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TWINERGY

Demand Flexibility Models

D6.2

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Deliverable

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TWINERGY	**957736**	**Intelligent Interconnection of prosumers in positive energy communities with twins of things for digital energy markets**

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Demand Flexibility Models

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DISSEMINATION LEVEL

✔ **P** **Public**

C Confidential, only for members of the consortium and the Commission Services

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v0.3	26.02.2022	Dave Sweeney et. al	IES R&D	Appendix added showing sample completed checklists from each pilot site
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v1.0	28.02.2022	Dave Sweeney et. al	IES R&D	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This deliverable contains original unpublished work except where clearly indicated otherwise.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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Executive Summary

The goal of the TwinERGY project is to introduce a first-of-a-kind Digital Twin framework that will incorporate the required intelligence for optimizing demand response at the local level without compromising the well-being of consumers and their daily schedules and operations. Key to this goal is the development of the demand flexibility models that will forecast the required behaviour and communicate it to the real world for implementation.

Flexibility is the total amount of demand response that a building or community is capable of in a set period of time. The flexibility model can optimise the aggregated demand profile of a community, and then determine the demand response actions necessary to achieve this optimal performance. Using the python optimisation library PyGMO and IES' Intelligent Communities Lifecycle (iCL) Digital Twin platform [3], the optimisation problem attempts to minimise the end-user energy costs, maximise the use of local renewable generation and maintain as stable and flat an energy consumption pattern as possible.

The algorithm has been validated using a synthetic digital twin with simulated appliance-level demand and domestic rooftop PV generation data. This work was then validated using a digital twin made of 5 buildings from the Benetutti TwinERGY pilot site. Only 5 buildings were included due to time constraints on the deliverable caused by delays in data collection at the pilot site due to the pandemic, however the model is still suitable to verify the robustness of the flexibility algorithm when considered in tandem with the synthetic digital twin.

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1 Introduction

The flexibility model developed as part of D6.2 are critical to the development and success of the TwinERGY Digital Twin framework that will be used to optimise demand response with no disruption to consumers' comfort or daily routines. The combined solution of digital twin modelling and flexibility algorithm forecast the required demand response behaviour and enables its communication to the real world for implementation.

This is achieved using both a Python-based optimisation programme known as PyGMO, and IES' iCL Digital Twin platform in tandem. A Digital Twin is a virtual replica of a building or community that is able to mimic the behaviours and energy simulations of the real world in order to inform how best to operate and use the associated assets, appliances and systems [1]. The optimisation algorithm uses this simulation to determine how to best schedule the energy demand of the building/community and communicates this either to the user or automatically to the asset in order to minimise cost, maximise the use of local renewable power and maintain stability for the grid throughout.

In order to achieve this, a relatively wide range of information and data is required from the real-world buildings and communities so that the digital twins, and associated optimisation of the flexibility and demand response actions, can be modelled in an accurate manner so that it is as valuable to the end users as possible.

2 What is Flexibility

In the context of the TwinERGY project, flexibility is defined as "the ability of a power system to maintain continuous service in the face of rapid and large swings in supply or demand" [1] One source of flexibility is in demand response actions where consumers can participate by "reducing or shifting their electricity usage in response to time-based rates or other forms of financial incentives" [1], and is in fact the typical method of realising flexibility in electricity markets [2] In the context of demand side management, flexibility can therefore be seen as demand response potential, or the total possible amount of demand response that can be enacted by the consumers in a given period. For clarity, this definition of flexibility (i.e., "demand response potential") will be used in this deliverable. Once the total flexibility has been calculated using the building digital twins (BDTs) and community digital twins (CommDT), it is up to either the user or an automated signal to enact the demand response actions that are included in this calculation. After the actuation of DR actions, it is possible to calculate how much demand has been shifted, and in the unlikely event that all possible demand response actions were taken, the demand response would equal the calculated flexibility potential.

The flexibility algorithm being employed in the TwinERGY project are only as useful as the input data provided. Accuracy in the digital twins also relies on the same high resolution of input information, which includes everything from time series demand data, building envelope information, appliance specifications and user preferences at the consumer and building level, up to detailed information on the distributed energy resources (DERs) available in the community, weather data and energy pricing signals. Although assumptions for each of these can be made, the quality of forecasting and output is diminished as the uncertainty of inputs increases. As such, accurate forecasting from the DTs is essential for the computation of flexibility in real buildings and communities. A building data checklist for digital twin development can be seen in Appendix 1.

These algorithms at their core are optimisation problems, defined by their variables, their constraints, and their objective function (the commodity that they are trying to maximise/minimise). The variables include the energy consumption of all relevant loads, the constraints include things such as user preferences and generation capacities of DERs, while the objective function can be to minimise carbon emissions or cost or maximise the amount of DER generation being used.

2.1 Flexibility at the Building Level

Flexibility at a building level is provided in three main areas: appliance scheduling, heating/cooling control and EV charging. Depending on the preferences of the user collected in the Consumer Comfort/Well-Being Module as defined in WP7, washing machines and dishwashers can be preloaded and turned on when the flexibility algorithm deems it optimal. The same can be done with the heating/cooling system in the building. If the ambient temperature allows it, the system can temporarily be shut off (during high tariff periods for example) and then switched back on before the building users perceives any difference. Again, the constraints of this problem are the users' preferences, but the fact that indoor building temperature is relatively slow to change can be exploited. Finally, with EV charging, the flexibility comes from the fact that it may be plugged in for a number of hours at a time, but most take less than one hour to fully charge. So, based off the user's charging habits and preferences, the flexibility algorithm can determine when is best to charge it. This, for example, could be during periods of high solar irradiance if plugged in during the day, or waiting for the lower energy tariff at night. All of this is modelled and forecasted using the BDT.

2.2 Flexibility at the Community Level

Flexibility at the Community Level is comprised of two different types. The first is an aggregation of the building level flexibility that is evaluated at a community level. The second is community-level assets, such as community battery storage, communal EV charging and communal buildings such as community centres. All of these assets come together to form the CommDT. Once the building operations have been optimised and scheduled, the problem is then evaluated at a community level to see if any further flexibility can be exploited. This information can also be used to feed into peer-to-peer trading platform, where the flexibility in the community can be exploited by the end users to either buy or sell energy within the local marketplace depending on what is available at the time. The creation of such a trading platform however is outside the scope of this deliverable and is mentioned purely for reference.

2.3 Taxonomy of Flexible Loads

There are a wide range of flexible loads that can be exploited by the demand response optimisation algorithm at both a building and community level. At a building level, these can include HVAC systems, heat pumps, EV chargers, battery storage units and appliances such as dishwashers and washing machines. At a practical level certain loads are only flexible/available at specific times of day. For example, a homeowner is not going to turn a washing machine on in the middle of the night unless they can be scheduled automatically. Similarly, user preferences can also define constraints, such as temperature limits preventing a HVAC schedule being manipulated during the wintertime.

At the community level, flexible loads include community-level battery storage, public EV charging, and heating/cooling of shared community buildings such as sports halls and community centres. Again, as with the building level loads, there are constraints on the flexibility, given that certain services are only in use at specific times of day.

2.4 Demand Response Actions

Now that the flexibility at both building and community level has been defined, it is important to understand how it can be exploited. This is where demand response actions are leveraged, and they can be separated into two distinct categories: implicit demand response and explicit demand response. "Implicit demand response (also sometimes called "price-based") refers to consumers choosing to be exposed to time-varying electricity prices that reflect the value and cost of electricity in different time periods", whereas "in explicit demand response schemes (sometimes called "incentive-based" or "volume-based") the result of demand response actions is sold upfront on electricity markets, sometimes directly for large industrial consumers or through demand response service providers" [3].

The flexibility algorithm developed for TwinERGY focuses on the price-based implicit demand response actions. These actions can either be manual or automated, but that doesn't matter from the point of view of the algorithm's decision making. An example of an automated action is the control of the HVAC system in a building, which can be switched on/off at a given point in time if it is determined to be optimal by the algorithm (which considers price), and the user comfort preferences are maintained (i.e. it never gets too hot or too cold in the building). A manual demand response action then is instead communicated to the user as an action to take, usually through a user interface of some kind, or a text message alert to their phone depending on the use case in question. So, for example, the algorithm might determine that the optimal time to turn on a dishwasher and washing machine is in the morning rather than the afternoon on a given day. The user would be instructed of the optimal time to turn on both appliances via some a web-based user interface, for example, and it is then up to them to then act on this.

By their nature, manual demand response actions are less likely to be implemented effectively when compared to the automated version, however given that it is not possible or practical to automatically control all types of domestic loads, both types are important when fully utilising implicit demand response. This real-world inconsistency of not all available demand response actions being enacted by the end user is captured in the testing process of the algorithm, with results shown in Section 3.2.

3 Flexibility Calculation Methodologies

3.1 Flexibility Algorithm Development

When developing any algorithm, the key elements include identifying the inputs required, selecting correct tools to provide the functionality, and finally extracting the correct outputs and results for further use. In the case of the TwinERGY flexibility algorithm, all of these elements are displayed in Figure 1 below. The inputs include simulated appliance level demand data from the StROBe library [5], pricing information from the ENTSO-E API [6], and local renewable energy modelling from the IES Intelligent Virtual Network (iVN) modelling tool. All of this information is collated in the IES iSCAN data management platform.

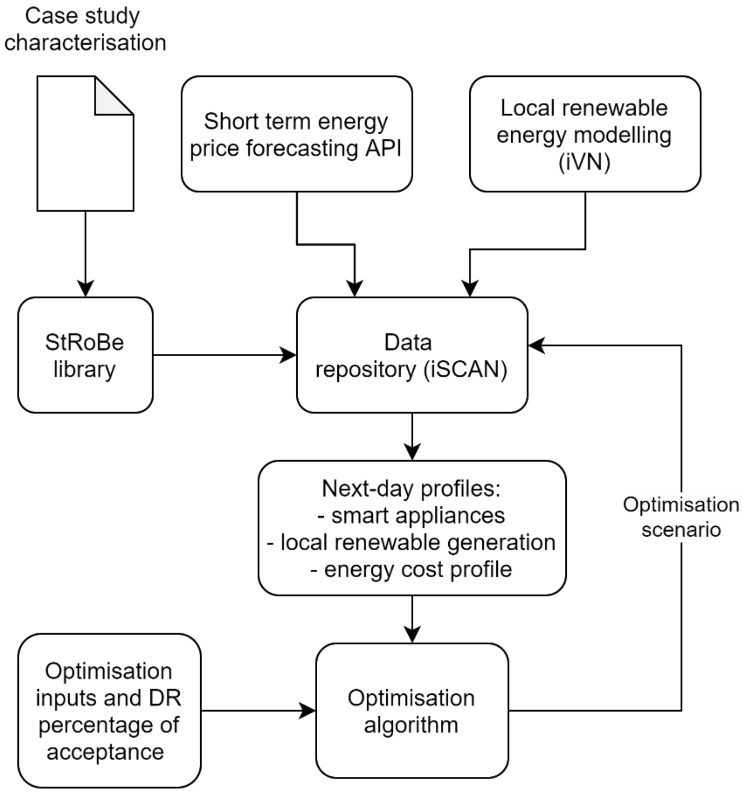

Figure 1.Twinergy Demand Response Optimisation Algorithm

The PyGMO library, an optimisation engine that facilitates multi-objective problem-solving [7] is then used to provide the functionality required to model flexibility. Other elements taken into consideration include the demand response percentage of acceptance and time-of-use constraints, with the final output being the optimised day-ahead aggregated demand profile for the community/pilot site in question.

Residential electric demand modelling

The StROBe library is a collection of stochastic occupant behaviour models that are used to simulate demand profiles for a typical range of domestic appliances. Inputs to the library include the building type and family composition, and from that time series data for a relevant and appropriate set of appliances is generated for each home.

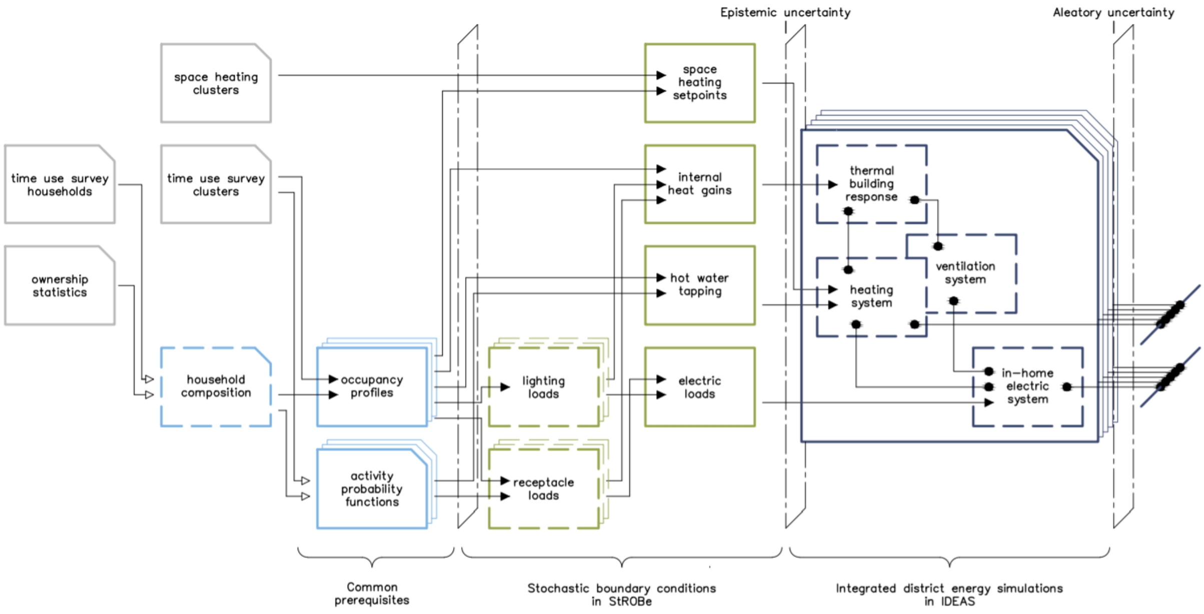

Figure 2.General Overview of the Implemented Algorithms in StROBe [4]

Each appliance is then designated as either flexible or non-flexible, and depending on the demand response acceptance criteria, which is explained in more detail in its own section shortly, are then included in the optimisation problem for the flexibility calculation for each building, and also the entire community as a consequence.

Network resource modelling

The IES Intelligent Virtual Network (iVN) modelling tool is built to simulate and aggregate the performance of physical networks including heat, electrical, water and wastewater. Input data includes electrical and heating demand data of assets/buildings connected to the relevant networks, and simulation of local generation data to satisfy this demand. This can either be conventional generation powered by fossil fuels that will generate as much power as is required and/or possible at every time step, or renewable generation, which uses weather data as an input to calculate its energy production.

Within the TwinERGY flexibility algorithm, the iVN is providing local renewable generation forecasts based on the local weather forecast for the pilot site in question. As well as requiring an accurate weather forecast file, the algorithm also requires details of the renewable generation installed on site, such as power capacity and positioning, and for PV arrays specifically, angle of installation and degradation factor if known. As is the case with the pilot site models, the more information that can be provided, the more accurate the energy forecast will be.

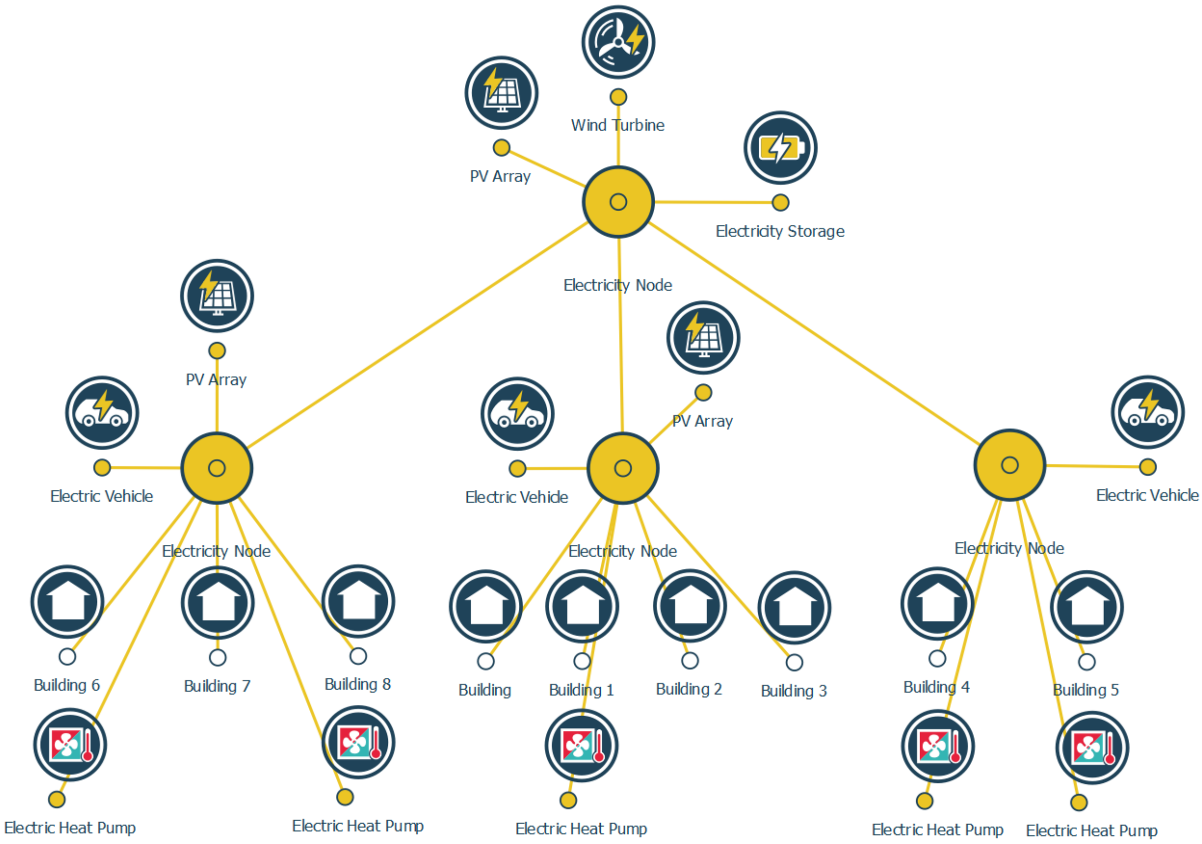

Figure 3.Example of an iVN electrical network model

Acceptance rate of DR programme and simulated scenarios

Ideally, the demand response programme would have full real-world participation every day. However, in practice this will never be the case as certain loads may not be available unexpectedly, or users may decide not to participate in the implicit demand response actions proposed by the algorithm. With this in mind, it is important to model different rates of demand response acceptance. For this proof of concept, 0%, 25%, 50%, 75% and 100% acceptance were modelled.

Practically, from the point of view of the algorithm, this parameter translated to the proportion of appliances in the model that were available to the optimisation algorithm. The impact of the different acceptance rates is visualised in Section 3.2, Algorithm Testing & Validation.

Multi-level optimisation

The optimisation algorithm employed in the flexibility programme allows the user to define multiple objective functions against which the problem can be optimised. In this case, three objective functions are defined:

- Minimisation of cost of use of appliances for each building
- Maximisation of use of renewable resources
- Maximisation of diversity factor

The first two are intuitive, in that the demand is shifted to periods of lower cost in the day, and periods when there is renewable power available respectively. The diversity factor is a method of defining how flat the demand profile is. So, the higher the value of the diversity factor, the flatter the aggregated demand profile. This is desired as this makes the operation of the electricity grid by the operator easier when the demand curve is more even. Again, as with the different demand response acceptance rates, the impact of defining these objective functions will be shown and explained in the next section.

3.2 Algorithm Testing & Validation

Generic Use Case

To begin with, a sample test case was used. The case in question was 39 semi-detached residential houses each with their own solar PV array (4kWp) and demand profiles for each of the appliances as generated by StROBe as described previously. This residential use case is similar in type and scale to the TwinERGY pilot sites. For example, the Benetutti pilot site is made up of 20 single-family and two-family residential buildings, and this is in line with the other pilot sites (Athens has 20 buildings, Bristol has 12 and Hagedorn has 56, with well over 90% being residential).

Each of these demand profiles was generated for a single day and aggregated across the community. This profile was then optimised against cost, renewable generation usage and diversity factor, with the simulation repeated with four different DR acceptance rates

(25%, 50%, 75% & 100%). The base case is represented by a DR acceptance of 0%. The results of this process can be seen in Figure 4 below.

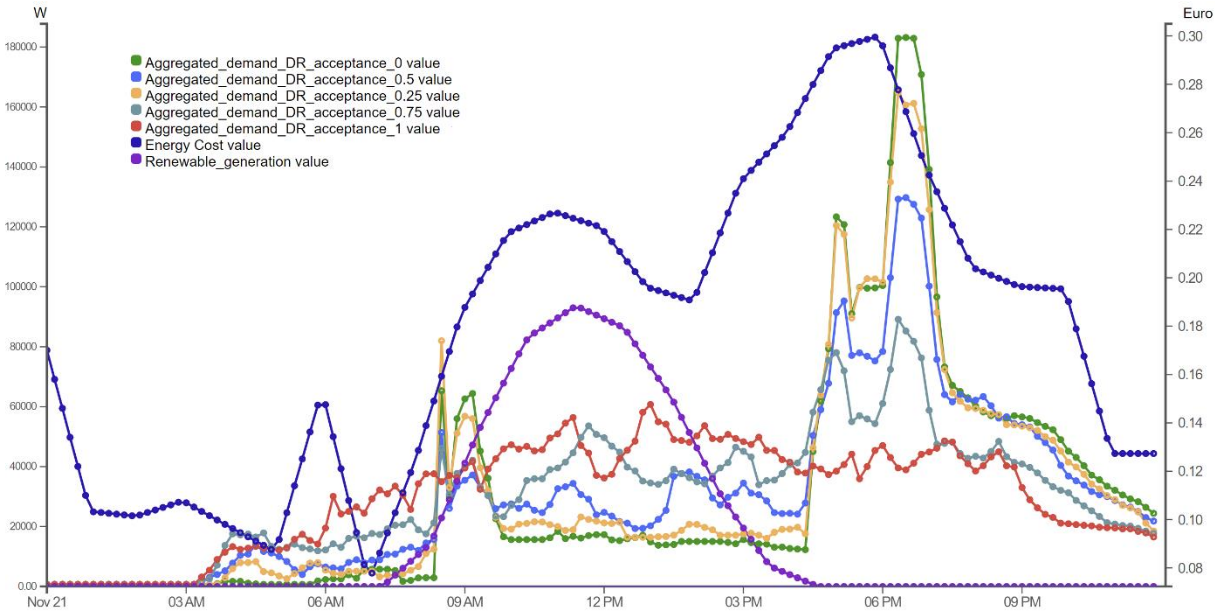

Figure 4.Demand Response simulation results for the test community

As expected, the higher the level of acceptance towards participating in demand response actions, the better performing the demand profile. This is most obvious when comparing the green (base case, or 0% acceptance) and red plots (100% acceptance). The unoptimised green profile is consuming the highest proportion of power in the evening, when the renewable energy is unavailable, and the time-of-use cost is highest. Compare this then to the most optimal red profile, which peaks during the time of maximum renewable energy generation, when the time-of-use cost is not at a peak and is also the most consistent across the day. A comparison of total costs can be seen in Table 1 to verify that the results are as expected, with costs reducing as the demand response acceptance rate increases, with the exception of the 25% acceptance rate case which has a slight increase. This is likely due to the fact that the algorithm is also optimising for renewable energy use and diversity factor as stated earlier and as such on balance is still a more optimal scenario.

Table 1.Total Cost of Generic Use Case – Flexibility Algorithm Results

	Total Daily Cost
Base Case (0% DR)	€127.36
25% DR Acceptance	€127.65

50% DR Acceptance	€120.93
75% DR Acceptance	€115.86
100% DR Acceptance	€110.48

Benetutti Example

Verification of the results found in the generic use case is important, and so a reduced version of the Benetutti pilot site CommDT was built for this purpose, made up of five BDTs. The CommDT is not complete due to time constraints on the deliverable caused by a delay in the data collection process at the pilot site due to the Covid-19 pandemic. This was the case with all of the pilot sites, and so it was decided that five buildings with the most complete data in the Benetutti site would be used to further validate the flexibility algorithm.

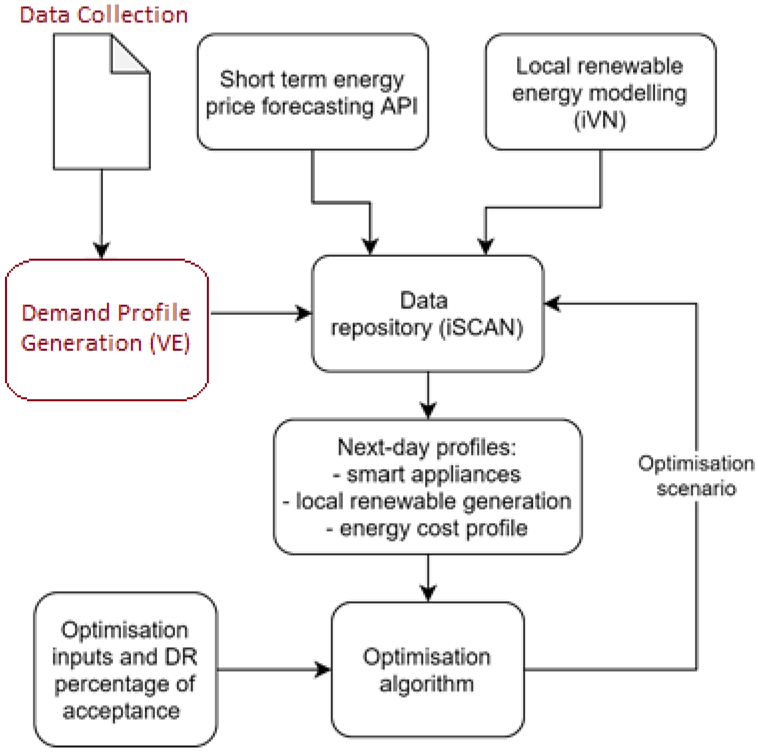

Figure 5.Adapted TwinERGY Demand Flexibility Optimisation Algorithm

As can be seen from Figure 5, a slight change to the workflow was the inclusion of the IES Virtual Environment (VE) in place of the StROBe library. The VE is the IES platform that allows the creation and simulation of building digital twins. The real-world data collection process is the input to this step. Other than that, given that the VE can generate demand

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profiles in the same way as the StROBe library, no further changes were required, other than a specific iVN model being created for the Benetutti pilot site.

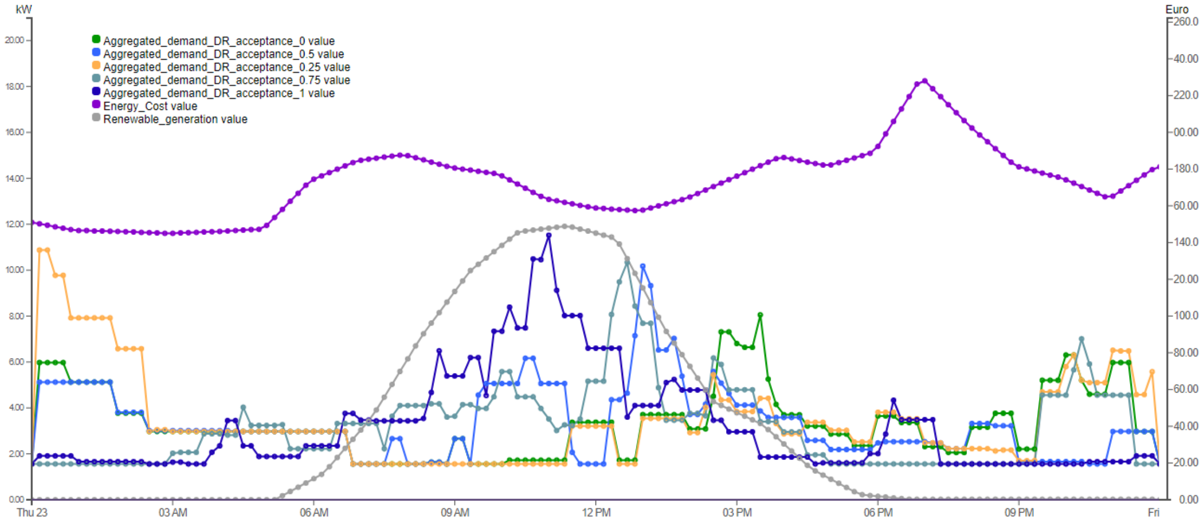

Figure 6.Demand Response simulation results for the Benetutti Pilot Site CommDT

As with the generic use case example, the demand profiles are augmented as the demand response acceptance rate increases so that as much energy as possible is consumed during the period of renewable energy generation. And also similar to the previous example, the cost reduces as the DR acceptance rate increases, again with one discrepancy for the same reason of having multiple objective functions.

Table 2.Total Cost of Benetutti Pilot Site CommDT – Flexibility Algorithm Results

	Total Daily Cost
Base Case (0% DR)	€8.79
25% DR Acceptance	€8.69
50% DR Acceptance	€8.75
75% DR Acceptance	€5.15
100% DR Acceptance	€4.04

The fact that the results of the Benetutti pilot site simulation match those of the generic use case validates that the flexibility algorithm can work for different use cases and as a result can be adapted for each of the pilot sites in the TwinERGY project. The objective functions can also be changed depending on the specific requirements of the pilot site in question, but for the purposes of validation for this deliverable remained the same across the two test simulations.

The next steps will be to expand the Benetutti CommDT to include all 20 buildings, and for the algorithm to be connected to the Athens, Bristol and Hagedorn pilot site digital twins once developed. Data collection for these sites as stated is now progressing well after some delays as previously mentioned. Examples of completed checklists from each pilot site can be found in Appendix 2.

3.3 Integration of Flexibility Algorithms within the DT

With the proof of concept now established in the previous section, there are a number of updates that will be made to the flexibility algorithm for it to be used in the TwinERGY DT platform. The TwinERGY DT platform will be built in the IES Intelligent Communities Lifecycle (iCL) platform. If there is enough information, a DT of each building in each pilot site will be built in the Virtual Environment (VE), IES' building energy simulation software. If not, the pilot site can also be modelled and simulated in the Intelligent Community Design (iCD) tool, a community-level modelling tool that is less detailed than the VE, but is capable of simulating the energy of multiple buildings across an entire community in the form of a less-detailed CommDT. However, it should be noted that the iCD does not offer the level of granularity required to facilitate the flexibility forecasting calculations at a building and appliance level.

In the context of the algorithm, these digital twins of the pilot sites can be calibrated using historical time-series data, and then used to forecast the demand data and take the place of the StROBe library as seen in Figure 1. In this context, it could be seen that the TwinERGY Consumer Demand Flexibility Profiling Module sits within the Community Demand Flexibility Profiling Module in the form of the VE models, i.e. BDTs. They then form the building blocks of the CommDT, which also considers the renewable energy forecasting from the iVN. This approach is taken as a result of how the optimisation engine and ICL is set up. The demand profiles generated in the VE can be fed both directly into the flexibility algorithm and into the iVN through iSCAN.

Work is now ongoing to create the remainder of the BDTs for the Greek, British, Italian and German pilot sites.

Figure 7.IES' iCL Digital Twin Platform

This data, as with the original algorithm, is hosted in iSCAN, a cloud-based data management platform, within which, separate projects are set up for each of the pilot sites. The optimisation engine itself then is also hosted on the cloud along with the iVN. The resulting optimised profiles are then made available to the TwinERGY interoperability platform through iSCAN's API, as well as associated instructions for the specific time periods to which the different assets and appliances should be shifted, and the data will be displayed in the Social Network module user interface as and when required.

4 TwinERGY Flexibility Framework

4.1 Flexibility within the TwinERGY Platform

As stated in the previous section, the Consumer Demand Flexibility Profiling Module and associated BDTs can be seen to sit within/feed into their Community-level counterpart, given that the performance of all appliances and buildings impact one another in the optimal performance of the entire community/pilot site. However, for the purposes of clarity within the TwinERGY module platform, as seen in Figure 6, the two modules are kept separate in this description.

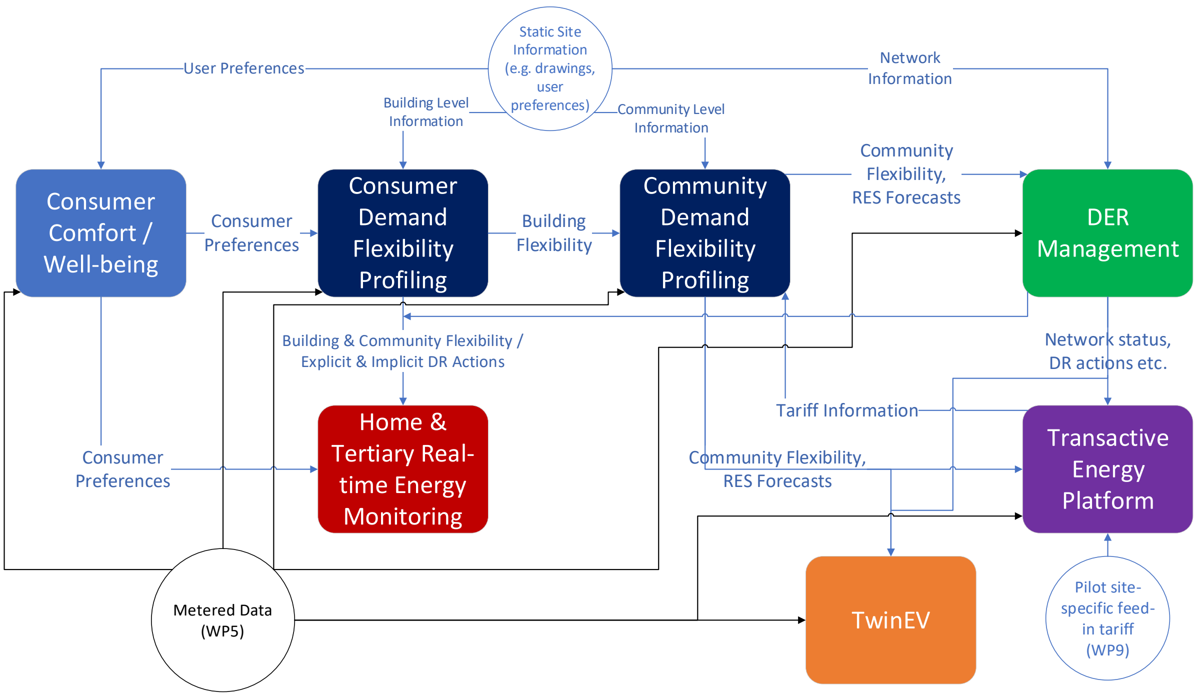

Figure 8.TwinERGY Module Flow Diagram

As seen in the workflow above, the consumer preferences from the Consumer/Comfort Well-being module will be taken into the flexibility modules and used as constraints for the optimisation problem. The renewable energy forecasts calculated in the iVN are made available to the DER management module via the iSCAN API, the implicit demand response actions (i.e. the output of the flexibility algorithm) will be communicated to the Home & Tertiary Real-time Energy Monitoring Module, and the demand flexibility will be output to the TwinEV module and Transactive Energy Platform (TEP). Tariff information from the TEP can then replace the ENTSO-E API information as an input to the flexibility algorithm if deemed appropriate.

4.2 The TwinERGY Energy Mapping Framework

The flexibility algorithm as it has been developed is entirely reliant on the accuracy and level of detail of the input information. Ideally, the algorithm will have information on every appliance and asset available to it in the real world pilot site. This will include forecasted demand data, any constraints such as time-of-use or energy use limits, and whether the asset can participate in implicit demand response.

Once the appliance level information is available and simulated, each of the VE, iCD and iSCAN can define and manage separate channels for each of the demand profiles for each of the assets & appliances in the pilot site that are participating in flexibility. While the algorithm will aggregate these profiles for the purposes of demand response optimisation, these channels will remain distinct throughout, with the resulting optimised profile available for each of the separate assets for dissemination to the user, or automated command depending on the load in question.

5 Conclusions

The testing and validation of the flexibility algorithm proved to be quite successful. The results were as expected for the simulated test case and then verified using the Benetutti pilot site. The demand profiles were optimised in line with the objective functions defined as expected. The IES ICL platform is capable of modelling the BDTs of each pilot site within the VE, and using them then to create the CommDTs within the iVN and/or iCD, depending on the level of information available. This work is now in progress for all four pilot sites.

The next steps will be to connect the algorithm to the complete Benetutti pilot site CommDT, as well as then for the Bristol, Hagedorn and Athens pilot site CommDTs once the modelling work has been completed.

References

[1] Twinergy Project Proposal, H2020 Proposal Number: 953020

[2] Rami El Geneidy, Bianca Howard, "Contracted energy flexibility characteristics of communities: Analysis of a control strategy for demand response", *Applied Energy, Volume 263,* 2020.

[3] "Everything you always wanted to know about Demand Reponse", *eurelectric, Electricity for Europe* D/2015/12.105/11

[4] IES: Digital Twins for the Built Environment (visited 22/12/21) - https://www.iesve.com/digital-twins

[5] R. Baetens and D. Saelens, "Modelling uncertainty in district energy simulations by stochastic residential occupant behaviour," *Journal of Building Performance Simulation*, 2016.

[6] L. Hirth, J. M¨uhlenpfordt, and M. Bulkeley, "The entso-e transparency platform–a review of europe's most ambitious electricity data platform," *Applied energy*, 2018.

[7] F. Biscani and D. Izzo, "A parallel global multiobjective framework for optimization: pagmo," *Journal of Open Source Software*, 2020. [Online]. Available: https://doi.org/10.21105/joss.02338

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Appendix

1 - Building Data Checklist for Digital Twin Development

Building Data Checklist	Required?
General building information	
Building ID	if applicable
Construction year	Yes
Condition (Bad, Fair, Good)	Yes
House Type (detached, semi-detached, terraced, apartment)	Yes
Ownership (Owner occupied, rented, etc)	Yes
How many rooms are in your house?	Yes
How many People live in your house	Yes
Age Group of House Applicants	Yes
Typical Occupied Hours	Yes
Building address	Yes
Fuel utilised	Yes
EPC (Energy Performance Certification) level (please if this is a national certification, provide document explaining how this works)	Yes (if available)
Site photographs	if possible
Is the building listed (protected)? E.g. historical building..	if applicable
Building layout drawings and models	
Footprint area	if available
Floor area (GIFA / Net)	if available
Floor plans	if available
Zone - Descriptions/end use (i.e. meeting room, labs, etc…)	if available
Zones - HVAC/Lighting/Equipment drawings	if available
Elevations	if available
Sections	if available
Fenestration	if available
Shading devices	if available
Adjacent buildings	if available
Building orientation	if available
3d Model (BIM, IES-VE, Revit, SketchUp, Rhino etc.)	if available (highly desirable)

If none of the above are available, can a high level sketch be provided?	Yes
AMR data and energy costs information	
Fossil Fuel Yearly (kWh)	Yes
Electricity Yearly (kWh)	Yes
Electricity bills	Yes
Fossil fuel bills	Yes
RECs, RHI, other energy costs/incentives?	Yes
Heating, Cooling & Ventilation Systems	
How is your building ventilated (mechanically ventilated, passive vents, operable windows, not ventilated, other)	Yes
If mechanical ventilation is used can you provide details of the ventilation system in use.	Yes
Can you provide a photo of the unit and its nameplate information?	Yes
Are you able to control your heating system? If so, what value do you set your thermostat to?	Yes
What type of heating system do you have in your house (radiators, underffloor heating, stoarage heating, convection heaters, heat pump, other)	Yes
What is the fuel source for your heating system?	Yes
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
Can you provide a photo of the boiler and its nameplate information? Alternatively please provide the make and model of the unit.	Yes
Do you have any mechanical cooling in your building?	Yes
What is the make and model of your cooling unit?	Yes
Can you provide a photo of the unit and its nameplate information?	Yes
What value do you set your cooling setpoint to?	Yes
How do you generate domestic hot water in your building (i.e. water used in your faucets, shower, bath, etc)	Yes
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
Can you send a photograph of your domestic hot water heater and its nameplate?	Yes
Household Appliances	
What fuel source do you use for cooking? (gas, electricity, other)	Yes
On average, how many hours per day do you cook?	Yes
Do you you have one or more Refrigerators? If more than 1, how many?	Yes

What is the make and model of each refrigerator? If not available, how old is each refrigerator?	Yes
Do you have one or more freezers? If more than 1, how many?	Yes
What is the make and model of each freezer? If not available, how old is each freezer?	Yes
What is the make and model of your washing machine?	Yes
On average, how many hours per day/week do you use your washing machine?	Yes
Do you have times during the week when you are more likely to use the washing machine or is it as needed?	Yes
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
Do you have a clothes dryer in your house? If so, what is the make and model of your clothes dryer?	Yes
On average, how many hours per day/week do you use your clothes dryer?	Yes
Do you have times during the week when you are more likely to use the clothes dryer or is it as needed?	Yes
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
Do you have a dish washer in your house? If so, what is the make and model of your dish washer?	Yes
On average, how many hours per day/week do you use your dish washer?	Yes
Do you have times during the week when you are more likely to use the dishwasher or is it as needed?	Yes
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
Do you have any other large appliances in your home? If so please provide details?	Yes
Lighting	
What type of lamps/bulbs do you typically use in your house?	Yes
Can you provide a count of the various lamps used in your house?	Yes
On average, how many hours a day would you use the lamps in each room in both summer and winter?	Yes
Do any of the lighting in your building have adjustable features? (e.g. dimmer switch, timer, etc)	Yes

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Other Electrical Loads	
Please confirm the number of, and average hours used of the following electrical items in your building?	Yes
Television	Yes
Cable Box / Internet Modem (e.g Sky TV Receiver)	Yes
DVD Player	Yes
Stereo/ Radio	Yes
Video Gaming Device	Yes
Laptop Computer	Yes
Desktop Computer	Yes
Personal Electronic Devices (Mobile Phone, Tablet, e-Reader, etc)	Yes
Coffee Machine	Yes
Kettle	Yes
Toaster	Yes
Microwave	Yes
Others	Yes
Electricity Generation	
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
Do you know what the capacity of your renewable system is?	Yes
Do you track your renewable generation?	if Applicable
Do you adjust your energy use in your house to match the generation? (yes, no, NA)	if Applicable
Does you house have any battery storage?	Yes
If yes, what type?	if applicable
If yes, what is the capaity?	if applicable
Would you be interested in installing renewable or storage systems in your home or community in the future?	Yes
Would you be interested in exporting your excess energy generation to your community?	Yes
If yes, how would you like to be compensated for this?	if applicable
Electric Vehicles	
Do you own an electric vehicle or do you intend to purchase one in the coming months?	Yes
If yes, what is the make and model of your vehicle?	if applicable
If yes, where do you primarily charge your car battery	if applicable
In general, at what time would you charge your car?	if applicable

Would you be able to adjust the time you charge your car based on electricity pricing/availability of renewables?	if applicable
Have you ever considered using your car battery to "feed in" electricity to your building during peak times?	if applicable

2 - Examples of Completed Checklist from each pilot site

Building Data Checklist	Required?	Benetutti		Athens		Bristol		Hagedorn	
General building information		Y / N	**Specify or Comment**	Y / N	**Specify or Comment**	Y / N	**Specify or Comment**	Y / N	**Specify or Comment**
Building ID	if applicable	Y	We can use the POD (Point Of Delivery of the energy demand) IT036E14990107					y	2a
Construction year	Yes		1989		2000		1921	y	1900
Condition (Bad, Fair, Good)	Yes		*Good*		Good		*Good*	y	good
House Type (detached, semi-detached, terraced, apartment)	Yes	Y	*Indipendent house on the ground floor and first floor*		*Semi-detached house*		*Terraced*	y	apartment
Ownership (Owner occupied, rented, etc)	Yes	Y	*Owner*		*Ownership*		*Owner occ*	y	owner occupied
How many rooms are in your house?	Yes		*3 bedromms - 2 bathroom - 1 Kitchen - 1 living room - 1 closet room - 1 Hall*		*1 kitchen, 2 bathrooms, 1 living rooms, 2 bedrooms*		*2 bed, 1 office, 1 kitchen, 1 sitting, 1 bath, 1 toilet, 1 dining*	y	2 bedrooms 1 living room 1 bathroom 1 kitchen 1 laundry room 1 store room
How many People live in your house	Yes	Y	*3*		*3 Adults*		*2 Ad, 2 Child*	y	1.5
Age Group of House Applicants	Yes	Y	*Public employees + young daughter*		*1 Under 30, 2 between 50-60*		*35-40, <10*	y	1.5 adults (45-50)
Typical Occupied Hours	Yes	Y	00:00-08:00, 14:00-16:30, 20:00-24:00		*06:00-08:00, 18:00 - 06:00 Mon - Fri & 24 hours on weekend*		24h/d	y	1 of 3 days
Building address	Yes	Y	*Via San Michele, 22*		Lykaiou 51 str.		*8 Brookleaze*	y	Steinheim

Fuel utilised	Yes	N	*no*		*Heating Oil for heating. Electricity for cooling. Solar water heater, Boiler and electric water heater for Domestic Hot Water (triple system)*		*Gas heating*	y	none
EPC (Energy Performance Certification) level (please if this is a national certification, provide document explaining how this works)	Yes (if available)	N	*N/A*		*Not available*		*D*	n	no
Site photographs	if possible	Y	*From Google Earth*					y	
Is the building listed (protected)? E.g. historical building..	if applicable	N	*No*		*No*		*No. But conservation area*	y	no
Building layout drawings and models		Y / N	**Comments**			Y / N	**Comments**	Y / N	**Comments**
Footprint area	if available	Y	*See house plan*		*110 m2*		*70 m2*	y	127m²
Floor area (GIFA / Net)	if available	Y	*See house plan*		-		*70 m2*	y	127m²
Floor plans	if available	Y	*See house plan*		-			n	
Zone - Descriptions/end use (i.e. meeting room, labs, etc...)	if available	Y	*See house plan*		-			n	living space

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Zones - HVAC/Lighting/Equipment drawings	if available	N			-			n	
Elevations	if available	Y	*Available in some houses plan*		*2,70 m*			n	
Sections	if available	Y	*Available in some houses plan*		-			n	
Fenestration	if available	Y	*Available in some houses plan*		-			y	16m²
Shading devices	if available	Y	*shutters*		-			y	pleats
Adjacent buildings	if available	Y	*No close buildings*		-			y	inner apartment, complete shadowing
Building orientation	if available	Y	*S-W*		-		*entrance to north, garden to south*	y	275°
3d Model (BIM, IES-VE, Revit, SketchUp, Rhino etc.)	if available (highly desirable)	Y	*N/A*		-		*Sketchup*	n	no
If none of the above are available, can a high level sketch be provided?	Yes	Y	See house plans and google earth		2 bedrooms 15m2 each, 1 kitchen/dinning room 60m2 and 2 bathrooms 10m2.			y	
AMR data and energy costs information		Y / N	**Specify or Comment**			Y / N	**Specify or Comment**	Y / N	**Specify or Comment**
Fossil Fuel Yearly (kWh)	Yes	N			-		*9000*	y	0kWh
Electricity Yearly (kWh)	Yes		*7993 kWh*		*8,174 kWh electricity*		*2900*	y	1500kWh electricity
Electricity bills	Yes		*1453,52 € each year - also some bills are provided*		*January - December - 8,174 kWh, 1105€*		*20£/m*	y	0.28 €/kWh

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Fossil fuel bills	Yes	Y	*No expance for fossil fuel*		-		*20£/m*	y	1066€/year
RECs, RHI, other energy costs/incentives?	Yes		2° Conto energia e contributo scambio sul posto					y	no
Heating, Cooling & Ventilation Systems		Y / N	**Specify or Comment**			Y / N	**Specify or Comment**	Y / N	**Specify or Comment**
How is your building ventilated (mechanically ventilated, passive vents, operable windows, not ventilated, other)	Yes	Y	*operable windows*		*No ventilation system in this building*		*opening windows, mech vent in bath*	y	windows by hand
If mechanical ventilation is used can you provide details of the ventilation system in use.	Yes	Y	*N/A*		-			y	no
Can you provide a photo of the unit and its nameplate information?	Yes	Y	*In the pictures folder*		-			y	no
Are you able to control your heating system? If so, what value do you set your thermostat to?	Yes	Y	*22°C*		*Yes, the apartment is controlled with one thermostat. 21deg C*		*TRVs are set to 19 deg*	y	temperature sensor for heat pump, 20°C

What type of heating system do you have in your house (radiators, underfloor heating, stoarage heating, convection heaters, heat pump, other)	Yes	Y	*Heat pump for a total of 4 splits (kitchen, sitting room, bedroom1 and bedroom2)*		*7 Hot Water Radiators 2 towel warmers*		*radiators in all rooms, plus elec underfloor in kitchen and dining*	y	floor heating except in bedroom, radiators in bedroom and bathroom
What is the fuel source for your heating system?	Yes	Y	*No*		*Heating Oil*		*Gas*	y	electricity
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	Y	*No*		*Modern boiler with efficiency of 85%*		*condensing boilder*	y	old boiler
Can you provide a photo of the boiler and its nameplate information? Alternatively please provide the make and model of the unit.	Yes				-		*Vaillant ECOTEC PRO 28 VUW 286/3-3 VUW 286/3-3 R1 R2*	y	no
Do you have any mechanical cooling in your building?	Yes	Y	*No*		*3 Air conditioner units*		*no*	j	no
What is the make and model of your cooling unit?	Yes		*Heat pumps - see picture*		*Midea , 1x24,000 btu & 2x12,000 btu*			n	

Can you provide a photo of the unit and its nameplate information?	Yes	Y	*see picture*		-			n	
What value do you set your cooling setpoint to?	Yes	Y	*24°C*		*21deg C*			n	
How do you generate domestic hot water in your building (i.e. water used in your faucets, shower, bath, etc)	Yes	Y	*electric immersion heater*				*no*	y	heatpump
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	Y	*Always available*					y	always available
Can you send a photograph of your domestic hot water heater and its nameplate?	Yes	N	*N/A*		-			y	see heatpump
Household Appliances		Y / N	**Specify or Comment**			Y / N	**Specify or Comment**	Y / N	**Specify or Comment**
What fuel source do you use for cooking? (gas, electricity, other)	Yes	Y	*gas, electricity*		*Electricity*		*induction*	y	electricity
On average, how many hours per day do you cook?	Yes	Y	*2,5 hour per day*		*3h per day*		*0.5*	y	3h per week

Do you you have one or more Refrigerators? If more than 1, how many?	Yes	Y	*1 full-size*		*1 full size fridge*		*1*	y	1 fridge /w freezer
What is the make and model of each refrigerator? If not available, how old is each refrigerator?	Yes	Y	*LG - see picture*		*Bosch KGN39VLDB*		*Liebherr, CN3033*	y	AEG Santo Öko 2012
Do you have one or more freezers? If more than 1, how many?	Yes	Y	*2*		*1 freezer as part of fridge*		*built-in*	y	chest type freezer
What is the make and model of each freezer? If not available, how old is each freezer?	Yes	Y	*10 years old*		*N/A*			y	Exquisit 2016
What is the make and model of your washing machine?	Yes	Y	*Candy A+*		*Whirlpool*		*Bosch WAW28560GB/09*	y	AEG Pro Sense Lavamat
On average, how many hours per day/week do you use your washing machine?	Yes	Y	*4 hour per week*		*12-15 hours per week*		*0.5*	y	8h per week (4 cylces)
Do you have times during the week when you are more likely to use the washing machine or is it as needed?	Yes	Y	*No typical time*		*as needed*		*no*	y	typically daytime

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	Y	*Yes*		*no - my time is fixed*		*unless you make a convincing case, no. we power everything from the Tesla PW*	y	yes
Do you have a clothes dryer in your house? If so, what is the make and model of your clothes dryer?	Yes	N	*No*		-		*no*	y	yes
On average, how many hours per day/week do you use your clothes dryer?	Yes	N			-			n	after every washing cycle
Do you have times during the week when you are more likely to use the clothes dryer or is it as needed?	Yes	N			-			n	after washing

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	N			-			n	after washing
Do you have a dish washer in your house? If so, what is the make and model of your dish washer?	Yes	Y	*Ariston*		*Miele G 600 SC*		*Zanus ZDF 501*	y	AEG Favorit Sensorlogic 2006
On average, how many hours per day/week do you use your dish washer?	Yes	Y	*6 hour per week*		*2-3 hour per week*		*2.5h/d*	y	3h per week
Do you have times during the week when you are more likely to use the dishwasher or is it as needed?	Yes	Y	*No typical time*		*typically Saturdays/Sundays*		*every day*	y	no
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	Y	*Yes*		*Yes*		*running btw 2 and 6.30 with low price energy tariff*	y	yes

Do you have any other large appliances in your home? If so please provide details?	Yes	Y	*Electric oven and microwave oven*		-		*nbo*	y	no
Lighting		Y / N	**Specify or Comment**			Y / N	**Specify or Comment**	Y / N	**Specify or Comment**
What type of lamps/bulbs do you typically use in your house?	Yes	Y	*LED*		*generally LED*		*LED throughout*	y	LED
Can you provide a count of the various lamps used in your house?	Yes	Y	*Bathroom: 2 of 50W - Bedromm: 10 of 25W - Kitchen: 5 Halogen of 25W - Living: 15 of 15W - Hall: n. 20 of 15W - others: n. 10 of 25W*		*Bathroom 1: 1 6W LED Bathroom 2: 1 6W LED Bedroom 1: 2 12W LED Bedroom 2: 1 12W LED Kitchen: 6 7W LED Living Room: 10 7W LED & 10 6W LED Hallway: 3 8w LED*		*Bathroom: 4 3W LED Bedroom 1: 6 3W LEDlight Bedroom 2: 1 12W LED Kitchen: 5 3W LED Living Room: 1 11 LED Hallway: 3 3w LED*	y	Living room: 9 LED kitchen: 4 LED dining room: 10 LED hallway: 5 LED bathroom: 1 LED bedroom: 9 LED laundry room: 3 LED storage room: 1 LED guests room: 3 LED
On average, how many hours a day would you use the lamps in each room in both summer and winter?	Yes	N	*N/A*		*Bathroom 1: 1 6W LED - 3h/day Bathroom 2: 1 6W LED - 3h/day Bedroom 1: 2 12W LED - 3h/day Bedroom 2: 1 12W LED - 3h/day Kitchen: 6 7W LED - 8h/day Living Room: 10 7W LED & 10 6W LED - 3h/day*		*Living Room: Summer - 2 hours per day, winter 6 hours per day, Bedroom - 1h/d*	y	living: 3 kitchen: 2 dining: 2 hallway: <1 bathroom: 1-2 bedroom: <1 laudry: <1 storage: <1 guests: <1

					Hallway: 3 7W LED - 8h/day				
Do any of the lighting in your building have adjustable features? (e.g. dimmer switch, timer, etc)	Yes	N	*No*		*3 dimmer switch*		*dimmer throughout*	y	no
Other Electrical Loads		Y / N	**Specify or Comment**			Y / N	**Specify or Comment**	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		*2 TV - N. 1 - 2 hours each day - and the rest on standby N. 2 = 6 hours each day - and the rest on standby*		*1 55" TV (used 8 hours a day and on standby otherwise) 1 32" TV (used 5 hours per day) 1 32" TV (used 0,5-1 hour per day)*		*.5h/d*	y	42" LCD TV 3h/day

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Cable Box / Internet Modem (e.g Sky TV Receiver)	Yes		*Modem Internet - Modem Sky*		*Modem active 24 hours per day* *Fiber to ethernet converter 24 hours per day* *2 TP-LINK Deco M4*		*no*	y	DSL router 24/7
DVD Player	Yes		*no*		-		*no*	y	1
Stereo/ Radio	Yes		*no*		-		*no*	y	
Video Gaming Device	Yes		*no*		-		*no*	y	
Laptop Computer	Yes		*3 laptop - 1 tablet*		*2 laptops plugged in 8 hours per day*		*12h/d*	y	1 laptop computer, <1h/day
Desktop Computer	Yes		*no*		-		*no*	y	
Personal Electronic Devices (Mobile Phone, Tablet, e-Reader, etc)	Yes		*n° 4 mobile phone - n. 3 Tablet n. 1 e-reader*		-		*2 phones*	y	1 mobile phone
Coffee Machine	Yes		*n. 1*		*yes - 1 hour per day*		*no*	y	
Kettle	Yes		*no*		*yes - 0.20 hours per day*		*0.33 hours per day*	y	
Toaster	Yes		*n. 1*		*yes - 0.10 hours per day*		*no*	y	yes, if needed
Microwave	Yes		*n. 1 per 20 minutes each day*		*yes, used 0.25 hours per day*		*no*	y	yes, approx. 5min
Others	Yes				-		*no*	y	no
Electricity Generation		Y / N	**Specify or Comment**			Y / N	**Specify or Comment**	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	Y	*Solar PV*	N	*Not applicable*		*yes - PV*	n	

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Do you know what the capacity of your renewable system is?	Yes	Y	*10,12kWp*	N	*Not applicable*		*2.7kW*	n	
Do you track your renewable generation?	if Applicable	Y	*Yes*	N	*Not applicable*		*Yes*	n	
Do you adjust your energy use in your house to match the generation? (yes, no, NA)	if Applicable	Y	*Partially*	N	*Not applicable*		*yes*	y	
Does you house have any battery storage?	Yes	N	*no*	N	*Not applicable*		*yes*	n	
If yes, what type?	if applicable	N	*n.a*	N	*Not applicable*		*Tesla PW 1x*	n	no
If yes, what is the capaity?	if applicable	N	*n.a*	N	*Not applicable*		*see manual*	n	no
Would you be interested in installing renewable or storage systems in your home or community in the future?	Yes	Y	*Yes*	N	*Not applicable*		*no*	y	yes, in the community
Would you be interested in exporting your excess energy generation to your community?	Yes	Y	*Yes*	N	*Not applicable*		*no*	n	
If yes, how would you like to be compensated for this?	if applicable	Y	*Economic incentives in the energy bills*	N	*Not applicable*			y	no
Electric Vehicles		Y / N	**Specify or Comment**			Y / N	**Specify or Comment**	Y / N	**Specify or Comment**

Do you own an electric vehicle or do you intend to purchase one in the coming months?	Yes	N	*No VE in the entire municipality*	N	*Not applicable*		*Yes*	n	no
If yes, what is the make and model of your vehicle?	if applicable	N		N	*Not applicable*		*Volkwagon Passat GTE*	n	
If yes, where do you primarily charge your car battery	if applicable	N		N	*Not applicable*		*At my home, from mains*	n	
In general, at what time would you charge your car?	if applicable	N		N	*Not applicable*		*Overnight, 2-6.3*	n	
Would you be able to adjust the time you charge your car based on electricity pricing/availability of renewables?	if applicable	N		N	*Not applicable*		*already do*	n	
Have you ever considered using your car battery to "feed in" electricity to your building during peak times?	if applicable	N		N	*Not applicable*		*not possible.*	n	