Development of the Digital Twin Interconnected Platform

D6.4

April 2022

Deliverable

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✔ P Public_{SEP}

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Version History

REVISION	DATE	AUTHOR	ORG...	DESCRIPTION
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V0.2	09.11.2021	Niall Byrne, David Sweeney	IES R&D	Updated draft to incorporate feedback and comments from the QCG
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V1.2	28.04.2022	Giselle Figueiredo Morabito, Mehmet Okumuş	IES R&D	Final draft submitted to PC
V2.0	29.04.2022	Giselle Figueiredo Morabito, Mehmet Okumuş	IES R&D	Final draft submitted to EC by the PC

Statement of Originality

This deliverable contains original unpublished work except where clearly indicated otherwise. Acknowledgement of previously published material and of the work of others has been made through appropriate citation, quotation or both.

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Nomenclature

Abbreviation	Explanation
AI	Artificial Intelligence
BDT	Building Digital Twin
CDT:	Consumer Digital Twin
CIBSE	Chartered Institution of Building Services Engineers
CommDT	Community Digital Twin
DoA	Description of Action
DSM	Dynamic Simulation Modelling
DT	Digital Twin
iCD	Intelligent Community Design
iCIM	Intelligent City Information Model
iCL	Intelligent Community Lifecycle
iCL-DT	Intelligent Community Lifecycle – Digital Twin
iPIM	Intelligent Portfolio Information Model
iVN	Intelligent Virtual Network Model
OSM	Open Street Map
PEB	Positive Energy Block
RES	Renewable Energy Systems
VE	Virtual Environment

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Abbreviation	Explanation
BREEAM	Building Research Establishment Environmental Assessment Method
LEED	Leadership in Energy and Environmental Design
EPC	Energy Performance Certificate

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Summary

The following report is intended to act as an update regarding the progress towards the creation of the TwinERGY Digital Twin Interconnected Platform. The current document is divided into four different sections that can be summarized as follows:

- Section 1 introduces Digital Twin technology, specifically defining what a Digital Twin is while also providing an overview of the IES Digital Twin suite of tools that will be used in the TwinERGY project
- Section 2 introduces and outlines the functionality of the Digital Twins that are being created through the TwinERGY project
- Section 3 provides the development of the Digital Twin Interconnected Platform
- Section 4 provides an update on the next steps in the development of the platform.

In addition to the sections outlined above, the report also contains one Annex that was used to obtain information related to the demonstration sites for the purposes of creating the building level digital twin.

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1/ Introduction

The following report is intended to provide a description of the development of the TwinERGY Digital Twin Interconnected Platform. This development is a key analytical tool that will be leveraged by the TwinERGY modules to improve the energy efficiency of buildings and communities while also promoting the uptake of Renewable Energy Systems (RES) and the implementation of flexibility and demand response actions. This platform will involve the creation of three levels of Digital Twin, namely the Consumer, Building and Community Digital Twins. The functionality and current status of the development of these tools is described in more detail in this report and the next steps are outlined briefly.

1.1 What is a Digital Twin?

Put simply, a Digital Twin (DT) is a virtual representation of a physical, real-world asset or group of assets[1]. Currently, many DTs of buildings, communities, grids and their assets primarily rely on static 3D models and data feeds from Building Energy Management Systems and SCADA models, for example, while any modelling occurs through the use of data-driven techniques such as Artificial Intelligence (AI). As a result, the relative intelligence that can be gleaned from such models can be somewhat limited and more suited to measurement and tracking of operational energy consumption while failing to unlock the true power of DT solutions at the building and community level.

When tools such as physics-based, dynamic simulation modelling (DSM) is integrated into the DT architecture, however, further capabilities beyond the visualization and data management functionalities can be unlocked that can empower building occupants, owners and managers to operate their buildings and communities in a more intelligent, energy efficient way[2]. Furthermore, the predictive power of such tools enables the DT to conduct 'what-if' analyses to explore the impact of altering control strategies, implementing retrofit projects and assessing the impact of occupant behaviour, for example, allowing relevant stakeholders to de-risk the operational alterations they make in order to reduce energy consumption in their buildings and within their communities.

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[1] https://www.gartner.com/en/information-technology/glossary/digital-twin

[2] https://www.iesve.com/digital-twins

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1.2 Introduction to the IES Digital Twin

The Intelligent Community Lifecycle – Digital Twin is a dynamic virtual representation of the built environment comprising a building, campus, portfolio or enterprise and associated building services[3]. The ICL-DT provides the connection between the virtual and the physical assets using physical and virtual sensors, together with homogenisation of data from different sources in different formats to plan, implement and manage sustainability and decarbonisation strategies for the built environment project. The ICL-DT provides a reliable mechanism for achieving and monitoring progress towards strategic goals including sustainability, health and wellbeing and decarbonisation. It facilitates operational optimisation to best serve the needs of occupants and the built environment, now and in the future. The ICL-DT can be created for new or existing communities, buildings or portfolios.

The Digital Asset resulting from the creation of the Digital Twin provides access to a scalable, flexible, visual, intuitive and evolving repository for all relevant environment data for the asset, campus or portfolio and will underpin decision making. All stakeholders have access to the most up to date information, tailored to suit their different needs. This information is accessible via a cloud collaboration portal to focus resources on strategic goals, increase productivity in terms of understanding where there are issues, avoiding unexpected interruption to service provision and in some cases predicting faults before they happen. The ICL-DT is in effect a high value digital asset capable of building performance optimisation beyond current practice by analysing and acting upon thousands of additional, calibrated virtual data points, facilitating deeper interrogation and insight into performance of all components.

The ICL-DT will augment physical metering and sensors providing far greater granularity on energy use, occupant comfort and wellbeing than the current systems traditionally deployed within the built environment.

Once the Digital Twin is set up and operational it can be used for continuous monitoring, active maintenance and performance optimisation – energy, water, occupant satisfaction. The modelled Key Performance Indicators will be compared at set intervals to prevent operational drift. The Digital Twin will be fundamental in developing and realising Zero Carbon Targets in a measurable way. At each milestone demonstrable achievements will be exemplified within the customised outputs. Where an intervention is not performing

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[3] https://www.iesve.com/

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as anticipated the reasons can be tracked and alternatives can be investigated and communicated to the stakeholder group. Once decarbonisation targets are achieved, ongoing monitoring and verification of performance using the Digital Twin will ensure that Net Zero or other form of sustainability status is maintained.

The ICL-DT leverages world-leading Dynamic Simulation Modelling software from IES. This is based on first principles building physics data and hundreds of person-years that have been invested by IES, in order to ensure that the Building Physics Intelligence within the ICL-DT is as accurate as possible. This technology has existed for many years and has been used to design over a million medium to large buildings across the world. However new disruptive solutions for the built environment are now enabling the technology to be applied to the existing built environment, improving the energy efficiency of existing buildings and planning strategies for future decarbonisation. These technologies include global digital mapping/streetscape, digital analytics, Artificial Intelligence (AI) and Machine Learning, the Internet of Things (IoT) and cloud technology to mention a few. These technologies work in co-operation with the building physics model, creating a hybrid physics-based/data driven approach for maximum accuracy and impact.

The ICL-DT works across the timeline of the Community, managing the present, road-mapping the future and logging the past. It considers individual constraints and requirements such as available finance, strategic development plans, government climate action plans or individual sustainability goals. As such the ICL-DT enables the decision maker to:
- Manage the present:
    - access data on a single platform,
    - identify key parameters or criteria at the touch of a button,
    - identify quick-wins for energy savings and select the highest impact opportunities,
    - proactively manage assets instead of reacting to emergencies,
- Roadmap the future:
    - examine different potential futures, which can be used to define strategy and policy,
    - identify the socio-economic impacts (technical, environmental, social, well-being and legal) of different potential strategic decisions,
- Learn from the past:
    - track progress of interventions or strategies towards sustainable targets
    - store data and learn from the past, to inform the roadmap of the future,

This enables informed decision making, at any stage of a Community's lifecycle, which de-risks investments and ensures value for money while maintaining maximum impact.

1.3: The IES Digital Twin Technologies

The ICL-DT uses core technology from IES called the IES Intelligent Community Lifecycle (ICL). The ICL has six technologies as shown in Figure 1- The IES Digital Twin Technologies, which are:
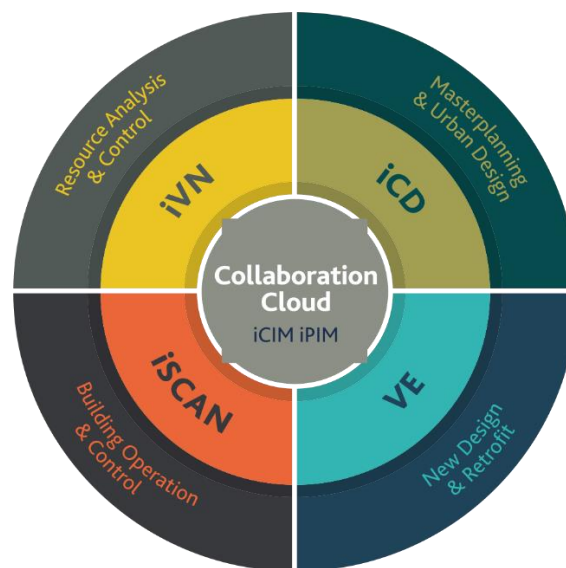
Figure 1.The IES Digital Twin Technologies

- **iCD:** intelligent Community Design
- **VE:** The Virtual Environment
- **iSCAN:** Building Operational Analysis
- **iVN:** intelligent Virtual Networks
- **iCIM:** intelligent City Information Model
- **iPIM:** intelligent Portfolio Information Model

These components work as individual technologies to identify different parameters for design or operational analysis of buildings, networks, assets etc., but can also work in combination to carry out specific processes based on the end user requirements, e.g. site solar analysis, energy efficient renovation analysis, how to create a Positive Energy Block (PEB), how to create a roadmap for decarbonisation between now and 2050 etc. These technologies therefore act as an integrated ecosystem to create the Digital Twin. All technologies integrate seamlessly with each other. Although six different tools comprise

the iCL platform, for the purposes of the TwinERGY DT platform, only four will be used in the project. These are iCD, VE, iSCAN and iVN. A brief description of these tools is provided as follows:

Intelligent Community Design (iCD)

The iCD is used for master-planning and analysis of buildings at the urban or portfolio scale. The iCD is a desktop software that integrates the IES Dynamic Simulation Modelling engine with Trimble sketch-up for quick model development and detailed analysis. The geometry of iCD can be quickly built from a variety of sources including publicly available datasets such as Open Street Map (OSM). The end user can quickly select the area of interest from a map, define a radius, e.g. 1km and an iCD model will be created, importing any of the associated data from OSM. As such, straight away there is an available 3D model of the Community with enough information to generate a baseline assumption of energy use and carbon emissions.

The iCD allows the user to assess the performance of a community of buildings anytime in the lifecycle of the community. As such, the iCD can provide the information to help make decisions for the near future or for the longer term i.e. how can a community decarbonise by 2050. The iCD model can be simple or complex. It can also be used at the early stage of design, for example to help finalise the energy and water demand for the site. The iCD model can also be imported to the VE for more detailed analysis. An iCD model is not only geo-located, but also defined in time. This point is particularly important as multi-year simulations are expected to be performed to assess climate resilience. The evolution of a model over time is also reflected in the simulation results. It is thus possible to run on the same model, different energy simulation for different years.

The iCD can also provide information to the iVN, to consider one or more community resource networks. This is extremely valuable to generate this information quickly to allow the correct decisions to be made with respect to the appropriateness or size of the network under consideration.

The Virtual Environment (VE)

The IES Virtual Environment (IESVE) is an innovative, award-winning and in-depth suite of integrated analysis tools. It allows the design and operation of buildings that enhance human comfort and consume significantly less energy. Whether working on a new build or on a renovation project, the VE allows designers to test different options, identify best passive solutions, compare low carbon & renewable technologies, and draw conclusions on energy use, CO2 emissions, occupant comfort, light levels, airflow, UK Building

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Regulations Compliance, BREEAM, LEED, EPC ratings etc. The IESVE 3D performance analysis software has been used to design tens of thousands of energy efficient buildings across the globe.

The VE system is the global leader in building simulation. It can perform a range of studies on a building that allows the user to ensure a more energy efficient building. Live data from a building can be imported into the VE model creating a hybrid model: part real information part virtual. This hybrid model can be calibrated to the highest levels of accuracy to facilitate good decision making on how to reduce capital and running costs, energy and carbon emissions.

iSCAN for Building Operational Analysis

iSCAN is a cloud-based data management and interrogation platform that can import time-series data from multiple sources to a single platform, e.g., from BMS, smart meters, IoT sensors, etc. With iSCAN you can interrogate the data manually or automatically using Machine Learning and AI. iSCAN has the capabilities to identify how the building is performing in real-time with respect to energy use, indoor environmental quality and running costs. Insights can be generated and analysis can then be performed on the data, to identify quick wins such as faults or easy to implement energy saving measures. Machine Learning and AI can be used to optimise performance on a day-to-day basis.

Time series data in iSCAN can be exported to ICL-DT ecosystem to be exploited by all technologies within the ecosystem. When this is carried out, those DTs are now a hybrid Digital Twin based on both physics data and metered data to create a higher level of accuracy and an ability to carry out more detailed analysis with respect to optimisation and intervention planning. For example, iSCAN can be imported to the iCD to create a hybrid Community model based on real energy end use data and not simulated assumptions; it can be imported to the VE to create detailed calibrated models for individual buildings; or it can be imported into the iVN to carry out real-time analysis on networks and their assets.

intelligent Virtual Networks (iVN)

The iVN is a desktop software that enables the analysis of a Community and its networks, i.e. heating, cooling, electricity and water. The energy demand from the community buildings can be generated in the iCD or the VE or taken from time-series data from iSCAN. The model can then consider different assets which could be added to the system for different scenario analysis, e.g., PVs to supply electricity, EV charging stations to account for increased penetration of EVs, a bio-gas CHP plant to provide heat to a district

heating network, a heat pump that exploits waste heat from a nearby data centre and also supplies a district heating network, batteries to store electricity and integrate a demand response and flexibility trading platform etc.

This enables early-stage design of a new local energy system, identifying the demand required by the buildings and the assets or networks that could be installed to manage and optimise the energy system in the most sustainable manner. This can also be considered across a timeline to ensure the system is also sized for future needs, e.g., new houses, offices and schools to account for projected population growth.

2/ Digital Twins & their Role in the TwinERGY Project

2.1 Digital Twins for TwinERGY

The TwinERGY platform seeks to leverage the capabilities of DTs at three different granularities, namely the Consumer DT, the Building DT and the Community DT. The intent is that each involved stakeholder within the community ecosystem is twinned to facilitate the detailed analysis of data and prediction of energy use and behaviour at any energy level within this community. The DTs that were created for the TwinERGY platform differ from traditional DT assets, as they are based on dynamic simulation models and will leverage actual data regarding the energy consumption and production of the buildings and communities to create fully calibrated DTs, which will support the analytical needs of the TwinERGY platform, particularly those of the modules that will be developed under Work Package 7 of the TwinERGY Description of Action (DoA)[4], particularly those requiring the energy forecasting data to function. Figure 2- The TwinERGY Digital Twin Platform has been taken from the TwinERGY DoA and outlines the different DTs as well as the data and IoT devices that will be leveraged during their operation.
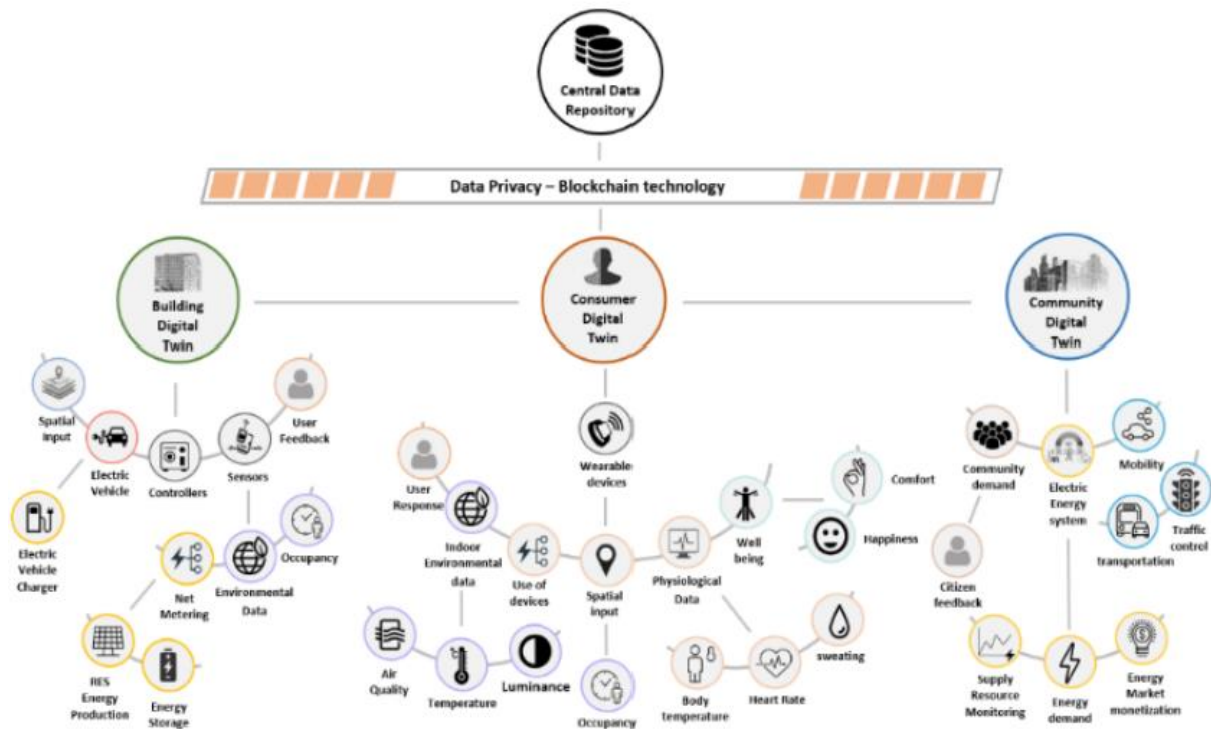
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[4] https://cordis.europa.eu/project/id/957736

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Figure 2. The TwinERGY Digital Twin Platform

The functionality of each level of DT developed for the TwinERGY platform can be
described as follows:

Consumer Digital Twin (CDT)

The CDT will be a virtual representation of the building occupant that will leverage the
individual's physiological data, that will be collected through the use of an IoT connected
wearable device, as well as data collected from other relevant IoT sensors and devices.
Through the creation of this level of CDT, the TwinERGY platform will leverage self-
learning algorithms to create dynamic constructs of prosumer energy behaviours, while
also identifying consumer preferences with respect to energy usage and openness to
engaging in flexibility and demand response actions. With this in mind, the CDT is the the
central element that will facilitate the employment of human-centric demand response
optimization strategies, enabling personalized control functions and automation in a non-
intrusive manner and without compromising prosumers' comfort, indoor environment
quality or daily operations / schedules for the provision of the required amount of
flexibility to aggregators. It will also ensure the improvement of demand forecasting at
the short and medium term through the utilization of real-life data streams from the
consumer assets to enable better predictability of future states of the distribution grid
and highly effective VPP configuration at the aggregator side and minimization of DR
strategies overrides. A screenshot of the interface of the CDT is presented in Figure 3.
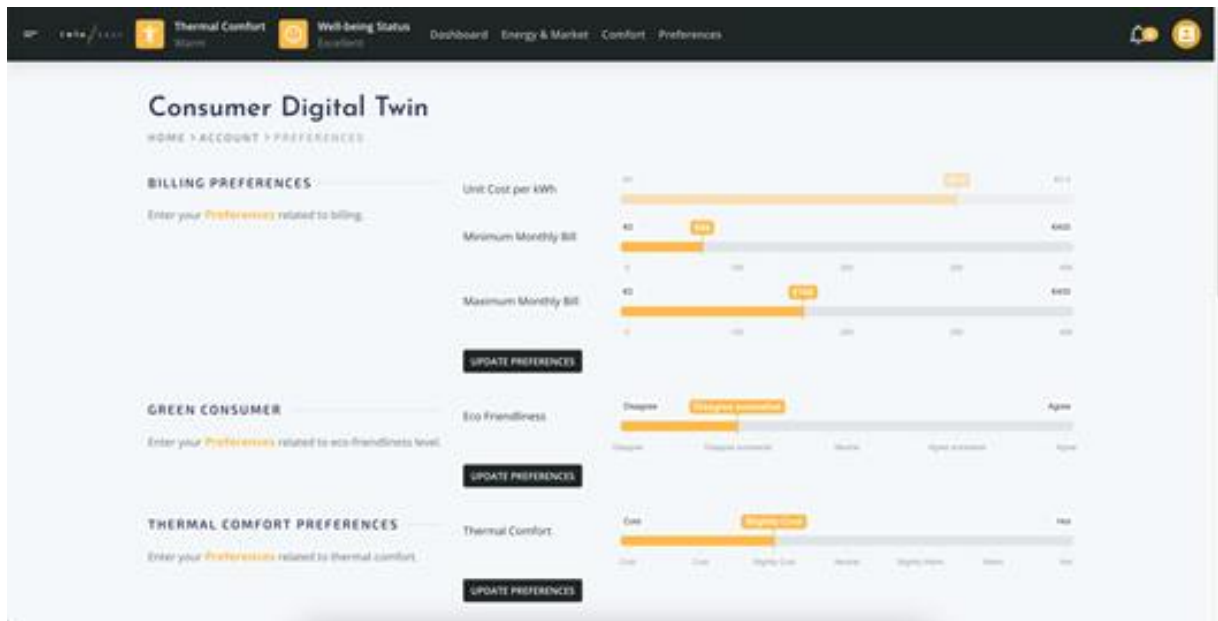
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Figure 3.: Mock-up screenshot of the CDT interface

Building Digital Twin (BDT)

The BDT was created using the IES Virtual Environment and iCL tools described above. The development of the BDT was conducted in two phases. Initially, physics-based, DSMs of the pilot buildings were developed based on static information, such as information regarding the components, equipment and systems within each of the buildings. This data was provided by the demonstration sites through the completion of an information intake form (provided in Annex A – Building Data Checklist). At this stage, these DSMs was calibrated using energy bills, during the project development time-series data will be collected from the buildings through the use of IoT sensors and meters or otherwise, will be used once they are installed and the data available on the platform. In addition, actual weather conditions for the site was used to ensure that the model is accurately representing the performance of the actual building.

Once the BDT is calibrated and is accurately predicting the performance of the building, the consumer preferences provided through the CDT, as well as real-time data from the IoT sensors within the building and real time weather forecasting will be provided to the BDT to allow for the optimized day-ahead forecasting of energy consumption within the building, as well as production of building level renewables. Flexibility algorithms that have been developed during Task 6.2 (Demand flexibility models) is integrated into the BDT to provide the user with guidance as to the most optimal operation of their building based on their preferences and unique requirements.

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Community Digital Twin (CommDT)

The output from the BDT will be aggregated to form the CommDT, which will represent the energy behaviour of the entire community. Further to the building level data, community level renewable and storage assets as well as electric vehicles will be integrated within the CommDT to accurately represent all energy consuming, producing and storage assets within the community. The CommDT will build on the analytics completed by the BDT to analyse the potential for flexibility and demand response actions at the community scale and the interface will be shown at the community and grid level (Figure 4 - Mock-up of the interface of the CommDT indicating individual buildings and RES assets). Through the use of optimization algorithms, the DT will identify the most appropriate manner in which the forecasted energy consumption can be satisfied based on the level of generation at the community level. In addition, a link to the Transactive Energy Platform will be created to enable the community grid operator to either utilize, import or export energy from or to the grid in the most cost-effective method possible, in the event that this is a point of preference for the community. The outputs from these algorithms will then be made available to the relevant modules that will leverage the analysis for their own computational requirements.
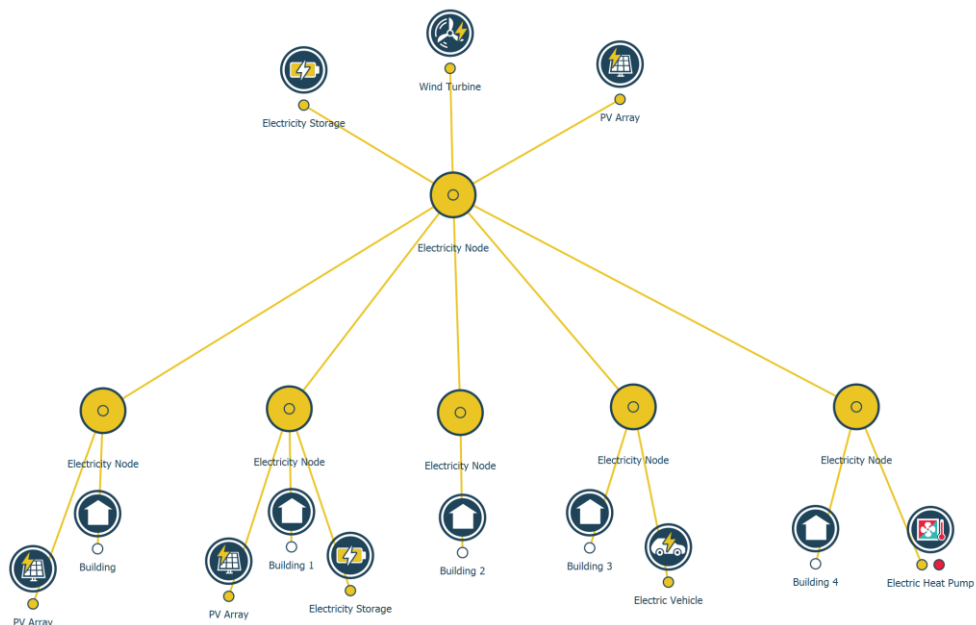
Figure 4.Mock-up of the interface of the CommDT indicating individual buildings and RES assets.

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2.2 The Role of DTs within the TwinERGY Platform

The figure 5 - High Level Architecture of the three levels of DT within the TwinERGY Platform below presents a high-level architecture of the TwinERGY software platform. As mentioned previously, the three levels of DT being developed through the TwinERGY project form the primary analytical platform that will be used by a number of the TwinERGY modules. The DTs will leverage building data that has been collected from IoT and other sensors that are installed in the demonstration buildings during the deployment phase. This data will pass through a data management layer that will clean the data before being forwarded to the iSCAN platform, through dedicated APIs, where it will be available for use by the DTs.

Figure 5.High Level Architecture of the three levels of DT within the TwinERGY Platform

The CDT will access the data related to the wearables and any other relevant data and will complete its analysis, identifying the consumer's preferences and behavioural

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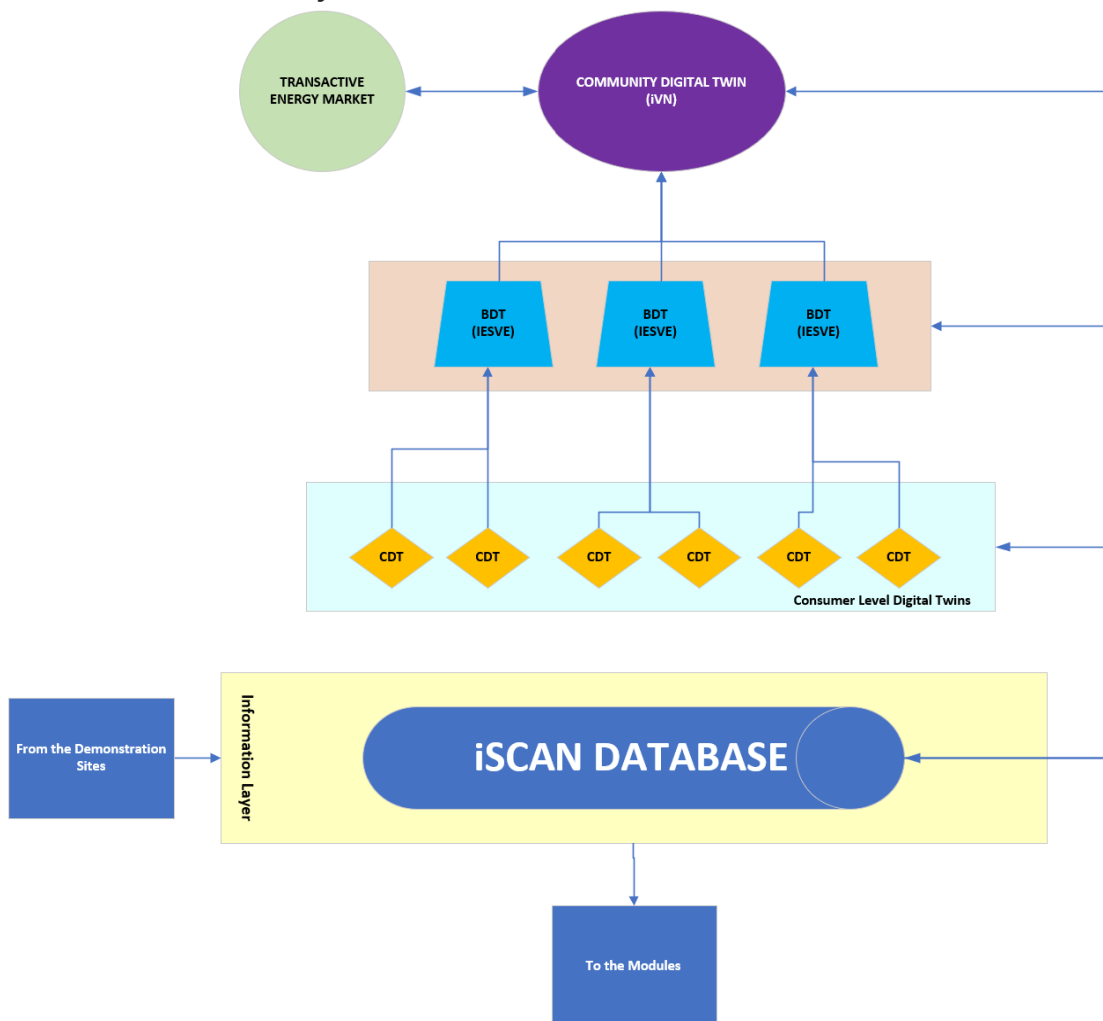programme under grant agreement No. 957736

tendencies as it relates to energy consumption within their building. This output will then be returned to the iSCAN platform where it will be accessed by the BDT and used as an optimization criterion for the calculation of the energy consumption forecasting and flexibility / demand response prediction at the building level.

Using real-time weather forecasting, the BDT will output time-series profiles for the energy consumption of the building as well as the projected energy generation for any renewables installed on the property. This forecasted consumption profile will be optimized based on the users' preferences.

The demand and generation profiles that shape the output of each of the BDTs then form the primary inputs for the CommDT, where they will be aggregated to produce a community grid level view. This DT will also consider the impact of EV charging and community level generation and storage equipment to ensure that the entire grid is optimized based on the community's preferences. Both implicit and explicit demand response actions will be considered, to ensure that the grid is performing at its most optimal way. In addition to aggregating the data produced through the BDT, the CommDT will also interlink with the Transactive Energy Platform, which is used as an optimization criterion for the flexibility algorithms. Although the objective functions to be used for optimization of the CommDT are still in development, it is anticipated that they will include:
- Maximization of RES Utilization
- Minimization of Energy Cost within the Building/Community
- Minimization of Carbon Emissions within the building/Community

At this point, the DTs will have completed their forecasting for the next day and the data and profiles will be available to the modules to use as required. The forecasted profiles from the BDT, for example, will be leveraged and dispatched by the Home & Tertiary Real-Time Energy Monitoring Module, while the CommDT profiles will be used as an input for the DER Management Module. The other interactions between the DTs and the modules are currently being developed through the activities of Work Package 7.

3/ Digital Twin Interconnected Platform

3.1 Consumer Digital Twin

The development of the CDT has been ongoing since M3 of the project, with Front-End, Back-End and Database development taking place over this period. The tool is intended to function as a web-based tool that will complete analytics and record the user preferences and requirements for use by other modules of the TwinERGY platform. The following is a list of the key developments completed to date. The final version of this deliverable will include more detailed information and screenshots as to the specific features of the tool and its functionality and operation. For the purposes of this report, key developments to date are subdivided into three four categories, namely Pages, Components, Scripts and Application Programming Interfaces (APIs).

Pages

- Consumer Preference
- Energy Consumption
- Heart Rate Animation
- Indoor Environmental Factors
- Activity Level
- Dashboards
- Comfort Level – Thermal Sensation
- Energy Production
- Indoor Air Quality (Wellbeing)
- Comfort Level – Thermal Comfort Vote
- Wellbeing Settings Preferences
- Flexibility / Demand Response Preferences
- Visual Comfort (Wellbeing)
- Acoustic Comfort (Wellbeing)
- Wellbeing Status

Components

- Outdoor Environmental Factors
- Visualization of Outdoor Weather Conditions

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- Locational Services
- Notification Services
- Navigation
- Sub-Menu for Wellbeing Pages
- Dashboards

Scripts

- Notifications
- Obtain Activity Level over previous 24 Hours

APIs

- Obtain Outdoor Weather Data
- Obtain Consumer Heart Rate
- Obtain Heart Rate Value
- Obtain Activity Level
- Export Thermal Comfort Level – Thermal Sensation & Associated Variables
- Obtain Import Data from Wearable Device

3.2 Building Digital Twin

The BDT is intended to be a virtual representation of the physical demonstration buildings that was developed using the IES Virtual Environment software package. The first phase in the development of the BDT was to acquire the static building information required to build the physics-based models. In order to obtain this data, the building data checklist displayed in Annex A of this report was developed and issued to the four demonstration sites to complete.

As shown in Table 1 - Data required to develop DTs, data collection window closed in M16 (February 2022) for all four-demonstration sites. The development of 27 BDTs within the Virtual Environments software was completed for all four pilots (5 Athens, 5 Bristol, 12 Benetutti, 5 Hagedorn). The information provided by the pilot sites were also implemented within the iCD and iCIM software that will contribute towards the CommDT to ensure that the current models are as complete as possible.

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Table 1. Data required to develop DTs

Demonstration Site	No. of Buildings
Bristol (UK)	13
Hagedorn (DE)	41
Athens (GR)	16
Benetutti (IT)	17

These models are linked directly to their corresponding representation in the CommDT to ensure that the detailed BDT is providing input to the community model.

Modelling at the Building Level

Calibration Metrics

The model calibration is a process for which the results of the physics-based dynamic simulation performed by the Virtual Environment software are compared to actual consumption data extrapolated from the utility bills at annual level. The acceptable calibration tolerance was set to 5% annually.

Methodology

The building architectural drawings, operational schedules, internal loads, and envelope construction components have been provided by the building owners for some of the buildings. For the building digital twin studies, the buildings which have the most information were selected.

The first step to create the DTs is to locate the model on the coordinates of the building so it's geolocated and import the surroundings in the Virtual Environment. Then, based on data provided and Google Street View's images, we built the 3D geometry of the building, Figure 6: Sample 3D model of Hagedorn-2.

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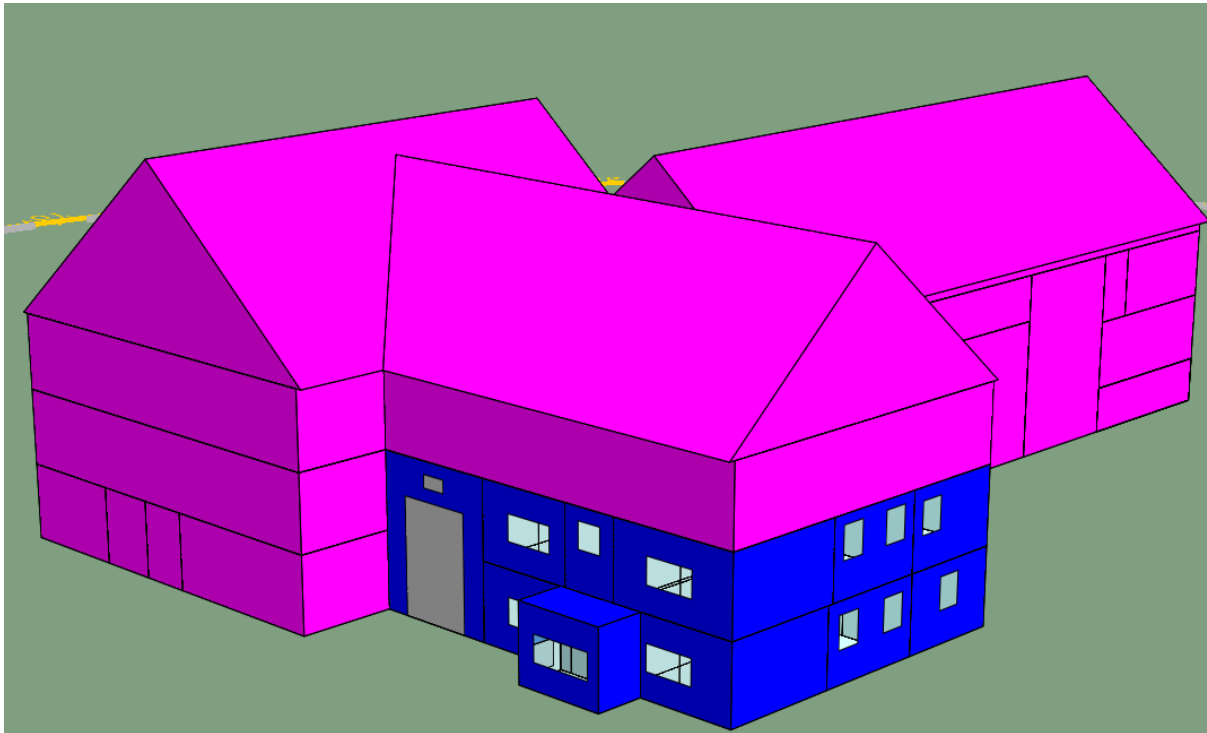
Figure 6.Sample 3D model of Hagedorn-2

The second step then was to enter building envelope properties. We entered the thermal transmittance values (U-value) of the buildings for which we have knowledge of the envelope components. If we do not have the building properties, we use the possible U-values of the old buildings in that region from the academic studies.

A thermal transmittance (U-value) is a sum of the thermal resistances of the construction layers that make up an entire building element – for example, a roof, wall or floor. It also includes adjustments for any fixings or air gaps.
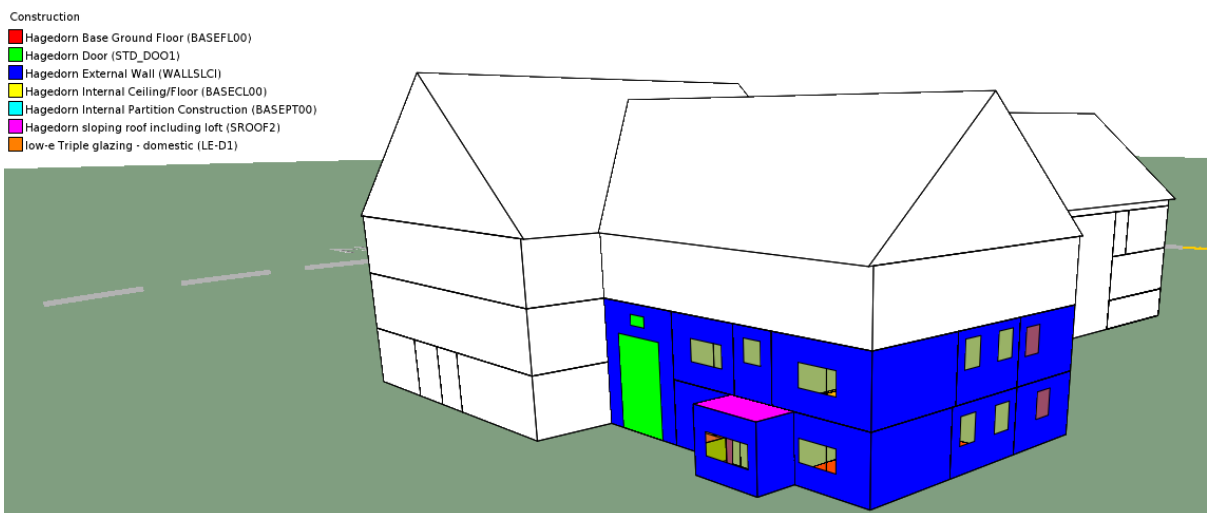
Figure 7.Building envelope constructions

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The third step then was to include all internal gains. Internal gains for each building were added to the energy model with separate energy meters to see each appliances' consumptions.

Creating the building HVAC system according to the provided information, was the fourth step. In this step, "Apache System template" (Figure 8) was used by importing a pre-existing HVAC system from UK NCM template based on the system listed in the survey form. Then, the heating, cooling, DHW and solar heating were adjusted according to the HVAC model otherwise the default value was taken into consideration.
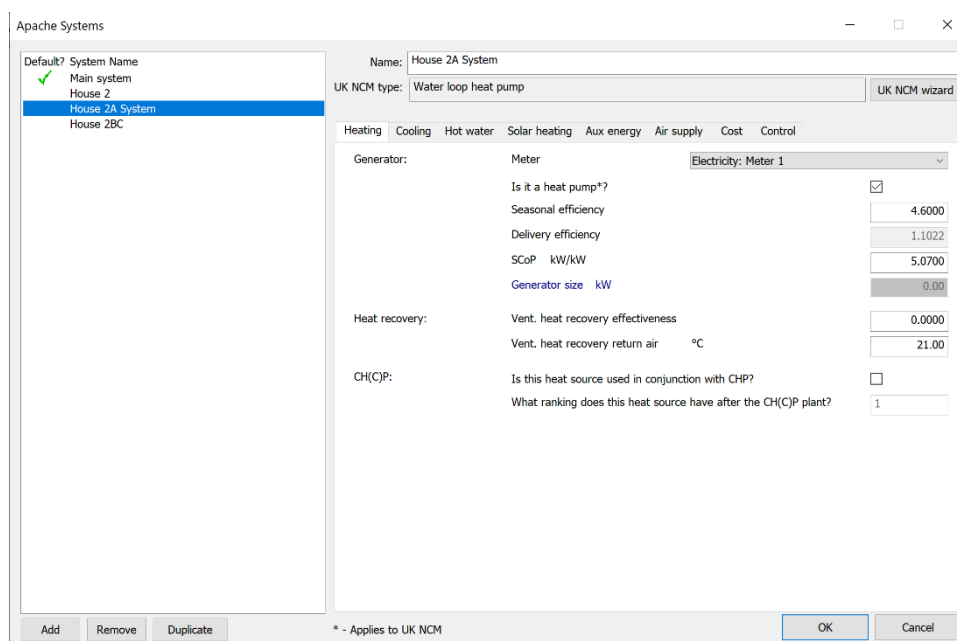
Figure 8. Apache System Template

The fifth step was to calibrate the simulated annual energy consumption according to the actual utility bills. In many instances, the percentage difference is outside the expected range. Data from certain appliances couldn't be found or was not provided. In such scenario, the data was taken from CIBSE guide or appliances data from other buildings in the same pilot site. Ambiguous appliances data or HVAC system were adjusted to meet the calibration metrics target.

Table 2. Annual PV Generation, Annual Energy Consumption, and Calibration Percentage

Annual Totals (MWh)	
PV Generation:	45.01299
Total Electrical Demand:	19.79916
PV Used Onsite:	8.26512
PV Exported:	36.74787
Grid Consumption:	11.53404
Electrical consumption	11.7
Perc Diff (%)	1.42

The sixth step was to create and simulate the models of other buildings with iCD. iCD simulation gives more generic simulation results for the buildings. There are two important settings needed for the iCD simulation. The first setting is the ICL template as shown in Figure 9 - ICL Templates for Hagedorn, the German pilot site. In this template, the energy simulation was set as IES VE and the simulation template was ICL Germany. It is crucial to input carbon emission coefficient for the fuel used for HVAC system in the pilot site.

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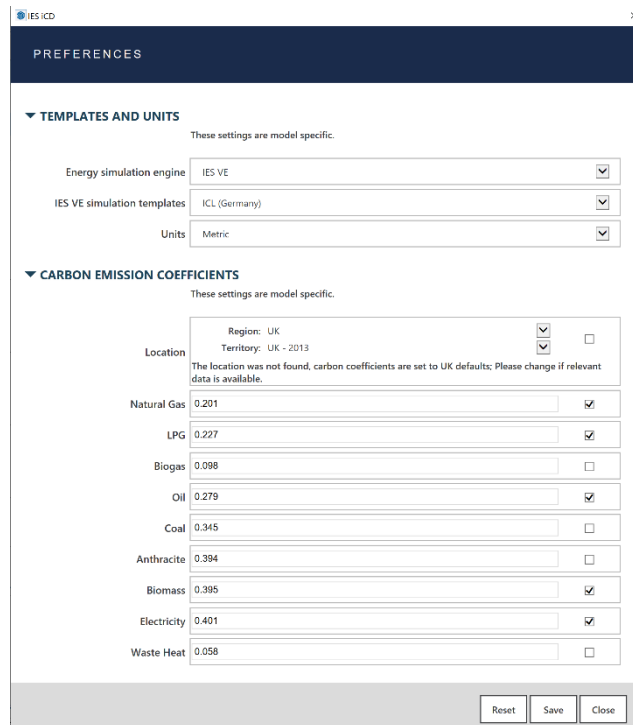
Figure 9.ICL Templates

Second important setting is the ICL setting that will constitute to the HVAC system, building use and space conditioning. It is also important to set the construction date for the building to run the iCD simulation.
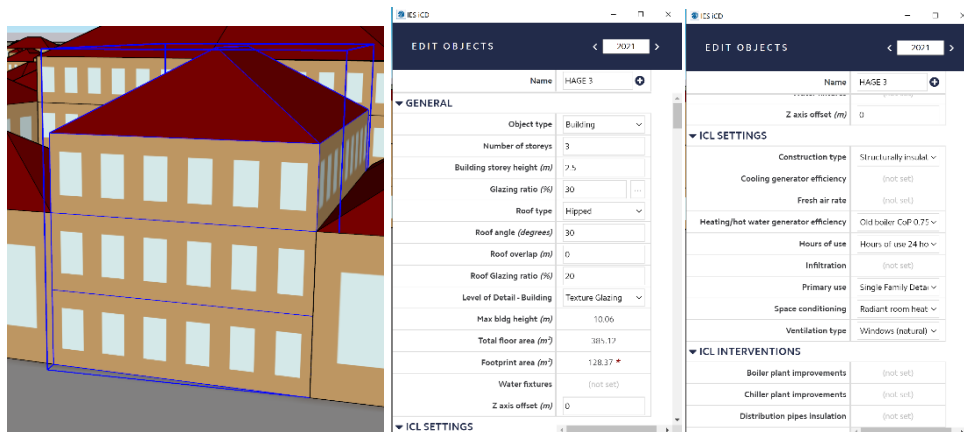
Figure 10. iCD Building Settings

3.3 Community Digital Twin

The development of the CommDT for all pilots has been completed, with high level models being created in the iCD platform using the Open Street Map functionality of the

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tool. At the time of writing, default template information has been provided to the majority of the buildings in both models, however, where information has been provided by the relevant pilot site partner, this has been tagged and included to the building, increasing the accuracy of the model. The figures below show the current CommDTs for both the Hagedorn (Figure 12), Benetutti (Figure 13), Athens (Figure 14), and Bristol (Figure 15) pilots, with the map view to illustrate the geographical extent of the models. Further to this, Figure 12 indicates a building in Hagedorn where detailed information has been integrated into the CommDT based on the data provided by the Hagedorn project partner. As more information is provided to the modelling team, the CommDT will expand and become more detailed, facilitating the analysis of the performance of the community as a whole. Community RES assets and EV infrastructure has not yet been integrated into the model, however this will be completed when the current CommDT is expanded to a grid level model (using the iVN software platform).

Modelling at the Community Level

After completing the buildings for Building Digital Twin studies, the sixth step was importing the calibrated VE models to the iSCAN tool with time steps of all subsystem energy consumption including separate appliances. Before importing the data, a "Scenario" must be created using the "scan.api" token that will link VE models to iSCAN channels.

Each pilot site had one scenario "Baseline" that contained all the channel appliances for each VE models. iSCAN does not have a feature to upload different appliances meters. CSV files with 10 minutes timestep were created for each VE model that was uploaded manually to the "Baseline" scenario.

iSCAN is an excellent tool to view data at a period of time. Data viewing can be broken into day, month and year depending on the scalability of the data imported. Nine separate channels data can be viewed together at a selected time as shown in Figure 11. This is a useful information for analyzing the consumption profiles of different appliances and making improvements to either boost or decrease usage. Users also have the ability to create a new channel on iSCAN by performing simple or, complex mathematical calculation(s) or even, creating alarm(s) to hint when a certain appliance hits a threshold setpoint.
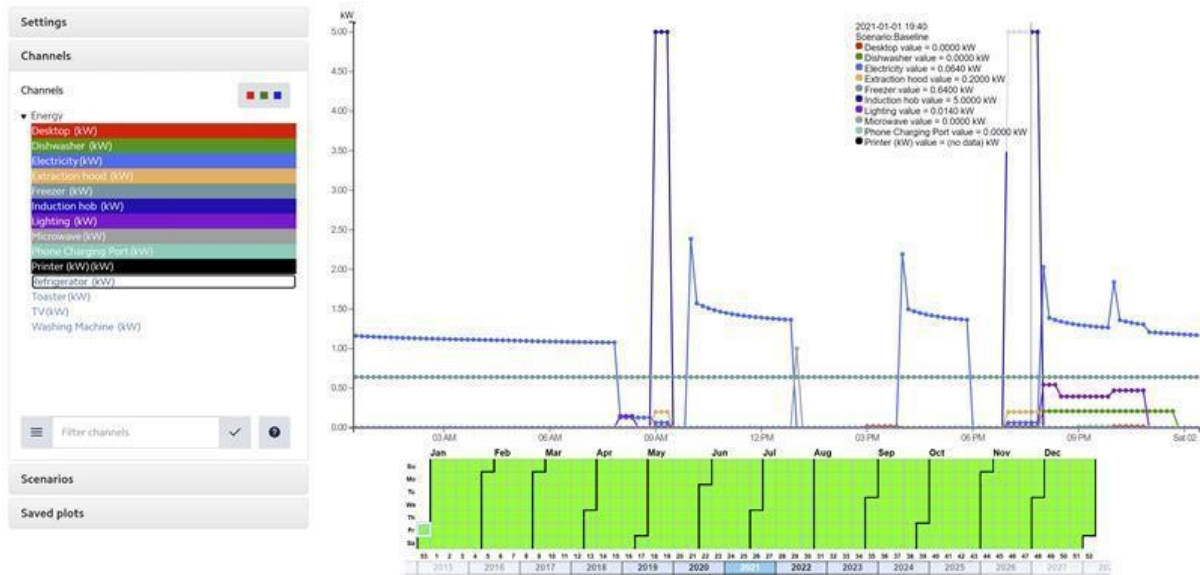
Figure 11. iSCAN Channels

The seventh step was connecting to the iCIM model with iSCAN token via iCD. Initially, iSCAN data was connected to iCD. Two mappings were created in iSCAN - "Name Mapping" and "Variable Mapping". These mappings served as a connection point between the iSCAN data and the building the data correspond to, in iCD.

The eighth step was creating and simulating other building models with iCD, then importing the consumption data to iCIM. Figure 9 and Figure 10 show the requirement for iCD building simulation.

Figure 12. Current CommDT of Hagedorn Demonstration Site

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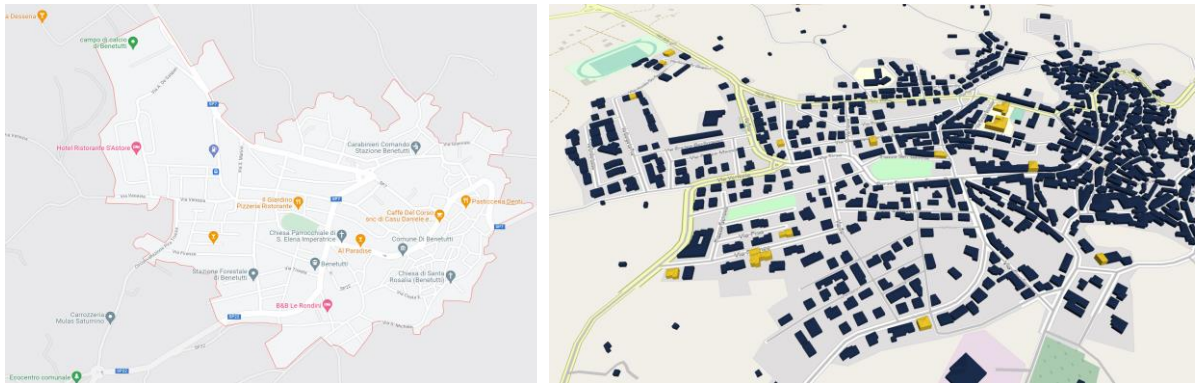
Figure 13. Current CommDT of Benetutti Demonstration Site
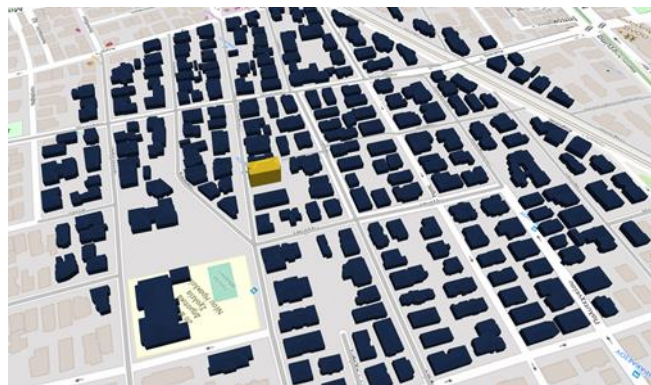
Figure 14. Current CommDT of Athens Demonstration Site

Figure 15. : Current CommDT of Bristol Demonstration Site

iCIM platform works as data visualisation tool. Several attributes were created in iCD to improve data visualisation on iCIM. For this project, the important attributes selected to display are Building Name, Address, Country, Construction Date, Appliances Consumption and iCD Simulation data.
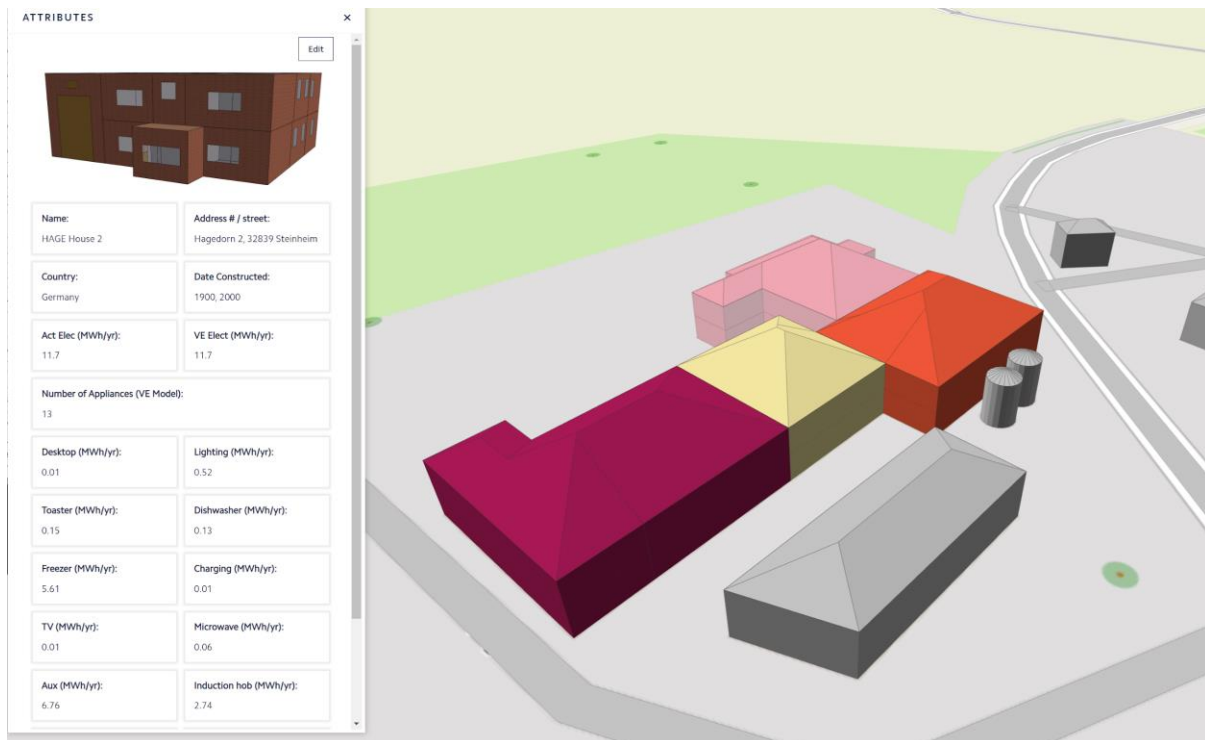
Figure 16. Screenshot of the Hagedorn CommDT showing building level data within the model for a single building

Scenes were created to show the location of the buildings and the data displayed by each building as shown in Figure 16 above. Users can modify building display data in the settings. The "Metrics Viewer" helps to improve visualisation of the site, by assigning a colour scheme for a data range as shown in Figure 17.
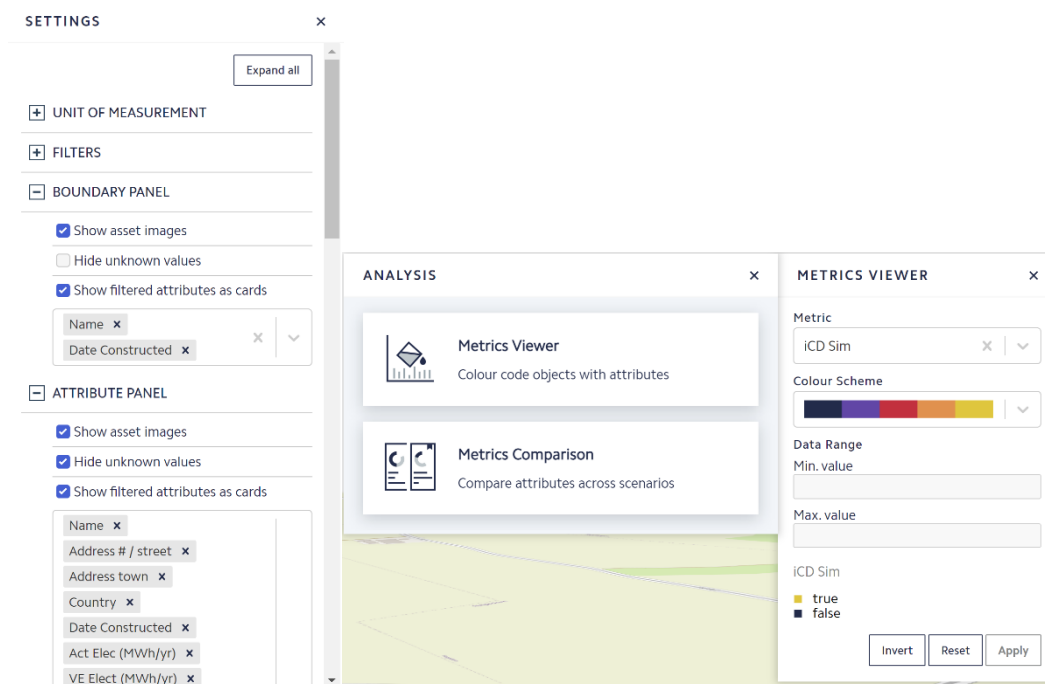
Figure 17. iCIM Card Settings and Metrics Viewer

4/ Conclusions & Next Steps

The development of the BDT depended on the provision of appropriate levels of detail regarding the systems of the buildings in their current state.

Once this information was provided and the physics-based models were developed, data related to energy consumption in the buildings (utility bills, sensor data, metered data) were used to calibrate the models and create the BDTs. The interlink between the CDT and BDT was created to ensure that the preferences of the individual building owner are captured when forecasting the energy consumption of the building.

These BDTs were then linked to their corresponding representation in the CommDT and used to complete the analysis of the grid at the community level. A grid level model was created and used for the optimization of the energy performance of the community. Finally, the interlink between the CommDT and the Transactive Energy Platform will be implemented.

Annexes
Annex A: Building Data Checklist

Building Data Checklist	Required?	Example	Name of building 1	
General building information			**Y / N**	**Specify or Comment**
Building ID	if applicable	*e.g. is there any national/local building identifier number/code? (note this is not the address)*		
Construction year	Yes	*e.g. 2002*		
Condition (Bad, Fair, Good)	Yes	*e.g. Good*		
House Type (detached, semi-detached, terraced, apartment)	Yes	*e.g. Mid-Terraced House*		
Ownership (Owner occupied, rented, etc)	Yes	*e.g. Tenancy*		
How many rooms are in your house?	Yes	*e.g. 2 bedrooms, 1 bathroom, kitchen, living room, mud room*		
How many People live in your house	Yes	*e.g. 2 Adults, 3 Children*		
Age Group of House Applicants	Yes	*e.g. Adults (35-40) Children (2 less than 4 & 1 aged 10-12)*		
Typical Occupied Hours	Yes	*e.g. 06:00-08:00, 18:00 - 06:00 Mon - Fri & 24 hours on weekend*		
Building address	Yes	*e.g. 123 Residential Street, Town 1*		
Fuel utilised	Yes	*e.g. Gas for heating and DHW*		
EPC (Energy Performance Certification) level (please if this is a national certification, provide document explaining how this works)	Yes (if available)	*e.g. B3 (eventually attach pdf with EPC description)*		
Site photographs	if possible	*e.g. jpeg files*		

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			Y / N	Comments
Is the building listed (protected)? E.g. historical building..	if applicable	*e.g. yes/no and comment with details (eventually provide national regulations on what can/cannot be done)*		
Building layout drawings and models			**Y / N**	**Comments**
Footprint area	if available	*e.g. 578 m2*		
Floor area (GIFA / Net)	if available	*e.g. 1987 m2*		
Floor plans	if available	*pdf, dwg, dxf files*		
Zone - Descriptions/end use (i.e. meeting room, labs, etc…)	if available	*e.g. toilet*		
Zones - HVAC/Lighting/Equipment drawings	if available	*e.g. ME drawings*		
Elevations	if available	*pdf, dwg, dxf files*		
Sections	if available	*pdf, dwg, dxf files*		
Fenestration	if available	*e.g. 345 m2*		
Shading devices	if available	*e.g. external louvres*		
Adjacent buildings	if available	*e.g. any relevant building which might affect analysis - such as very tall building which shades the addressed building most of the time*		
Building orientation	if available	*e.g. degrees from North (clockwise - take front door as reference)*		
3d Model (BIM, IES-VE, Revit, SketchUp, Rhino etc.)	if available (highly desirable)	*e.g. any available model (current or past)*		
If none of the above are available, can a high level sketch be provided?	Yes	*e.g. handdrawn sketch of building layout with approximate dimensions*		

AMR data and energy costs information			Y / N	Specify or Comment
Fossil Fuel Yearly (kWh)	Yes	*e.g. 2250 kWh gas*		
Electricity Yearly (kWh)	Yes	*e.g. 1862 kWh electricity*		
Electricity bills	Yes	*Total energy costs for electricity, or break down of month energy bills in kWh / cost e.g. Jan - 100kWh, €60 feb - 120kWh, €70 etc...*		
Fossil fuel bills	Yes	*Total energy costs for fossil fuel, or break down of month energy bills in kWh / cost e.g. Jan - 100kWh, €60 feb - 120kWh, €70 etc...*		
RECs, RHI, other energy costs/incentives?	Yes	*e.g.government incentives; if yes, specify*		
Heating, Cooling & Ventilation Systems			Y / N	Specify or Comment
How is your building ventilated (mechanically ventilated, passive vents, operable windows, not ventilated, other)	Yes	*e.g. Mechanically Ventilated*		
If mechanical ventilation is used can you provide details of the ventilation system in use.	Yes	*e.g. Fantech Heat Recovery Ventilator model SH704 40W 58CFM, used during occupied hours*		
Can you provide a photo of the unit and its nameplate information?	Yes	*e.g. jpeg files*		
Are you able to control your heating system? If so, what value do you set your thermostat to?	Yes	*e.g. Yes, my thermostat is set to 21deg C at all times.*		

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What type of heating system do you have in your house (radiators, underffloor heating, stoarage heating, convection heaters, heat pump, other)	Yes	*e.g. Radiators in each room*		
What is the fuel source for your heating system?	Yes	*e.g. Natural Gas*		
If your building uses a boiler for heating, how would you describe the boiler (high efficiency condensing boiler, modern boiler, old boiler, very old, N/A)	Yes	*e.g. Modern boiler with efficiency of 85%*		
Can you provide a photo of the boiler and its nameplate information? Alternatively please provide the make and model of the unit.	Yes	*e.g. jpeg files*		
Do you have any mechanical cooling in your building?	Yes	*e.g. Yes - packaged air conditioning unit installed on each window.*		
What is the make and model of your cooling unit?	Yes	*e.g. Global Industrial PTAC w/ 3.5kW Cooling*		
Can you provide a photo of the unit and its nameplate information?	Yes	*e.g. jpeg files*		
What value do you set your cooling setpoint to?	Yes	*e.g. 24deg C*		
How do you generate domestic hot water in your building (i.e. water used in your faucets, shower, bath, etc)	Yes	*e.g. gas fired instantaneous water heater or electric immersion heater*		
Is your hot water heater always available, timed or switch enabled? If not always available, how many hours per day would you enable your hot water heater (if known)?	Yes	*e.g. On a timer and available between 19:00 & 20:30 each day*		
Can you send a photograph of your domestic hot water heater and its nameplate?	Yes	*e.g. jpeg files*		
Household Appliances			**Y / N**	**Specify or Comment**

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What fuel source do you use for cooking? (gas, electricity, other)	Yes	*e.g. Gas stove*		
On average, how many hours per day do you cook?	Yes	*e.g. 1 hour per day M-F, 2.5 hous on the weekend.*		
Do you you have one or more Refrigerators? If more than 1, how many?	Yes	*e.g. 1 full size fridge and 1 mini-fridge*		
What is the make and model of each refrigerator? If not available, how old is each refrigerator?	Yes	*e.g. Insignia NS-RTM18 WH8Q, small fridge purchased in 2019.*		
Do you have one or more freezers? If more than 1, how many?	Yes	*e.g. 1 freezer as part of refridgerator and 1 chest freezer.*		
What is the make and model of each freezer? If not available, how old is each freezer?	Yes	*e.g. as above, chest freezer is Insignia NS-CZ50WHO-C)*		
What is the make and model of your washing machine?	Yes	*e.g. LG 5.2Cu Ft WM3500CW*		
On average, how many hours per day/week do you use your washing machine?	Yes	*e.g. 3 hours per week*		
Do you have times during the week when you are more likely to use the washing machine or is it as needed?	Yes	*e.g. typically Saturdays 11:00-14:00*		
If you typically use your washning machine at a specific time, would you be willing to use at an alternative time based on the price of electricity/availability of renewable electricity?	Yes	*e.g. no - my time is fixed*		
Do you have a clothes dryer in your house? If so, what is the make and model of your clothes dryer?	Yes	*e.g. LG DLEX3700V*		
On average, how many hours per day/week do you use your clothes dryer?	Yes	*e.g. 2 hours*		
Do you have times during the week when you are more likely to use the clothes dryer or is it as needed?	Yes	*e.g. As needed*		

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			Y / N	Specify or Comment
If you typically use your clothes dryer at a specific time, would you be willing to use at an alternative time based on the price of electricity/availability of renewable electricity?	Yes	*e.g. yes*		
Do you have a dish washer in your house? If so, what is the make and model of your dish washer?	Yes	*e.g. Yes, Bosch LDFN4542S*		
On average, how many hours per day/week do you use your dish washer?	Yes	*e.g. 1.5 hours per day*		
Do you have times during the week when you are more likely to use the dishwasher or is it as needed?	Yes	*e.g. Use every day*		
If you typically use your dishwasher at a specific time, would you be willing to use at an alternative time based on the price of electricity/availability of renewable electricity?	Yes	*e.g. Yes*		
Do you have any other large appliances in your home? If so please provide details?	Yes	*e.g. Kitchen ventilation exhaust, used 1 hour per day, KitchenAid model KVWC956JSS*		
Lighting			**Y / N**	**Specify or Comment**
What type of lamps/bulbs do you typically use in your house?	Yes	*e.g. generally LED with some CFL lamps*		
Can you provide a count of the various lamps used in your house?	Yes	*e.g. Bathroom: 1 32W CFL* *Bedroom 1: 1 12W LED ceiling light & 2 6W bedside lamps* *Bedroom 2: 1 12W LED & 1 60W bedside incandescent* *Kitchen: 2 32W CFL tubes* *Living Room: 1 28W CFL & 2 8W LED floor lamps* *Hallway: 3 8w LED* *Exterior: 1 250W Halogen Spotlight*		

Question		Example	Y / N	Specify or Comment
On average, how many hours a day would you use the lamps in each room in both summer and winter?	Yes	e.g. Living Room: Summer - 2 hours per day, winter 6 hours per day, Bedroom…		
Do any of the lighting in your building have adjustable features? (e.g. dimmer switch, timer, etc)	Yes	e.g. exterior light uses photocell and living room lighting has dimmer switch that is used when watching tv		
Other Electrical Loads			**Y / N**	**Specify or Comment**
Please confirm the number of, and average hours used of the following electrical items in your building?	Yes			
Television	Yes	e.g. 1 50" TV (used 2 hours a day and on standby otherwise) & 1 32" TV (used 6 hours per day and standby otherwise)		
Cable Box / Internet Modem (e.g Sky TV Receiver)	Yes	e.g. Sky Broadband Receiver active 24 hours per day		
DVD Player	Yes	e.g. no		
Stereo/ Radio	Yes	e.g. 1 radio, used 8 hours per day		
Video Gaming Device	Yes	e.g. 1 Playstation 4 used 1.5 hours per day and standby ourside this		
Laptop Computer	Yes	e.g. 2 laptop computers plugged in 3 hours per day		
Desktop Computer	Yes	e.g. 1 desktop with 19" monitor used 3 hours per day and standby outside this time		
Personal Electronic Devices (Mobile Phone, Tablet, e-Reader, etc)	Yes	e.g. 3 mobile phones and 2 iPads that are plugged in to charge overnight		

Coffee Machine	Yes	*e.g. yes - 1 hour per day*		
Kettle	Yes	*e.g. yes - 0.33 hours per day*		
Toaster	Yes	*e.g. no*		
Microwave	Yes	*e.g. yes, used 0.25 hours per day*		
Others	Yes	*e.g. electric induction cooker used 1 hour per week*		
Electricity Generation			**Y / N**	**Specify or Comment**
Do you have any renewable systems in your home? If yes, please state the type you have (e.g. wind turbine, solar PV, solar thermal, etc)	Yes	*e.g. Yes, solar PV panels on the roof*		
Do you know what the capacity of your renewable system is?	Yes	*e.g. 5kW*		
Do you track your renewable generation?	if Applicable	*e.g. Occassionally I will check production*		
Do you adjust your energy use in your house to match the generation? (yes, no, NA)	if Applicable	*e.g. Yes I use electrical appliances during the day to match my solar PV generation*		
Does you house have any battery storage?	Yes	*e.g. Yes*		
If yes, what type?	if applicable	*e.g. Lithium Ion (Tesla) battery*		
If yes, what is the capaity?	if applicable	*e.g. I don't know*		

			Y / N	Specify or Comment
Would you be interested in installing renewable or storage systems in your home or community in the future?	Yes	*e.g. Yes*		
Would you be interested in exporting your excess energy generation to your community?	Yes	*e.g. Yes*		
If yes, how would you like to be compensated for this?	if applicable	*e.g. I would like to sell my excess energy to my neighbours for cash*		
Electric Vehicles			**Y / N**	**Specify or Comment**
Do you own an electric vehicle or do you intend to purchase one in the coming months?	Yes	*e.g. Yes, I am purchasing an electric car later this year*		
If yes, what is the make and model of your vehicle?	if applicable	*e.g. Volkswagon ID.4*		
If yes, where do you primarily charge your car battery	if applicable	*e.g. At my home, I have installed a charging station*		
In general, at what time would you charge your car?	if applicable	*e.g. Overnight*		
Would you be able to adjust the time you charge your car based on electricity pricing/availability of renewables?	if applicable	*e.g. somewhat - I could charge during the day twice per week*		
Have you ever considered using your car battery to "feed in" electricity to your building during peak times?	if applicable	*e.g. no I didn't know that was possible but would be interested in learning more*		

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Thermal template	Gain 1 Reference	Gain 1 Max. Sensible Gain (W)	Gain 2 Reference	Gain 2 Occupancy (People)	Gain 3 Reference	Gain 3 Max. Sensible Gain (W)	Gain 4 Reference	Gain 4 Max. Sensible Gain (W)	Gain 5 Reference	Gain 5 Max. Sensible Gain (W)	Gain 6 Reference	Gain 6 Max. Sensible Gain (W)	Gain 7 Reference	Gain 7 Max. Sensible Gain (W)	Gain 8 Reference	Gain 8 Max. Sensible Gain (W)	Gain 9 Reference	Gain 9 Max. Sensible Gain (W)
Laundry	WashingMachine	138.24	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Living room 3	Fluorescent Lighting L/R3	80	People Living room Occupancy	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Living room 2	Fluorescent Lighting L/R2	100	People Living room Occupancy	2	Television	5	-	-	-	-	-	-	-	-	-	-	-	-
Living room 1	Fluorescent Lighting L/R1	214	People Living room Occupancy	2	Television	5	-	-	-	-	-	-	-	-	-	-	-	-
Bathroom GF	Fluorescent Lighting Bathroom GF	160	People Bathroom GF Occupancy	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Bathroom FF	Fluorescent Lighting Bathroom FF	80	People Bathroom GF Occupancy	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
bedroom 4	Fluorescent Lighting B/R 4	11	People Bedroom 2 Occupancy	1	MobilePhone_Charging	15	-	-	-	-	-	-	-	-	-	-	-	-
bedroom 3	Fluorescent Lighting B/R 3	100	People Bedroom 3 Occupancy	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
bedroom 2	Fluorescent Lighting B/R 2	220	People Bedroom 2 Occupancy	1	Tablet	15	-	-	-	-	-	-	-	-	-	-	-	-
bedroom 1	Fluorescent Lighting B/R 1	40	People Bedroom 1 Occupancy	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hallway_GF	2Bulbs_Hallway_GF	80	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Kitchen	1LED_Kitchen	14	People_Kitchen	1	Refrigerator	400	2Freezer	640	Induction hob	5000	Dishwasher	208.45	Kitchen extraction hood	200	Toaster	1310	Microwave	1000

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Mud Room	1Bulbs_MudRoom	14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hallway_FF	1Bulbs_Hallway_FF	40	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Entrance	1Bulbs_Entrance	14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-