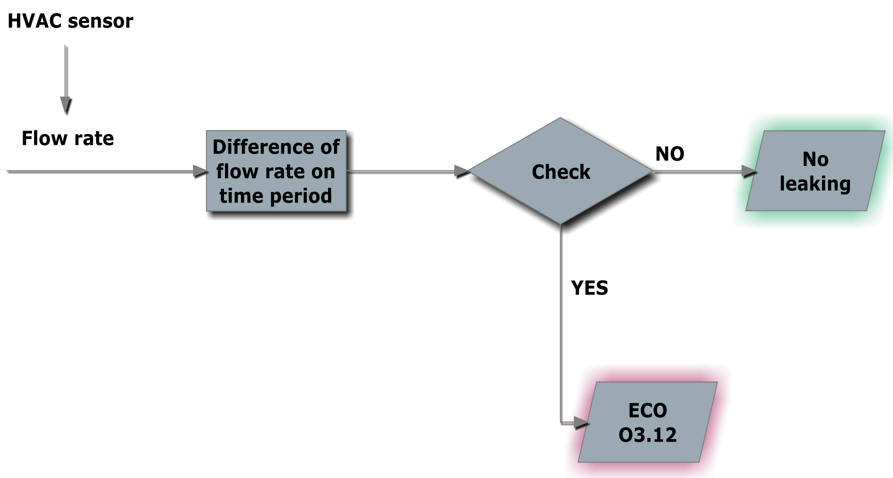
7.1 ECO Application Framework

The ECOs have been written as collaboration between K2n, UL and ULg. UL and Ulg have written ECOs, and K2n have integrated them into HERO. The ECOs are available through ECO reports that are scheduled and run in the same way as any other HERO report.

The ECOs are written in MATLAB, compiled into ASP.NET packages and then executed through HERO using the MATLAB Compiler Runtime. The ECOs use JDCB to read the data that they require from the database. The output from each ECO is a flag indicating whether the ECO could be applied, a set of values indicate min, max and average savings and a list of comments/assumptions that have been made.

7.2 Example ECO Process - Replace ducts when leaking (P3.12)

Below is an example of an ECO process diagram. The ECO is implemented as a MATLAB function. For the ECO to be applicable there needs to be a Flow Rate sensor attached to the HVAC system and producing data. If there is no flow rate sensor or there is a flow rate sensor but no data then the ECO sets the flag to indicate that the ECO cannot be applied and terminates. If there is data then the function checks whether there is a difference in flow rate that would indicate a leak. If there is a difference the function will generate an estimate of the potential savings that could be made if the leak in the HVAC system were fixed.



Appendix A Example Meter Reading File Format

Meter data comes in a number of formats, some with one line per day and multiple columns for the time slots, and others have one line per timeslot. The iSERV application will be able to import a small number of defined file formats as there will be no online support available. The data below is an example of half hourly electricity consumption:

			00:00	00:30	01:00	01:30	02:00	02:30	03:00	03:30	04:00	04:30
COREMPAN	Date	Reading Type										
2199989614924	01/10/2009	kWh	57.7	57.6	57.1	57.3	56.7	56.5	57.8	61.3	64.5	75.3
2199989614924	02/10/2009	kWh	58.1	58.4	57.2	58.6	58.6	58.5	59.6	62.3	71.8	79.9
2199989614924	03/10/2009	kWh	54.3	54.2	53.5	54.1	53.7	54.3	55.7	56.9	57.6	58.3
2199989614924	04/10/2009	kWh	53.5	54	53.7	53.1	54.4	54.4	55.2	56.3	58.3	58.1
2199989614924	05/10/2009	kWh	54.6	55.3	54.7	54.2	54	53.9	55.3	57.7	72.2	79.5
2199989614924	06/10/2009	kWh	57.3	55.8	55.3	56.5	56.4	55.7	57.1	60.4	73	79.3
2199989614924	07/10/2009	kWh	63.4	63.5	62.8	63.9	62.6	63.2	62.3	65.7	73.6	82.7
2199989614924	08/10/2009	kWh	60	60.4	58.2	61.8	60.2	59.2	59.7	64.8	73.3	77.2
2199989614924	09/10/2009	kWh	56.2	56.6	56.2	56.8	56.2	56.8	57.2	60.9	71.9	77
2199989614924	10/10/2009	kWh	54.4	53.6	53.2	55.1	54.3	54.2	55.5	56.5	57.3	57.9
2199989614924	11/10/2009	kWh	54.7	54.4	54.3	54.2	54.9	52.7	54.9	55.5	57.3	58.6
2199989614924	12/10/2009	kWh	53.6	53.4	53.8	53.9	55.1	56.4	53.8	58.1	67.1	77
2199989614924	13/10/2009	kWh	58.6	58.5	59.7	58.5	58.8	58.3	58.6	61.7	76.5	82.7
2199989614924	14/10/2009	kWh	60.1	60.5	59.3	61.9	60.6	59.8	60.4	66.2	76.7	86.4
2199989614924	15/10/2009	kWh	58.6	56.5	56.4	58.5	55.9	57.1	58.4	61.2	73.8	82.2
2199989614924	16/10/2009	kWh	61.2	58.7	58.7	60.9	59.6	61.9	63.5	67.2	76.4	80.3
2199989614924	17/10/2009	kWh	57.7	57.9	58.4	57.3	57.7	58.9	58.7	60.8	61.5	63.6
2199989614924	18/10/2009	kWh	57.2	57.1	57.8	56.3	58.3	56.9	57.3	59.2	62	61.7
2199989614924	19/10/2009	kWh	57.3	56.7	56.6	57.2	56.6	56.2	58	61.5	73.5	79.5
2199989614924	20/10/2009	kWh	60.8	60.1	60.9	59.4	61.6	60.2	62.3	65.9	76	84.1
2199989614924	21/10/2009	kWh	66.8	65	66.6	65.2	65.3	64.2	66.5	68.6	77.6	84.7