INNOVATIVE DESIGN TOOLS FOR RENOVATION AT BUILDING AND DISTRICT LEVEL

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ABSTRACT

This paper describes the methodology and software platform developed as part of the NewTREND project. NewTREND is a H2020 funded research project, which seeks to improve the energy efficiency of the existing European building stock and its current renovation rate, by developing a methodology supported by a BIM based online modelling and simulation platform to aid the energy retrofit of buildings and neighbourhoods. This platform consists of a collection of web tools developed to support collaborative design, facilitate energy modelling, and allow the evaluation of suitable retrofit options at both building and neighbourhood level. In the early stages of the retrofit design process, the Data Manager assists the acquisition of key data required for the creation of Information Models of the existing buildings and neighbourhood. Then, the Simulation and Design Hub is the cloud-based engine allowing the design team to evaluate the current state and future retrofit scenarios for their district, taking into account energy but also economic, environmental and user comfort criteria, tailored to the specific priorities of the different stakeholders involved. The results are post processed and displayed to the user in a meaningful way using normalised Key Performance Indicators and interactive diagrams in the Collaborative Design Platform. Finally, the NewTREND platform is validated in three real refurbishment projects in Hungary, Finland and Spain carefully selected to allow the evaluation of results in three diverse climatic regions.

BACKGROUND AND CONTEXT

It has been well acknowledged that the existing built environment in the European Union is currently responsible for approximately 40% of total energy use and 36% of greenhouse gases emissions (European Commission, n.d.). This has resulted in an increase in the development of new technologies and opportunities to improve energy efficiency, financial incentives by government to improve the building stock and new legislation and policies to ensure better design and performance. However despite this, the renovation rate of the existing building stock remains at only 1-2 % per year (Albatici, et al., 2016), while it is projected that the most of the existing building stock will still be in use by 2050 (Moseley, 2016).

Moreover, developments in technology have opened the door to new opportunities for small to medium-scale distributed generation. However, to date, renovation projects are very rarely tackled at a neighbourhood/district level, and do not fully exploit the potential of the local 'clean' energy generation and the synergies that groups of buildings might offer. In conventional retrofit projects, decisions are mostly made by individual owners with experts advising, usually with reference to case studies examples of successfully applied retrofit technologies in other buildings.

However, the optimal integration of district retrofitting solutions always require planning and implementation at a district scale from the early planning stages, and this also escalates from a single stakeholder decision to a multi-stakeholder decision (Moseley, 2016). All the above have created the necessity for developing better methodologies and integrated solutions to motivate and accelerate energy retrofit projects in a larger scale since the urban regeneration towards nearly zero energy is considered as an unquestionable solution to reduce the energy used in the built environment (García-Fuentes, et al., 2014).

NewTREND is proposing a new integrated methodology, supported by software tools, that aims to increase the uptake of renovation across the EU, exploiting the potential for refurbishment at the neighbourhood level. A principal aim of the NewTREND methodology is the integration of energy efficient design within the urban district. This includes the integration of the building with its adjacent buildings and neighbourhood energy systems, scaling up from Building Information Model (BIM) to District Information Model (DIM). BIM is widely recognized as a cornerstone of future tools and practices in the construction industry (Robert, et al., 2012). However, BIM is currently rarely applied to refurbishment projects due to the difficulties in retrieving the necessary information to build a BIM model for an operating building. Furthermore, collecting reliable building asset information is often a challenge in the early stages of a building design, and BIM is mainly used for architectural purposes, while energy aspects are included only in the end of the process as a final validation of design decisions already taken.

NewTREND proposes the use of energy simulations of buildings and districts, starting from the early stages of a retrofit process, when the retrofit decisions are made. Users of the NewTREND methodology will be able to utilise models for predicting energy consumption in the building stock, targeting an overall reduction in the total energy consumption across the entire district.

INTEGRATED DESIGN METHODOLOGY FRAMEWORK

The Integrated Design Methodology (IDM) proposed by NewTREND, divides the retrofitting project into ten phases, in which certain process and objectives are to be fulfilled for the project team to be able to design and realize the retrofitting project in the most cost effective and energy efficient manner. The project process starts from the initiation phase, and continues with the preparation phase, the diagnoses phase, the strategic definition phase, the concept phase, the decision-making phase, the design development and tendering phase, the construction phase followed by the handover and close out phase and finally the in-use phase. Each of these phases sets a number of objectives, which the project team need to fulfil to further proceed to the following phase.

The NewTREND IDM allows consideration of energy related aspects during the whole design process using different accuracy modes in each phase of retrofitting project by using three different modes of operation namely; Basic, Advanced and Premium. These modes offer the use of different output options, as per the extent and accuracy of the provided data for the project in question. Basic and Advance modes require a 3D energy model of the building and the neighbourhood, enriched with semantic data as a starting point, and dynamic thermal modelling and physics calculations are used to determine the performance in current and future retrofit conditions. The main difference between the Basic and Advanced modes lies in the accuracy of the BIM geometric model and the amount of semantic data of the building/neighbourhood associated with it. Premium mode requires real utility data as input and is useful in the post occupancy period.

THE SOFTWARE PLATFORM

To support the retrofit project team with the execution of the new methodology, NewTREND project consortium has developed a software toolkit to support the energy retrofit design process throughout all the IDM stages. The platform attempts to introduce cloud-based collaboration combined with sophisticated energy modelling tools, which can be used starting from the early design stages, and support the project team during post-retrofit operation and validation. An overview of the NewTREND software toolkit system is shown in Figure 1.

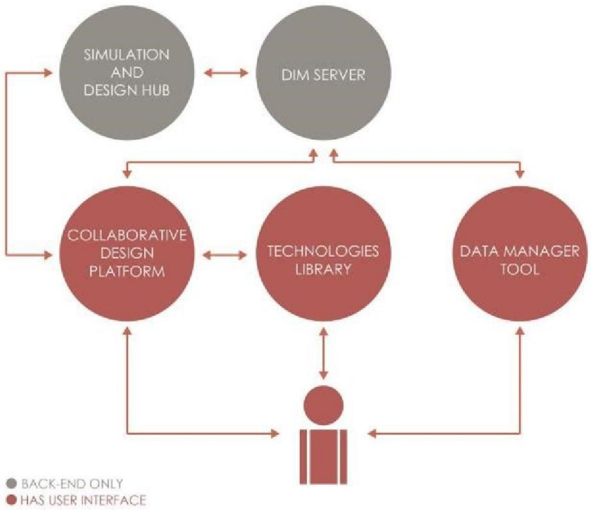

Figure 1: Overview of the NewTREND software toolkit

The NewTREND toolset includes:

- A Simulation and Design Hub (SDH), a collection of integrated design tools where all the calculations and dynamic simulations are executed.
- A Data Manager (DM) tool, that allows the user to collect semantic building and neighbourhood data.
- A Collaborative Design Platform (CDP) where users manage the retrofit project, trigger simulations and compares various retrofit scenario predictions.
- A Technologies Library, where the user is informed about the retrofit technologies currently available on the market.

- A District Information Model (DIM) server, which stores all the data entered in all software tools. These tools interact with each other, allowing the user to execute the IDM in an efficient manner. All the software components of the NewTREND toolset together with interactions are described in the following paragraphs.

Data Manager

The Data manager (DM) is a web application developed to assist the data collection process throughout the duration of a retrofit design project in a district. The complexity and variety of today's building systems makes analysis and collection of building data a challenging task (Robert, et al., 2012). The DM can be useful in data collection phase, which is often a complex task for retrofit projects, especially in the large scale. It is very common for the information and drawings to be scattered or even not available, especially for older buildings and districts. DM guides the team members on what data need to be collected, providing a checklist of items to allow for a minimum quality model to be created, this being useful in decision making during the design process.

Data collected via DM is stored directly on the DIM server and is used for the configuration of Building/ District Information (BIM/DIM) models by the Simulation and Design Hub. The attributes collection pages are structured in several categories and forms, allowing the users to collect information at various levels of detail: from district level (e.g. District Heating Generator Type) to room level (e.g. Thermostat setting). Figure 2 depicts a screenshot of the DM, showing the page where the district level attributes are collected. The user is able to specify the characteristics of the energy generating installations within the district, for example, district heating generators, photovoltaic panels, wind turbines etc. The DM also allows users to upload documents, pictures and notes of relevance for their project to the DIM server and link them to model objects like buildings, storeys or individual rooms.

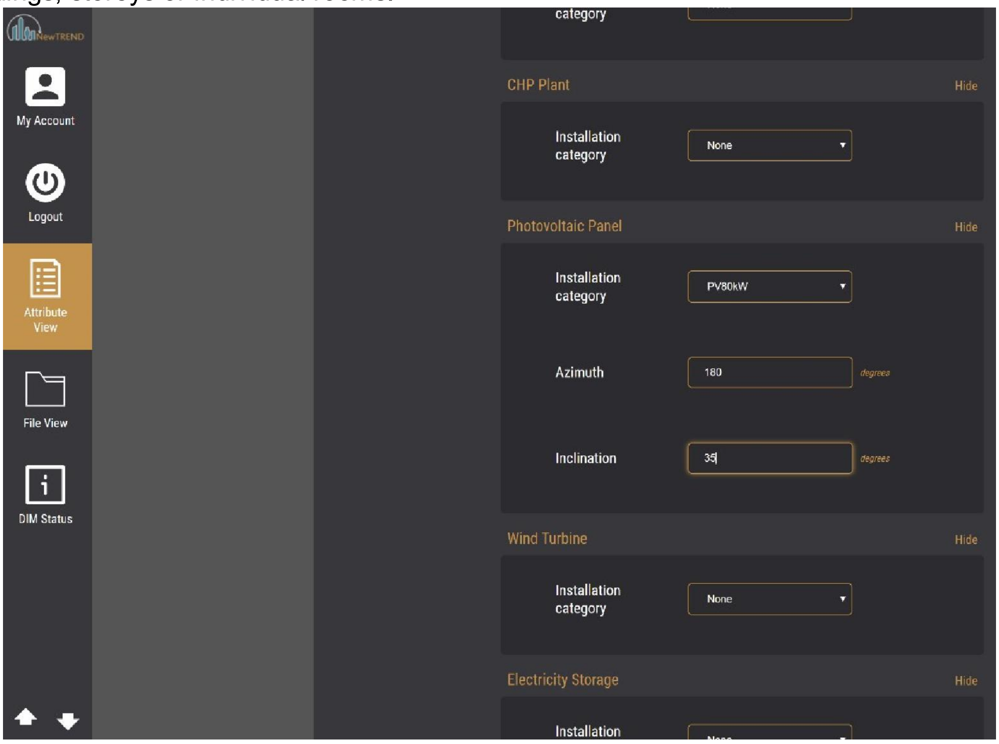

Figure 2: Data Manager – District level attributes

Finally, the DM provides an overview of the configuration status for their District Information Model. This feature is of greatest use when accessed after the data collection, as it informs the users about the mode of the analysis they can proceed with, depending on the data they entered on the DM.

Simulation and Design Hub

The Simulation and Design Hub (SDH) is the NewTREND platform's backend intelligent calculation engine. The users do not interact directly with the SDH: All user interaction to configure, start and analyze simulations is performed through other NewTREND tools, mainly the DM and the Collaborative Design Platform (CDP). This dynamic simulation engine operates on the cloud, and the backbone is the existing IESVE software suite of integrated building analysis tools, together with the Virtual Power Plant (VPP), a high level design tool for resource network at district level, developed by IES.

The IESVE is an in-depth suite of integrated analysis tools and capable of providing high quality dynamic thermal simulations, based on information taken from a single Data Model. The dynamic thermal simulation engine, integrated in IESVE, is based on principles of mathematical modelling of the heat transfer processes occurring in and around a building, which qualifies as a Dynamic Model in the CIBSE system of model classification, and exceeds the requirements of such a model in many areas (IESVE, 2018). Within this engine, conduction, convection and radiation heat transfer processes for each element of the building fabric are individually modelled and integrated with models of room heat gains, air exchanges and HVAC systems. The simulation is driven by real weather data and may cover any period from a day to a year. The time-evolution of the building's thermal conditions is traced at intervals as small as one minute.

VPP on the other hand is a high level design tool for performing simulations of city/district level electricity and heat distribution networks using a combination of accounting and physics concepts. It is based upon load aggregation of energy demand and generation data, and modelling of electricity and heat generation at district level. VPP is also capable of performing physics simulations of photovoltaic panels, wind turbines and other renewable energy technologies and performing energy balance calculations, taking into account existing storage provisions in a district, scaling from a small group of buildings up to the city level. Initially, VPP was developed by IES in the context of the iURBAN project (iURBAN, 2016). However, development continued, and the VPP prototype was improved and extended in the frame of the NewTREND project.

For performing energy modelling within NewTREND, both IESVE and VPP operate on the cloud and interact with each other: IESVE operates during the dynamic thermal simulations at building level, and feeds into the VPP with results as input data. VPP then connects the buildings in a network, together with any local installations, and performs analysis in District level. Both tools combine BIM geometry models with semantic data collected via the DM to generate energy models. In summary, energy models representing the current status of the district are generated. Following this, the users are able to populate these energy models with retrofit solutions via the CDP and predict their effect on the results calculated by SDH.

As mentioned previously, the analysis can be performed at different levels of detail, namely the Basic, Advanced and Premium mode. According to the IDM, during briefing or concept development stage, the user can opt to use NewTREND in Basic mode. This mode uses simplified building models with a lower level of data requirements in order to perform quick energy simulations, that allow rapid preparation of solution variants. The Basic mode takes advantage of the neighbourhood topology in the form of 2D footprint geometry obtained by maps or aerial photographs. The geometry of the buildings is auto-generated based on the 2D footprint and the attributes entered by the user in the DM (e.g. 4 floors, 25% of windows, hipped roof). The thermal characteristics of the building envelope materials and the conditioning systems are introduced using a number of default template datasets that allow mapping different thermal and physical building properties, set by a minimum number of user entered characteristics in the DM, such as building type, year of construction, heating type. The challenge in this early stage is to support the fast analysis of current and future retrofit scenarios with limited data availability, as energy modelling usually requires a large amount of building and district attributes as input to produce reliable results. To overcome this obstacle, NewTREND adopts the thermal templates approach, initially developed and used on predecessor research projects like European FP7 projects FASUDIR (FASUDIR, 2016), INDICATE (Indicate, 2016) and UMBRELLA (UMPRELLA, 2015) during which template-based energy model creation has also been used. These thermal templates are configured to approximate the characteristics of some common building typologies, such as Office, Apartment, Primary School etc. Additionally, historic construction types for buildings in the same countries or regions and the same construction period very often share certain common characteristics, since construction of buildings in most European countries underlies certain minimum legal and regulatory requirements for each construction period and building type. Therefore it is possible to derive common typologies within the building stock, according to their location and construction period. These preconfigured attributes included in the thermal templates are critical for the thermal energy model and usually require in-depth knowledge and monitoring of the building, which is not feasible in the early decision making stages of a retrofit project. Some examples include internal gains and air exchanges, occupancy patterns etc. Hence, the accuracy of the simulations is sufficient for the requirements in the early design phase in which the impact of different retrofitting variants on the total result is more important than the absolute values of the simulation results. By using this method, planners can consider energy-related aspects for their building and neighbourhood retrofitting projects from the early design phase without depending on hard-to-obtain comprehensive building data.

As the retrofit project progresses, and the more detailed characteristics are becoming available, the SDH allows for more detailed simulation and evaluation of the retrofit solution chosen, using the Advanced mode. In this mode, the geometry of the energy model is obtained by a detailed 3D BIM geometry model in IFC format, uploaded via the CDP and stored on the DIM server. The level of detail of the semantic data in this mode can reach the room level.

Comparing to Basic mode, the user in Advanced mode is now able to enter the absolute values of construction details of the building's envelope (e.g. Thermal mass, U-values) and detailed characteristics for all the rooms in the building (e.g. infiltration, heating set point). For a more comprehensive analysis in the Advanced mode, NewTREND platform also embeds thermal comfort, user behaviour models and algorithms into the SDH developed by Università Politecnica Delle Marche (UNIVPM). These are able to simulate alternative management and control of building systems and occupants. Thus, the project team can take into account how changes to the building, occupant behaviour, and operational policies affect energy consumption and occupant comfort.

During all stages of the project, the buildings of interest are not treated in isolation, but considered as part of a neighbourhood. The SDH is capable of connecting all the buildings together to analyse them as a whole. The capabilities of the VPP tool allow the analysis of the infrastructure of a whole city or country, however, in the context of the NewTREND prototype tool it is limited to neighbourhoods no more than 10 buildings. The following schematic network diagram represents a simple example of how the NewTREND platform models and analyses the electricity distribution network of a small neighbourhood consisting of three buildings.

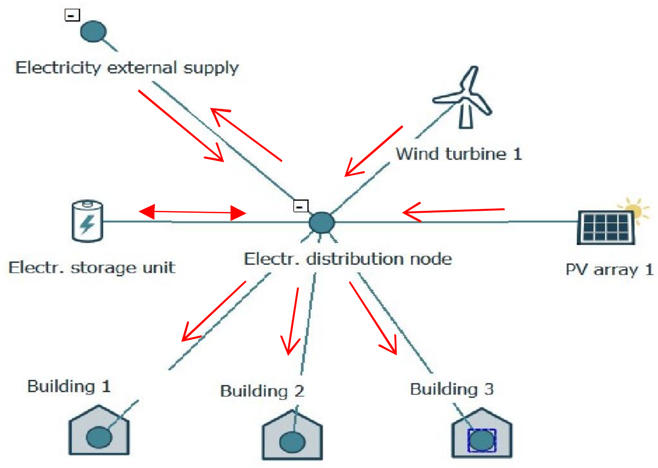

Figure 3: Network schematic diagram of a electricity distribution network in IES-VPP

As highlighted in Figure 3, the distribution of electricity starts at the top left corner, where the node represents the electricity supply from the grid, which serves the whole neighbourhood. The node in the centre is operating as the hypothetical electricity distribution transformer, where all the prosumer units (e.g. buildings, street lights) and installations (batteries, PV panels) are connected and interact with each other. The SDH considers that the electricity flow starts from the nodes and installations and goes all the way to the prosumer units, as indicated by the arrows in Figure 3. In case of battery installations, or energy generated by prosumers (e.g. roof top PV panels) the electricity flows both ways. Additionally, in times of surplus electricity production, VPP can calculate the electricity sent back to the grid. The tool aggregates the demand for particular commodities, such as Electricity and Heat and allocates provision to specific providers in order to meet the demand. For example, adding a wind turbine to the network will generate electricity when it is windy, reducing the amount needed to be imported from the grid, reducing the carbon emission factors for the housing served by the wind farm and helping to charge storage devices with electricity in times of low demand; the effect on the neighbourhood is estimated naturally as a consequence of adding the wind farm to the network. In this way, the VPP tool can quantitatively predict the impact of various interventions on the neighbourhood scale. The following are a small sample of the questions that the VPP tool can address:

- What is the size of the wind turbine a particular district needs to install in order to cover approximately 30% of the electricity demand in a year?
- What is the total reduction in carbon emissions associated with installing photovoltaic panels on every home in a particular suburb?
- What is the effect of installing a large battery to serve a group of buildings?

- What is the benefit of replacing the individual heating systems with a district heating network? To calculate the total energy requirements of the whole group of buildings the VPP requires energy demand data as input. In SDH, the data input for the demand is taken from the single building dynamic simulations, calculated either in Basic or Advanced mode by IESVE software.

The typical calculation period in SDH is a full calendar year. Furthermore, a weather file representing the climatic conditions of the neighbourhood is required. In case of NewTREND, weather files are auto assigned to the model based on the geolocation of the study district.

Finally, the user can operate NewTREND platform in Premium mode. This mode is introduced in order to reflect the post-retrofitting controlling of the implemented retrofitting variants by using real time metered and measured building data instead of calculated and designed data. Therefore, it is possible to compare the real values against the simulated results from the different design phases of the retrofitting process and updating.

Once the analysis is completed successfully, the SDH runs post processing algorithms to calculate specific sustainability metrics and Key Performance Indicators (KPIs), meaningful for the project team to understand the condition of the district and evaluate the impact of the different retrofit options. The various retrofit solutions are ranked based on predefined KPIs and a weighting system, which takes into account the priorities of all stakeholders involved, providing information about the best solution that matches their district. The results are stored in the DIM server and users can access and visualise them in the CDP.

Collaborative Design Platform

The CDP is the communication interface between all stakeholders involved in the retrofit project. It is accessible by all project team members through their web browser. It serves as the main contact point for the project team and consist of several components for collaboration, such as project management and e-collaboration tools. To enable users to carry out simulations of their buildings' and neighborhood's current state as well as potential retrofit scenarios, the CDP interfaces with the SDH and allows for preparing retrofit scenarios and detailed results analysis. The CDP also provides access to the NewTREND Technology library, a comprehensive library of retrofit options and business models for refurbishment.

At the time of writing this paper, CDP software development is still in progress.

District Information Model Server

The District Information Model (DIM) server is the core data storage model for the project. Users interact with the DIM server indirectly via other NewTREND tools, since there is no Graphical User Interface for the DIM server. The DIM is hosted on an interoperable data exchange server where all project model data shared by the project team for subsequent use are stored during the whole refurbishment process.

The server's data exchange is specific to the information that is required for energy efficient design and integration of neighbourhood systems: CityGML and IFC are the core data storage and open source interoperable exchange formats for the building and district geometry files on the server. Comma Separated Values (CSV) and JavaScript Object Notation (JSON) files are also used for data exchange. The DIM server has an open architecture that others could adopt so that in the future multiple databases will be able to communicate to one another through an open source Advanced Programming Interface (API).

<u>CASE STUDY</u>

To demonstrate the capabilities and validate the simulated results produced by the NewTREND software, a theoretical case study has been undertaken, using a hypothetical neighbourhood of 10 buildings built in the early 90's in Lochside Knoydart, where the owners have decided to form a Housing Association and explore retrofit, district heating and renewable electricity generation solutions.

There is a mix of end users as follows:

1. 2 homes are retired couples who are home most of the day but have an active social life in the evening
2. There are 3 young families, all with working parents and not home between 8am and 6pm
3. There are 2 young families who have one parent with children home all day
4. There are 2 single home owners who work from an office and are not home between 7am and 8pm
5. There is 1 single home owner who works from home 4 days of the week

In this study, the community wants to explore the benefits of installing rooftop photovoltaic panels in six of the buildings, serving the whole community, accompanied by a large lithium battery.

The energy models have been prepared in IESVE using box geometries and semantic data based on the behavioural profiles and selected thermal and electrical templates to approximate the end-users' consumption. A sample of the data used can be found in Table 1.

Table 1: Input data for Lochside Knoydart theoretical case study

Input data	**Value**
Lighting maximum power consumption	7.3 W/m^2
Equipment maximum power consumption	5.1 W/m^2
Domestic hot water consumption	7.5 l/(h*person)
PV panels south facing	36kW combined
Lithium battery storage capacity	20kW

The graph below is a typical output of the SDH, representing the aggregated electricity loads in the neighbourhood during a week in early summer. The results reveal that the peak electricity load occurs in early morning and late evening hours, and this pattern is followed throughout the whole week. Each line in the graph represents the variables below:

- Total discharged (blue): The electricity supplied to the neighbourhood by the battery
- Total generation (purple): The electricity generated by the PV panels
- Total stored (green): The electricity stored in the battery
- External supply (yellow): The electricity supplied from the grid
- Total primary consumption (red): The electricity consumption for the whole neighbouhood

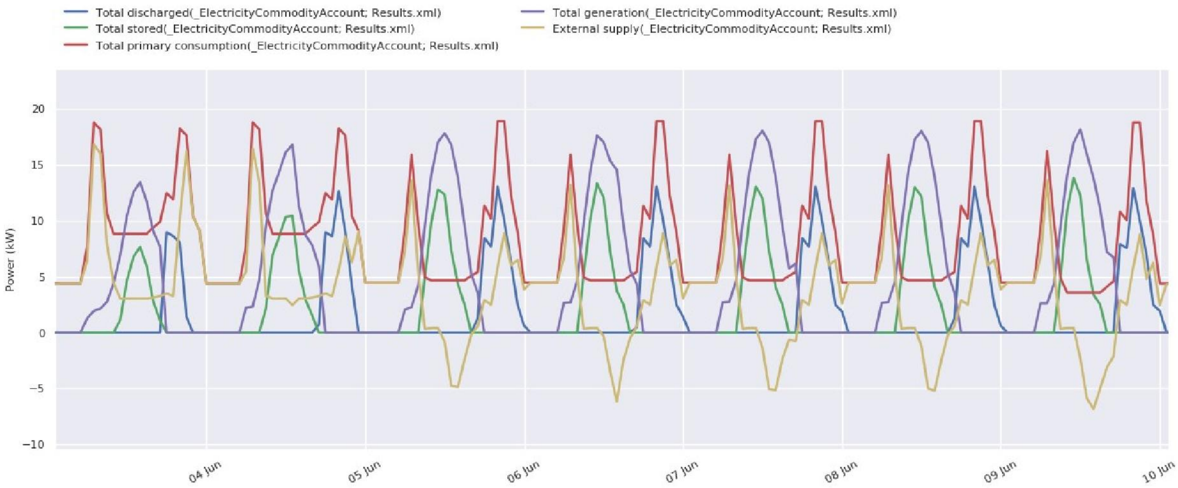

Figure 4: A typical weekly peak electricity loads in summer for Lochside Knoydart theoretical case study, calculated by VPP

In Figure 4, isolating the results for a single day (4th June), the majority of the energy requirements during the peak loads is covered by the external electricity supply from the grid (yellow line), since the PV panels are not generating enough electricity during the morning and evening to cover the demand (purple line). However, during the day, the PV panels generate electricity, enough to cover the demand and also charge the battery (green line). The battery stores the excess electricity and releases it during the evening (blue line), which reduces the electricity supplied from the grid. Results also reveal that in days with sunshine, for example in 6th of June in the graph, the excess electricity generated by the PV panels is sent back to the grid when the battery is fulle charged (negative curve in the yellow line). In a full calendar year, the SDH calculated that the combined PV and battery system can cover the 40% of the electricity demand for the whole neighbourhood. However, in examples like this, NewTREND methodology always suggest individual building users, after evaluating those results, to consider and include in the analysis building interventions that reduce the electricity used in their buildings for example replacing the lighting systems more efficient ones. This way, the whole neighbourhood will benefit even if only part of the building stock is retrofitted. Repeating the analysis with LED lighting bulbs for all the buildings, the PV and battery system coverage reached 60% of the total electricity consumption.

SOFTWARE VALIDATION IN REAL CASE STUDIES

The methodology and software tools are currently demonstrated and validated in three real design projects located in Spain, Finland and Hungary. The three projects have been selected to cover different climatic regions as well as to consider different renovation practices across Europe. At this stage, the NewTREND project members involved in the real case study demonstrations are currently in the data collection phase, evaluating the usability and functionality of the DM when collecting the necessary data. Additionally, they have already prepared the BIM and DIM models, also necessary to perform the energy modelling in the SDH. At the time of preparing this study, the software validation is still in progress and detailed results will be presented in project deliverable reports and future studies.

CONCLUSION

The NewTREND project seeks to improve the energy efficiency of the existing European building stock and develop a new integrated design methodology targeted to ensure that energy is considered during renovations of buildings and neighbourhoods. This methodology is accompanied by a software platform, operating on the cloud, exploiting the benefits of utilising Building and District Information Modelling in building retrofits. The advantage of the software platform is that it is designed to assist the stakeholders by predicting the outcomes of retrofit scenarios, using dynamic thermal simulations, throughout the whole retrofit process. In the data collection phase, Data manager tool allows the easy collection of semantic data related to the district under study and the buildings included in it. The Simulation and Design Hub (SDH) is a collection of intelligent calculation engines, capable of performing complex energy simulations at both building and neighbourhood scale. The SDH is capable of operating in 3 different modes depending on the availability of data and on the stage of the project. In the early design stages, the simulations can be executed with limited data availability, since the energy models can be created using just building footprints and template data in basic mode. The use of complex energy modelling in the early design stages provides a benefit to the design team, comparing to current practices, by allowing them to make an informed decision on which retrofit solutions best match the buildings in the district. Additionally, SDH allows the design team to predict the energy outcome of larger retrofit solutions at district scale, such as district heating systems and community renewables. A retrofit design question example that SDH can answer would be: What is the benefit of replacing the individual heating systems with a district heating network? A simple study on a theoretical community in Scotland has shown that, using SDH, the planners can predict the outcomes of installing PV panels accompanied by a battery, serving all the buildings in the community. Plotting the electrical load profile during a typical summer week revealed that, based on the assumed behavioural profiles, the peak electricity consumption in the district occurs during early in the morning and late in the evening. Furthermore, storing the excess electricity generated by the PV panels using batteries can reduce the reliance on electricity from the grid during peak hours. In such a way, the NewTREND toolkit can assist communities to reduce the reliance of energy via traditional sources and make informed decisions around purchasing retrofit solutions for their district. Once a retrofit project moves forward, SDH allows more complex energy modelling and analysis using more detailed data, allowing the design team to perform more accurate studies. In the context of the NewTREND toolkit, all the data collected are stored in an interoperable District Information Model (DIM) server, while displayed to the users in a meaningful way using normalised Key
Performance Indicators and interactive diagrams in the Collaborative Design Platform (CDP). The results of NewTREND project are currently being applied, demonstrated and validated on three real case studies in three diverse locations across Europe. Using NewTREND software in real buildings, the planners can predict and identify the best solutions to reduce reliance from traditional energy sources and reduce the energy usage throughout the whole neighbourhood.

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