Energy in Buildings and Communities Programme

An International Survey of Electrical and DHW Load Profiles for Use in Simulating the Performance of Residential Micro-cogeneration Systems

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October 2014

A Report of Annex 54 "Integration of Micro-Generation and Related Energy Technologies in Buildings"

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On behalf of IEA EBC Annex 54

Energy Technology Network

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Ken Darcovic (Subtask A Leader), Evgueniy Entchev, Peter Tzscheutschler (Operating Agents)

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1 Introduction

The IEA Annex 54 on "Integration of Micro-Generation and Related Energy Technologies in Buildings" is undertaking an in depth analysis of micro-generation and associated energy technologies. The scope of activities encompasses:

- multi-source micro-cogeneration systems, polygeneration systems (i.e. integrated heating / cooling / power generation systems) and renewable hybrid systems;
- the integration of micro-generation, energy storage and demand side management technologies at a local level (integrated systems);
- customised and optimum control strategies for integrated systems;
- the analysis of integrated and hybrid systems performance when serving single and multiple residences along with small commercial premises; and
- the analysis of the wider impact of micro-generation on the power distribution system.

To broaden the impact of the Annex's output there will be significant effort to disseminate its deliverables to non-technical stakeholders working in related areas such as housing, product commercialisation and regulatory development.

In view of the above outlined activities, the expected outcomes are:

- An update on occupant related DHW and electric load profiles.
- Component models and their implementation in building simulation tools.
- Review of best practice in the operation and control of integrated micro-generation systems.
- Predictive control algorithms to maximize the performance and value of micro-generation.
- Experimental data sets for the calibration and validation of device models.
- Performance assessment methodologies.
- Country-specific studies on the performance of a range of micro-generation systems.
- Studies of the viability of micro-generation systems in different operational contexts and of the impacts of micro-generation on the wider community and the potential benefits, in particular for the electricity network.
- An investigation of interactions between technical performance and commercialization/regulatory approaches for micro-generation.

Annex 54 builds upon the results of Annex 42 "The Simulation of Building-Integrated Fuel Cell and Other Cogeneration Systems", and can be viewed as a continuation, extension, update and refinement of the information, models and findings established in Annex 42. All the documentation from Annex 42 remains highly relevant to Annex 54, and the repository of its documents represent the foundation upon which the Annex 54 is based. The documents from Annex 42 are available in their entirety online at http://www.iea-ebc.org/projects/completed-projects/ebc-annex-42/

Annex 54 has been divided into three Subtasks to facilitate organizing and classifying its constituent activities and outputs. In broad terms, Subtask A is Technical Development, Subtask B is Performance Assessment and Subtask C is concerned with mechanisms of microgeneration diffusion. In more detail, Subtask A encompasses load profiles and system models methodology for model development, data collection for micro-generation systems, as well as work on predictive controls development and optimization. The present report is focused on the load profile data gathering activities, as well as related modeling efforts for residential electricity use and domestic hot water use.

1.1 Subtask A: Technical Development

This Subtask undertook the model development and data collection activities that will underpin the work of Subtasks B and C, with the emphasis on the optimised operation of micro-generation systems. This will require the development of models of contemporary micro-generation devices and controllers to maximise the energy performance for local and possibly community energy needs in different operational scenarios.

Work will also involve the specification of boundary conditions for the modelling of micro-generation, especially the establishment of appropriate hot water and electrical demand profiles.

Specific objectives for Subtask A are:

- The micro-cogeneration models (SOFC, PEM, ICE and Stirling Engine) developed in Annex 42 will be updated with performance characteristics from more modern devices. Initially this will be done using some of the data emerging from the final tests undertaken on more up-to-date devices in Annex 42.
- Subtask A will also include some laboratory tests to acquire new performance data using the Annex 42 testing protocol for a limited number of micro-generation and energy storage devices. The data emerging from these tests will be used for calibration and validation of existing models.
- New balance of plant models (i.e. Lithium-ion battery storage and a thermally-activated-cooling device) will be developed where necessary.
- In Annex 42, the control applied to micro-cogeneration devices was rudimentary (i.e. on-off heat load following). More advanced controllers tasked with optimising performance for local and energy network needs and reflecting the potential for incorporating demand side management (DSM) will be investigated. The control structures, communications protocols and data inputs that could be used to inform the operation such controllers will be identified through a review of related technologies such as state-of-the-art BEMS, smart metering and DSM. Additionally, a review of current best practice in micro-generation will be undertaken to identify effective operation and control strategies. Potential control vectors, for instance: variable electricity tariffs and real time energy pricing will also be examined.
- New control algorithms for the optimum operation of single device systems, hybrid (multi-source systems), poly-generation and systems incorporating storage and DSM will be developed. The new algorithms will be expected to optimise performance against both local energy needs and within the context of wider heat and power networks. The dwelling and device models developed in Subtask B will be used as the test-bed for this activity.
- Finally, the proposed Annex will continue to measure/collate occupant related electric and hot water demands to assist in defining load profiles for different operational scenarios.

This present report comprises work performed to fulfill the last above mentioned objectice: the update of occupant related electricity, space heating and hot water demand profiles.

As will be detailed here, there has been on-going work in several participating institutions in developing electricity and hot water demand profiles, through continued measurements, and more notably, through improvements in modeling approaches. The improved modeling enables the creation of plausible and suitably accurate synthetic load profiles, obtained through approaches that are capable of encompassing a range of environmental factors, physical components and occupancy scenarios.

A principal thrust of Annex 54 is to investigate a range of scenarios and environments in which microcogeneration systems are deployed, in order to demonstrate their energy use benefits in general, as well as to identify effective technology configurations for specific national or regional implementations. A basis for effectively carrying out this exercise is the measurement or simulation of detailed, accurate and up-to-date electricity and domestic hot water (DHW) load profiles. These load profiles delineate the expected performance requirements for microcogeneration (MCG) systems and represent capacity and design standards for physical equipment system development aimed at commercial opportunities, national energy policies and standards and consumer acceptance.

1.2 Background and Present Aims

The final Subtask A report from Annex 42 [1] still represents the most comprehensive and up to date document which summarizes various national electric power and hot water consumption data profiles. Further, the organization and presentation of the material in [1] was specifically oriented to the aims of Annex 42, and therefore Annex 54 as well, and it thus remains the benchmark reference to be used for load profile information in the absence of any updates. Several European countries as well as USA and Canada in North America supplied load profile data for use in the report [1]. Table 1 below summarizes the inputs exploited for compiling the Annex 42 report.

Table 1: Domestic Hot Water (DHW) and non-HVAC Electricity consumption data sets provided to Annex 42.

	DHW		non-HVAC Electricity	
Country	**No. of Profiles (used in analysis)**	**Monitoring interval [min]**	**No. of Profiles (used in analysis)**	**Monitoring interval [min]**
Canada	12 (10)	5 and 60	85 (57)	5, 15 and 60
USA	4 (2)	1,5, and 60	9 (1)	1, 5 and 60
Switzerland	1 (1)	60	NA	NA
Finland	6 (6)	60	6 (6)	60
Belgium	2 (0)	15	2 (0)	15
UK	5	60	69 (69)	5
Germany	1	60	1	15
Portugal	NA	NA	1	10
EU	3 (1)	60	NA	NA

It was recognized however, that the data presented there were still lacking in a number of regards, and it was thus an objective of the present Annex to work towards some improvements to facilitate and upgrade the energy use modeling done based on these load profiles.

Some key areas where improvements were sought were a more detailed breakdown of electricity use, appliance-by-appliance if possible, with more frequent data points (one minute intervals ideally) and with as much qualifying information as possible to allow coherent and rational interpretation of results analysis.

Several of the participating members in Annex 54 proposed contributions to Subtask A in connection to electrical load or domestic hot water (DHW) load profiles, aiming to offer improvements on the existing body of data employed in Annex 42. These are summarized below in Table 2.

Table 2: Overview of demand profile activities in Annex 54.

Organization		Demand Profile Updates
KIER	**(Korea)**	Monitoring of houses
Carleton University	**(Canada)**	1 min electricity, 12 SFHs
TU Munich	**(Germany)**	SH, DHW, electricity, residential and small commercial
Japanese consortium	**(Japan)**	various electric and thermal profiles
University of Strathclyde	**(UK)**	appliance demand profile model
FfE e.V.	**(Gemany)**	Thermal load for public swimming pool
ENEA	**(Italy)**	Electrical loads in office building
2nd University of Naples	**(Italy)**	Domestic hot water and electric demand profiles

1.3 Overview of Technical Content

This report discusses the measurement and synthesis of realistic standard electrical and domestic hot water consumption profiles suitable for use in the assessment and comparison of the economic, carbon and energy performance of microgeneration systems.

The profiles specifically required are meant to be representative of residential electrical consumption profiles (excluding Heating, Ventilation and Air-Conditioning (HVAC) loads) and Domestic Hot Water (DHW) consumption profiles. The profiles obtained needed to be suitable for assessing annual loads, while allowing for demonstration of lightest and heaviest demand according the climatic season, whose applicability is defined for certain countries.

A further ambition was to provide energy profiles suitable for assessing the detailed operation of cogeneration systems, i.e. the profiles should be recorded in the order of second intervals. The main purpose of the profiles is to be a standard dataset, which can then be used to allow comparisons between the energy performances of various residential cogeneration systems as modelled in the remainder of the Annex, and would be based on accurate data and realistic occupancy patterns.

1.4 Methodology

Existing studies and data collections as outlined in Annex 42 provided a suitable basis for subsequent modeling and simulation work aimed at demonstrating and scenario testing micro-cogeneration systems and configurations in national environments of the various Annex members.

In particular, this means:

- Review existing studies and data collections, and ascertain which consumption profiles or profile generators were available to the Annex.
- Obtain real data from these existing studies where feasible.
- Depending on the data availability, then analyze this against building and occupant characteristics.
- Produce standard datasets at as frequent a time interval as the data will allow, with supporting documentation for use within the Annex.

One significant advance since Annex 42 has been the development of a number of more sophisticated approaches to formulate realistic synthetic profiles based on measured data. Rather than averaging techniques used in the past, new efforts have taken a more detailed statistical stochastic approach whereby profiles are generated to reflect environmental conditions, occupancy, socio-economic factors, time-of-use pricing schemes etc. [2,3] In general averaging techniques are of valuable on a community level where power supply to a large number of dwellings is being considered, but for cases where a particular micro-cogeneration (MCG) system is being analysed and tested, the load profiles of specific appliance on the smallest possible time scale is needed to assess the operational demands that will be placed on the MCG equipment. Averaged profiles tend to show broader, lower peaks, and do not reflect realistic sharp start-up behavior, peak demands, and load duration curves of any number of electric appliances.

The importance of both the magnitude and temporal distribution of electrical loads has led numerous researchers to conduct field measurements of electrical loads. For example, Pratt et al. [4] report the results of hourly integrated measurements of electrical loads in 454 residences in the USA. All the houses that were measured were electrically heated and end-uses such as HVAC, water heating, clothes dryers, and other appliances were measured individually. Parker [5] reports the results of the monitoring of 204 residences in Florida, USA. The whole-house electrical demand of these homes was measured at 15-min intervals as well as the power draw for space heating, space cooling, domestic hot water heating, clothes dryers, cookers, and pools.

In the UK, the whole-house electricity consumption of 72 households was monitored at 5-min intervals and over a 2-year period in [6] and [1]. Firth et al. [6] also presented techniques for disaggregating the whole-houseload into ‘standby’ and ‘active’ appliances. A detailed monitoring programme encompassing electricity as well as other secondary energy sources was conducted on a representative sample of 400 houses in New Zealand [7]. Data were gathered at 10-min intervals and measurements were taken of a number of important end-uses of electricity, including lighting, cooking, laundry, and refrigeration.

Monitoring campaigns are both costly and require considerable time to gather sufficient data to consider seasonal effects. This has motivated many researchers to develop models to predict electric load profiles. For example, Stokes et al. [8] have developed a model for domestic lighting demand based upon half-hourly measured data from a sample of 100 homes in the UK. This model is capable of predicting demand patterns at 1-min intervals of this important end-use of electricity. Both deterministic and stochastic models for predicting temporal patterns of electricity use from time of use activity data have been developed [9-11]. These methods are alternatives to directly measuring electricity draw patterns in occupied houses. Another method for generating synthetic electric load profiles from activity profiles for cooking, laundering, etc. is presented by Richardson et al. [3]. In this, probabilistic daily activity profiles are combined with data on statistical appliance ownership and subject to a stochastic process to determine the temporal distribution of loads. This method has been validated using whole-house electricity consumption measurements taken at 22 houses in the UK.

For the purposes of simulating the performance of residential micro-cogeneration systems, Armstrong et al. [12] developed annual synthetic profiles of non-HVAC electricity draws at 5-min intervals. Profiles were developed for Canadian houses that represent low, medium, and high electricity consumers. These were created using a bottom-up approach based upon appliance saturation rates, annual appliance energy consumption data, and probabilistic and stochastically modelled occupancy patterns.

For the present Annex, as opposed to the electric load profile report from Annex 42 [1], the orientation of this report will focus more simply on providing updated references to data sets and studies that will assist interested parties in obtaining quality data and sound approaches to generating load profiles for carrying out their simulations, scenario tests and equipment evaluations.

1.5 Data sets and profile generators

From a review of existing literature, as well as experimental work and measurements conducted by Annex members, it is known that from a top-down perspective, domestic non-HVAC electrical energy consumption is primarily dictated by the following factors:

- Floor area of the dwelling
- Number of occupants
- Geographical location
- Occupancy patterns
- Seasonal and daily factors
- Ownership level of appliances
- Fuel type for DHW, heating and cooking etc.
- Social status of occupants

As final output from Annex 42, the profiles were required for assessing the design of cogeneration systems for domestic properties. The effect of the number of occupants and the occupancy patterns were ignored, except for the effects on weekday and weekends generally. The rationale for that was that it was not possible predict the number or working patterns of the likely occupants of any domestic property, therefore the approach shifted to designing a cogeneration system to meet the likely range of consumptions for any particular dwelling.

It remains to be determined, given the updated load profiles and associated data that have been made available, whether the level of detail outlined in the point list above can be meaningfully incorporated into synthetically generated load profiles. Improved data sets, in terms of temporal resolution, and breakdown by contributions of constituent appliances now enables a more sophisticated and detailed analysis of residential electricity and hot water consumption, such that, accompanied by updated modeling approaches ie; [2,3], simulations can now generate specialized, and custom demand profiles for the cases to be investigated.

Provided the data were recorded and are available, account could be taken of geographical, diurnal and seasonal effects, which can be overlaid onto a building simulation considering floor area, solar and wind exposure and MCG equipment together with conventional heating sources along with a standard or custom set of household electrical appliances to provide the basis for system energy use evaluations.

2 Updated National Initiatives

2.1 Canada

Occupant behaviour plays a key role in the energetic performance of a residential building. This is especially true for buildings with distributed energy systems (such as a micro-cogeneration device or a lithium-ion battery for electricity storage). The performance of such building distributed energy systems can be sensitive to an occupant's electricity consumption profile at a very fine time-scale resolution.

Prior to the research performed by Saldanha and Beausoleil-Morrison and documented in [13], real world data characterizing occupant electricity consumption profiles were not available at a fine enough time-scale resolution to be used to simulate many buildings with distributed energy systems realistically using whole-building performance simulation methods. To address this need [13] contains occupant electricity consumption data sampled at a fine time-scale resolution (1 minute) from twelve houses in Ottawa, Canada for a period of one year.

In each of the volunteer houses, several different circuits at the electrical panel were instrumented with current-transformer based energy transducers so the electricity consumption profiles of different end-uses could be resolved. In each house, total (mains), furnace and air-conditioner end-use circuits were monitored. Non-HVAC consumption profiles were derived by subtracting furnace and air-conditioner profiles from total use profiles. This non-HVAC profile for one of the twelve houses for one day is shown in Fig. 1 as an example.

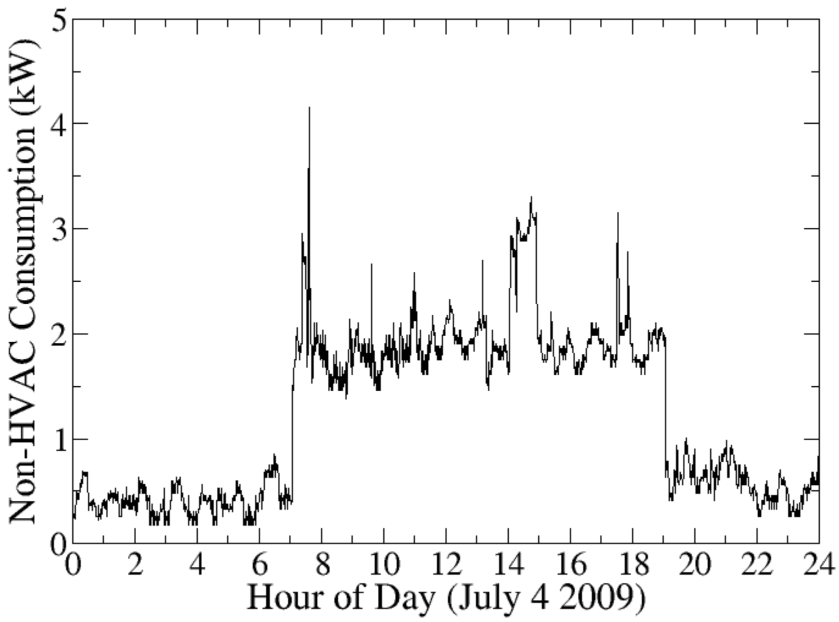


Fig. 1: Non-HVAC electricity consumption data for one day from one of twelve separate houses [13]

These non-HVAC profiles represent occupants' appliance and lighting consumption profiles. In select volunteer houses, the electricity consumption profiles of the, range (cooker), clothes dryer, dishwasher and electric domestic hot water were measured as well. For future research efforts, Saldanha and Beausoleil-Morrison [13] made available all of the data that they gathered and the profiles that were derived through the publication of their work.

An analysis of the gathered occupant electricity consumption data it became visible that annually-integrated non-HVAC, air-conditioner and furnace electricity consumption do not correlate well with the liveable floor area of a house. However, there is an observable correlation between the number of occupants in a house and the annually-integrated non-HVAC consumption. These observations led to the conclusion that occupant tendencies are a strong determining factor for the annual non-HVAC consumption of a building.

The analysis of the gathered data also revealed that an occupant's electricity consumption profile varies significantly between buildings. Furthermore, a comparison between the non-HVAC profiles derived from the gathered data and profiles that were synthetically generated in Annex 42 revealed that the synthetically generated profiles under-represent the frequency of high power non-HVAC electricity draws (such as the approximately 4 kW draw shown in Fig. 1). This underscores the importance of using non-HVAC profiles based on real world gathered data for use with whole-building performance simulations of distributed energy systems. The increased awareness of the need for non-HVAC profiles based on data gathered from real world occupants has resulted in the initiation of a follow-on research project to gather more electricity consumption data from an additional eleven houses.

Data repository

The data obtained from the above project have been archived in two formats to facilitate their use for future research. The first format (found in the directory "logged_data") includes the average power draw of each measured circuit over each 1-minute interval for each house's complete monitoring period (greater than one year).

The second format (found in the directory "processed_data") includes exactly one year's worth of data for each house at 1-minute intervals. Section 3 of reference [13] describes the methods that were employed to select, fill, smooth, and derive the data to generate these files.

These data are available for download. Details on how to gain access to them can be obtained from Ian Beausoleil-Morrison (ian_beausoleil-morrison@sbes.ca).

2.2 Italy

2.2.1 Domestic hot water and electric demand profiles

Introduction

Detailed electrical and domestic hot water demand profiles are very important as an input to simulations of small-scale energy systems. Direct, highly-resolved measurements can provide such data, but the number of devices required make the measurements is complex and costly. Even if some monitoring studies with different degrees of detail have been performed in Europe and elsewhere in the world [14-19], the data produced are insufficient to provide adequate coverage of the range of possible situations in reality. Given this lack of detailed measurements, and also to reduce expenses, load modelling is an alternative.

The current section illustrates the domestic hot water and electric load profiles used by the Seconda Università degli studi di Napoli (Italy) as inputs for simulating and assessing the performance of micro-cogeneration systems coupled with residential buildings by means of the software TRNSYS [20] under different operating scenarios [21-24].

Domestic hot water demand profiles

Ulrike Jordan and Klaus Vajen have developed a tool to generate realistic Domestic Hot Water load profiles [25, 26] in the framework of IEA/SHC Task 26 [27]. Those load profiles can be used with TRNSYS, and their authors have kindly accepted to share them with TRNSYS users.

Sets of yearly load profiles for the domestic hot water demand in the time scales of 1 minute, 6 minutes, and 1 hour were defined. Each profile consists of a value of water flow rate for every time step; the values of the flow rate and the time of occurrence of every incidence were selected by statistical means. Each set of load profiles contains profiles with different average basic load (100, 200, 400, 800, ... l/day) and different initial random values in order to get a load profile for any multi-family house by superposition. A probability function, describing variations of the load profile during the year (also taking into account the daylight saving time), the weekday, and the day is considered. The Accumulated Frequency Method is used to distribute the incidences described by the probability function across the year.

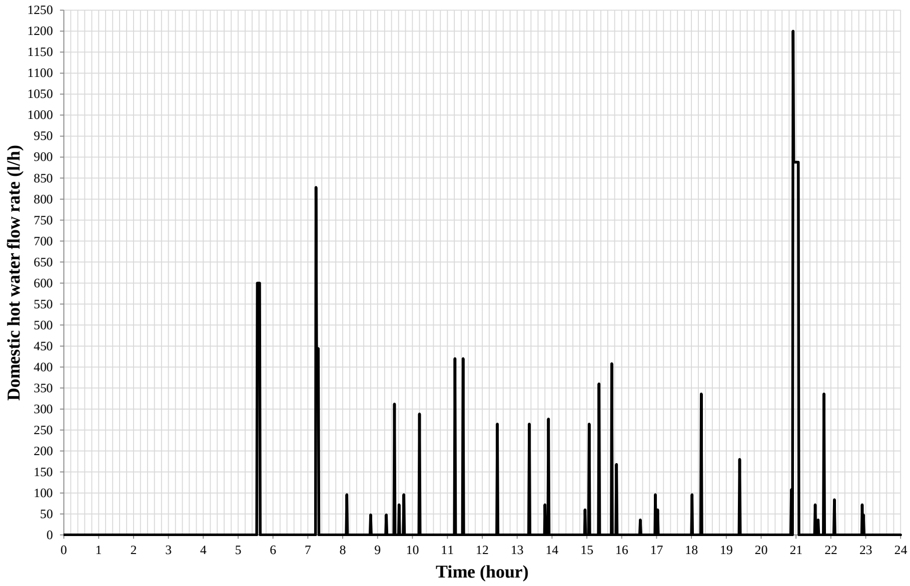


Fig. 2: Typical daily domestic hot water demand profile [25, 26].

The values of water flow rate are based on research studies about domestic hot water consumption patterns in Switzerland and Germany, investigated by measurements of the electrical power demands of electric domestic hot water units, measurements of temperatures or flow rates.

As example, Fig. 2 shows the domestic hot water demand profile with an average basic load of 200 l/day in the time resolution of 1 minute, during a typical day.

Electric demand profiles

Fig. 3 highlights the daily electric demand profile resulting from the operation of both the lighting systems and other domestic appliances (such as vacuum cleaner, dishwasher, washing machine, TVs, PC, fridge) associated to a typical single family house of 96 m^2.

The curve reported in this figure was obtained by considering the operation of both the lighting systems and other domestic appliances as specified in Tables 3 and 4. Light sources with high luminous efficiency were considered, with a total electric capacity of 294W. The electric consumption of domestic appliances was derived from the data specified by the Loughborough University [28]. No difference between week days and weekend days was considered in the modelling. The electric demand profile considered in this study corresponds to a single flat, with electric consumption of 36.6 Wh/m^2 per day.

Access to raw data

The raw data presented in this section for the Italian environment are available online. The domestic hot water data can be found at: http://sel.me.wisc.edu/trnsys/trnlib/library15.htm#IEA26Load (downloadable in *.txt extension) while access to the electricity demand data is at: http://hdl.handle.net/2134/5786 (downloadable in *.xlsm extension).

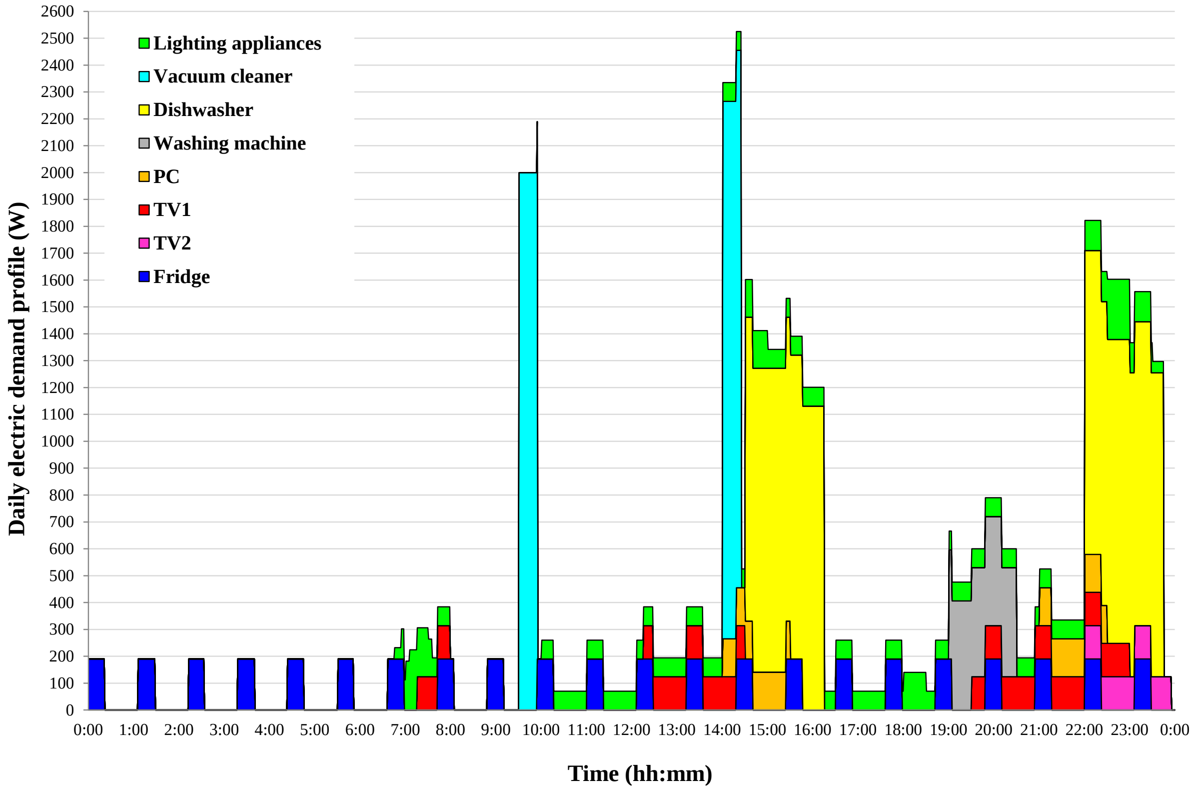


Fig. 3: Single flat daily electric demand profile.

Table 3: Operation and consumption of lighting appliances.

Location	Unit electric consumption (W)	Time of operation	Number of appliances
Kitchen	70	7:00÷8:00 10:00÷15:00 18:00÷23:00	1
Living room	70	14:30÷18:30	1
Hallway	28	6:55÷7:35 22:30÷23:20	1
Toilet	42	6:55÷7:35 22:30÷23:30	1
Bed room 1	42	6:45÷7:15 22:30÷23:45	1
Bed room 2	42	7:05÷7:30 22:00÷23:30	1

Table 4: Operation and consumption of domestic appliances

Appliances	Electric Consumption (W)	Time of Operation
Fridge	190	Cycling operation with mean cycle length equal to 22 minutes
PC	141	14:00÷15:30 21:00÷22:30
First TV	124	7:15÷8:00 12:15÷14:30 19:30÷23:00
Second TV	124	22:00÷23:55
Washing machine	406	19:00÷20:30
Dishwasher	1131	14:30÷16:15 22:00÷23:45
Vacuum cleaner	2000	9:30÷9:55 14:00÷14:25

2.2.2 Electrical Load Profile for Italian Multifamily Houses and Italian Office Buildings

Introduction

A case study to construct the typical electrical load profile for some types of apartments in Italy, with different occupation characteristics, and at different times of year, is presented below. The construction of the electrical load profile is possible via observation of the behavior of residents in respect of electrical loads.

This is followed by aggregation of the load shapes of various households so as to derive the end-use area load profile. It is realized by applying a time vector to time shift loads of single units, considering the natural behavior of the occupants.

The aggregation of the different apartments is implemented by an algorithm simulation using the software MATLAB. Also a GUI (Graphics User Interface) was constructed to insert the input data, to view the load diagrams of individual apartments, and to view the final aggregation.

In order to estimate power, energy and load profiles, the residential units are subdivided in 3 typologies:

- Economy;
- Standard, with air conditioned for one room and more power for lighting and washing machines;
- Luxury, with air conditioned for all the rooms and more power for lighting, washing and dryer machines.

Each unit is equipped with electric boilers for domestic hot water production. The load profile is differentiated for the residential units considering a "single/couple occupation" and a "family with children occupation", in summer or winter, respectively. The difference among these categories is in number, type and power rating of the appliances present in the house. The reference standard used, CEI 64-8/3, gives the minimum criteria and the minimum equipment of the electrical system, with reference to different levels of performance and usability. The area of the typical residential unit was 100 m^2 composed by dining room, kitchen, three bedrooms, two bathrooms and a balcony.

Load profile model

The day is divided into 96 intervals of 15 minutes, each interval is characterized by a constant value of power, equal to the value of the average power consumption in the interval itself.

For the single residential unit, the power of the individual load Pl,i (t) is expressed by:

$$P_{l,i}(t) = P_{N,i} \cdot c.u._i(t) \cdot p_i(t) \quad [W] \qquad (1)$$

where:

$P_{N,i}$ is the nominal power of the *i*th electrical load [W];

c.u.$_i$(t) is the utilization coefficient, which varies between 0 and 1. The utilization coefficient is a vector of 96 values, one for each time interval. The system designer has to determine the values (≤ 1) of this parameter based on experience.

p_i (t) is a vector of 96 values, one for each interval, that indicates the activation of the ith load. If during the i-th interval the load is activated, the corresponding i-th value in the vector is 1, otherwise it is 0.

The diversity factor, in the case of apartment inhabited by a family and by a couple, was by-passed having performed the electrical loads in respect of behavioral analysis. In this way it was possible to consider the time slots in which it is more likely the use of the devices considered. In addition, we made use of the support provided by a previous work done by the "Politecnico di Milano", that shows the load curves of the main appliances and lighting fixtures of 110 houses.

The diversity factor was applied only to the loads on the lighting because, although the division into time slots, the environments are never considered all lit up.

In Fig. 4 the load diagram for a Standard Unit is shown.

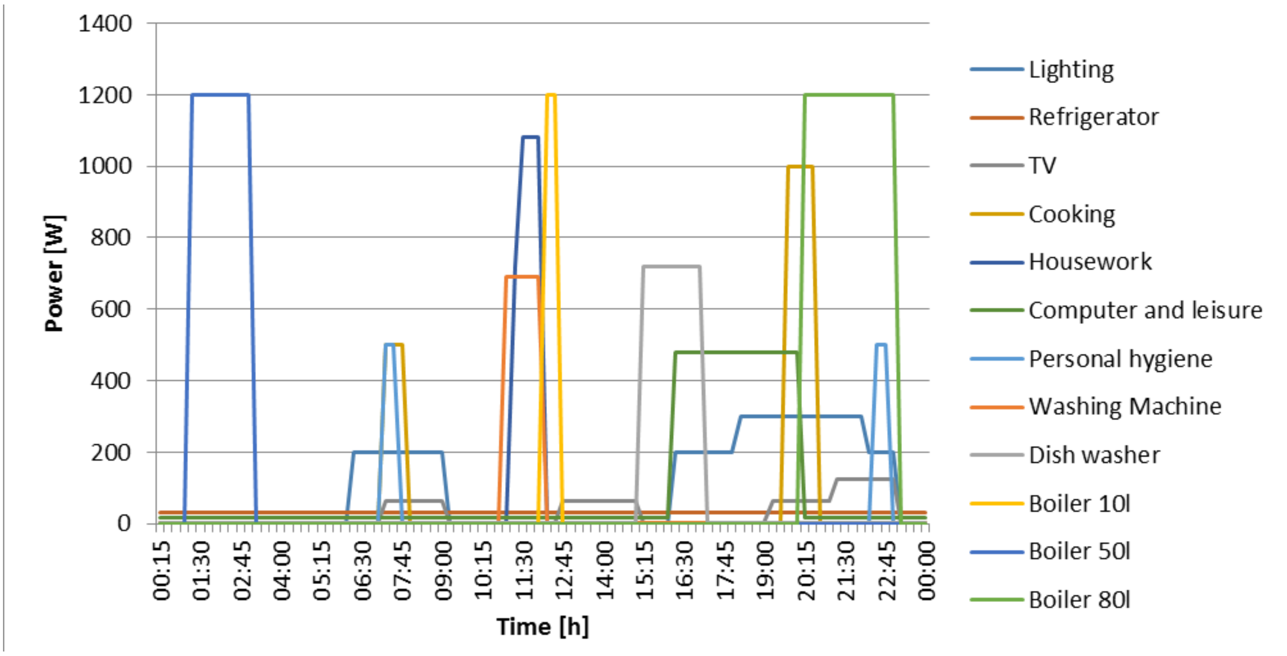


Fig. 4. Load diagram for a standard unit.

In order to facilitate the aggregation of residential units, the loads are classified as:

Uncontrollable loads: loads for which it is not possible to implement any control strategy, such as the timing, or maintain the absorption power within thresholds. These loads depend on the habits of the occupants (e.g. lighting)

Plannable (schedulable) loads: loads for which it is possible to implement a control strategy, such as choosing the starting time, providing a delay in the start of the cycle and ensuring the closure of the cycle without interruption (e.g. household appliances);

Controllable load: loads for which it is possible to provide both a time delay in starting the cycle and it can be switched on/off without damage and degradation of consumer quality of experience (e.g. boilers for hot water, within certain storage temperature limits).

The following quantities can be calculated.

Total power absorbed by uncontrollable loads:

$$P_{uc}(t) = \Sigma_i^N P_{i,uc}(t) = \Sigma_i^N P_{Ni,uc} \cdot c.u._{i,uc}(t) \cdot p_{i,uc}(t) \quad [W] \tag{2}$$

Total power absorbed by controllable loads:

$$P_c(t) = \Sigma_i^M P_{i,c}(t) = \Sigma_i^M P_{Ni,c} \cdot c.u._{i,c}(t) \cdot p_{i,c}(t) \quad [W] \tag{3}$$

Total power absorbed by plannable loads:

$$P_p(t) = \Sigma_i^K P_{i,p}(t) = \Sigma_i^K P_{Ni,p} \cdot c.u._{i,p}(t) \cdot p_{i,p}(t) \quad [W] \tag{4}$$

Where:

N is the number of uncontrollable loads;
M is the number of controllable loads;
K is the number of plannable loads;
$P_{i,uc}$ is the daily profile of the ith uncontrollable load. It is a vector of 96 values, where each value is for 15 minutes;
$P_{Ni,uc}$ is the nominal power of the ith uncontrollable load;
c.u.i_{uc} is the coefficient of utilization of the i-th uncontrollable load. It is a vector of 96 values;
pi,uc is the a vector of 96 values that indicates the activation of the i-th load;

The same method can be used for controllable and plannable loads;

In Fig. 5 is shown the load diagram for Economy Unit with family behavior, in winter, with uncontrollable, controllable and planable loads.

The graph is constructed in order to highlight, for the single unit, the portion of the uncontrollable, controllable and plannable loads.

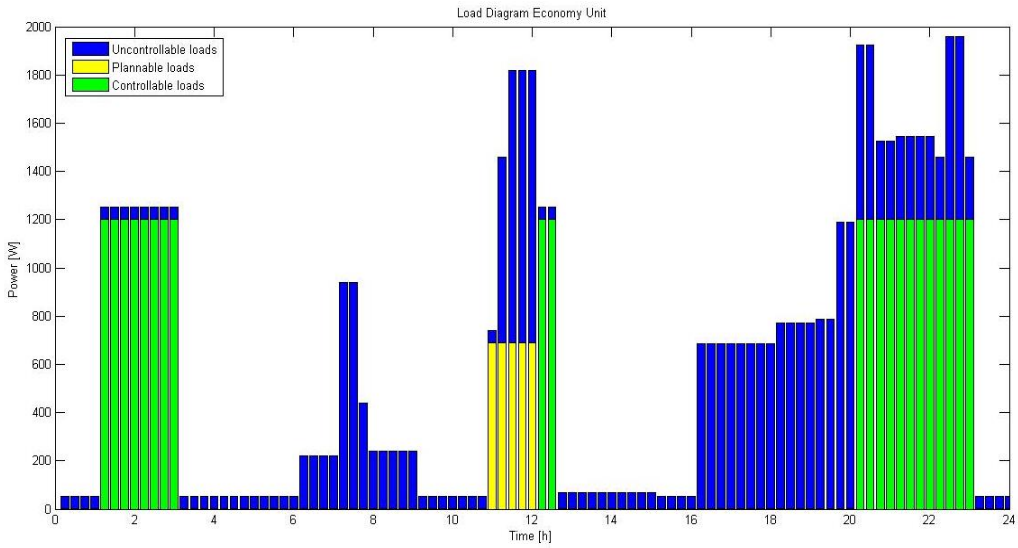


Fig. 5. Load Diagram Economy Unit.

Aggregation of loads profiles

The aggregation of residential units can't be carried out as the product of a number of apartments for the relative load profile, but it must take into account the natural lag in the activation of loads.

The aggregation of the load shapes of various households, so as to derive the end-use area load profile, is realized by a vector time with which to make the time shift loads of single unit. The load profile of the individual unit has been built focusing the most likely start time of the loads in the time slot. The time vector is based on a Gaussian distribution having:

- zero mean (μ), to represent the fact that there is a greater probability that the loads are activated at the time proposed;
- variance (σ) is equal to 16/3: the probability that the load is activated over a value (μ +3 σ) is lower than 1%.

Furthermore, zero mean, it will have positive elements of time vector to mean a displacement of the loads to the right, with a time delay respect to the proposal load profile, and negative elements representing a left shift that is an advance in the activation of electrical loads. It is possible to change mean and variance of the Gaussian.

The curve of the electric load of the aggregate is achieved by considering a linear combination, by a time shift of the loads of the single unit, based on vector time, in general we have:

$$P_{uncontrollable}(t) = P_{uc}(t - t') + P_{uc}(t - t'') + \cdots P_{uc}(t - t^{n_{ap}}) \quad [kW] \tag{5}$$

$$P_{controllable}(t) = P_c(t - t') + (t - t'') + \cdots P_c(t - t^{n_{ap}}) \quad [kW] \tag{6}$$

$$P_{plannable}(t) = P_p(t - t') + P_p(t - t'') + \cdots P_p(t - t^{n_{ap}}) \quad [kW] \tag{7}$$

$$P_{aggregate}(t) = P_{uncontrollable}(t) + P_{controllable}(t) + P_{plannable}(t) \quad [kW] \tag{8}$$

Where (t-t ') is representing the shift in time of the electrical loads according to the vector time.

Case Study

In the case study 50 units are considered: 25 with a family behavior (5 economy, 15 standard and 5 luxury) and 25 with a couple behavior (15 economy, 5 standard and 5 luxury). Each unit is equipped with electric boilers for domestic hot water and the period is winter.

The aggregation of individual appliance demand so as to produce an individual household demand profile is achievable by pressing the button Load Diagram present in the Output panel of the GUI interface.

In Fig. 6 is shown the GUI interface with inputs data.

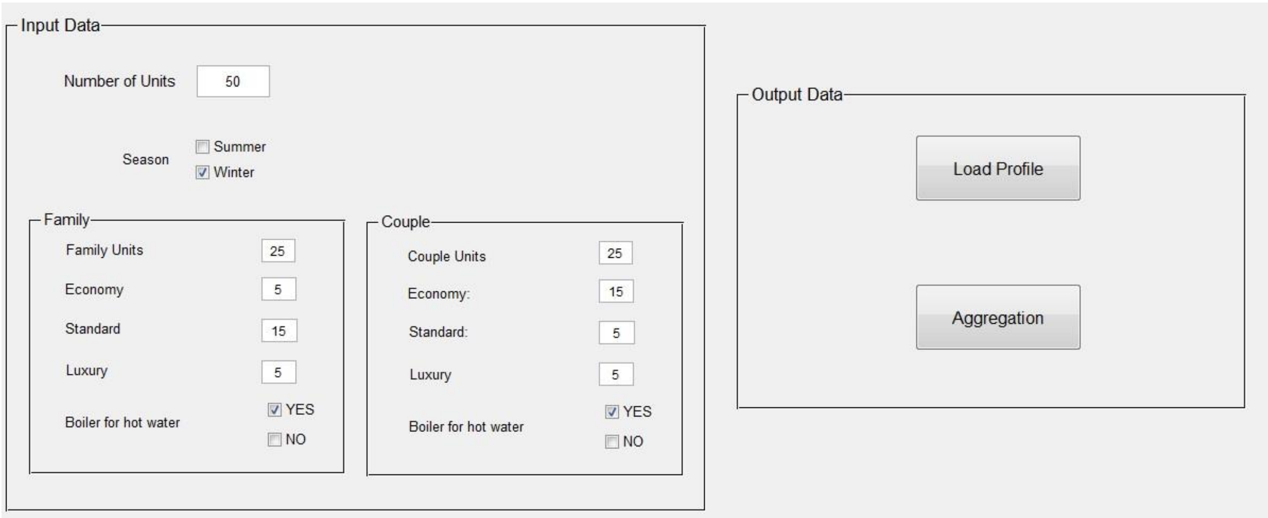


Fig. 6. Interface GUI.

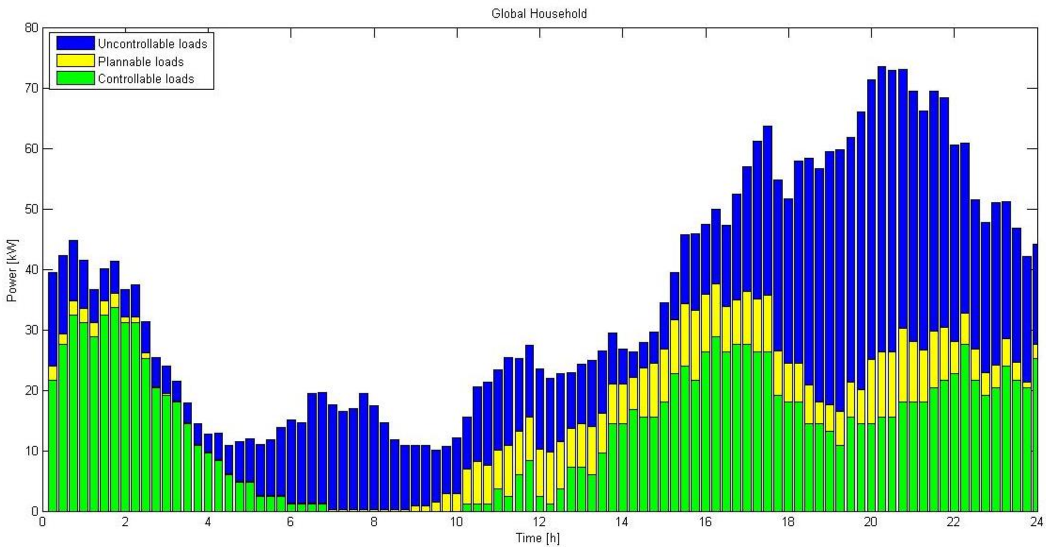


Fig. 7. Load profile for the building in a winter day.

The values used to make the load charts are imported from an excel file. The excel file becomes the source of the program, with the possibility of being changed by the user.

The load profile for the whole building in a winter day, shown in Fig. 7, reflects the typical trend with two peaks characteristic of the domestic loads.

Conclusion

A case study to construct the typical electrical load profile for some types of apartments in Italy, with different occupation characteristics, and at different times of year, has been presented. The construction is possible by observing the behavior of residents in respect of electrical loads.

This is followed by aggregation of the load shapes of various households so as to derive the end-use area load profile. It is realized by a vector time with which to make the time shift loads of single unit, considering the natural behavior of the occupants. It is possible change the vector time by changing mean and variance of the Gaussian Distribution, thus obtaining a different load profiles.

The load profile for the building reflects the typical trend with two peaks characteristic of the domestic loads.

Electrical load profile for Italian office buildings

Introduction

A case study to construct the typical electrical load diagram for some types of Italian office buildings with different total floor surface and density of occupation, at different times of year, is presented below.

The aim of the study is to define a classification of buildings according to their use profile and electricity consumption, in order to obtain a standard normalized electrical profile for each classification.

Office buildings monitored

In order to obtain a standard electrical profile some office buildings located in Rome have been monitored since 2009. Four years of electric profile, with a temporal resolution of five minutes, are available.

The main characteristics of the monitored office buildings are listed in the table below:

Table 5. Operation and consumption of domestic appliances

	Electrical Power installed [kW]	Total floor surface [m2]	Total occupants [n]	Data Collection Period from
Building 1	82	3650	62	July 2009
Building 2	77	3250	79	July 2009
Building 3	31	1200	50	February 2012
Building 4	410	9000	300	July2009

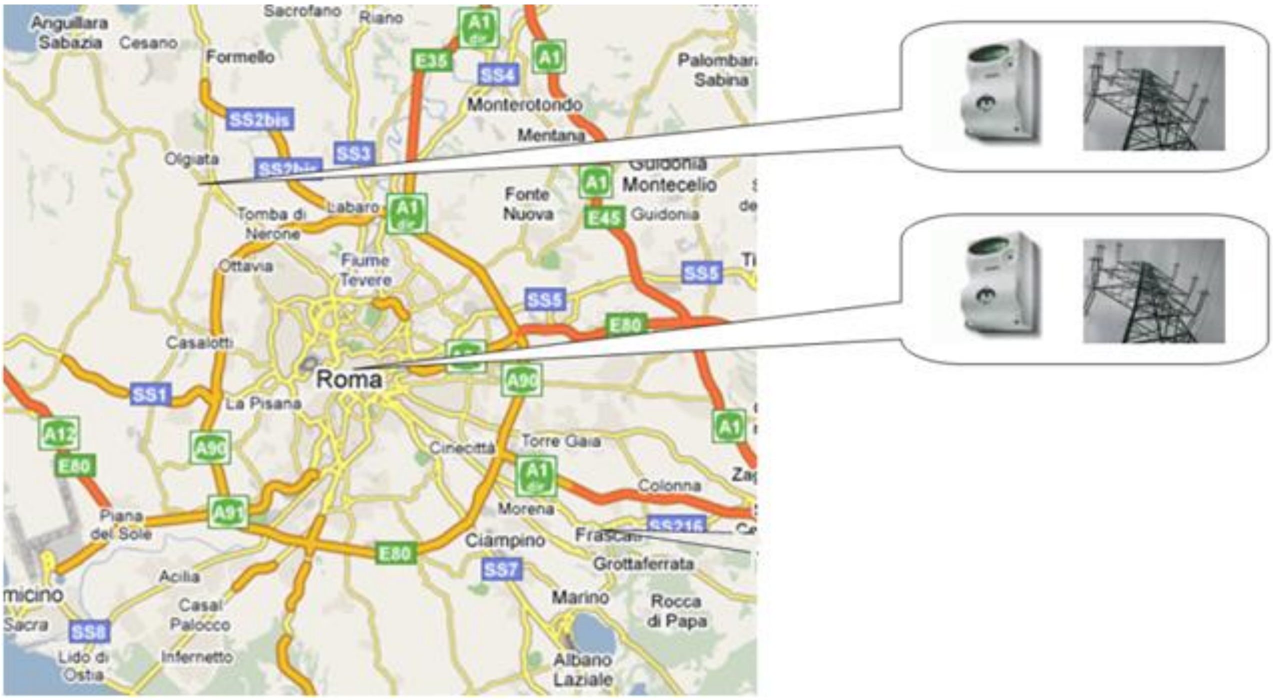


Fig. 8: monitored buildings

Circuits monitored were:

- Lighting power line
- Device power line (PC, printer, ecc)
- Central Heat pump power line

For each circuit the following quantities are measured:

- 3PhaseVoltage [V]V
- 3PhaseCurrent [A]
- 3PhaseAvgCurrent [A]
- 3PhasePowerFactor [Cos phi]
- 3PhaseActivePower [kW]
- 3PhaseReactivePower [kVAR]
- 3PhaseApparentPower [kVA]

The measured electrical data are sent to a virtual server (located at ENEA Casaccia Research Center) via a TC/IP protocol signal, allowing an on line monitoring of the data and a data storage of the electric profile of each monitored building.

The stored data are displayed and processed through a special software platform (Mcubo) accessible via the internet. More info about the on line monitoring web site are available at following link: http://www.efficienzaenergetica.enea.it/generazione-distribuita/strumenti/m-energy--sistema-di-monitoraggio-per-l-energia.aspx

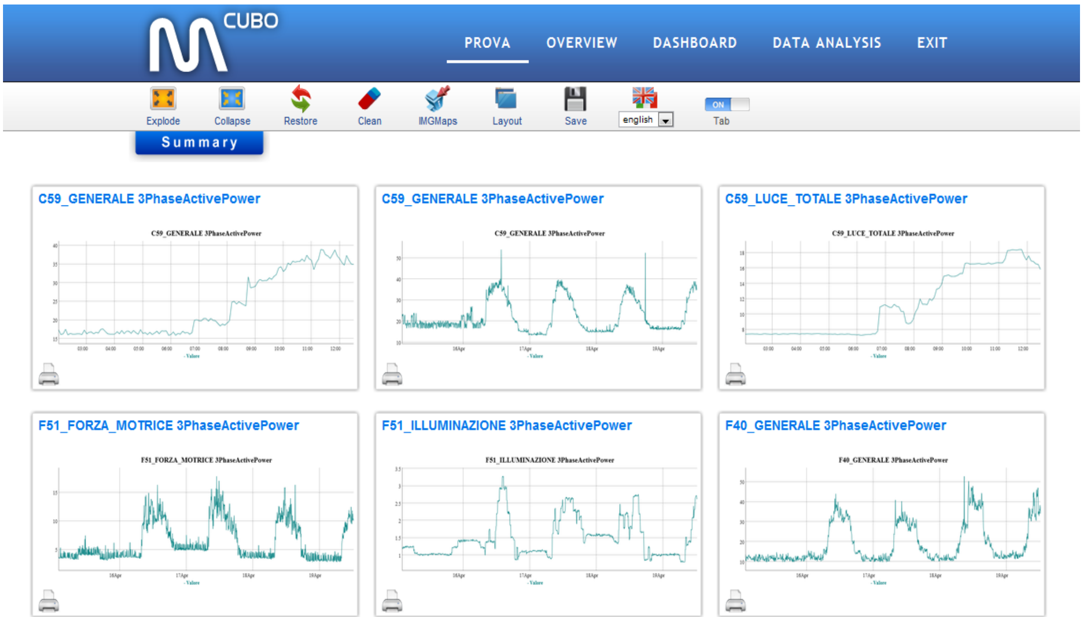


Fig. 9: Example of the dashboard of the online monitoring Web site for electric profiles

The data of the total three phase active power, collected from July 2009 to July 2012 with a five minute time step, have been post-processed by means a spreadsheet model in order to obtain a single profile for each monitored building.

Load profiles

The calculated load profiles are shown in annex as a fraction of the contract power demand of the building. The contract demand for each building has been chosen equal to the maximum power absorbed by the buildings during the monitoring period.

For each monitored building the following profiles are calculated:

- **the daily electrical load profile for the average working day, for each month**. The daily load profile for the average working day of each month has been obtained by averaging, for each month, the data measured from Monday to Friday, excluding holidays, as described in the following equations:

$$A_n = [A_{n,0}\ A_{n,1}\ \cdots\ A_{n,23}] \tag{9}$$

$$A_{n,h} = \frac{1}{WD} \cdot \sum_{i=1}^{WD} P_{i,n,h} \qquad \text{with} \qquad h \in \{0, 1, \cdots, 23\} \tag{10}$$

where

- A_n is the daily electrical load profile for the average working day of the *n*-th month
- $A_{h,h}$ is the electrical load at the *h*-th hour for the average working day of the *n*-th month
- $P_{i,n,h}$ is the active power monitored at the *h*-th hour of the *i*-th working day of the *n*-th month
- WD are the working days of the *n*-th month

- **the daily electrical load profile for the average winter working day and for the average summer working day** as described in the following equations:

$B = [B_0 \; B_1 \; \cdots \; B_{23}]$ daily load profile for the average winter working day (from October to March)

$$B_h = \frac{1}{WM} \cdot \sum_{n=1}^{WM} A_{n,h} \qquad \text{with} \qquad h \in \{0, 1, \cdots, 23\} \tag{11}$$

$C = [C_0 \; C_1 \; \cdots \; C_{23}]$ daily load profile for the average summer working day (from April to September)

$$C_h = \frac{1}{SM} \cdot \sum_{n=1}^{SM} A_{n,h} \qquad \text{with} \qquad h \in \{0, 1, \cdots, 23\} \tag{12}$$

where

- B_h is the is the electrical load at the *h*-th hour for the average winter working day
- WM is the number of winter and autumn months monitored from 2009 to 2012
- C_h is the is the electrical load at the *h*-th hour for the average summer working day
- SM is the number of summer and spring months monitored from 2009 to 2012

Conclusion

The number of monitored buildings is too few to create a "standard" electrical load profile for an Italian office building. However, according to this first analysis, as shown in Fig. 10 and 11 below, buildings that have a similar specific load (kW/m2), and have a very similar average seasonal load profile both in terms of load shape and magnitude. The monitoring and analysis activity is still in progress.

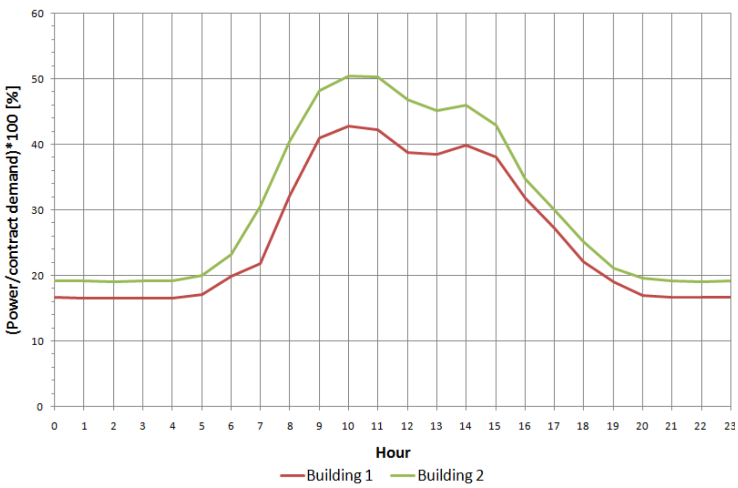


Fig. 10: Average load profile for winter working day

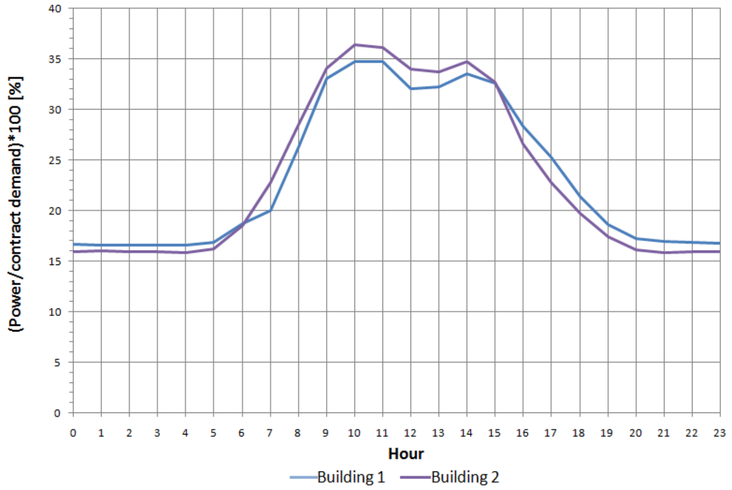
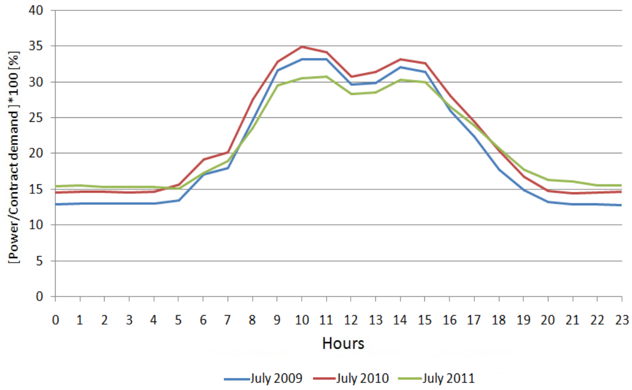
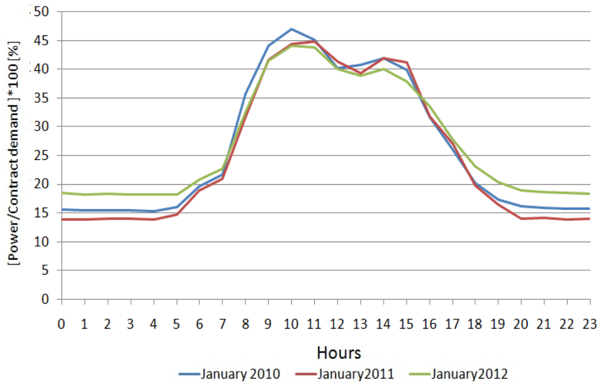


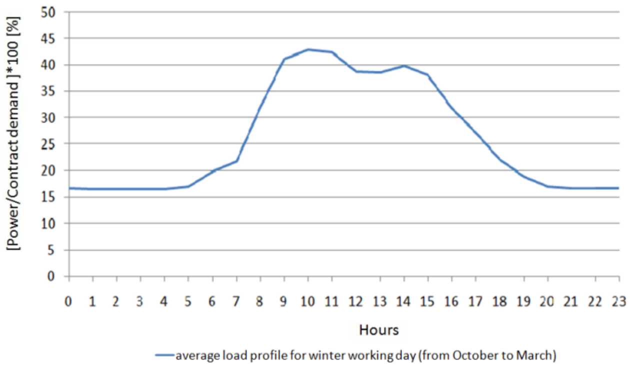
Fig. 11: Average load profile for summer working day

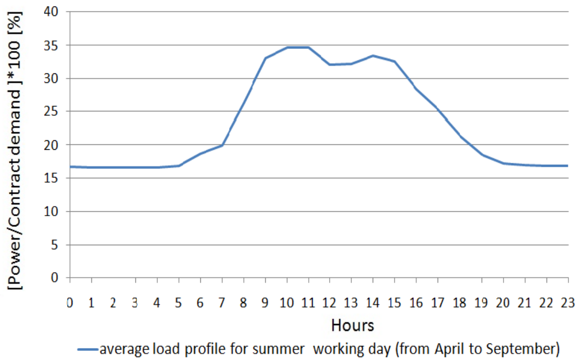
Building 1

Contract demand	82	kW
Number of occupants	62	
Total floor surface	3650	m^2
specific load	0,022	kW/m2
Line monitored	Lighting and Device (PC, printer, ecc)	
Note		



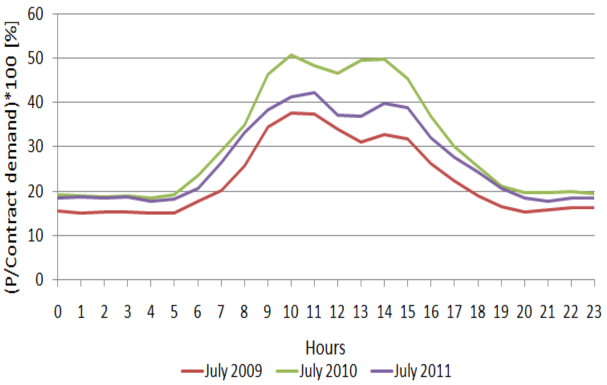


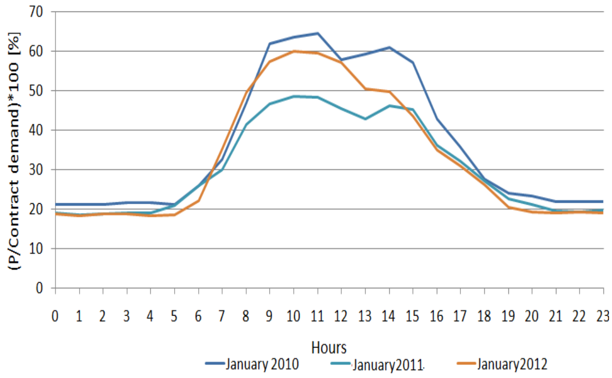


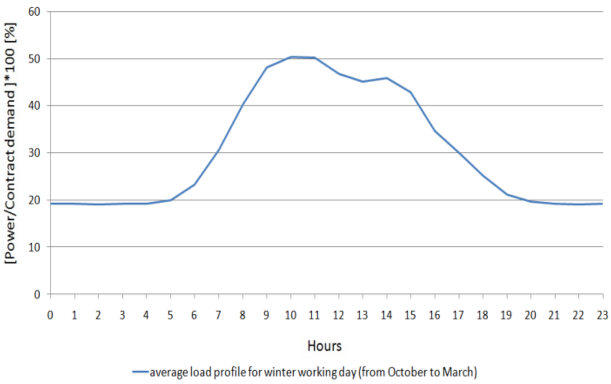


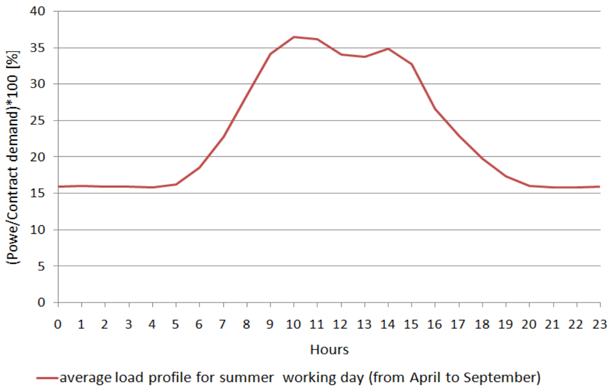
Building 2

Contract demand	77	kW
Number of occupants	79	
Total floor surface	3250	m^2
specific load	0,023	kW/m2
Line monitored	Lighting and Device (PC, printer, ecc)	
Note		



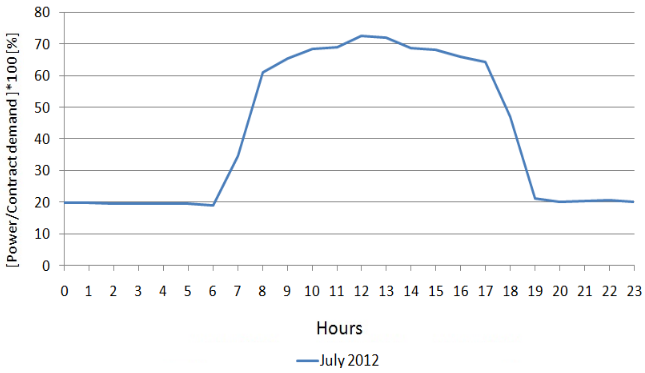


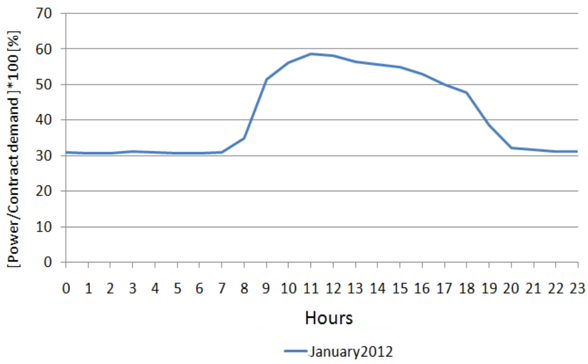


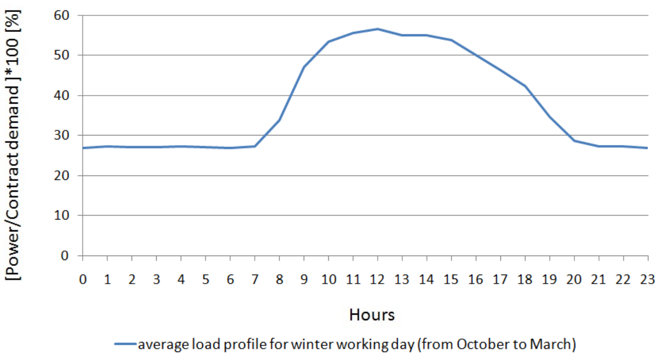


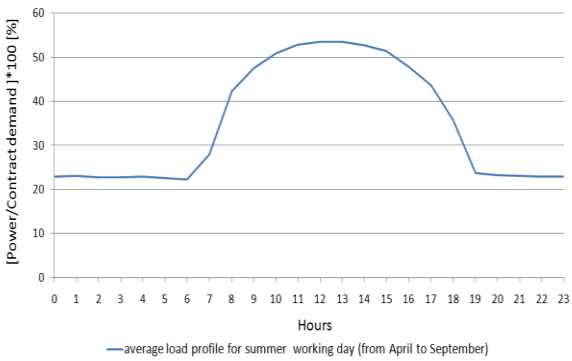
Building 3

Contract demand	31	kW
Number of occupants	40	
Total floor surface	1200	m^2
specific load	0,025	kW/m^2
Line monitored	Lighting and Device (PC, printer, ecc)	
Note	limited data available, monitoring period beginning February 2012	



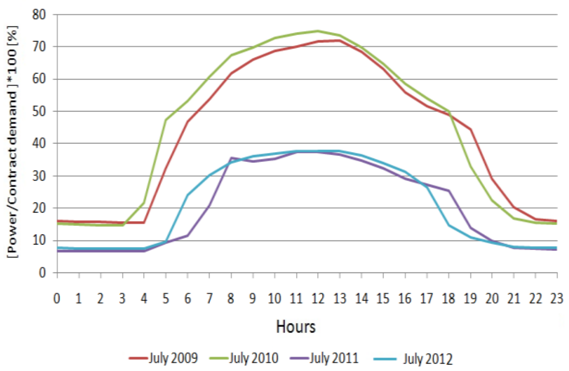


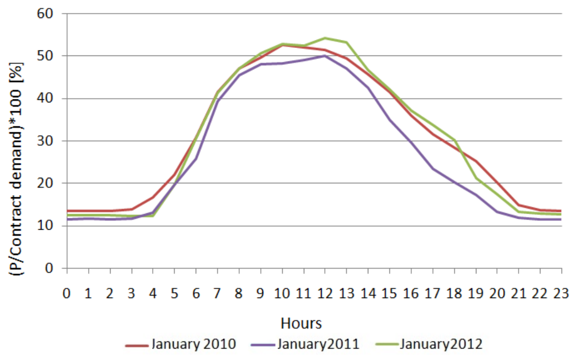


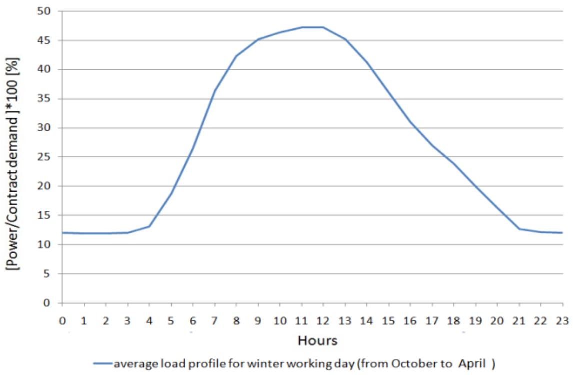


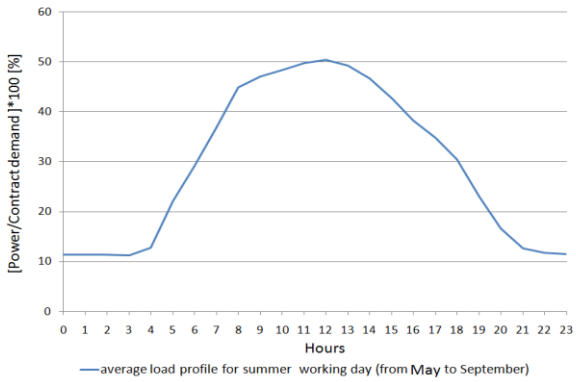
Building 4

Contract demand	419	kW
Number of occupants	300	
Total floor surface	9000	m^2
specific load	0,046	kW/m^2
Line monitored	Lighting, Device (PC, printer, ecc) and chiller for summer air conditioning	
Note	Since the summer of 2011, consumption declined for energy efficiency measures on the air conditioning palnt	









2.3 Japan

The Japanese consortium participating in Annex 54 was able to collect a broad range of extensive data sets for electricity demand, as well as domestic hot water demand for a number of different types of dwellings. These new data are invaluable to the Annex in that Japan was not a participant in Annex 42, so the data outlined below serves as benchmark data for MCG studies moving forward. Contributions of load profile data came from the following participants: Tokyo Gas, Osaka Gas, Toho Gas and the Institute for Building Environment and Energy Conservation.

The data described below were obtained with the involvement of a number of private industrial partners, and remain proprietary. Disclosure of the raw data was for internal use only of the Japanese consortium members, and was made available to participating members of Annex 54 during the working phase of the Annex.

Five different cases were studied. Each case is described below, along with a sample representation of data associated with it.

Case 1: Electricity and hot water demand for apartment and detached house (26 sites)

The Japanese Institute for Building Environment and Energy Conservation has compiled demand profiles for electricity and domestic hot water demand for the cases of both apartments and detached homes, collected over 365 day periods from 2002 to 2004. The electricity demand profiles are provided with one minute resolution, while the DHW profiles have data 10 minute intervals. The data were taken at various locations around Japan, at a total of 26 different sites.

In 8 of the 26 cases, electrical demand profiles were obtained for homes that had a fuel cell cogeneration unit installed on the premises. These data represent a unique insight into how power draws for homes is affected on a long term basis, over seasons and with house to house variation, when cogeneration systems are employed.

The DHW data shows total demand, as well as a separate column for bath water use. It should be noted that an evening bath is a far more prominent feature in Japan as compared to in other nations participating in the Annex.

Figs. 12-17 show a number of examples of the electricity demand profiles. The one minute resolution represents a very high data quality, and is more than adequate for deriving synthetic profiles for any desired scenario.

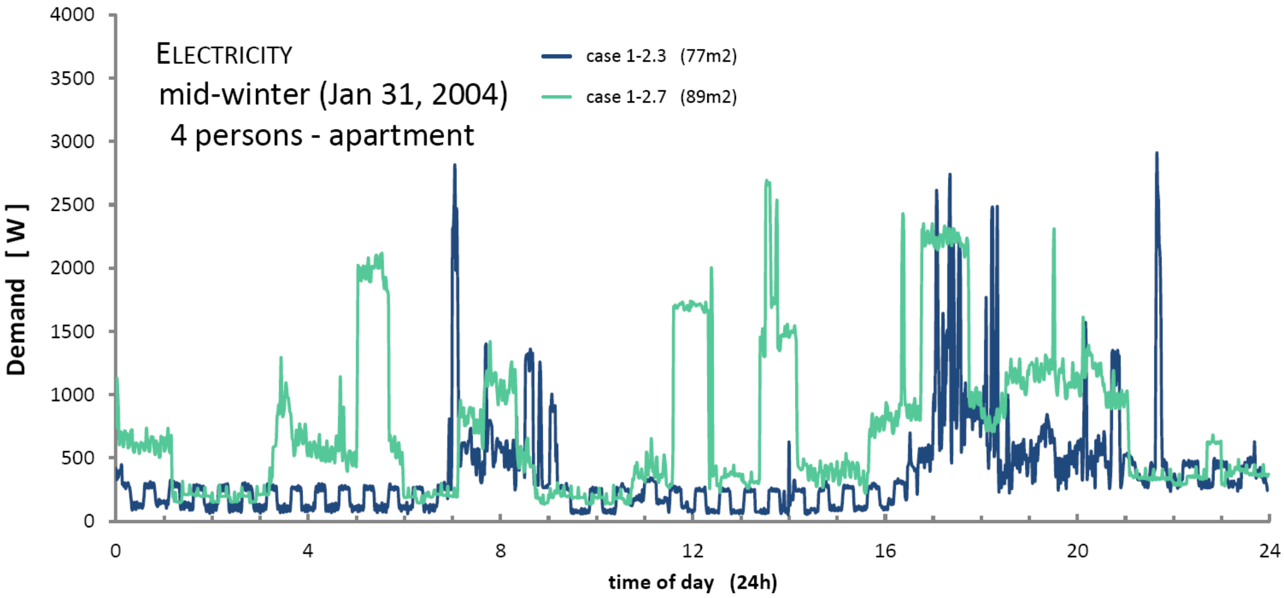


Fig. 12. Electricity demand profiles for two different apartments with 4-person occupancy for 24 hour period during the winter.

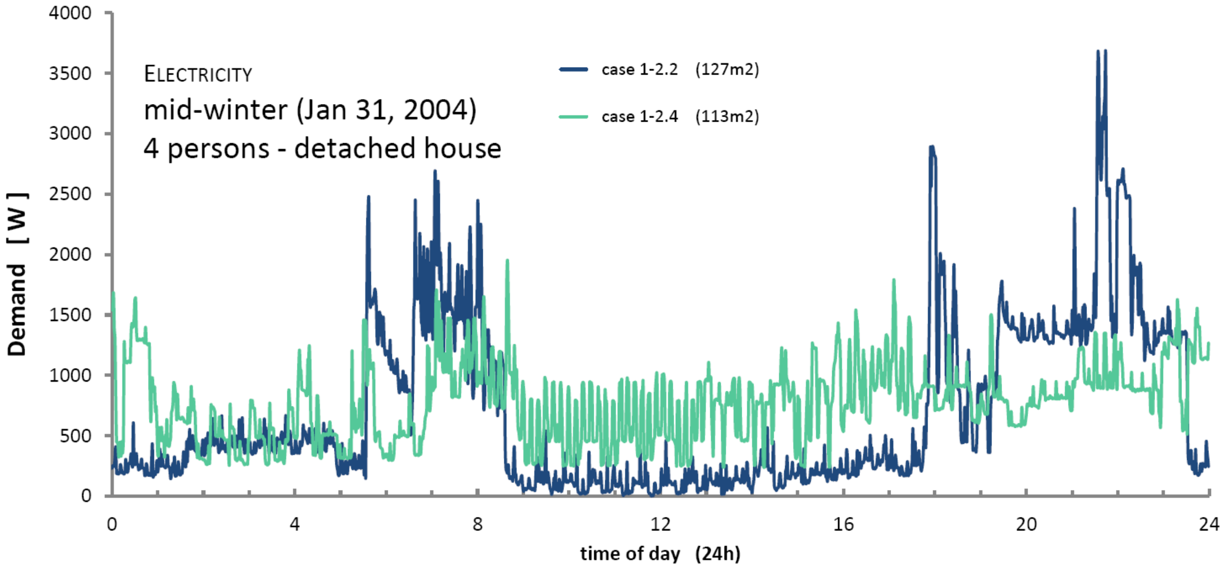


Fig. 13. Electricity demand profiles for two different detached houses with 4-person occupancy for 24 hour period during the winter.

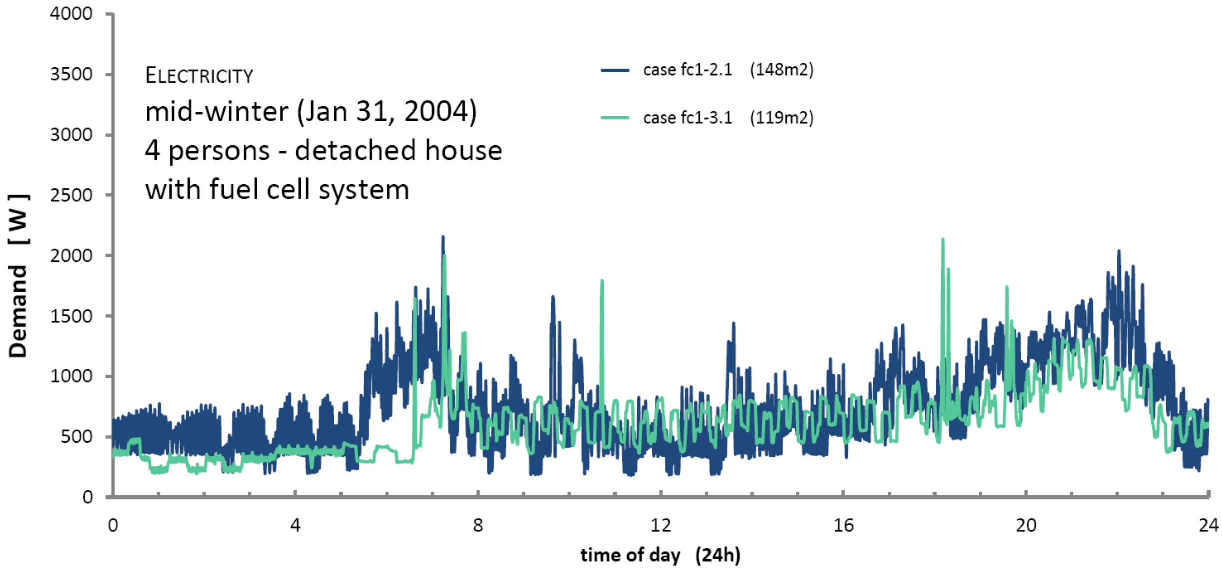


Fig. 14: Electricity demand profiles for two different detached houses with fuel cell micro-cogeneration unit with 4-person occupancy for 24 hour period during the winter.

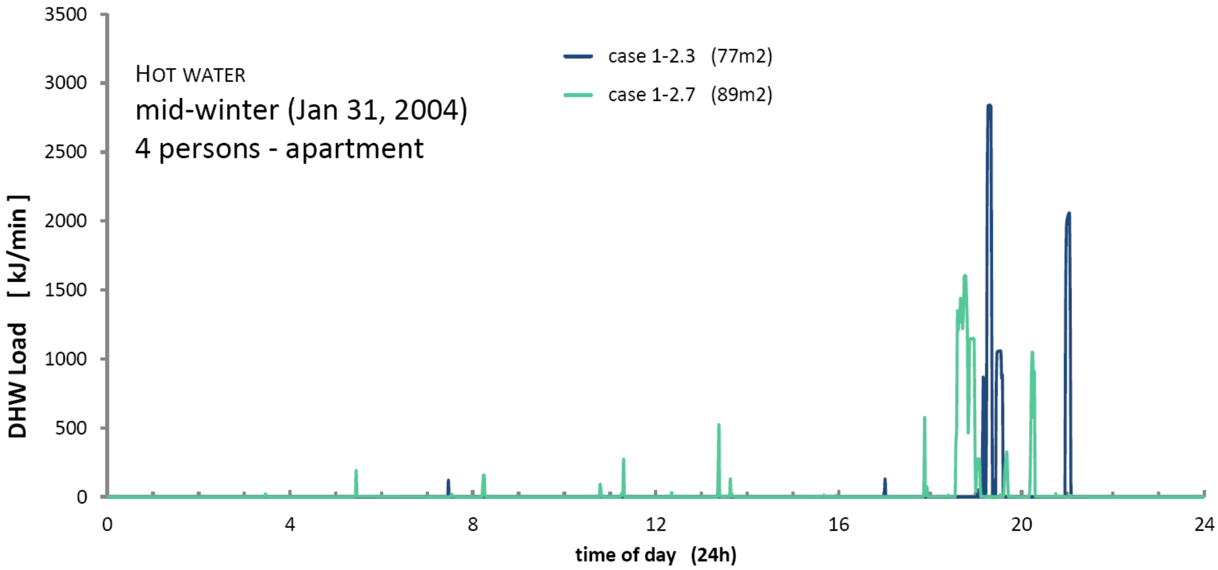


Fig. 15: Domestic hot water demand profiles for two different apartments with 4-person occupancy for 24 hour period during the winter.

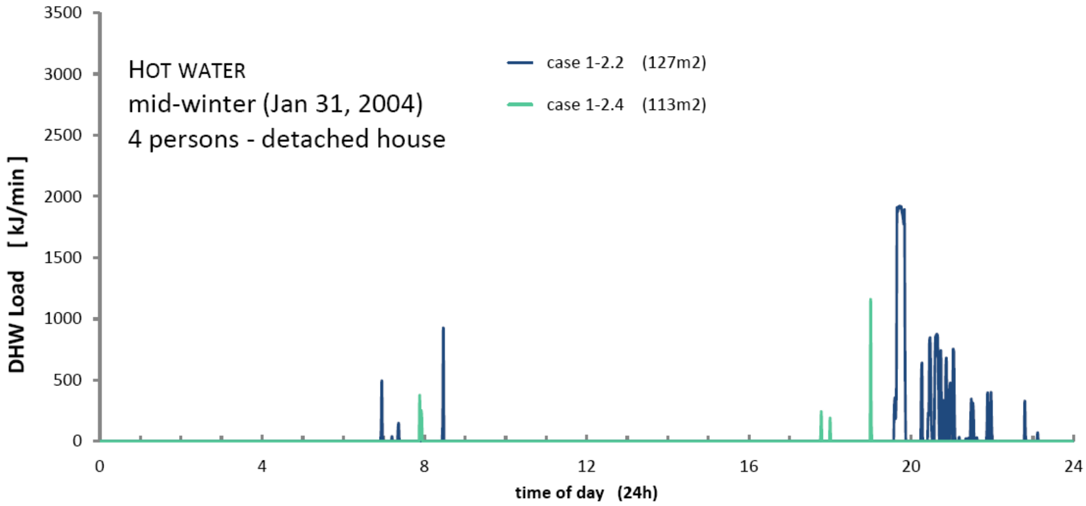


Fig. 16: Domestic hot water demand profiles for two different detached houses with 4-person occupancy for 24 hour period during the winter.

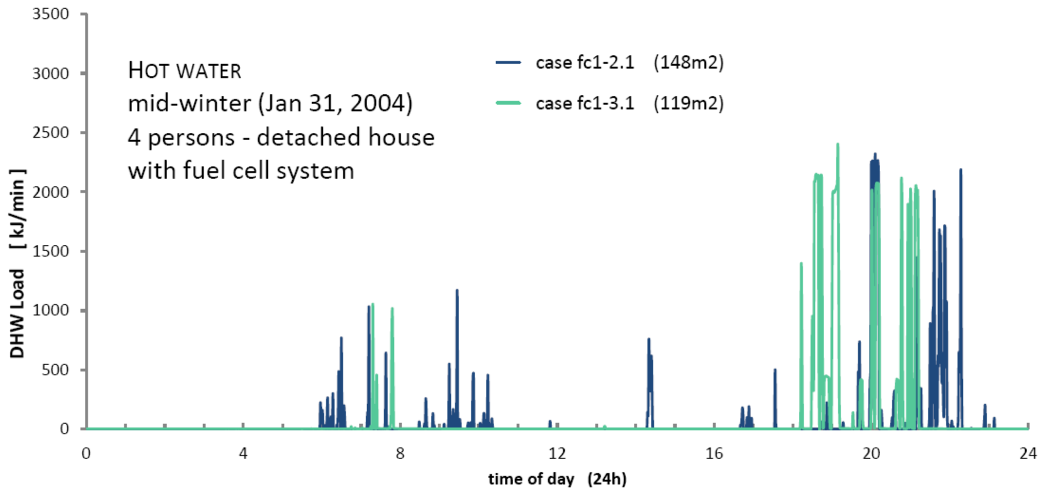


Fig. 17: Domestic hot water demand profiles for two different detached houses with fuel cell micro-cogeneration unit with 4-person occupancy for 24 hour period during the winter.

Case 2: Hot water demand of 6 single family apartments, Osaka

Osaka Gas was able to supply DHW demand profiles measured in six single family homes over 200 day periods, taken from June 2007 through January 2009. The data include the total hot water demand, as well as special draws, namely bath, shower and dishwasher. The data are given as the integrated energy requirement value of hot water demand expressed in kWh. The temporal resolution of the data was in 10 minute intervals. These profiles were referred to in a published study examining MCG with distributed heat storage [29]

Fig. 18 shows an example of a one day period, January 26, 2009.

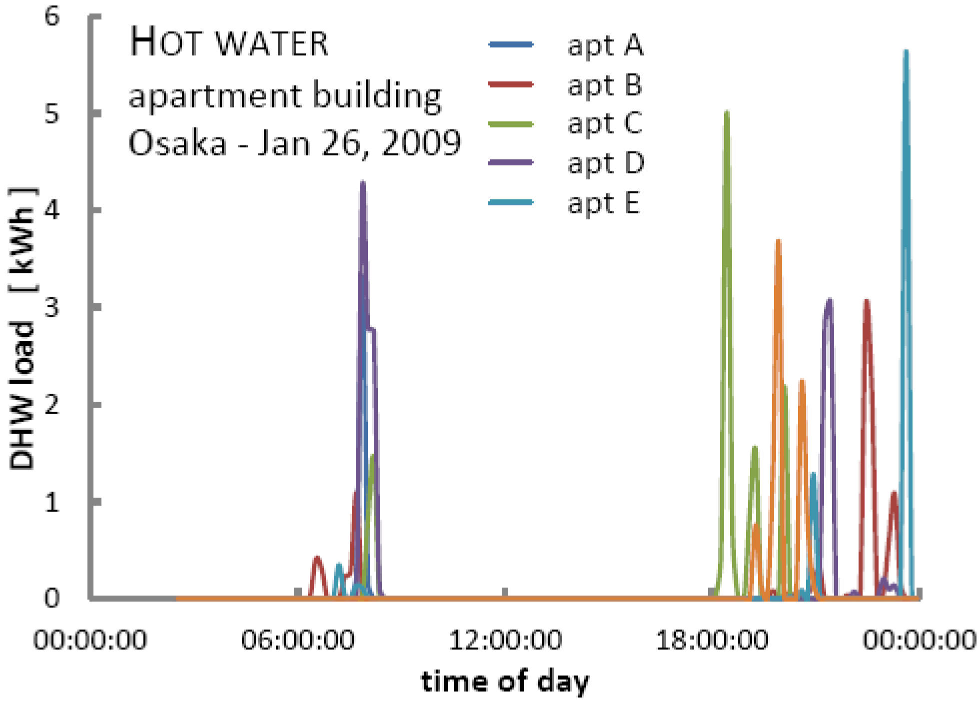


Fig.18: Domestic hot water demand profiles for six different apartment units in a large apartment building in Osaka, for one 24-hour period in winter 2009.

Case 3: Electricity, hot water and environmental condition of an apartment building, Nagoya

Toho Gas in Aichi Prefecture has provided extremely detailed data covering electricity, hot water as well as outdoor environmental conditions for a 50-unit block of bachelor flats in the city of Nagoya. The data were taken over a period of almost one year, from February 2010 through December 2010. A complicating factor for interpreting these data is that a range of 20 to 30 of the flats were occupied during the data collecting period.

The electricity data, DHW draws and climatic data were all recorded at one second intervals. The data reported were for the entire building, thereby aggregating all the occupants' actions.

The electricity data consists of Electrical demand, DHW demand, Battery charge and discharge, CHP power generation and PV power generation. The environmental condition data consists of temperature, humidity, wind speed and amount of insulation.

Fig. 19 shows the electricity demand profile over the course of a single day (April 17, 2010) in full one second resolution. Also shown in the plot are hourly averages as well, to illustrate the loss of detail that occurs with averaging.

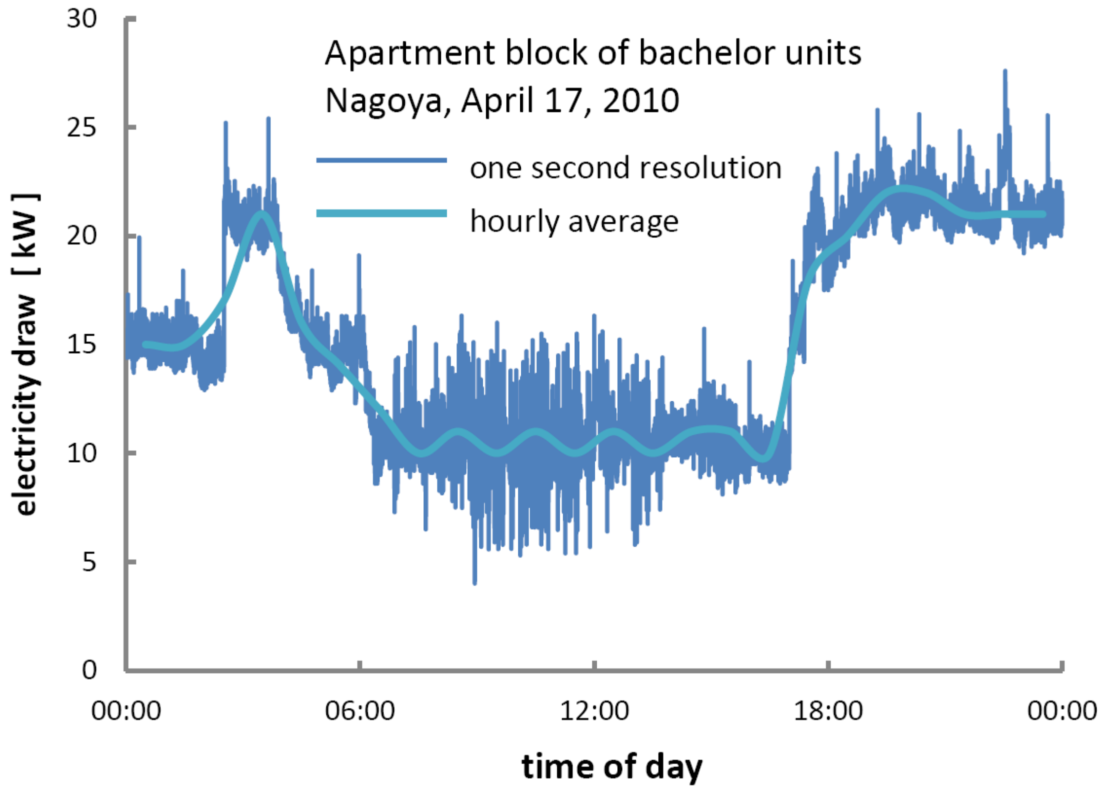


Fig.19: Sample of 24-hour period electricity draw for an entire apartment building in Nagoya in April 2010, showing one second data resolution and hourly average values.

Case 4: Small office building with district heat supply, Kumagaya

A broad range of data was taken by Tokyo Gas from a small office building in Kumagaya, Saitama Prefecture, for an ongoing period beginning in September 2010. Measurements included electrical demand, hot water demand, air conditioning demand, PV generation, micro-CHP electrical generation, solar thermal heat generation, outside temperature and solar radiation, at one hour intervals. The energy management in this building included sending hot water to a neighboring hotel.

The heat data was separated into some individual demands such as air heating/cooling and water heating. The data are expressed as integrated values of each demand in either kWh or MJ. Fig. 20 shows the electrical demand for a day (January 26, 2011) for the small office building studies in Case 4.

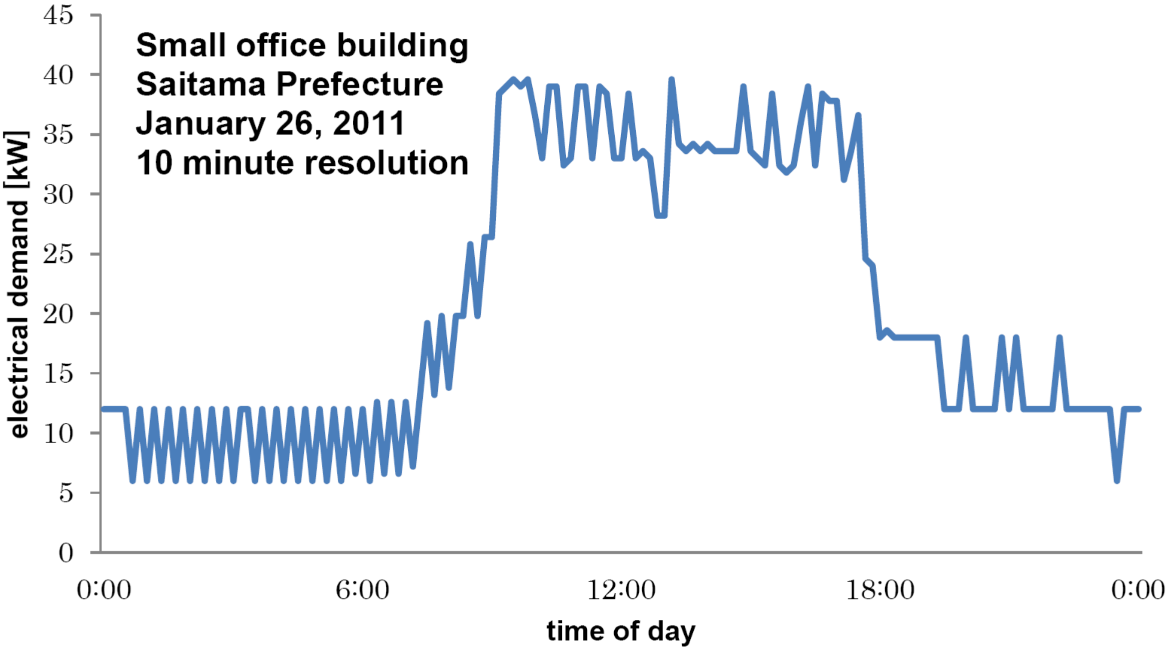


Fig. 20: Sample of 24-hour period electricity demand for a small office building in Saitama prefecture, with 10 minute data resolution.

Case 5: Small office building, Yokohama

A second such study has also been simultaneously carried out in the fiscal year 2004 by Tokyo Gas with a small office building in Yokohama, Kanagawa Prefecture. The slight differences in this case are that the building also employs a micro gas engine for electrical generation, and that all of the hot water is consumed within the building.

2.4 South Korea

2.4.1 Monitoring of Heating and Cooling Loads in Residential Buildings

Monitoring of heating and cooling loads of residential building was done in one house in city of Daejeon, South Korea. This house is two-story building, with the total area of 194 m^2 (total area of 1st floor and 2nd floor). Moreover, the area of this house which needs to be supplied by heating and cooling systems (HVAC systems) is 151 m^2. Window to wall ratio (WWR) is fixed to be 11.9%. In addition, this house has some features which are high insulation, high efficiency window, and passive technology. Renewable energy devices are also installed here, they are solar thermal and geothermal hybrid system as well as photovoltaic modules. It is also able to independently supply the energy up to 80 ~ 90% of the demand, whereas the rest of it is supplied by grid. The following table 6 is the summary of this residential building properties:

Table 6. The properties of residential building in Daejeon, Korea

Building Properties	Information
Location	Daejeon, Korea
Stories Number	2
Total Area	194㎡
HVAC Area	151㎡
WWR	11.9%
Features	High insulation, high efficiency windows and passive technology
RE Devices Installed	Solar + Geothermal Hybrid System, Photovoltaiic
Energy self-sufficiency rate	80~90%

As can be seen on the Fig. 21, the heating period is approximately twice longer than cooling period. It is caused by the building has the high level insulation, therefore it is able to keep the temperature inside the building stable. On the particular ambient temperature ranges (on the hour 2929 to hour 3905 and hour 6345 to hour 7000), it does neither need the heating, nor need the cooling.

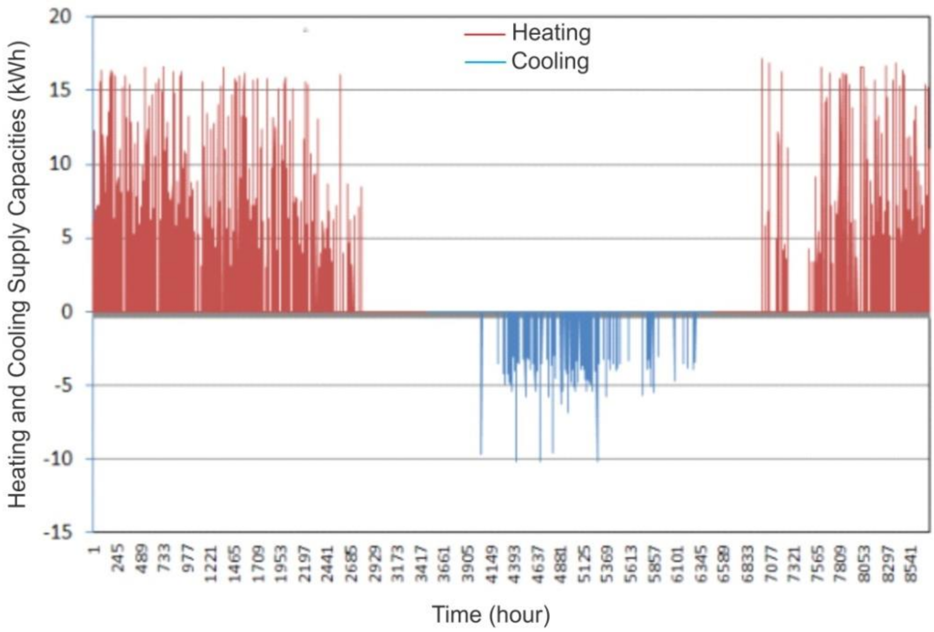


Fig. 21: Hourly annual heating and cooling supply capacities on residential building in Daejeon, Korea

On Fig. 22, it can be observed that the highest heating load occurred at December and January (totally up to 1,800 kWh), whereas the highest cooling load occurred at July (totally up to 400 kWh). The peak of cooling load usually happens at August in Korea, however there are some factors in this particular building which made the cooling peak happened in July instead. Those factors are, first, the fan coil performance test for another experiment which was still undergoing at August that somehow made the cooling load be decreased, and the second one, there was heavy rain occurring mainly during whole August causing the ambient temperature was lower than it was supposed to be.

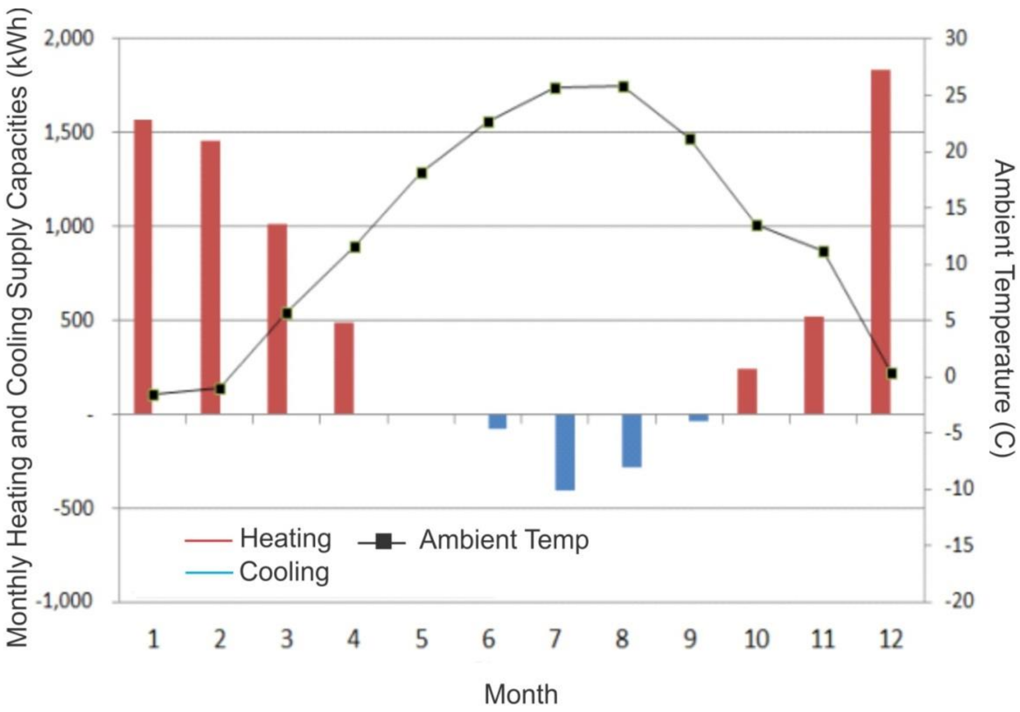


Fig. 22: Monthly annual heating and cooling supply capacities on residential building in Daejeon, Korea

2.4.2 Monitoring of Heating and Cooling Loads in Office Building

Monitoring of heating and cooling loads of non-residential building was done in one office in city of Incheon, South Korea. This house is three-story building with one story as basement (underground) and two story above ground. The area of the land where this building was built is 3,075 m^2, whereas the occupied land area for the building is 1,140.47 m^2 and the total building area is 2,449.24 m^2. Moreover this building employs the reinforced concrete as the body structure and roof structure. The total height of building is fixed to be 15.6 m which consists of basement height of 4.5 m, 1st floor height of 5.7 m, and 2nd floor height of 5.1 m. It also has roof top with the height of 4.8 m. The following table is the summary of this office building properties.

As can be seen on the Fig. 23, the heating period is approximately one month longer than cooling period. On the particular ambient temperature ranges (on the hour 1972 to hour 3724 and hour 6352 to hour 7886), it does neither need the heating, nor need the cooling. Heating peak load was 90 kWh, whereas cooling peak load was 60 kWh, It showed the unusual trend where the heating peak load should usually be less than cooling peak load. It happened because this building had lower operation ratio (lower internal gains) than the normal one so that the heat generated inside the building was also reduce. It caused the cooling load was relatively low and the heating load was conversely high. On Fig. 24, it can be observed that the highest heating load occurred at December and January (totally up to 4,600 kWh), whereas the highest cooling load occurred at August (totally up to 3,200 kWh).

Table 7. The properties of office building in Incheon, Korea

Building Properties	Information
Location	Incheon, Korea
Land Area	3,075 ㎡
Building Area	1,140.47 ㎡
Total Floor Area	2,449.24 ㎡
Configuration	1 story on the underground
Structure	Reinforced Concrete (Roof: Reinforced concrete)
Total Height	15.6 m
Height in each floor	Underground :4.5m, 1st floor:5.7m, 2nd floor :5.1m, rooftop: 4.8m

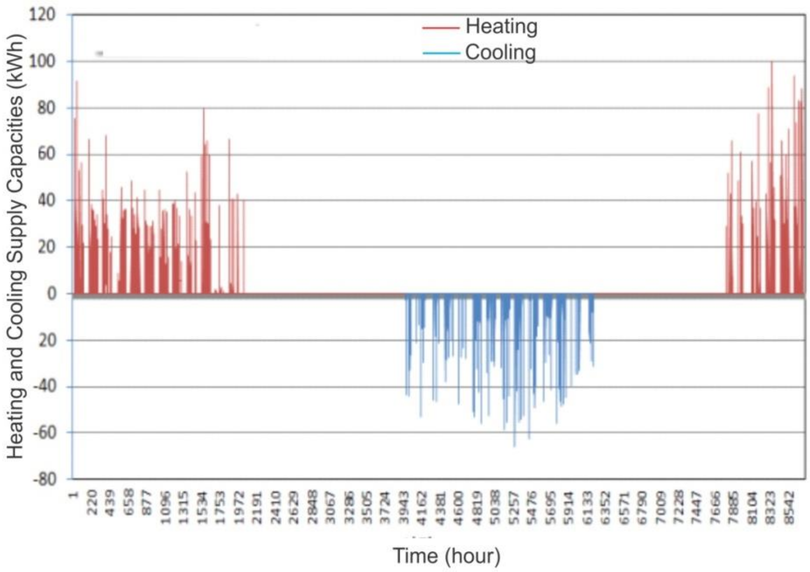


Fig. 23: Hourly annual heating and cooling supply capacities on office building in Incheon, Korea

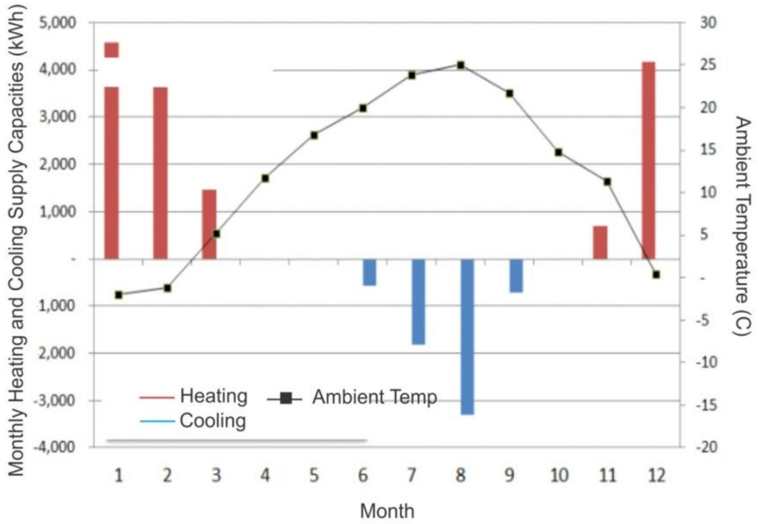


Fig. 24: Monthly annual heating and cooling supply capacities on office building in Incheon, Korea

2.4.3 Load Sharing of residential and office buildings

Load sharing method was done by implementing computer simulation. The input data used came from the monitoring data of residential building in Daejeon and non-residential building in Incheon as described in the previous sections. They were simulated to be close each other and using the common equipments (boiler and chiller). The sample data of cooling load in one week were observed during August 6th to August 12th, as shown on Fig. 25.

Fig. 25: Hourly cooling load of load sharing (house + office) in one week

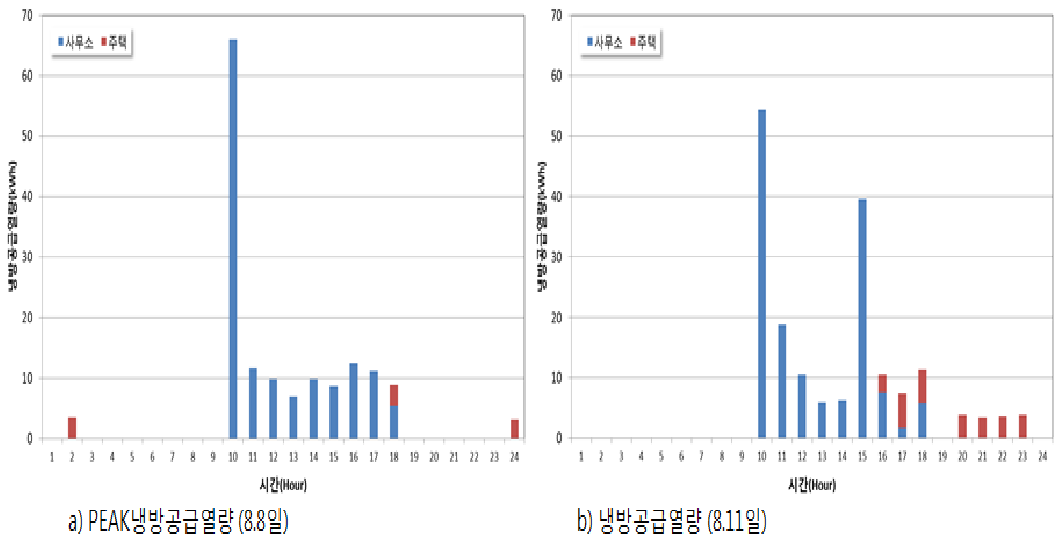


Fig. 25: a) Peak cooling load at August 8th b) Typical cooling load at August 11th

The first two days were weekend (Saturday and Sunday), where there were no loads from office. The peak load at Saturday was around 4 kWh, and at Sunday was 10 kWh. On the other hand, on the weekdays, the peak loads were extremely higher than the weekends. The trend showed that the peak loads occurred in the morning time (around at 10 am), where the highest one did belong to Monday morning which reached 65 kWh. The charts below also show that the second highest loads occurred at afternoon time (around at 3 pm). Furthermore, the off-peak during the day time generally occurred at lunch time (around at 12 – 1 pm), when everybody was away from their rooms.

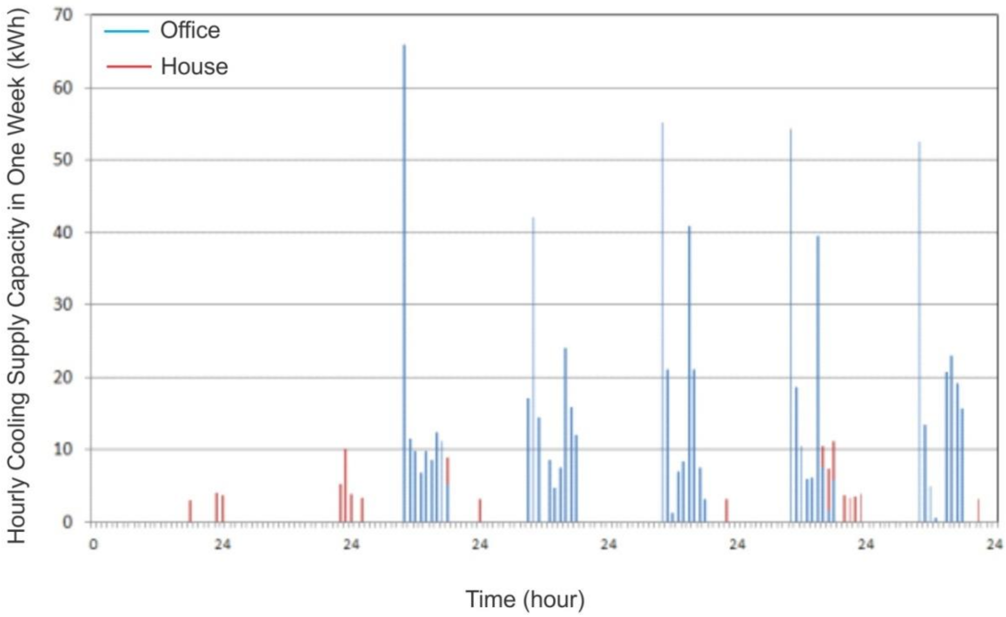


Fig. 26: Hourly cooling load of load sharing (house + office) in one week

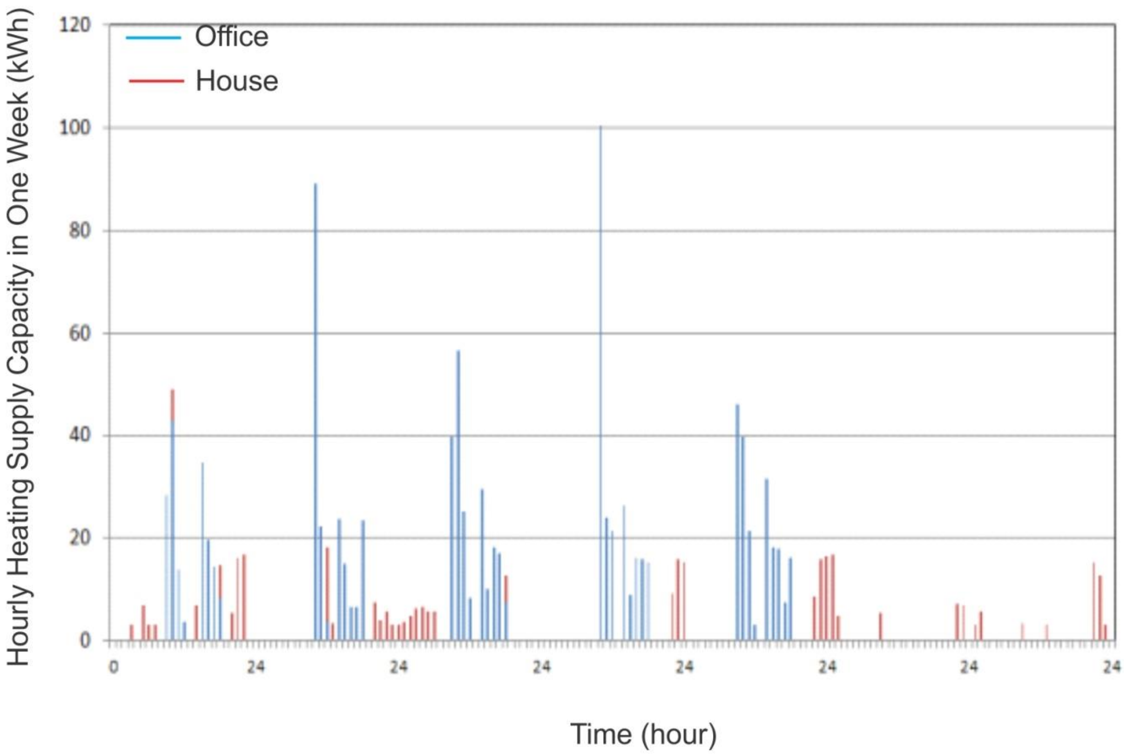


Fig. 27: Hourly heating load of load sharing (house + office) in one week

The same things happened for heating case, the sample data of cooling load in one week were observed during December 12th to December 18th , as shown on Fig. 27. The last two days were weekend (Saturday and Sunday), where there were no loads from office. The peak load at Saturday was around 5 kWh, and at Sunday was 17 kWh. On the other hand, on the weekdays, the peak loads were extremely higher than the weekends. The trend showed that the peak loads occurred in the morning time (around at 10 am), where the highest one did belong to Thursday morning which reached 100 kWh. The charts below also show that the second highest loads occurred at afternoon time (around at 2-3 pm). Furthermore, the off-peak during the day time generally occurred at lunch time (around at 12 – 1 pm), when everybody was away from their rooms.

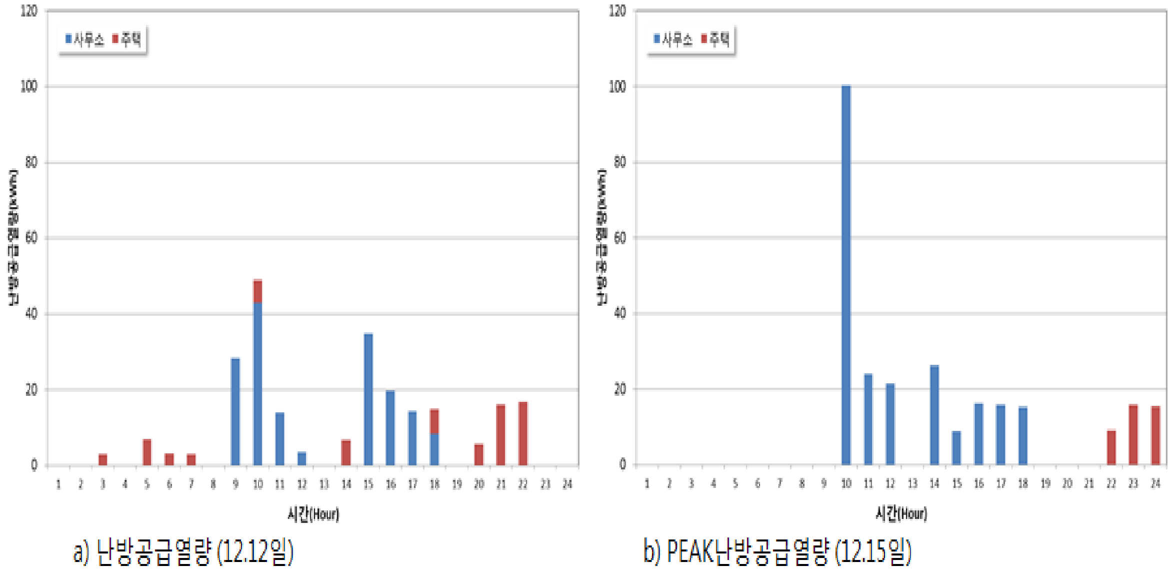


Fig. 28: a) Peak heating load at December 12th b) Typical heating load at December 15th

From these charts, they can be concluded that by implementing load sharing method, it is possible to reduce the number of equipement / facilities without any output / supply reductions. It was also noticed that there were no overlapping loads occurring during the peak load.

2.4.4 Electricity consumption at Apartment Houses in Daejeon, Korea

The monitoring was also done in ten apartment houses in Daejeon, Korea. The total of the houses which were observed is 13,995. Survey period was started at January 1st, 2010 and ended at December 31st, 2010 by measuring hourly power consumption. Among those houses, the maximum area which needs to be supplied by the HVAC equipment was 141 m^2 and the minimum one was 93 m^2. The year built of those ten apartments are in the range of 1992 to 2000. The summary of the apartments information are summarized in Table 8:

Table8. The information of ten apartments in Daejeon, Korea

Properties	Apt. A	Apt. B	Apt. C	Apt. D	Apt. E	Apt. F	Apt. G	Apt. H	Apt. I	Apt. J
Year Built	1998	1993	2000	1994	1992	1993	1997	1993	1992	1994
Number of House	1,251	1,980	2,892	1,632	1,632	672	2,200	840	462	394
HVAC Area of each house	132㎡	103㎡	116㎡	115㎡	141㎡	93㎡	105㎡	106㎡	97㎡	94㎡
Average area	132.2㎡	102.5㎡	115.7㎡	115.7㎡	142.1㎡	92.6㎡	105.8㎡	105.8㎡	95.9㎡	92.6㎡
Heating System	Local Heating	Center Heating	Center Heating	Center Heating	Center Heating	Local Heating	Local Heating	Local Heating	Center Heating	Local Heating

Fig. 29 and 30 provide information about monitoring data of hourly and monthly power consumptions respectively. As the results of the charts below, it shows that the base load (minimum hourly power consumption) of one apartment house in Daejeon is about 400 Wh, whereas the monthly power consumption (average of 10 apartment houses) reached the peak at August which was 444 kWh, while the lowest monthly power consumption was at May which was 351 kWh.

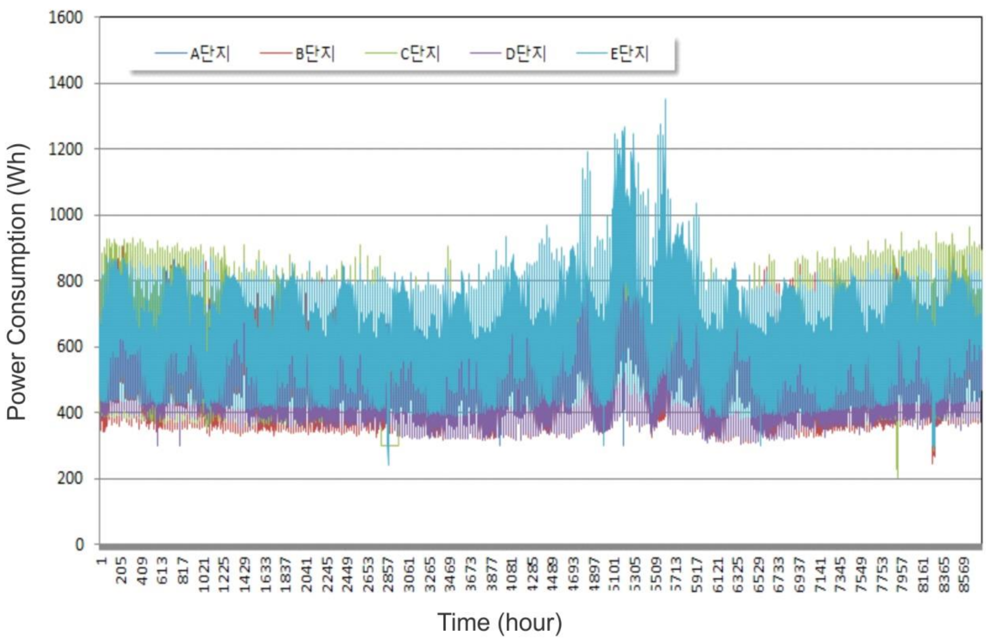


Fig. 29: Hourly annual power consumption on 5 apartment houses in Daejeon, Korea

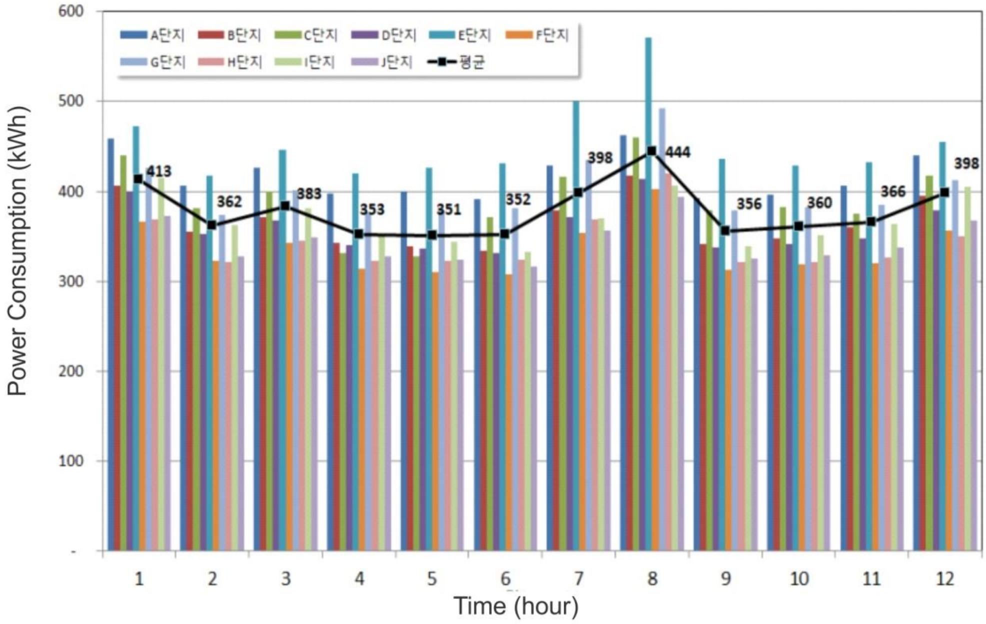


Fig. 30: Monthly annual power consumption on 10 apartment houses in Daejeon, Korea

2.4.5 Electricity Consumption

Furthermore, as shown on Fig. 31, the average of daily power consumption is relatively constant regardless of weekday or weekend, which was always in the range of 12.3 kWh to 12.5 kWh.

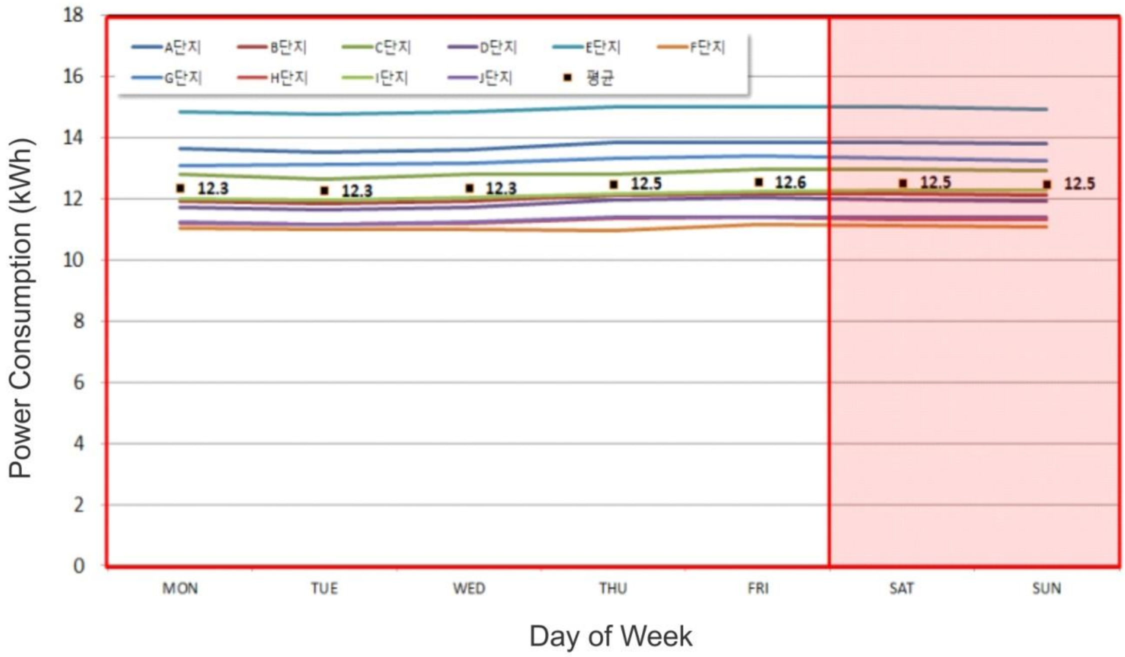


Fig. 31: Weekday and Weekend daily power consumption comparison

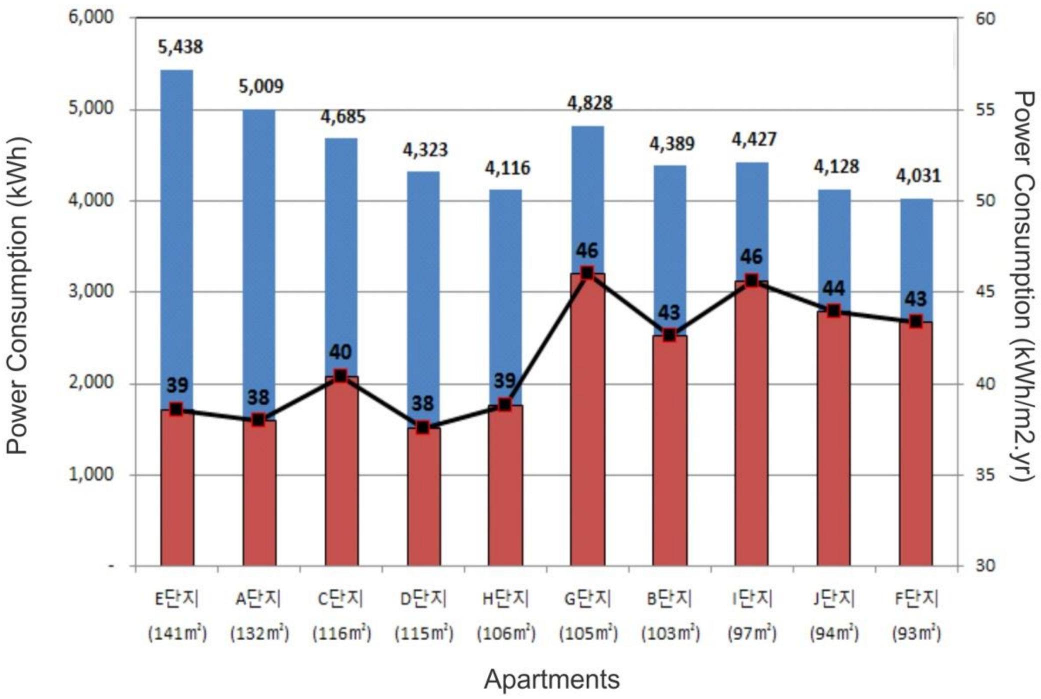


Fig. 32: Monthly annual power consumption of each apartment

Fig. 32 shows that the highest of average monthly annual power consumption was on apartment E (5,438 kWh) and lowest one was on apartment F (4,031 kWh). Even though each house in apartment E has area of 141m^2 which was the biggest one among the others and each house apartment F has the area of 93m^2 which was the smallest one, it does not mean that area of house is the most-affected factor in determining the power consumption. Based upon the observation, the number of occupants and the life style of occupants are the factors which gave more effect to the amount of power consumption in each house. In addition, the average of the monthly power consumption per specific area per time among the 10 apartments are 41.6 kWh/m^2.yr.

2.4.6 Conclusions

Monitoring of heating and cooling loads of non-residential building was done in one office in city of Incheon, South Korea. This house is three-story building with one story as basement (underground) and two story above ground. The area of the land where this building was built is 3,075 m^2, whereas the occupied land area for the building is 1,140.47 m^2 and the total building area is 2,449.24 m^2. Moreover this building employs the reinforced concrete as the body structure and roof structure. The total height of building is fixed to be 15.6 m which consists of basement height of 4.5 m, 1st floor height of 5.7 m, and 2nd floor height of 5.1 m. It also has roof top with the height of 4.8 m. The heating period is approximately twice longer than cooling period. It is caused by the building has the high level insulation, therefore it is able to keep the temperature inside the building stable. On the particular ambient temperature ranges (on the hour 2929 to hour 3905 and hour 6345 to hour 7000), it does neither need the heating, nor need the cooling. It can be observed that the highest heating load occurred at December and January (totally up to 1,800 kWh), whereas the highest cooling load occurred at July (totally up to 400 kWh). The peak of cooling load usually happens at August in Korea, however there are some factors in this particular building which made the cooling peak happened in July instead. Those factors are, first, the fan coil performance test for another experiment which was still undergoing at August that somehow made the cooling load be decreased, and the second one, there was heavy rain occurring mainly during whole August causing the ambient temperature was lower than it was supposed to be.

On the other hand, monitoring of heating and cooling loads of non-residential building was done in one office in city of Incheon, South Korea. This house is three-story building with one story as basement (underground) and two story above ground. The area of the land where this building was built is 3,075 m^2, whereas the occupied land area for the building is 1,140.47 m^2 and the total building area is 2,449.24 m^2. Moreover this building employs the reinforced concrete as the body structure and roof structure. The total height of building is fixed to be 15.6 m which consists of basement height of 4.5 m, 1st floor height of 5.7 m, and 2nd floor height of 5.1 m. It also has roof top with the height of 4.8 m. the heating period is approximately one month longer than cooling period. On the particular ambient temperature ranges (on the hour 1972 to hour 3724 and hour 6352 to hour 7886), it does neither need the heating, nor need the cooling. Heating peak load was 90 kWh, whereas cooling peak load was 60 kWh, It showed the unusual trend where the heating peak load should usually be less than cooling peak load. It happened because this building had lower operation ratio (lower internal gains) than the normal one so that the heat generated inside the building was also reduce. It caused the cooling load was relatively low and the heating load was conversely high. it can also be observed that the highest heating load occurred at December and January (totally up to 4,600 kWh), whereas the highest cooling load occurred at August (totally up to 3,200 kWh).

Load sharing method was also implemented. Load sharing is the method which combines the loads of house and office to be supplied by one common equipments. It was possible to reduce the number of equipments / facilities without any output / supply reductions. It was also noticed that there were no overlapping loads occurring during the peak load.

The monitoring was also done in ten apartment houses in Daejeon, Korea. The total of the houses which were observed is 13,995. Survey period was started at January 1st, 2010 and ended at December 31st, 2010 by measuring hourly power consumption. Among those houses, the maximum area which needs to be supplied by the HVAC equipment was 141 m^2 and the minimum one was 93 m^2. The year built of those ten apartmens are in the range of 1992 to 2000. As the results, it shows that the base load (minimum hourly power consumption) of one apartment house in Daejeon is about 400 Wh, whereas the monthly power consumption (average of 10 apartment houses) reached the peak at August which was 444 kWh, while the lowest monthly power consumption was at May which was 351 kWh.

2.5 United Kingdom

There has been considerable and significant work done recently in the UK on the subject of electrical and domestic hot water load profiles. Of note are efforts aiming to model load profiles from a stochastic perspective, in the sense that a load profile can be built up from its constituent components, namely a mix of continuous operation of some equipment, and a number of statistically-predicted discrete operations of the various electrical appliances and equipment normally present in a household. The new electrical load profiling goes beyond the work reported in [30] in that it looks ahead to the impact of energy efficiency improvements in appliances and the effect that this will have on detailed load profiles. The results have been published in [31].

Furthermore, a synthetic hot water demand component model has been added into the general ESP-r release and has been trialed in the research setting. This remains a work in progress. It is based on the work done in IEA SHC Annex 26, the background of which is described in [32].

2.5.1 A high-resolution energy demand model for electricity use.

A significant paper was published in 2010 which provides a detailed description of the rationale and methodology put into developing a practical predictive model for domestic electricity demand [33].

It was found that the pattern of electricity use in an individual domestic dwelling is highly dependent upon the activities of the occupants and their associated use of electrical appliances. The paper presented a high-resolution model of domestic electricity use that is based upon a combination of patterns of active occupancy (i.e. when people are at home and awake), and daily activity profiles that characterize how people spend their time performing certain activities. One-min resolution synthetic electricity demand data is created through the simulation of appliance use; the model covers all major appliances commonly found in the domestic environment. In order to validate the model, electricity demand was recorded over the period of a year within 22 dwellings in the East Midlands, UK. A thorough quantitative comparison is made between the synthetic and measured data sets, showing them to have similar statistical characteristics. A freely downloadable example of the model has been made available and may be configured to the particular requirements of users or incorporated into other models.

Scope of model

The model uses the appliance as the basic building block, where “appliance” refers to any individual domestic electricity load, such as a television, washing machine or vacuum cleaner. The appliances in the model are configured using statistics describing their mean total annual energy demand and associated power use characteristics, including steady-state consumption or typical use cycles as appropriate, as well as considering when the specific appliances are likely to be used.

Appliance use within a dwelling is naturally related to the number of people who are at home and awake, known as “active occupancy”. The model of active occupancy uses an input of the total number of residents (one to five) in a simulated dwelling, and thus creates the electricity demand data with appropriate aggregate daily profiles. The appliances in the model are activated at appropriate times of day, according to observed usage patterns. Further, some situations dictate that appliances are shared by occupants or combinations of appliances have correlated usage.

A 1-min time resolution was chosen as a balance between data volume and demand curve smoothing.

Basing the model on individual appliances provided a straightforward means of representing reactive power consumption, which is important for example in network load-flow studies. The model represents the reactive power demands of each appliance through the assignment of an appropriate power factor.

Electricity demand data was recorded at 22 domestic dwellings around the town of Loughborough in the East Midlands, UK. The data was recorded at a 1-min interval throughout 2008. The measured Loughborough data was used extensively to validate the model by way of a comprehensive comparison of the statistical characteristics of the synthetic and measured data.

An example implementation of the model is made available [34] for free download as a Microsoft Excel work book. The data and Visual Basic macros are included to provide a self-contained 1-day simulation for a single dwelling. This may be user-configured or incorporated into other models as required.

Structure of the model

The structure of the model is presented in Fig. 33.

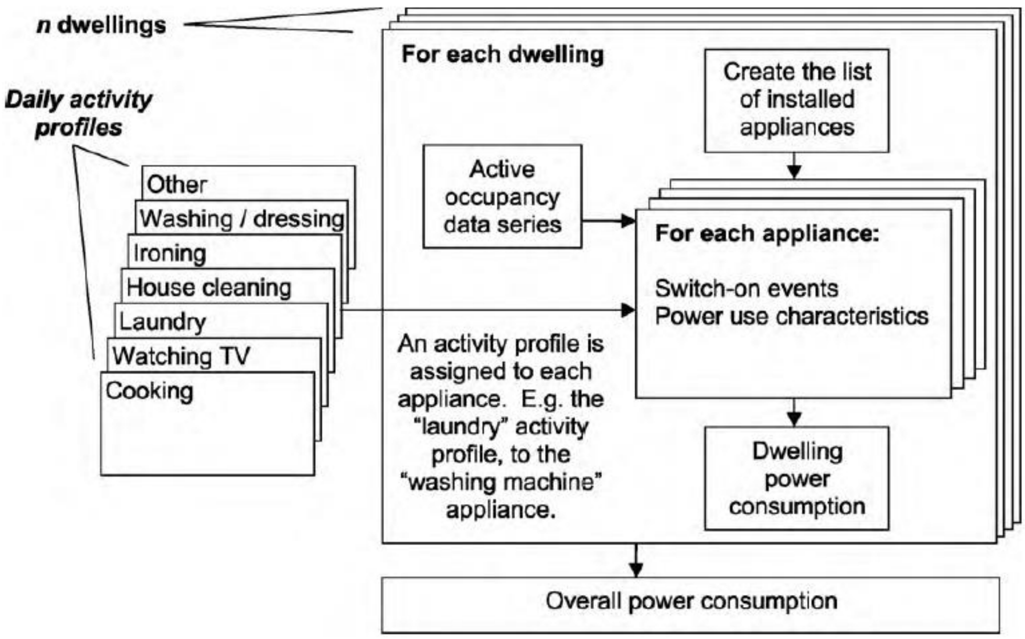


Fig. 33. Electricity demand model architecture.

On the left of the diagram, there are a set of daily activity profiles, which represent the likelihood of people performing activities as a function of time. Dwellings are represented on the right of the diagram. Each dwelling is assigned an active occupancy data series and a set of appliances, mapped to a daily activity profile. When an appliance switch-on occurs, the appliance power use characteristics are activated to show electricity demand (including the reactive power demand). Adding the power demands of all appliances within a dwelling gives the whole dwelling demand. The full set of daily activity profile data is available from the activity statistics sheet of the downloadable example [34].

At the beginning of a run, the model populates each dwelling with appliances. This is done on a random basis using statistical ownership data from the UK Department of Energy and Climate Change (DECC) [35], the UK Market Transformation Programme [36], the Lower Carbon Futures and 40% House reports from the ECI, Oxford University, UK [37,38] and the UK's Ofcom [39]. A full list is included in the appliance configuration sheet in the downloadable example [34].

Appliance energy use and power characteristics were input into the model. These values were based on the sources used in constructing the list of appliances above, together with further data from the UK Energy Saving Trust [40], and is adjusted to represent dwellings in the East Midlands region of the UK, where the annual mean demand is 4358kWh [41]. A full list of the adopted, derived and adjusted values and their sources is provided on the appliance configuration sheet of the downloadable example [34].

Example simulation

An example simulation output for a single dwelling, for a winter day, is shown in Fig. 34.

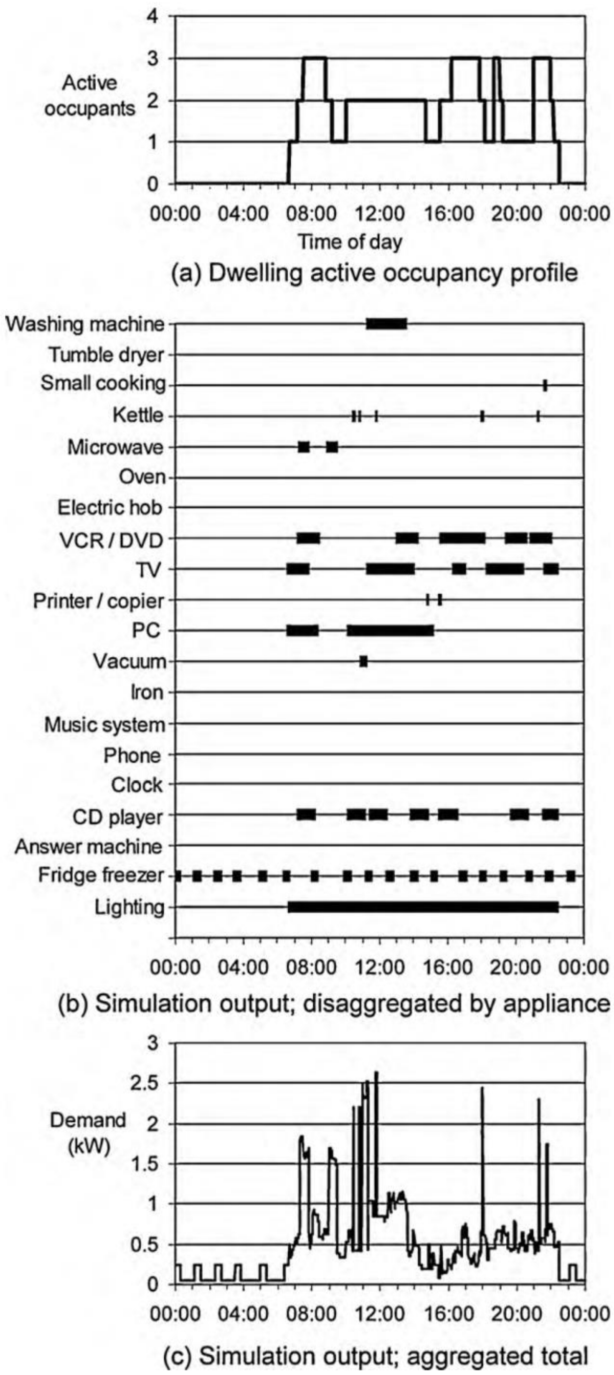


Fig. 34. Example simulation output (one dwelling, winter day).

The model initialisation routine has populated the dwelling with 20 appliances as listed in Fig. 2(b) alongside the modelled usage of these appliances throughout the day. The television, DVD, PC and CD player are used for relatively long periods throughout the day, whilst the microwave, kettle and small cooking appliances are used for much shorter periods. The washing machine is used just once during the middle of the day. Notice that the modelled usage of these appliances is closely related to the active occupancy in Fig. 34(a).

Towards the bottom of Fig. 34(b) the fridge–freezer can be seen to be cycling at intervals throughout the whole day and irrespective of active occupancy.

The lighting use presented at the bottom of Fig. 34(b) is consistent with this being a winter day. It is a simplified representation, indicating whenever any light is in use. The underlying lighting model actually represents each individual lighting unit present in the dwelling [42].

The aggregate demand is shown in Fig. 34(c). During the night-time period, when there is no active occupancy, only the fridge–freezer can be seen using electricity. A ramp in demand occurs as soon as the occupants become active in the morning. The spikes in demand are caused by the use of the short-time high demand appliances such as the kettle and microwave.

Validation of the model

In order to validate the model, a substantial set of measured data was collected from 22 volunteer dwellings in and around the town of Loughborough in the East Midlands, UK. With the support of Central Networks, high-resolution whole-house demand meters were installed at each of the 22 dwellings and equipped with GSM modems to transmit data. The meters were configured to record demand at 1-min intervals, and these data (∼10 million data points) were successfully collected throughout 2008.

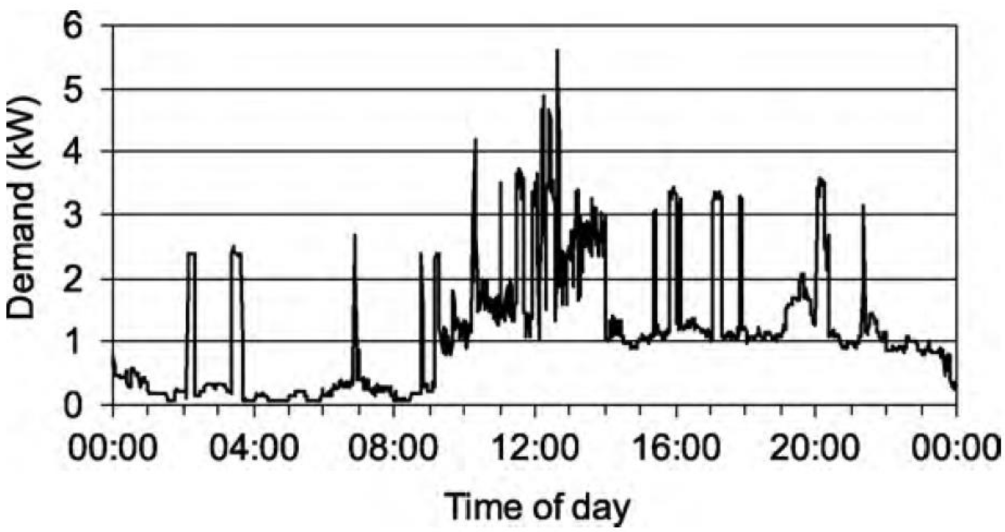


Fig. 35: A measured daily demand profile (1-min resolution).

An example 24 h demand profile for a single dwelling taken from the measured data set is shown in Fig. 35 and may be compared with the synthetic profile shown previously in Fig. 34(c). They are of course random profiles and are not expected to be the same shape. What is important to note is that they have similar characteristics. By inspection it can be seen that they do both exhibit low electricity use at night, increased use throughout the day, and show a similar overall number and magnitude of peaks.

Daily demand profile

The synthetic and measured mean daily profile throughout the year is shown in Fig. 34. Also shown on the diagram is a typical UK profile. In general, the profiles all follow a similar pattern.

For a comparison with national data, the dotted line in Fig. 36 shows an annual demand profile for UK domestic unrestricted customers, from the standard profiles developed by the Electricity Association [63]. The synthetic data matches this UK domestic profile even more closely than it does the locally measured data.

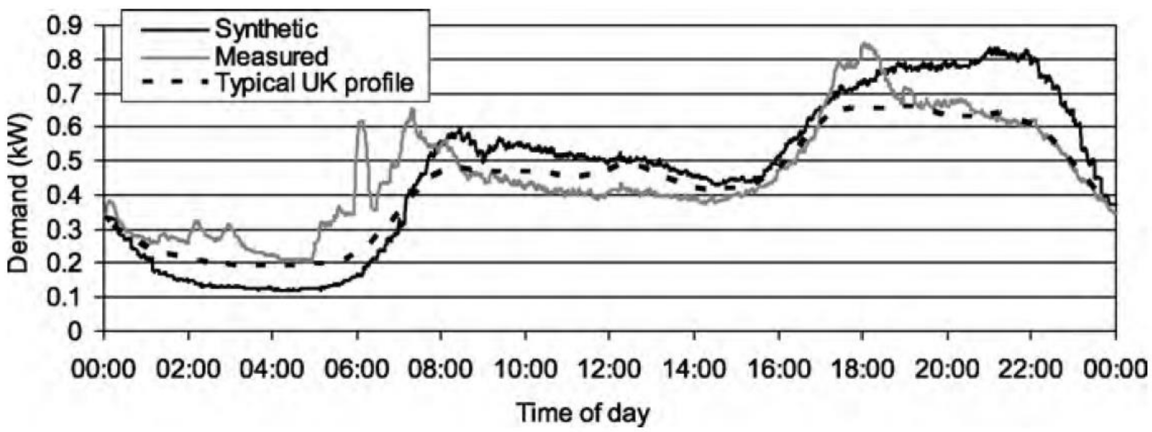


Fig. 36: Annual mean daily demand profile.

Discussion and Conclusions

The paper cited in [33] provided analysis and commentary on a number of related subject including, minute to minute demand volatility, time-coincident demand, after diversity maximum demand , load duration and the nature of its curves , and power factor, a coefficient of an appliance's maximum power draw as a function of duration of use session.

A number of conclusions were drawn from the study and modelling work reported in [33]. A domestic electricity demand model based on occupant time use data was developed and presented. It maps occupant activity to appliance use and stochastically creates synthetic demand data with a 1-min time resolution. The model uses concepts previously developed by the same authors in the construction of a domestic lighting model [42]. It was constructed using individual appliance power consumption data and nationwide ownership statistics. High-resolution measured data from 22 local dwellings was used only for validation.

The synthetic data compared very well with the measured data and thus the model meets the general aims set for it. It appears particularly good at representing the time-coincidence/diversity of demand between multiple dwellings. This is important in the design of local electricity distribution networks. Volatility of the individual dwelling demand from minute to minute is well represented in the mid-range of transitions, while small and large transitions were underrepresented.

The annual mean daily demand profile shows good agreement with the typical UK profile, but under-represents the demand during the night, primarily because the model does not represent people leaving lights on whilst asleep or the use of timers to run appliances. Such behaviour could readily be included into the model, if it could be supported by quantifying data.

The model under-represents the seasonal variations of electricity demand. This is partly because the extent to which people stay in more during winter cannot be quantified from the Time Use Survey data set and so the resulting increase in general appliance use is not represented in the model. Again, enhancement in this respect is constrained by data availability. However, a more significant aspect of seasonal variation may be the greater use of electrical heating appliances (including central heating pumps) during winter, which is not fully represented in the model at this stage.

The demand model also has many other possible applications and the authors have provided an open-source freely downloadable example of the model [34] in the hope that other researchers will adopt and adapt it for their own purposes. The linking of electricity demand to occupant activities is central to the model and should facilitate its application to studies relating, for example, to human factors in domestic energy use.

From this project, a number of insights were gained leading to further work. Whilst the model is already complete and useful for many applications, there are of course plans to develop it further. In particular, the aim is to represent the building thermal behaviour alongside and linked to the occupant behaviour and thus provide stochastic, but duly correlated, thermal demand data for large numbers of dwellings. Initially, this may be used in relation to central heating pumps and direct electrical heating. More importantly, it will underpin the integrated simulation of heat pumps and micro-CHP. Similarly integrated simulation of electric vehicle charging is also planned.

In parallel, the model is being enhanced with regard to demand side management, and in particular flexible demand involving the time-shifting of appliance use. The switch-on probability calculation will be extended to include an external variable such as a real-time price, which will cause the bringing forward or delaying of appliance use within the model.

The model described above has been made available as a working resource for practitioners seeking a method and tool for load profile generation. An Excel Workbook which provides a high-resolution model of domestic whole house electricity demand can be found online. The use of domestic appliances within a single UK dwelling can be simulated over a 24-hour period at a one-minute time resolution. The simulation incorporates and utilises previously developed models of active occupancy (http://hdl.handle.net/2134/3112) and domestic lighting (http://hdl.handle.net/2134/4065). The user may configure the month of the year, the total number of residents that live at the dwelling and whether a week day or a weekend day simulation is required. The Workbook contains all the necessary data to run the simulation and includes the Visual Basic for Applications (VBA) source code. The model is discussed in the journal paper "Domestic electricity use: a high-resolution energy demand model" (http://hdl.handle.net/2134/6997).

The load profile generator may be found online at:

https://dspace.lboro.ac.uk/dspace-jspui/handle/2134/5786

http://hdl.handle.net/2134/5786 should be used for citation purposes.

Fig. 37 below, is a sample graphic depicting the interface of the load profile generator.

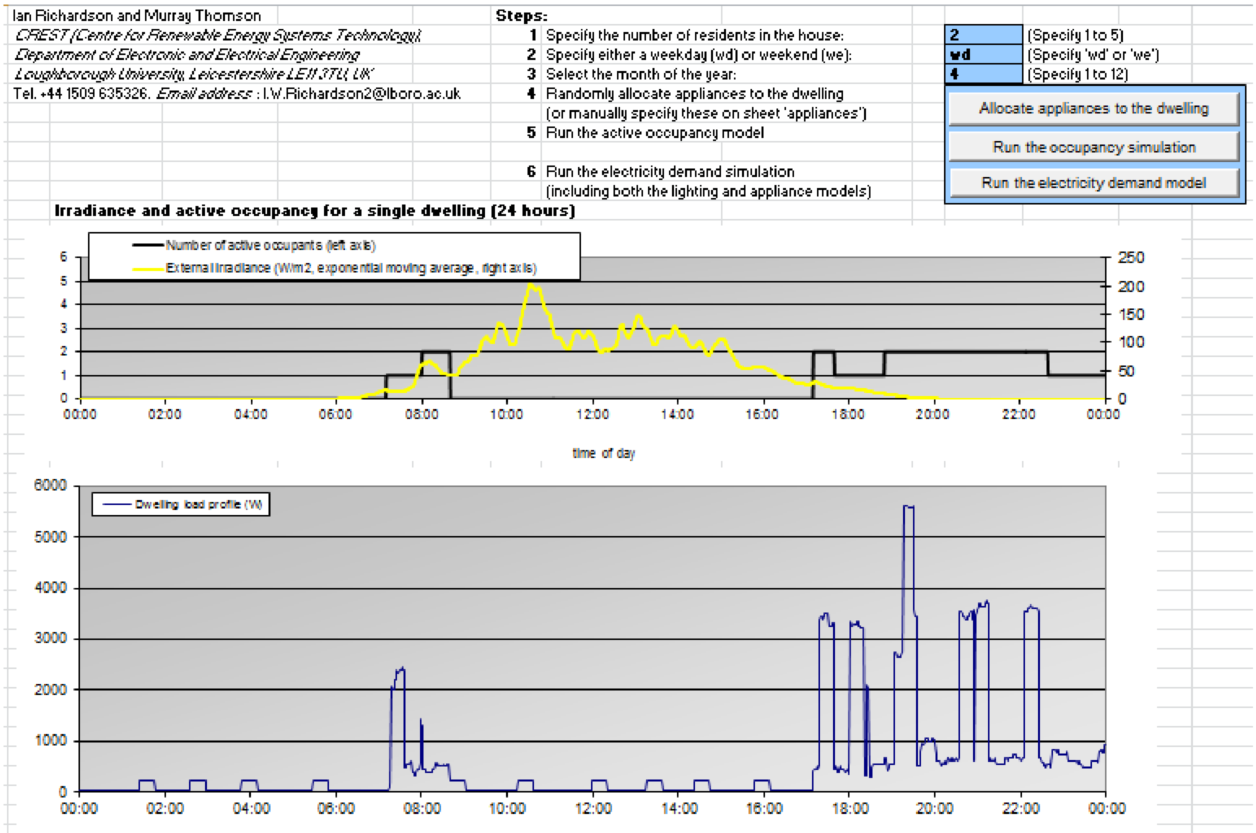


Fig. 37: Example of graphical output from Loughborough load profile generator.

2.5.2 A model to calculate high resolution appliance demand profiles for European dwellings

Introduction

Electricity consumption across Europe has increased significantly over the past years such that it now accounts for around 21% of final energy demand (DG, 2009). The domestic sector alone accounts for almost 25% of final energy consumption and almost 30% of electrical energy demand (DG, 2009). The key drivers for increasing electrical demand in housing have been a rapid increase in the number of electrical appliances [44]; a significant increase in the use of certain appliances such as PCs and televisions (45, 46]; an increase in the installation and use of domestic air conditioning [44]; and social/demographic changes that mean that there are a larger number of smaller households [45]. This has been particularly evident in southern European households. Over the period 2002 to 2008, electricity consumption in EU countries bordering the Mediterranean has increased by an average 3.7% per year; compared to a 2% increase registered by the remaining EU Countries (Eurostat). The demand model is described in more detail in [47].

Modelling Methodology

The approach adopted for the generation of electrical high resolution demand profiles described here uses one-hour resolution electrical demand data derived from field monitoring as the starting point. The generation of profiles is done on an appliance-by-appliance basis; a profile for each appliance is generated and the population of appliance profiles can then be aggregated to give a high-resolution electrical demand profile for the dwelling. Additionally, the calculation of the detailed demand profile is augmented with a means to adapt the profile based on future estimations of improvements in appliance energy efficiency; this allows detailed profiles to be generated for future scenarios.

The work builds on previous work [48-51] who have all employed similar approaches. For example, [49] utilise demand data generated using UK 'time-use' survey data [52]; 'time-use surveys' are detailed diaries kept by individuals recording their activities on a daily basis at 10 minute intervals. This data is then manipulated to produce one minute resolution electrical demand profiles.

The initial base data for the profile generation are hourly datasets of the individual appliances' energy consumption. In this case, these datasets were obtained from the REMODECE energy end-use measuring campaign [53], which was an EU funded project conducted in a number of European countries between 2006 and 2008. The data consisted of both real field measurements and questionnaires returns. The work in this paper specifically used the REMODECE Italian dataset, which consisted of measurements done in 60 households. Data was collected on the most energy intensive appliances and the 10 most used lamps [54]. Additional measurements were also taken across the main switchboard to measure the overall household electrical energy consumption. The energy consumption for each appliance and each hour was then averaged over the measuring period (2 weeks) to create one representative daily profile of energy demand at an hourly time resolution representative of the whole month for each appliance monitored; these are the base profiles to which the transformation process described below is applied.

The generation of synthetic, high resolution electrical demand data profiles for a particular appliance type was a 3-stage process. Using a single REMODECE 1-day, hourly resolution appliance profile as a starting point, 12 day-long profiles (one for each month of the year) at 1-min resolution are generated, that can also incorporate the effects of future appliance energy efficiency improvements. The specifics of the process are as follows.

- Stage 1—using one of the REMODECE datasets of a single appliance (comprising 1-day, hourly resolution demand data for a single month of the year) as a starting point, the first transformation generates 12, 1-day hourly resolution profiles, one for each month. This is achieved by applying a modifier function to the original data; this modifier is partly a time-dependent sinusoidal function and partly a random number. The equation's constant, amplitude, phase and standard deviation of the modifier function are calibrated from a statistical analysis of all of the available REMODECE data for the specific appliance type. Therefore, stage 1 extrapolates a 1-day dataset representative of one month of the year, to 12 1-day datasets spanning the full calendar year.
- Stage 2—the 12 datasets from stage 1 are then used to produce 12 day-long, 1-min resolution datasets for the appliance type; this creates finer resolution and a more variable profile that better represent the variability inherent in real electrical demands. The means of generating a high-resolution profile from the hourly data is detailed in Section 4.1.2.

- Stage 3—applies the effects due to appliance energy-efficient improvements to the profiles. Stage 3 can be applied either to Stage 1 (hourly resolution) or Stage 2 (1-min resolution) results as discussed later in Section 4.1.3.

The overall result of the three transformation process is therefore to obtain high-resolution minute long profiles representative of the changes brought about by the change-over to more energy-efficient appliances from coarse resolution appliance hourly datasets.

Stage 1 – hourly data and monthly variations

The original REMODECE Italian datasets for each appliance were first grouped by appliance type and then sorted on a per month basis as represented by the left hand side matrix shown in equation (14). Given the different appliances' ownership rates, frequency of use and operating behaviour (repetitive/cyclic, such as in the case of refrigerators or single-off events, such as washing machines), multiple sets of hourly data were available for each month for the most commonly owned, frequently used or repetitive/cyclic behaviour appliances such as refrigerators (32 datasets), electronic equipment (27 datasets), televisions (32 datasets), lighting (600 datasets) and water heaters (17 datasets). Conversely, for the other less commonly owned, less used single-off event appliances such as dish washers (12 datasets), microwave ovens (12 datasets), electric ovens (12 datasets) and washing machines (34 datasets) the data available was mostly enough to produce just one single data entry for each individual month.

$$\begin{bmatrix} Hour_1, Month_1 & \cdots & Hour_{24}, Month_1 \\ \vdots & \ddots & \vdots \\ Hour_1, Month_{12} & \cdots & Hour_{24}, Month_{12} \end{bmatrix} appl_k \rightarrow \begin{bmatrix} \frac{Hour_1, Month_1}{Max\,(Hour_1, Month_n)} & \cdots & \frac{Hour_{24}, Month_1}{Max\,(Hour_{24}, Month_n)} \\ \vdots & \ddots & \vdots \\ \frac{Hour_1, Month_{12}}{Max\,(Hour_1, Month_n)} & \cdots & \frac{Hour_{24}, Month_{12}}{Max\,(Hour_{24}, Month_n)} \end{bmatrix} appl_k \quad (14)$$

Each hourly electrical energy consumption value for an individual appliance was normalised, dividing it by the maximum consumption value recorded that hour from the original dataset as shown on the right hand side of equation (14). This gives a flexible, dimensionless hourly value that can be scaled to represent variations in demand over the course of a year . Once the columns shown on the right hand side of equation (14) were obtained for each individual appliance, each column was then used to find the coefficients of the general trend described in equation (2) for each individual hour *i* using a curve fitting algorithm.

$$p_{Appk,Monthj,Houri} = \left[\theta_i + A_i \sin\left(2\pi * \left(\frac{Month_j}{12}\right) + \varphi_i\right) + Rand\,(-\sigma_{STDEVi}, \sigma_{STDEVi})\right] \quad (15)$$

Equation (15) which describes the normalised electrical energy consumption E for a specific domestic Appliance k during Hour i of Month j, Ek,j,i ; this is made up of three parts: a constant θi; a sinusoidally varying component with amplitude Ai and phase angle ɸi and a third part made up of a random 'noise' value.

Table 9 shows some of the parameters calculated for a refrigerator.

Once the coefficients were obtained for each individual appliance, the original datasets could be scaled to include for seasonal variation. The original dataset containing the hourly electrical energy consumption of a particular appliance was first divided by the corresponding normalised (maximum hourly) electrical energy consumption $E_{k,j,i}$ calculated for that month. The resulting value was then multiplied by $E_{k,j,i}$ calculated using equation 2 for the desired month in order to obtain the electrical energy consumption for that specific appliance at a particular hour in that month.

Table 9 – Parameters for seasonal variation equation for a refrigerator

Hour i	**Constant** (θ_i)	**Amplitude** **(A_i)**	**Sine Phase** (φ_i)	**Standard Deviation** **($\sigma_{STDEV\,i}$)**
[0,1]	0.264	-0.072	0.818	0.079
[1,2]	0.288	-0.071	0.540	0.069
[2,3]	0.263	-0.066	0.509	0.076
:	:	:	:	:
[21,22]	0.292	-0.068	0.534	0.071
[22,23]	0.230	-0.064	0.816	0.079
[23,24]	0.218	-0.068	1.020	0.086

Using this approach two sets of appliance data are available for the whole year: the original averaged measured dataset based on all the measured appliances' data and a modelled dataset based on equation (15).

Aggregate Household Demand

The aggregation of the appliances' energy demand available from the original dataset will not, add up to the total electrical energy demand of a household - some of the household's consumption remains unspecified. This unspecified demand may be broadly divided into two categories—a continuous base load demand as suggested by Widen and [50] and a number of random miscellaneous loads as suggested by [48]. In order to calculate the amount of unspecified demand attributable to each category, a similar procedure to that adopted to find the monthly variation of individual appliances was applied to the general electrical energy consumption values from the REMODECE data. First the minimum difference between the measured and calculated aggregate demand was attributed to a base load. Second, any difference between the aggregated appliance load and the calculated aggregate electric energy consumption (plus the base load value) on an hourly basis was awarded to a catch-all miscellaneous load.

The Stage 1 methodology can be adapted to discriminate between weekdays and weekends in that two individual sets of trends can be calculated separately for both weekdays and weekends; one reflecting the monthly hourly variation on weekdays and the other the monthly hourly variation on weekends. However this is only possible if suitable data is available. A limitation of this study is that the original data used in this research does not distinguish between weekdays and weekends, hence differences between weekdays and weekends are not taken into account.

Stage 2 – Converting to one-minute time resolution

Producing the 1-minute time resolution load profiles from the hourly data require the following assumptions were made regarding the operation of appliances:

- appliances (including television sets, entertainment appliances, water heaters, fridges, cooking and lighting) can be assumed to follow a simple square ON/OFF pulse pattern varying between zero power during its OFF state and the steady-state operating power during its ON state [50]; or
- appliances such as washing machines, consume a known amount of energy over an hour, which can be re-modelled using a known energy utilisation pattern.

Appliances with an On/Off pattern

For an appliance *k* having a steady-state operating power $P_{On\text{-}Appk}$ in Watts (W), whose electrical energy consumption during Hour *i* was $E_{Appk,Houri}$ in Watt-Hours (Wh), the active time in minutes, $\boldsymbol{min_{On(Hour\ i)}}$, for that appliance can be calculated using:

$$min_{On\,(Houri)} = \frac{E_{Appk,Houri}\,x\,3600}{P_{On-appk}\,x\,60} \qquad (16)$$

If the appliance has a stand-by power consumption, $P_{Stand\text{-}By}$, in Watts, then equation (3) becomes:

$$min_{On\,(Houri)} = \frac{\left(E_{Appk,Houri} - P_{Stand-By}\right)x\,3600}{\left(P_{On-appk} - P_{Stand-By}\right)x60} \qquad (17)$$

The start of the appliance's power use during an hour is assigned on a random basis using a uniform distribution. Typical appliance demands ($P_{On\text{-}appk}$) are shown in Table 10.

Complex demand patterns

For those appliances with complex demand patterns, such as dishwashers and washing machines, data from by [48] was used, which provides the minutely power demand over the duration of a whole cycle for different appliances. Again the start of the cycle is awarded on a random basis following a uniform distribution. This time however since the cycle can be longer than one hour, a single cycle may continue over to the following hour.

Stage 3 – Accounting for improvements in energy-efficiency

In order to obtain the scaling factors by which the individual appliance profiles could be transformed to reflect changes due to efficiency improvements, data from the UK's Department for Environment, Food and

Rural Affairs (DEFRA) Market Transformation Program (MTP) [55-64] was used: the assumptions and policy instruments used in the MTP are mostly based on the EU wide energy-efficiency labelling program helps and so are applicable to the REMODECE data. The MTP sets out the envisaged improvements due to energy-efficiency in specific appliances up to 2020. Table 11 shows the applicable for the most common household appliances and whether these reduce the power demand or the time-of-use of the appliance.

Table 10 - Range of steady-state power ratings for selected appliances

Appliance	Range of steady-state operating power ratings ($P_{On\text{-}Appk}$) (Watts)	Comment
Refrigerator, Fridge Freezers and Freezers	80 - 250	
Television (CRT) [65]	32 - 185	Active stand-by may account to a maximum of 12 Watts.
Television (LCD) [65]	31 - 421	Active stand-by may account to a maximum of 18 Watts.
Microwave (Defrost) [48]	200 - 300	
Microwave (Cooking) [48]	700 - 1,300	Typical peak power is of 900 Watts although variations including other accessories which might increase the power consumption exist.
Electric Oven [48, 50]	1,000 - 3,000	
Electric Water Heater [51]	1,000 - 3,000	Size of the water heater, depends on the number of occupants present in the household.
Hi-Fi [65]	4 - 40.6	
Laptop [65]	40 – 100	Different active stand-by and hibernation modes make it difficult to establish a single stand-by power demand. Indicative figures for the two modes of stand-by mentioned are 40 and 20 Watts respectively.
Desktop [65]	50 – 175	Different active stand-by and hibernation modes make it difficult to establish a single stand-by power demand. Indicative figures for the two modes of stand-by mentioned are 70 and 20 Watts respectively.
Set-Top Boxes [65]	20	During stand-by periods, which can account to 80% of the active time a continuous demand of 9 Watts is drawn.

Table 11 – 2020 Scaling factors for selected appliances under the future Earliest Best Practice Scenario

Appliance	2020 Scaling factor compared to 2008 present scenario	Application of scaling factor	Rationale behind assumed change
Refrigerator	0.467	reduced power demand	Shift towards A++ technology [55].
Fridge Freezer	0.650	reduced power demand	
Electric Oven	0.690	reduced time-in-use	Downward trend is attributable to a reduction in cooking time, driven by technology improvements and aptitude towards more ready-made meal [56].
Microwave Oven	1.016	increased time-in-use	More frequent use [56].
Electric Water Heater	0.943	reduced time-in-use	Slight improvement brought about by better insulation leading to lower heating times [56, 57].
Television	0.782	reduced power demand and standby	Technology evolution leading to OLED. Envisaged that new technologies will be mature and efficient by 2020 with additional energy-efficiency features such as automatic switching off during prolonged stand-by periods or motion sensor [59].
Domestic Lighting	0.502	reduced power demand	Increased use of Compact Fluorescent Lamps (CFLs) and LEDs, with direct replacement of tungsten filament lamps [60]. Given that a range of power ratings is equivalent to an incandescent bulb the scaling factor represents a conservative average of the future demand.
Computer	0.364	reduced power demand	General improvement in energy-efficiency [58].
Set-Top Boxes	1.050	increased power demand	Although, more elaborate and powerful set-top boxes will be available, efficiency is expected to improve slightly [61].
Dishwasher (65 DegºC cycle) (55 DegºC cycle)	 0.845 0.902	reduced power demand	Improved technology and better detergents [62].
Washing Machine (90 DegºC cycle) (60 DegºC cycle) (40 DegºC cycle)	 0.958 0.895 0.902	reduced power demand	Improved technology with better laundry load management [62].

Example Application

The modelling approach was applied to produce a current and future (2020) demand profile for a typical European dwelling, factoring in future appliance efficiency improvements. Fig. 38 shows the total daily power demand profile for the future scenario superimposed on that of the present scenario for a characteristic day in February.

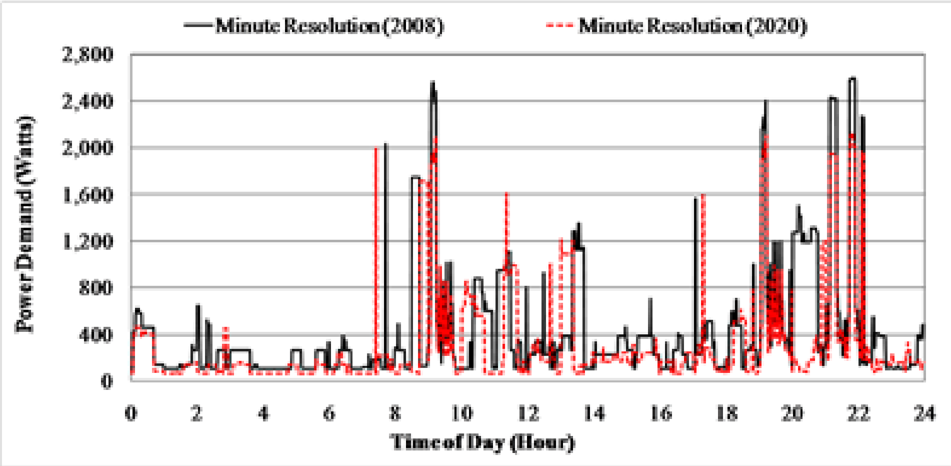


Fig. 38: Daily household power demand profile for a characteristic day in February for the present and future scenario.

The total daily electrical energy demand and the average daily demand will both experience a decrease of around 26%, the daily peak demand occurring during the day will decrease by 22%, down from 2,597 W to 2,129 W. Similarly for a characteristic day in August as shown in Fig. 39, the total daily electrical energy demand and the average daily demand will both experience a decrease of around 26% whilst the daily peak demand occurring during the day will decrease by 12%, down from 3,042 W to 2,712 W.

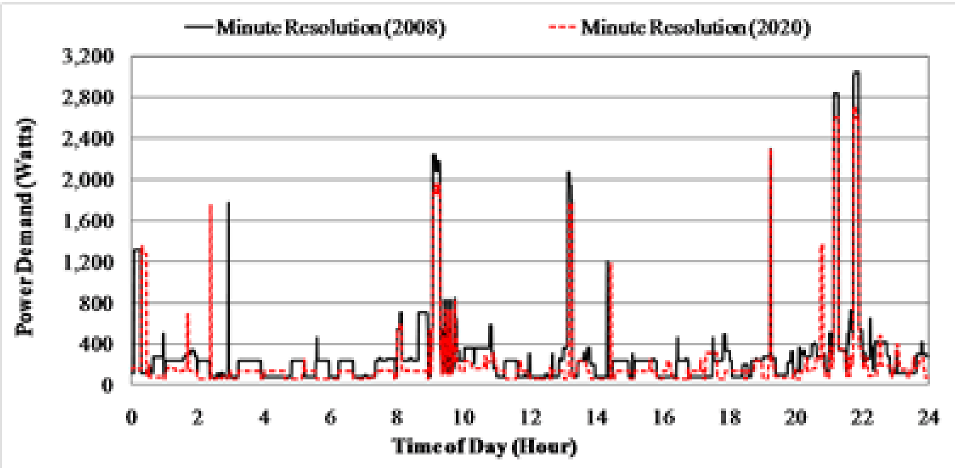


Fig. 39: Daily household power demand profile for a characteristic day in August for the present and future scenario.

Verification

Several mechanisms were used to verify the output from the tool including comparing measured and calculated annual demands and also to compare the statistical frequency distribution of the aggregated load of all 8 households. Individual household domestic load profiles do not follow any specific frequency distribution [66], however low voltage aggregated load profiles tend to follow skewed statistical distributions such as Gamma, Weibull or Beta distributions [67]. Fig. 40 shows the fit obtained when the 3 Probability Density Functions (PDFs), are superimposed on the demand frequency histogram created using the aggregated 1-minute resolution electrical demand of all eight households calculated for a characteristic day in February in the present scenario. The level of significance calculated using the Kolmogorof-Smirnov test exceeds the minimum threshold of 0.05. Values in this case are normalised using the highest daily occurring load.

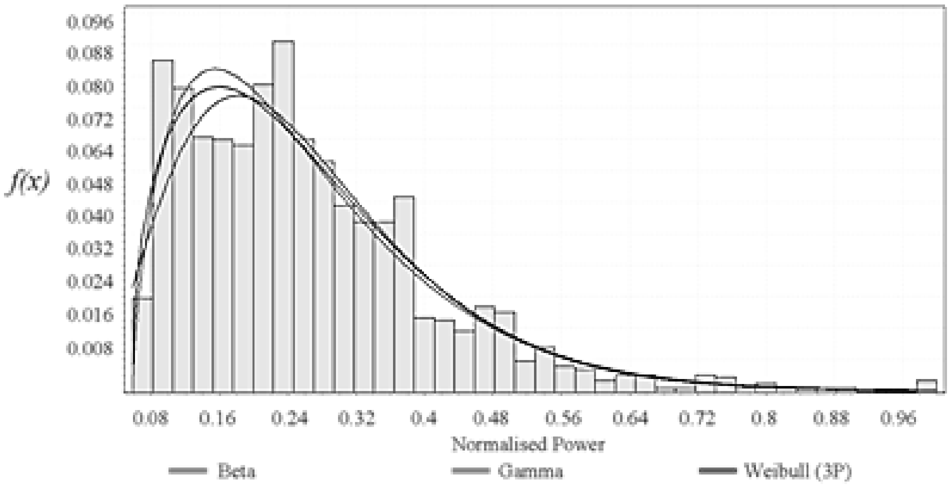


Fig. 40: Demand frequency histogram with the probability density functions superimposed

Conclusions

In this paper a method has been presented whereby low-resolution electrical demand datasets can be used to create high-resolution demand data reflecting the effects of appliance energy-efficiency improvements in future years. The method makes use of a three stage transformation technique which first creates seasonal variations of individual monthly data, then converts the low-resolution hourly data into high-resolution minute data and finally projects the data into a future scenario reflecting improved appliance energy-efficiency.

2.6 Germany

2.6.1 TU Munich projects

At TUM load profile data could be derived by field testing of different micro CHP systems. Table 122 gives an overview on the building type and the installed CHP system.

Data acquisition equipment was installed to determine all relevant energetic flows within the installations. On the supply side the consumption of natural gas, heat supply and electricity generation was measured. On the demand side, the consumption of space heating, domestic hot water and electricity was metered. Typically, the sampling rate was one second also capturing dynamic behavior of these systems.

Table 12: Supplied objects and applied systems in field testing

Object	Building Type	System	System Type	Period
STE_1	Single family home	REMEHA eVita	Stirling	10/2009 – 3/2012
STE_2	Single family home	REMEHA eVita	Stirling	9/2009 – 1/2013
STE_3	Single family home	REMEHA eVita	Stirling	9/1009 – 3/2013
STE_4	Single family home	REMEHA eVita	Stirling	9/2009 – 2/2013
CB_1	Health club	2x Senertec Dachs	ICE	10/2011 – 7/2013
CB_2	Small hotel + butcher shop	Senertec Dachs	ICE	7/2011 – 7/2013

Table 13 contains the energetic data obtained from field-testing normalized to annual values. DHW consumption also covers losses of the DHW storage and the circulation system. In case of systems ST_1 to ST_4, CHP unit and auxiliary burner form one integrated system so it is not possible to separate the consumption of both components. Due to problems with the metering sensors, grid import of STE_1 and fuel consumption of CB_1 could not be obtained for a sufficient amount of days to calculate annual values.

Table 13: Energetic data of supplied objects on annual basis [ESB12, FORETA12]

Object	Fuel		Electricity			Heat			
	Cons. CHP	Cons.PLB	Cons.	Grid import	Gen CHP	Cons. Heating	Cons. DHW	Gen. CHP	Gen PLB
	[MWh]	[MWh]	[MWh]	[MWh]	[MWh]	[MWh]	[MWh]	[MWh]	[MWh]
STE_1	30.5		6.4	n.a.	2.3	19.4	4.6	24.0	
STE_2	33.9		5.9	4.4	2.7	23.5	3.5	27.0	
STE_3	24.5		6.1	4.9	1.8	18.0	2.0	20.0	
STE_4	32.6		4.6	4.2	2.3	21.3	4.7	26.0	
CB_1	n.a.	n.a.	172.9	122.6	53.5	116.2	64.4	122.9	58.7
CB_2	125.0	46.0	145.0	112.4	32.6	69.5	34.6	79.8	24.3

One important difference regarding the Stirling micro-CHP systems is the way in which thermal storage can be integrated.

- **Combi storage:** in case of STE_1 and STE_3, micro-CHP and auxiliary burner deliver heat directly to a thermal storage of about 800 l water content. From these units, heat is directly supplied to the heating circuit. A heat exchanger coil integrated in the thermal storage allows to prepare domestic hot water.
- **DHW storage:** in case of STE_2 and STE_4, micro CHP and auxiliary burner feed heat directly to the heating circuit and to a tubular heat exchanger coil integrated into a domestic hot water storage.

The following Figures (Fig. 41 and Fig.) show daily load profiles of the systems STE_1 and STE_2 during winter and transition season. Three modes of operation are visible:

- **CHP only mode:** Only the Stirling system is operating, providing about 5 kW of thermal energy to the heating/DHW system
- **burner level 1 mode:** In addition to the CHP the auxiliary burner operates at level 1. The total thermal output is about 10 kW.
- **burner level 2 mode:** to service peak heat demand, the auxiliary burner operates at full load. The total heat output is above 15 kW.

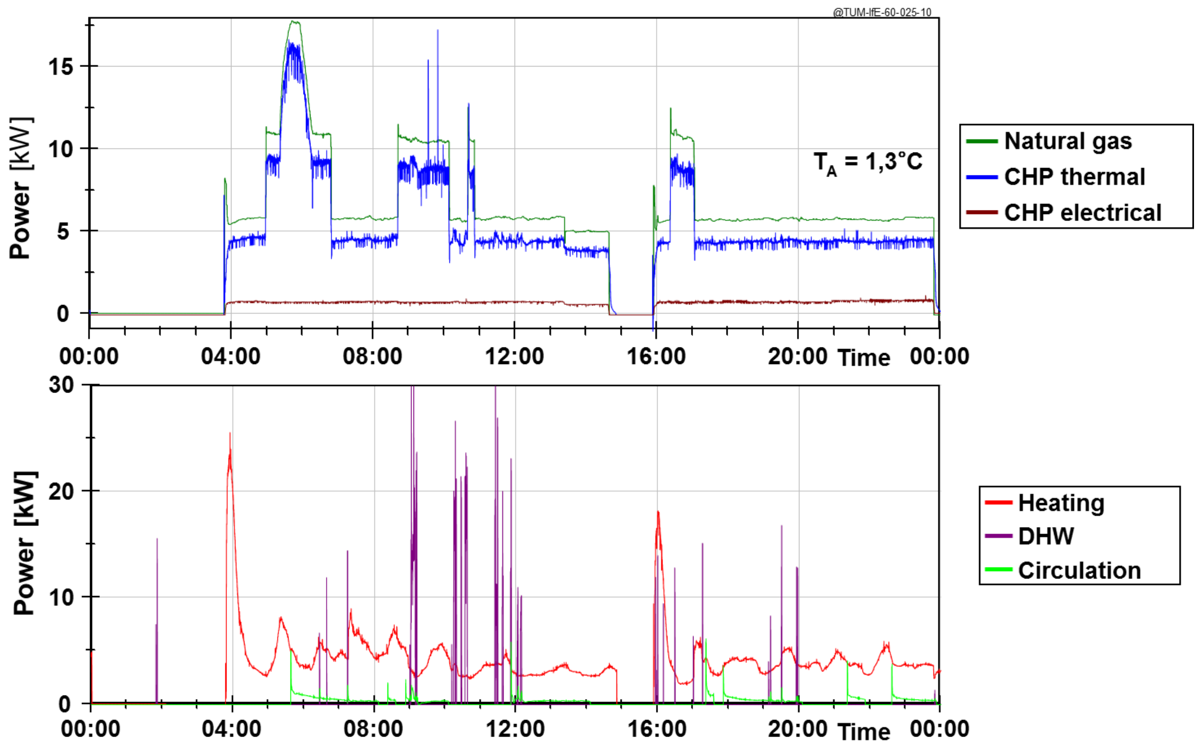


Fig. 41: Load Profile of STE_1 (combi storage) on a winter day

During the winter day the micro CHP systems are operating more than 19 h and switch off during night setback. The arising peak at the end of the night setback cannot be covered by the in CHP only mode so level 1 and for a short time also level 2 of the auxiliary burner has to be activated. The combi storage of STE_1 (39) levels out the heat demand so the burner only has to operate four times during the day while the burner of STE_2 has to be activated more than 20 times.

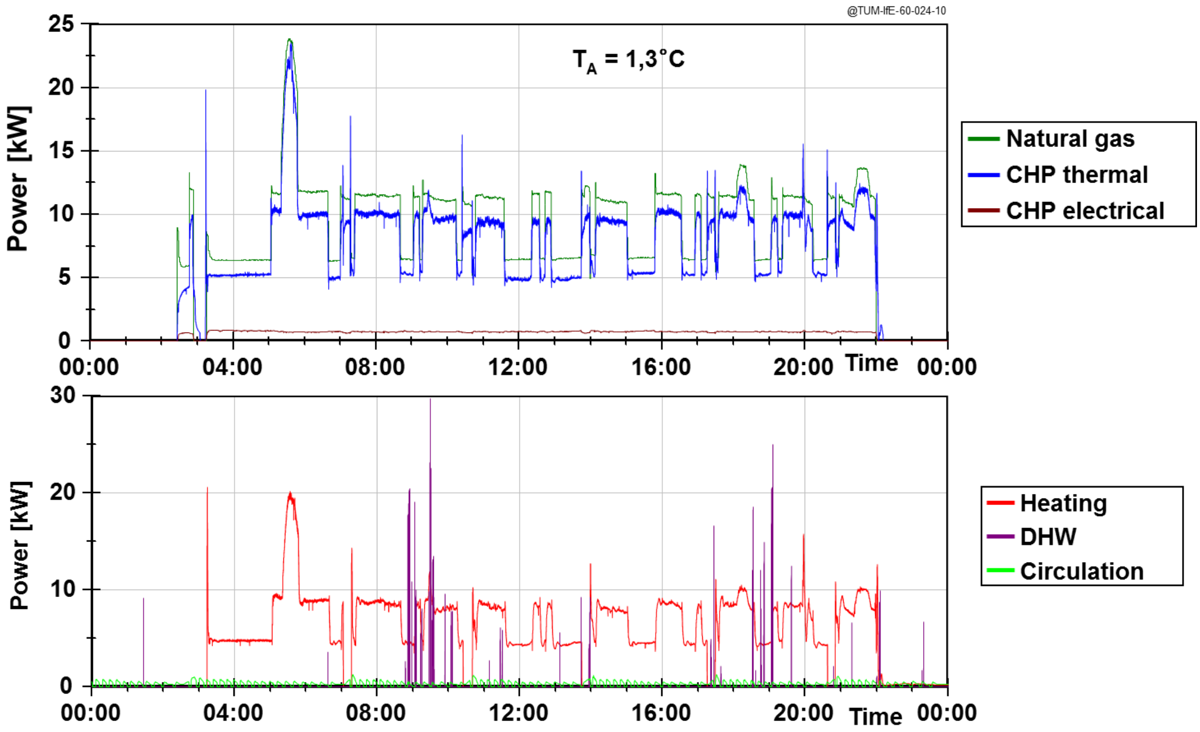


Fig. 42: Load Profile of STE_2 (DHW storage) on a winter day

Comparing the operation of both systems on a transition day makes the influence of the thermal storage even more clearly:

Fig. 43 shows that in case of STE_1 the micro CHP system can operate for about 11 hours during the day. The auxiliary burner is not activated. The two peaks in the heat demand at 4:00 and 17:00 can be covered by drawing heat from the thermal storage. The Stirling system has to start and stop five times.

The micro CHP system of STE_2, as shown in Fig. 43, has to directly follow the space heating demand. Therefore, the Stirling system has more than 40 starts and stops during the day sometimes only operating for some minutes. As some of the peaks cannot be covered through heat recovery of the Stirling system, the auxiliary burner has to be activated 9 times, once even on level 2.

As frequent start and stop operations increase losses and decrease lifetime of the system, a thermal storage should be used.

The data described above is available with sampling rate of 1 sec for a period of about 3 years. Each day is one data file in National Instruments tdms format. There are tools available to import datafiles into MS Excel or MatLab. To get access to the data please contact Peter Tzscheutschler at TUM (ptzscheu@tum.de).

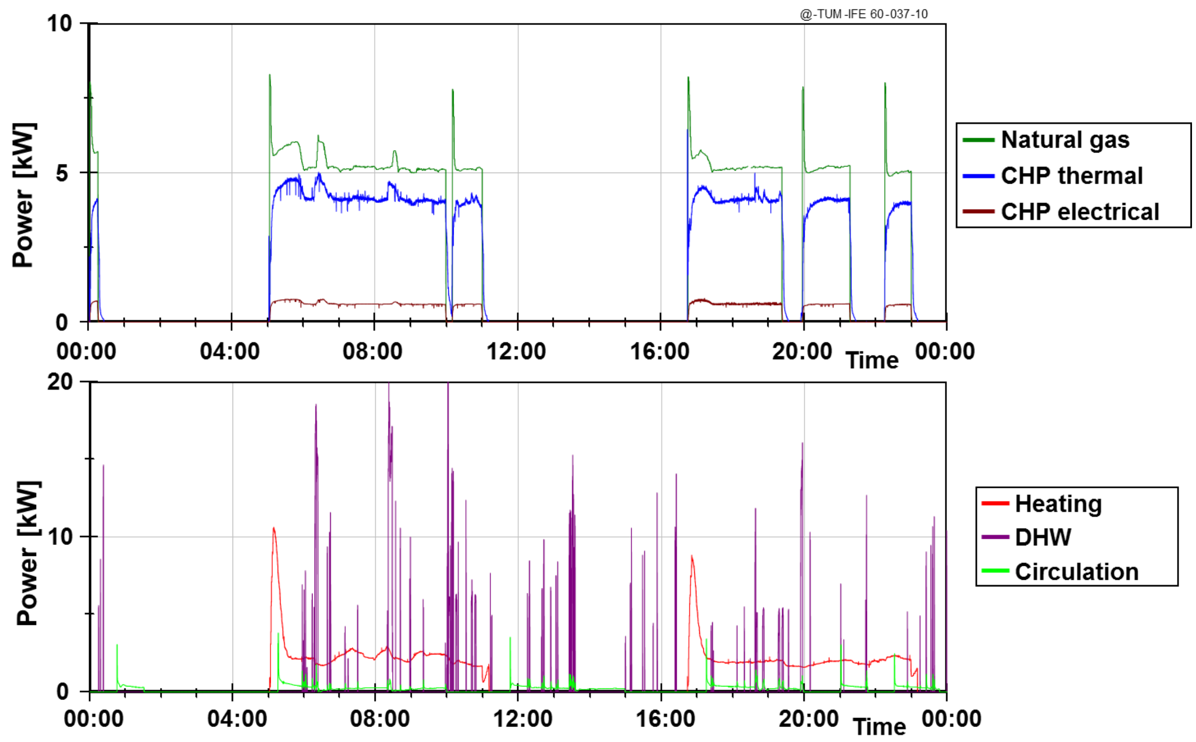


Fig. 43: Load Profile of STE_1 (combi storage) on a transition day

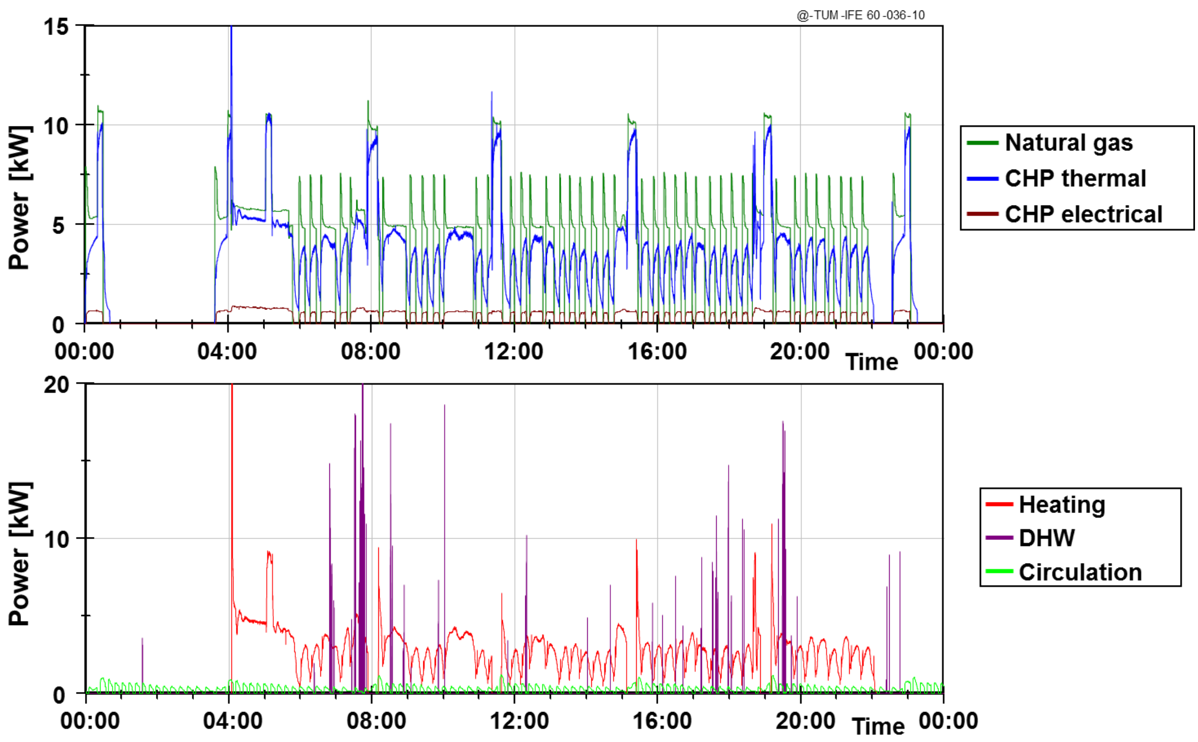


Fig. 43: Load Profile of STE_2 (DHW storage) on a transition day

2.6.2 Projects from the Research Center for Energy Economics (FfE)

During the participation in that IEA Annex 54 activity the FfE has developed models to characterize the interconnection of decentralized plants as a virtual power plant. The objective is to identify optimized operation strategies and to evaluate the revenues on different markets. In order to model a realistic device scheduling process thermal load forecasts and their deviations are focussed in that work. To evaluate the influence of linked CHP devices with heterogenic load profiles, scenarios of different CHP applications have been simulated. The corresponding load profiles are based on measured data and have been made available by project partners. Table 1 states model and data examples.

Table 14: Relevant data sets of the FfE concerning Annex 54

data set number	data set name	description	publication
1	Thermal heat demand of public bath	Profile of thermal demand and outside temperature in 1-hour-resolution over a period of 250 days (October 2009 to June 2010)	public
2	Thermal heat demand of a hotel	Thermal load profile of a hotel	public
3	Thermal heat demand of a hospital	Thermal load profile of a hospital	public
4	Load profile of a greenhouse	Thermal load profile of a greenhouse, which uses a cogeneration unit for heating and lighting.	public

Thermal load profile of a public bath

Monitoring work was conducted on a building of a public bath with outside swimming pool and additionally supplying a district heating in Munich. In Fig. 45: the design of the installation is shown. The two gas fired ICE prime movers with an electric output of 970 kW_{el} each are operated parallel to the gas boilers (3.5 MW_{th} each). Together they supply heat to the bath (designed load 2.3 MW_{th}), to some bigger consumers (high school and old people's home) and to several residential buildings via the local district heating. The peak of the common heat demand is 6.4 MW_{th}. Basically the two non-modulating prime movers cover the heat demand; the boilers are used to operate during the peaks. In charging mode the big hot water tank with a volume of 35 m^3 is flown parallel to the consumer. While discharging the direction of flow is reversed and the stored hot water is mixed to the supply flow. The storage charging is triggered by the return flow temperature and enables a more constant operation of the boilers and prime movers.

The thermal load was calculated on the basis of measured supply and return flows and their temperatures. Data was taken at a 2-minutes interval, over the period from October 2009 to June 2010. The aggregated profile in 1 hour resolution is published in the Annex 54 webpage or via the Research Center for Energy Economics (FfE).

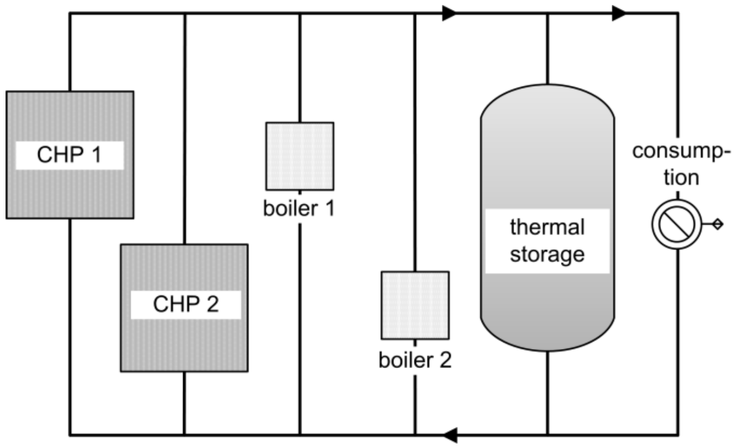


Fig. 45: Simplified design of the heat supply for the public bath

As the heat demand of the bath and the surrounded consumers was not predicted before a forecast based on a simple linear regression was generated. The relationship between the outside temperature and the thermal load was determined by the following equation:

$$\dot{Q}_{forecast}(\text{hour of day}) = a(\text{hour of day}) \cdot \vartheta_{outside} + b(\text{hour of day}) \quad (18)$$

The coefficients a and b have been set for each hour of the day by applying the least square method. In total 24 parameters are required to generate the forecast. According to the information of the local utilities, the forecast quality is comparable to thermal load forecasts used for other CHP devices and could be a sufficient basis for scheduling. A major deviation was only discovered in spring, when the outside pool area was opened and the water therefore warmed up in a one week process.

An example of the profile and the load forecast for the date of October 23, 2009 are shown in Fig. 46.

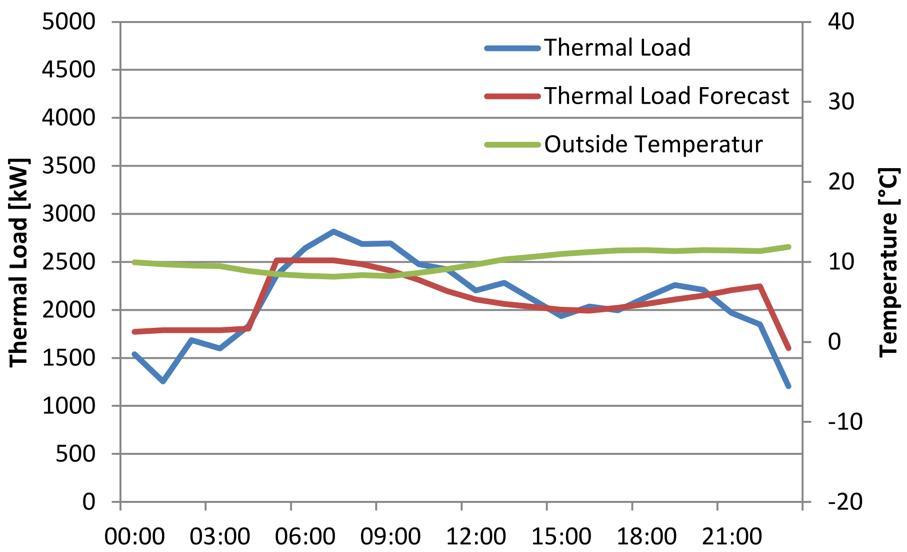


Fig. 46: Profile of the predicted and actual heat demand on an autumn day

Thermal load profile of three facilities in North Germany

The load profiles were used to investigate the impact of linking devices with different load profiles. These facilities were selected because of their different heat loads which are caused by the served heat demand. Facility 1 is a hotel with two prime movers that are subsumed as one in the model. Facility 2 is a hospital and facility 3 is a greenhouse.

Table 1515 summarizes the device parameters used in the simulation. Basically the maximum and minimum powers of the prime movers and the boilers as well as the storage capacity were known, the other parameters were assumed regarding the utilities' information.

Table 15: Parameters of the CHP devices

Device Parameter		Unit	Facility		
			#1	#2	#3
Prime Mover	El. Minimal Power	kW	155	155	232
	El. Maximal Power	kW	476	238	357
	El. Efficiency in Min. Load	%	32	32	32
	El. Efficiency in Max. Load	%	34	34	34
	Fuel Costs	EUR/MWh	25.0	25.0	25.0
	Start-up Costs	EUR	0.2	0.2	0.2
	CHP combined efficiency	%	86	86	86
Boiler	Minimal Power	kW	0	0	0
	Maximal Power	kW	3,500	2,800	3,174
	Operation Costs	EUR/MWh	30.0	30.0	30.0
Thermal Storage	Capacity	kWh	1,452	726	1,058
	Charge and Discharge Heat Rate	kW	1,000	1,000	1,000
	Thermal Losses	%/h	0.5	0.5	0.5

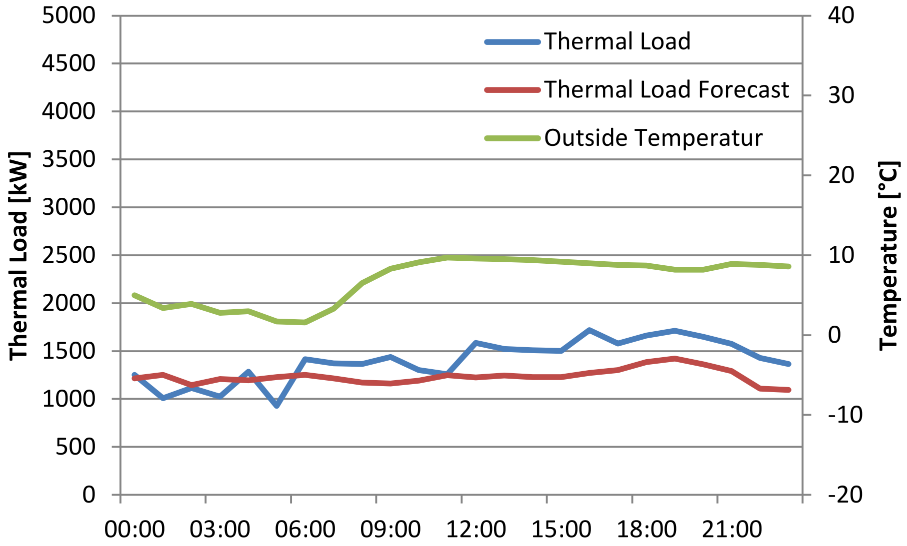


Fig. 47: Heat demand profile and the forecast for the hotel on October 18, 2010

The thermal loads of these housings were measured over the period from January 2010 to December 2010. However, the data set contains some holes, as there were a few brief periods where no measured values were available.

With the same procedure as used for the public bath, a forecast based on the outside temperature was conducted. An example of the profile and the load forecast for the hotel on October 18, 2010, are shown in Fig. 47.

Thermal load profile of a greenhouse

Load profiles were also taken on a greenhouse near Bremen in Germany. Here electric power was used for illumination of greenhouses, thermal power for heating of greenhouse. The greenhouse was equipped with a CHP unit with output of 357 kWel, 530 kWth and a boiler of unspecified power. The demand was found to be highly dependent on the type of crops being raised.

The predictive generator for thermal load forecast in this case was based on the rate of sunlight. The sunlight time was defined as the number of sunny minutes in an hour. The least squares method (between measured thermal load and thermal load forecast) is applied on every hour of the day to determine two parameters (a and b) for the thermal load, expressed as:

$$\dot{Q}_{forecast}(\text{hour of day}) = a(\text{hour of day}) \cdot r_{sunshine\ time} + b(\text{hour of day}) \tag{19}$$

8 depicts the predictive model as applied to the greenhouse for the date of February 16, 2010. A prediction based on the outside temperature showed a minor correlation.

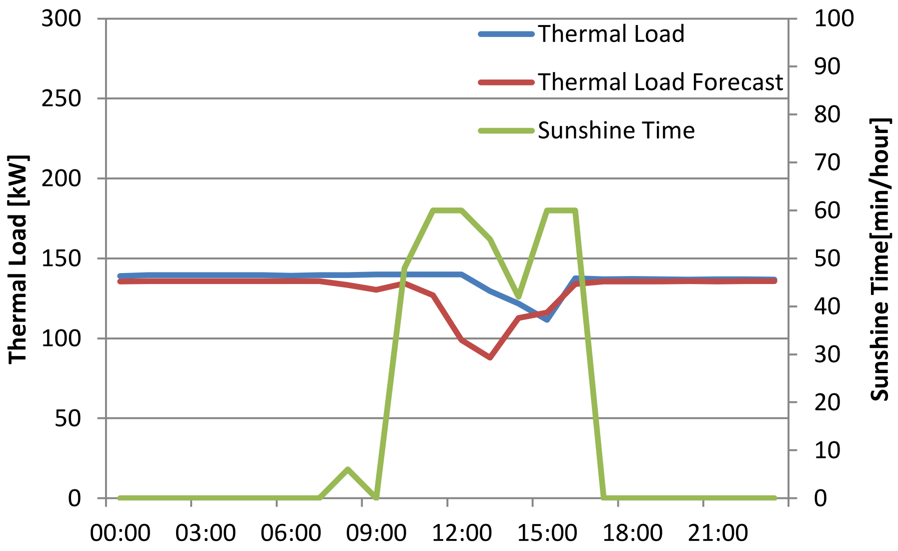


Fig. 48: Forecast of the CHP operation in the greenhouse based on sunshine hours

The thermal profiles are available on the Annex 54 data repository or via contacting the Research Center for Energy Economics (FfE), www.ffe.de.

3 Overview and Concluding Remarks

The load profile data for electricity use and domestic hot water consumption compiled under Annex 42 still stand as a benchmark reference for input for energy use simulations in the built environment. The aims, methodology and orientation of the data collection activities were expressly for the research community performing environmental simulations, and the Annex report presented this material in that particular light. Electricity load profiles were obtained for several participating nations: Canada, UK, Finland, Belgium, Italy, Netherlands, Germany and Portugal.

As part of the commitment of Annex 54 to contribute to the existing repository of load profile data, new member nations not present during Annex 42 were requested to provide load profile data. The present Annex includes this new load profile data from the new member nations, Japan and South Korea. The Japanese contribution covered several different types of residences and buildings, and included domestic hot water use as well as electricity consumption. For the case of South Korea, heating and cooling load data are given for a single family home and small office building. Electricity load profiles are provided for two sizes of apartment buildings on a detailed level. General average profiles were also provided.

Moving forward to the present, the accompanying subject of micro-generation has witnessed a shift in focus towards system design, integration and optimization, as the technologies and the know-how linked to their implementation have gained maturity. Accordingly, the changes occurring with micro-generation have given rise to gaps in the suitability of existing load profile data as input for energy use simulations. New understanding about system operations has demonstrated the stochastic nature of energy use, and consequently, temporal load profile data that properly reflects this is required. Characterizations of the operation of several different individual household appliances has shown that electric demands with very rapidly changing loads over quite short time scales frequently occur. Notably, the start up peaks for various equipment can show peak heights that are not seen on time averaged load profiles with a 5 or 10 minute interval basis.

Updated efforts have improved the quality of synthetically produced load profiles by use of stochastic methods which aggregate the various different and individual electric loads which collectively constitute a load profile. Data have been obtained, notably in studies carried out at Loughborough in the UK and at Carleton University in Canada, where very detailed measurements were taken on very short time scales (down to one minute intervals in the Carleton case), enabling a clearer understanding of the composition of residential load profile. These profiles can also be correlated with climate data, occupancy data and size and type of house.

As the present Annex has broadened the scope of the equipment and system configuration under consideration, so too have efforts in gather load profile data broadened in recent years. A variety of building types, and some with specialized activities have been studied. In Germany, electricity and hot water data has now been obtained for single family residences as well as a hotel, a commercial greenhouse, a public swimming pool, a health club and a small butcher shop. In additional to family homes in Italy, new data has recently been collected and reported for small offices buildings.

A study was also conducted which cataloged the demand profiles of an extensive range of household appliances. This enables the user to construct a customized scenario for occupancy simulations. Further, an online tool has been developed which serves as working resource for practitioners seeking a method and tool for load profile generation. A second such similar online tool is under development by ENEA in Italy.

The adoption of micro-generation technologies in the residential sector continues to progress. Researchers in this area have also continued to advance the status of electricity and domestic hot water load profile data, to continue to serve simulation work and technology demonstrations aimed at promoting its wider spread uptake and implementation.

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Background

International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an international energy programme. A basic aim of the IEA is to foster co-operation among the twenty-eight IEA participating countries and to increase energy security through energy conservation, development of alternative energy sources and energy research, development and demonstration (RD&D).

Energy in Buildings and Communities

The IEA co-ordinates research and development in a number of areas related to energy. The mission of one of those areas, the EBC - Energy in Buildings and Communities Programme, is to develop and facilitate the integration of technologies and processes for energy efficiency and conservation into healthy, low emission, and sustainable buildings and communities, through innovation and research. (Until March 2013, the EBC Programme was known as the Energy in Buildings and Community Systems Programme, ECBCS.)

The research and development strategies of the EBC Programme are derived from research drivers, national programmes within IEA countries, and the IEA Future Buildings Forum Think Tank Workshop, held in April 2013. The R&D strategies represent a collective input of the Executive Committee members to exploit technological opportunities to save energy in the buildings sector, and to remove technical obstacles to market penetration of new energy conservation technologies. The R&D strategies apply to residential, commercial, office buildings and community systems, and will impact the building industry in five focus areas of R&D activities:

- Integrated planning and building design
- Building energy systems
- Building envelope
- Community scale methods
- Real building energy use

The Executive Committee

Overall control of the program is maintained by an Executive Committee, which not only monitors existing projects but also identifies new areas where collaborative effort may be beneficial. To date the following projects have been initiated by the Executive Committee on Energy in Buildings and Communities (completed projects are identified by (*)):

Annex 1: Load Energy Determination of Buildings (*)
Annex 2: Ekistics and Advanced Community Energy Systems (*)
Annex 3: Energy Conservation in Residential Buildings (*)
Annex 4: Glasgow Commercial Building Monitoring (*)
Annex 5: Air Infiltration and Ventilation Centre

Annex 6: Energy Systems and Design of Communities (*)
Annex 7: Local Government Energy Planning (*)
Annex 8: Inhabitants Behaviour with Regard to Ventilation (*)
Annex 9: Minimum Ventilation Rates (*)
Annex 10: Building HVAC System Simulation (*)
Annex 11: Energy Auditing (*)
Annex 12: Windows and Fenestration (*)
Annex 13: Energy Management in Hospitals (*)
Annex 14: Condensation and Energy (*)
Annex 15: Energy Efficiency in Schools (*)
Annex 16: BEMS 1- User Interfaces and System Integration (*)
Annex 17: BEMS 2- Evaluation and Emulation Techniques (*)
Annex 18: Demand Controlled Ventilation Systems (*)
Annex 19: Low Slope Roof Systems (*)
Annex 20: Air Flow Patterns within Buildings (*)
Annex 21: Thermal Modelling (*)
Annex 22: Energy Efficient Communities (*)
Annex 23: Multi Zone Air Flow Modelling (COMIS) (*)
Annex 24: Heat, Air and Moisture Transfer in Envelopes (*)
Annex 25: Real time HVAC Simulation (*)
Annex 26: Energy Efficient Ventilation of Large Enclosures (*)
Annex 27: Evaluation and Demonstration of Domestic Ventilation Systems (*)
Annex 28: Low Energy Cooling Systems (*)
Annex 29: Daylight in Buildings (*)
Annex 30: Bringing Simulation to Application (*)
Annex 31: Energy-Related Environmental Impact of Buildings (*)
Annex 32: Integral Building Envelope Performance Assessment (*)
Annex 33: Advanced Local Energy Planning (*)
Annex 34: Computer-Aided Evaluation of HVAC System Performance (*)
Annex 35: Design of Energy Efficient Hybrid Ventilation (HYBVENT) (*)
Annex 36: Retrofitting of Educational Buildings (*)
Annex 37: Low Exergy Systems for Heating and Cooling of Buildings (LowEx) (*)
Annex 38: Solar Sustainable Housing (*)
Annex 39: High Performance Insulation Systems (*)
Annex 40: Building Commissioning to Improve Energy Performance (*)
Annex 41: Whole Building Heat, Air and Moisture Response (MOIST-ENG) (*)
Annex 42: The Simulation of Building-Integrated Fuel Cell and Other Cogeneration Systems (FC+COGEN-SIM) (*)
Annex 43: Testing and Validation of Building Energy Simulation Tools (*)
Annex 44: Integrating Environmentally Responsive Elements in Buildings (*)
Annex 45: Energy Efficient Electric Lighting for Buildings (*)
Annex 46: Holistic Assessment Tool-kit on Energy Efficient Retrofit Measures for Government Buildings (EnERGo) (*)

Annex 47: Cost-Effective Commissioning for Existing and Low Energy Buildings (*)
Annex 48: Heat Pumping and Reversible Air Conditioning (*)
Annex 49: Low Exergy Systems for High Performance Buildings and Communities (*)
Annex 50: Prefabricated Systems for Low Energy Renovation of Residential Buildings (*)
Annex 51: Energy Efficient Communities (*)
Annex 52: Towards Net Zero Energy Solar Buildings (*)
Annex 53: Total Energy Use in Buildings: Analysis & Evaluation Methods (*)
Annex 54: Integration of Micro-Generation & Related Energy Technologies in Buildings (*)
Annex 55: Reliability of Energy Efficient Building Retrofitting - Probability Assessment of Performance & Cost (RAP-RETRO)
Annex 56: Cost Effective Energy & CO2 Emissions Optimization in Building Renovation
Annex 57: Evaluation of Embodied Energy & CO2 Emissions for Building Construction
Annex 58: Reliable Building Energy Performance Characterisation Based on Full Scale Dynamic Measurements
Annex 59: High Temperature Cooling & Low Temperature Heating in Buildings
Annex 60: New Generation Computational Tools for Building & Community Energy Systems Based on the Modelica & Functional Mockup Unit Standards
Annex 61: Development & Demonstration of Financial & Technical Concepts for Deep Energy Retrofits of Government / Public Buildings & Building Clusters
Annex 62: Ventilative Cooling
Annex 63: Implementation of Energy Strategies in Communities
Annex 64: LowEx Communities - Optimised Performance of Energy Supply Systems with Exergy Principles
Annex 65: Long-Term Performance of Super-Insulation in Building Components and Systems

Working Group - Energy Efficiency in Educational Buildings (*)
Working Group - Indicators of Energy Efficiency in Cold Climate Buildings (*)
Working Group - Annex 36 Extension: The Energy Concept Adviser (*)

(*) – Completed

Annex 54

The **Annex 54 “Integration of Micro-Generation and Related Energy Technologies in Buildings”** undertook an in depth analysis of micro-generation and associated other energy technologies.

Scope of activities

- multi-source micro-cogeneration systems, polygeneration systems (i.e. integrated heating / cooling / power generation systems) and renewable hybrid systems;
- the integration of micro-generation, energy storage and demand side management technologies at a local level (integrated systems);
- customised and optimum control strategies for integrated systems;
- the analysis of integrated and hybrid systems performance when serving single and multiple residences along with small commercial premises; and
- the analysis of the wider impact of micro-generation on the power distribution system. To broaden the impact of the Annex’s output there will be significant effort to disseminate its deliverables to non-technical stakeholders working in related areas such as housing, product commercialisation and regulatory development.

Outcomes

- An update on occupant related DHW and electric load profiles.
- Component models and their implementation in building simulation tools.
- Review of best practice in the operation and control of integrated micro-generation systems.
- Predictive control algorithms to maximize the performance and value of micro-generation.
- Experimental data sets for the calibration and validation of device models.
- Performance assessment methodologies.
- Country-specific studies on the performance of a range of micro-generation systems.
- Studies of the viability of micro-generation systems in different operational contexts and of the impacts of micro-generation on the wider community and the potential benefits, in particular for the electricity network.
- An investigation of interactions between technical performance and comercialization/ regulatory approaches for micro-generation.
- Compilation of case studies of the introduction of microgeneration technologies.

Annex 54 was built upon the results of Annex 42 "The Simulation of Building-Integrated Fuel Cell and Other Cogeneration Systems".

To accomplish its objectives Annex 54 conducted research and development in the framework of the following three Subtasks:

Subtask A - Technical Development

The subtask contains a broad range of activities related to models and load profiles development, data collection and micro-generation systems predictive controls development and optimization.

Subtask B - Performance Assessment

The subtask uses simulations to develop an extensive library of performance studies and synthesis techniques to identify generic performance trends and "rules of thumb" regarding the appropriate deployment of micro-generation technologies.

Subtask C - Technically Robust Mechanisms for Diffusion

The subtask contains work related to the interaction between technical performance, economic instruments and commercialization strategies and provision of this information to the relevant decision makers. Given the importance of micro-generation in meeting many countries' climate change targets the subtask assesses the ability of micro-generation to enter the market and deliver on national and international energy policy objectives.

Research Partners of Annex 54

Belgium	Catholic University of Leuven
Canada	Natural Resources Canada
	National Research Council
	Carleton University
Denmark	Dantherm Power A/S
Germany	Research Center for Energy Economics (FfE)
	Technische Universität München (TUM)
	University of Applied Science of Cologne
Italy	Università degli Studi del Sannio
	Seconda Università di Napoli (SUN)
	National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA)
	Università Politecnica delle Marche
Japan	Tokyo University of Agriculture and Technology
	Osaka University
	Nagoya University
	Tokyo Gas
	Osaka Gas
	Toho Gas
	Saibu Gas
	Mitsubishi Heavy Industry Ltd
	Yanmar Energy Systems Ltd
Korea	Korean Institute for Energy Research (KIER)
Netherlands	Technische Universiteit Eindhoven (TU/E)
United Kingdom	University of Strathclyde, Scotland
	Imperial College London, England
	University of Bath, England
United States	National Institute for Standards and Technology (NIST)