Household electricity load modelling: cooking and non-cooking

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Working Paper 30 July 2020

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This material has been funded by UK Aid from the UK government; however the views expressed do not necessarily reflect the UK government's official policies

Executive Summary

The modellers of MECS Workstream 2.2 are developing an approach for creating load profiles for electricity use for cooking and non-cooking activities at the level of the individual household, and then the aggregate profiles for groups of households and potentially other user types. The paper describes the development of the model, starting from and building on the existing CREST Demand Model. The data requirements are explored, for both baseline characterisation of a household, and to represent the uncertainty and diversity in demand between days and across different households. Illustrative results are reported for household load profiles.

1 Introduction

1.1 Overview of MECS Workstream 2.2 modelling

The core of WS2.2 comprises Newcastle University (Neal Wade and Chris Mullen); University of Strathclyde (Stuart Galloway and team); Jaqi Lee and Matt Leach (independent, linked to Gamos) and Nigel Scott (Gamos). The overall aim of WS2.2 is to develop a toolkit of models and analysis that can represent the benefits and impacts of specified approaches to delivering cooking services: in a range of contexts, from individual off-grid homes, through users connected to mini-grids or to main grids; across full supply chains and all life-cycle stages; and considering environmental, social and economic effects.

The approach being taken is to establish:

- a set of "user stories", each characterising a household and the context within which they live and cook;
- a coherent representation of the cooking 'system' components, including any grid the user may be connected to;
- consistent parameterisation for those components, using agreed data categories;
- a repository and/or coordination on data used as model inputs;
- standardised output types.

The modelling that underpins the first two bullets comprises four distinct areas, each of which in their own rights will produce results and published outputs, but which will also interact with each other. The four areas are:

1. Representing the cooking practices and associated cooking energy demands of individual households
2. Techno-economic design of the eCook system to meet given cooking requirements (led by Matt Leach, further details are in Leach et al. (2019), eCook Modelling Nov 2019 Working Paper).
3. Analysis of the effects of eCooking on grids to which a household is connected (led by Stuart Galloway at Strathclyde)
4. Life Cycle Assessment of the eCook system (led by Jaqi Lee further details are in Lee (2019) Environmental Life Cycle Assessment in MECS)

Bullets 3 to 5 represent a conceptual approach to ensuring consistency in the modelling, as well as practical steps that need to be taken. A working paper on this overall "integrative framework" for the modelling will follow.

1.2 Purposes and needs for demand modelling in MECS

The third area of modelling above requires detailed characterisation of the electricity supply grid and of the cooking loads to be connected to it. initial work on network modelling by the team at Strathclyde will be published in a separate working paper and will discuss the range of questions asked, the modelling undertaken and emerging findings. The ambition is to understand how the addition of electric cooking will change load patterns, and what impacts that might have on electricity supply systems.

In broad terms, if the aggregate load on the network at a moment in time exceeds certain thresholds, technical performance will degrade and eventually the network will fail. As Richardson et al. (2010) point out, summing the individual maximum demands from each household over a period of time (say a day) gives the "maximum non-coincident demand". However in reality, the maximum for each household is likely to occur at slightly different time and thus the maximum time-coincident demand of all households together is lower and is known as the "maximum diversified demand".

To estimate the maximum diversified demand (and other important characteristics of how loads on the network change over time), data are needed on the full set of loads that are connected to the distribution network, including their magnitude and how those vary over time. The baseline scenario could exclude cooking, to represent use of electric lights, radios, TVs, mobile phone charging etc, with use of electric cooking appliances added on top.

MECS research into cooking takes a bottom-up approach, starting with the individual household cook and their preferences and practices, gathered for example through Cooking Diary studies (Leary et al. 2019). As such, there is a growing dataset on household energy use for cooking. However to date there has been limited analysis of how cooking, and the energy use resulting, varies by time. There has also been very little attention within MECS to non-cooking activities and energy use.

The Workstream 2.2 modellers thus set out to develop an approach for representing cooking and non-cooking activities at the level of the individual household, and then the aggregate profiles for groups of households and potentially other user types.

The requirements of the approach are:

- Develop a tool for creating load profiles for electricity use
- for cooking and non-cooking activities,
- at the level of the individual household or user type,
- suitable for rural and urban users in MECS target countries.
- Built on variable parameter values to represent different user types.
- Capture variability in loads (for more realistic representation, and to reflect diversity into aggregations).
- Allow aggregation of load profiles for groups of users, or assemble sets of profiles

The existing "CREST Energy Demand Model" provides a good starting point. The model was originally formulated some ten years ago by researchers led by Dr Murray Thompson at CREST, Loughborough University to represent the electricity usage of the residential sector in the UK, minute by minute, and disaggregated by individual electricity uses and appliances (Richardson *et al.*, 2010). It has since been extended by members of the original team to integrate heat and hot water demand. The various versions of the model have also been applied and further developed by numerous researchers internationally (see https://www.lboro.ac.uk/research/crest/demand-model/ for list and citations).

The rest of this working paper explores the structure and operation of the CREST demand model; describes alterations and additions made to apply to the specific needs for MECS; and then illustrates the outputs that can be produced. A further paper will be produced later that presents results for a wide set of household types and their aggregations, and how those link into the network modelling.

2 Description of the CREST model

The current version of the model is available at https://dx.doi.org/10.17028/rd.lboro.2001129. However Murray Thompson suggested starting with an older version of the CREST model, CREST_Integrated_PV_electricity_demand_model_1.0B(1).xlsm. This version excludes much of the modelling of heating that is a key feature of the recent versions. The code is fully accessible, and well documented. The key publication for this version of the model is (Richardson *et al.*, 2010; J Leary *et al.*, 2019).

2.1 CREST model structure and operation

The structure of the model is shown in Figure 1. Daily activity profiles describe the probability that particular activity types take place at each time period in the day. This is intended to represent the diversity of activity patterns across the complete population of households (which was the UK dwelling stock for the original CREST modelling team). Individual households are represented by data on their "active occupancy" patterns – the probability of the number of people present and awake in each time period (Richardson, Thomson and Infield, 2008) – and the set of electricity-using appliances they have. The appliances are mostly linked to one of the daily activity profiles, and are characterised by some form of power-use profile.

For each 24-hour run of the model, the household being modelled is allocated a set of appliances, as a random draw based on the ownership patterns of the complete population. The load modelling starts from 12:00 midnight; for each minute thereafter, each appliance is considered in turn. The appliance will be available to be switched on if the linked activity is relevant to that time period and if a random draw from the occupancy model results in one or more residents being present and awake. Whether it actually is switched on in that minute is governed by a further series of probabilities, calibrated so that the expected electricity use of the appliance over many model runs will sum to the measured use of the study population. This is repeated for every appliance in that minute, and then for every minute in the day. Once an appliance has 'started' it will run for a period determined by the appliance or activity type, with a random factor. Appliances can be assigned a 'restart delay' period before another switch-on will be considered. The overall household electricity demand profile for the 24 hour period is the sum of the appliance demand profiles.

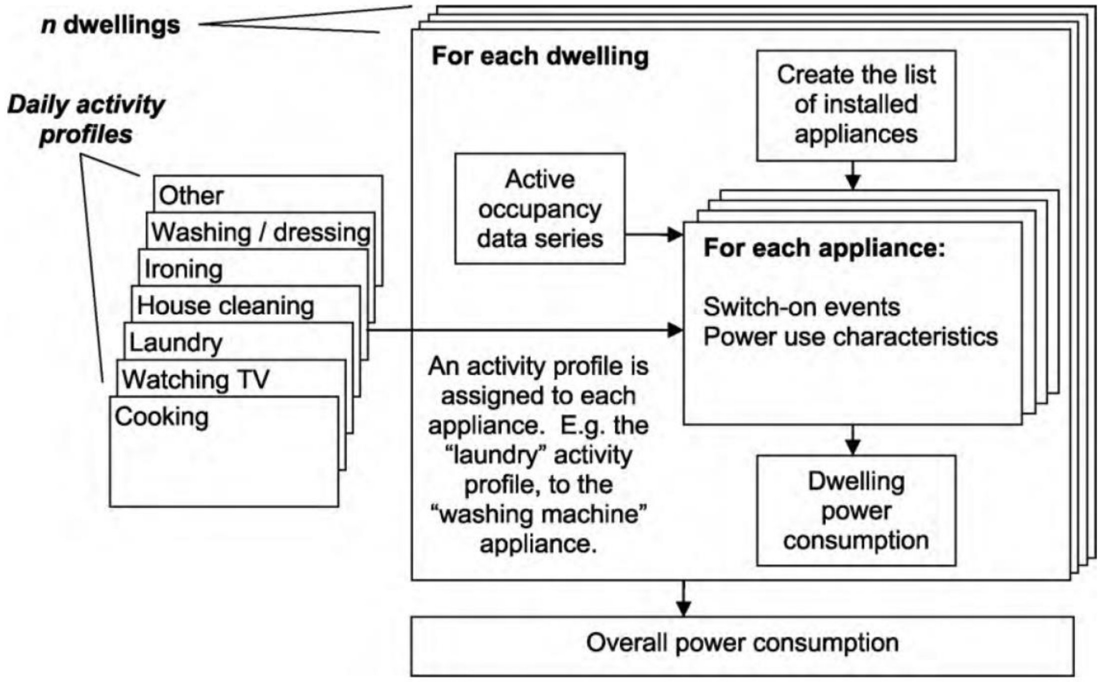

Figure 1 Electricity demand architecture of the CREST model
Source: Richardson et al. (2010)

As above, the CREST model generates profiles of active occupancy and of electricity demand by appliance. A model of electricity use for lighting is included, taking a similar approach but also factoring in a simulation of external irradiance, driving probabilistic determination of the use of a set of light bulbs allocated to the household (Richardson *et al.*, 2009). The version of the model used also includes characterisation of the electricity production of solar photovoltaic generation installed on the dwelling, and then the resulting electricity demand profile with PV production netted off.

2.2 Suitability to the MECS demand modelling needs

The model simulates 24 hours of operation, for one household. The active occupancy model has a time step of 10 minutes whilst the demand model has a time step of 1 minute. The probability of a particular activity taking place in any one minute time period depends on the number of active occupants determined for the household at that time. Most demands are related to appliances serving a particular activity type (such as getting washed/dressed, cooking, ironing, watching TV) whilst appliances such as fridges, freezers and clocks operate irrespective of active occupancy and are not linked to a particular defined activity.

The model takes a probabilistic approach throughout, with the value assigned to most parameters for any time period subject to some form of probability. The combination of the various probability distributions used are calibrated such that running the model many times should lead to an aggregate load profile that approximates the observed load profile of the UK residential sector. As such, any one model run produces results which may be broadly representative of some sort of UK household, but the nature of that household changes fundamentally from one run to the next. For example, the ownership of appliances is assigned randomly, as is the pattern of occupancy. A few parameter values are fixed by the model user (eg total number of household residents).

Basing aggregate load profiles on a probabilistic approach is consistent with MECS needs, but it would be very difficult to implement the model in its current form. MECS will typically have bottom-up data on a small set of households and rather little data on load profiles and occupancy patterns of wider populations, and thus the calibration of probability factors cannot be achieved as intended. Furthermore . Ways to modify the existing CREST model, to maximise its advantages but being consistent with the MECS context are the focus of this paper.

3 Structure of the CREST model spreadsheet

The following gives a brief description of each tab on the spreadsheet:

- **main** tab provides buttons to initiate each calculation step and provides charts of resulting loads
- **PV_model** tab has the data and calculations for PV production, plus simulation outputs
- **ClearnessIndexTPM** tab has the Transition Probability Matrix for atmospheric “clearness” from one state to another
- **appliances** tab contains the characteristics for each appliance
- **appliance_sim_data** tab gives the model results in terms of the power demand broken down by appliance for each time step of one minute.
- **activity_stats** tab contains the Time Use Survey-based data on proportion of households with one or more occupants engaged in an activity, for each activity, for each ten minute period
- **light_config** tab defines the lighting model
- **bulbs** tab provides a set of 100 sample light bulb configurations for a household, with the number of bulbs present and their individual power ratings. (Note the bulb ratings are out of date, evidently being based on incandescent bulbs).
- **light_sim_data** reports the output of the lighting model: a randomly chosen bulb configuration, and the power use per bulb per minute, that is influenced by the pattern of occupancy and the external light levels
- **occ_sim_dat**a tab shows occupancy results in terms of numbers of occupants at every 10 minute time step.
- **occ_start_states** tab provides the tables of the number of occupants that start to become active (0-6) in the dwelling between 00:00 and 00:10 for different total numbers of residents in the dwelling (1-6), for weekdays and weekends. Used to set initial conditions for calculation of occupancy of the model.
- **tpm1_wd** sets the probability of active occupancy transition from a given number of active occupants in a ten minute period to each possible number of active occupants in the next ten minute period. This tab is for a single resident dwelling on weekdays. There are matching tabs for each number of total residents (1-6), and weekdays and weekends for each. The transition tables are mainly used to model the household residents coming and going. But this could presumably also be used to reflect extra visitors being present. However, calculated activity energy use doesn’t seem to reflect occupant numbers for any activities or appliances (including for cooking).

4 Modelling one household: CREST model and alterations made

As mentioned in section 2, the CREST model is not intended to provide a representation of an individual household, but rather to aggregate multiple runs to represent all households in a country. The purpose of the MECS load modelling is to integrate detailed analysis of cooking patterns by individual, real households, with estimates of non-cooking electricity use. As such it seems important that the MECS implementation of the CREST model allows a representation of a particular household, before probabilities are used to reflect diversity amongst larger collections of users.

The CREST model method has the numbered steps below. Changes that have been made are shown in bullets. Section 5 draws these suggestions together in a summary table.

1. Specify the **overall number of residents** in the house (set by user); specify either a **weekday or weekend** (set by user)

    - Both were used in the occupancy calculator. This has been replaced by a new occupancy model based on cooking diary data: this does include a parameter for the household size, and could in future include differences in cooking patterns on different days of the week.

2. Configure and run the **PV model** for a given location (parameters, including Latitude and Longitude, are set in PV_model tab).

    - The MECS demand model will focus on electricity use and will ignore PV production at this stage.

3. Simulate the **clearness of the sky**. Clearness index is set by a probability matrix which governs change from one clearness index state to another, based on data for Loughborough in 2007. This is used for the PV model, but also to define the minute by minute Outdoor Global Irradiance, which is checked in the lighting model for probability of lights being switched on.

    - The probability matrix used is the result of significant previous research, and cannot be easily replicated for new locations. However, its most significant contribution was to provide a probabilistic representation of PV output, which is highly sensitive to outdoor light levels. With the PV model set aside, a simpler approach to global Irradiance can be used to drive the use of indoor lighting. Hourly data by global location are available online based on satellite data. A new tab has been added to interpolate to 1 minute values from hourly data from the PVGIS website, replacing the values stored in "PV Model" tab. As for original CREST model, the user needs to choose which day of the year the run is for, and the geographic location; and then the appropriate data need to be extracted from PVGIS and be pasted in.

4. Allocate **ownership of appliances** to the dwelling. For each appliance (in a fixed list of options), the probability that the modelled household owns it is based on a random number weighted by empirical evidence of the proportion of all households with that appliance. There seems to be no correlation between assumption of ownership of one appliance and any others (eg the allocation method can't reflect an overall pattern of high or low appliance ownership etc).

    - As the MECS implementation is seeking to represent a specific household or user type, which must include assumptions on wealth and hence appliance ownership, the random allocation of appliance ownership has been replaced by specification of appliance ownership.

5. Run the **active occupancy model**. The model calculates the number of active occupants for each ten minute period, up to the input value for overall number of residents. Two sets of empirical data tables are used for occupancy: (a) the probability distribution of active occupant numbers for the ten minutes from midnight, from zero to the overall resident number, for weekdays and weekends separately; (b) the probability of transition from any one active occupancy level to any other, for each ten minute period, for each of weekdays and weekends and for each overall number of residents. The results is a new profile of active occupancy each time the model is run: this may well reflect the real diversity in the UK, if the model is run thousands of times and aggregated, but the results do not neatly represent any 'typical' pattern for one household.

    - The existing occupancy data are for the UK. For other applications, tables (a) could be sensibly guessed at. Tables (b) are complex and to be used as intended would require either a bespoke dataset, or some heroic assumptions. A new occupancy model has been added; this starts with cooking diary data on cooking times and the number or people cooked for and creates a representation of 24 hour active occupancy from that. Occupancy between meals is set at the lowest of the number of people at the meals either side. Wake and sleep times are specified. The result is a single number for active occupants per ten minute period. This could be further tailored to reflect other known features of the modelled household's activities, as needed.

6. **Effects of active occupancy level**. When at zero, many appliances 'stop' or don't start. For lighting 'effective occupancy' is calculated, which weights the chance that any light switches on after dark (so the probability does not rise directly in proportion to occupancy).

    - The MECS implementation retains the mechanisms by which occupancy affects appliance us. The weights used for the effective occupancy mechanism for lighting can be better tailored if new data on lighting use can be obtained.

7. Run the **electricity demand simulation** (including both **the lighting and appliance models**)

    The **Lighting model**: randomly choose an irradiance threshold at which lights might be used, from an input normal distribution. Randomly assign one of 100 bulb ownerships configurations (number of bulbs, individual ratings). For each bulb, cycle through each minute of the day: switch on bulb if outside illuminance falls below threshold chosen, AND if random condition met (scaled by an overall scaling factor used to get overall lighting consumption to match UK statistics). Chance of switch on is weighted by the effective occupancy. Once switched on, a bulb stays on for a duration selected randomly from within one of nine duration ranges, allocated randomly; or until active occupancy falls to zero.

    - For MECS, the irradiance threshold is user input in tab "light_config". The bulb ownership configurations have been updated, allowing for fewer bulbs, and reflecting LED power ratings. The bulb ownership configuration to be used is specified. The probabilistic treatment of bulb use is retained (with the scaling factor to be updated).

    The **appliance model** cycles through each minute of the day, and at each time step may 'start' an appliance operating, based on a probability derived from Time Use Survey data for activity patterns in the UK and on probabilities reflecting the overall usage patterns of each appliance type. The TuS data has probabilities that a household is engaged in any of six activities (TV watching, cooking, laundry, showering, ironing, house cleaning) for each ten minute period, by weekday and weekend and by number of active occupants in that period. The appliance-specific probabilities are based on a "calibration scalar", set so that the mean annual consumption of the appliance will be correct over a very large number of stochastic simulation runs.

- This overall approach to appliance use is central to the CREST model, and nicely reflects the real variability of activities for anyone household. This approach is retained, but with simpler time-use data, since there is no prospect of replicating the sort of TuS data currently used. For cooking: a new tab has been added containing meal times recorded in cooking diary studies, user-specified choices on cooking appliances used per meal, and the typical load profile per minute for them. The model will use a random draw for each minute to decide whether to start the appropriate appliances within the relevant meal period, and once started it will operate with the specified load pattern.

- Many of the other appliances most relevant to MECS target households (eg mobile phone charging, radio, fridge) are not linked to activity patterns so don't need time-use activity data. TV, ironing and laundry are linked to activity patterns, and if those are required, replacement time use data will be required.

Each appliance can have a specified period after operation has finished during which it notionally doesn't start again (mainly used for the cold appliances).

- This is retained, and is particularly important for cooking, as otherwise an appliance specified as relevant for a meal might operate multiple times within that meal period.

Appliance power level. Appliances each have a standby and a mean power level when operating. However the actual operating power recorded is taken from a normal distribution, with the user-specified mean. The appliance power that is used whenever the appliance is operating remains the same throughout the day. Each new model run (ie running the model for a different household, or for a different day) will allocate a different operating power for each appliance, drawn from the normal distribution.

- The probabilistic treatment of appliance power levels reflects real variation between different appliances within a type, and hence variation between households. For the MECS baseline implementation the mean power is always applied, so that the model represents a specific household.

An appliance can have a bespoke power profile, with minute-by-minute power levels set. At present within the CREST model only the washing machine has such a profile coded in.

- The bespoke power profile process used for washing machines has been replicated for the new cooking model, with profiles added for a hotplates and an EPC: power level and duration of initial pre-heat, and number of cycles and power levels for dwell/reheat. These profiles are user-specified in the new cooking tab. The initial pre-heat period is calculated based on the number of people the meal is being cooked for and cooking diary data on energy use per person.

5 Modelling a variety of households, and treatment of diversity

The CREST model has strong focus on active occupancy transitions, and on time-use of appliances/activities as the basis of lighting and appliance switch-on; and for each, they have numerous uses of random processes to introduce diversity. Every run of the CREST model produces a load pattern that is representative of a different household, as for example the appliance ownership patterns are allocated each time. The apparent intention is that any single run of the model produces a load profile result which is statistically sensible when aggregated with other profiles produced from the model, eg as one household profile amongst 20million+ for the UK, or one household in a sample of those. So to create a representation of an aggregate load profile for a set of say 100 houses, you would just have to run the model 100 times and arithmetically add the resulting 100 profiles. But so many of the outputs for a model run are influenced by random selections that the results of that run don't readily represent any particular household type or context.

5.1 Baseline model of electricity use

For MECS' use, the demand model should be able to represent a specified household type and context individually, so that the influence of a variety of alternative changes in that household type's profile (eg adding eCooking of different types) can be explored. Thus a more consistent 'baseline' model has been produced, as described in section 4.

- The baseline model thus represents one specific household, with a specified number of residents, a specified set of lightbulbs and appliances, a specified cooking pattern (eg for each meal, how many people fed and the general timing) and in a place with a specified pattern of irradiance.
- Within that, the precise timing of cooking and the precise switch on and off of lights and other appliances will vary. So to represent the "typical" electrical load of that household, repeated runs are needed, which could show the peak and variation, or the average, etc
- Addition of cooking loads can then be explored for the effect on the overall load for that household
- The baseline model can be used to represent different household types and different contexts, by varying the values of the numerous parameters mentioned in section 4.

5.2 Diversity modelling

"Diversity" in the characteristics and behaviours of different individual households within a household type need to be represented, to capture the diversity expected in the energy used between them. The resulting set of load profiles for one household type can then be combined to give a representation of the aggregate load profile of a collection of such users, and/or the profiles of different household types can be combined.

Random processes are needed to introduce diversity when the baseline model is used to add multiple instances of one household type, or instances of different types, together. Table 1 summarises the approach taken for each of the main model steps: for the original CREST model, for the MECS baseline and then for diversity runs, both within and between household types.

Table 1. Treatment of diversity in CREST and MECs demand models

Aspect	**CREST 1.0B**	**MECS-CREST**		
		Baseline runs for a household type	***Diversity within same household type***	***Diversity between household types***
Number of residents	User defined	User defined	Unchanged	
Day	Weekday & weekend	Single day for now	Unchanged	Unchanged
PV	Included, for net load to grid	Ignored	Ignored	Ignored
Clearness	Input to PV model; input to lighting model. Outdoor global irradiance: empirical data from Loughborough on probability of clearness state transitions	Deterministic Outdoor global irradiance obtained from PVGIS; hourly data for one year (using 2016 currently). Applying hourly value for each minute. (Some probabilistic variation on irradiance could usefully be added, but minor effect)	Same for all households in a region	Nothing extra
Ownership of appliances	Yes/no random, weighted by empirical data on proportion of all households with that appliance	Specified ownership	Unchanged. (Could sample from MTF database for ownership variation within a household type)	Different specified ownership patterns., eg dependent on 'persona' type, or quartile energy consumption
Active occupancy	(a) probability distribution of active occupant numbers for the ten minutes from midnight (b) probability of transition from one active occupancy level to another	Specified active occupancy patterns; Cooking diaries used for occupancy at meal times and inferring occupancy across the day.	Probabilistic variation, based on the range of people per meal from cooking diaries	Cooking diary data for different household types
Lighting model	Irradiance threshold, from an input normal distribution	Specified irradiance threshold (at mean of current distribution)	Back to CREST model: Irradiance threshold, from an input normal distribution	Nothing extra
Lighting model	Randomly assign one of 100 bulb ownerships configurations	Specified ownership	Randomly assign ownership, but from a smaller set of configurations relevant to this household type	Different specified ownership patterns
	Bulb switch on: if outdoor illuminance<threshold and random scaling factor	Retain	Nothing extra	(Nothing extra, but note different bulb ownership)

	(weighted by effective occupancy)			
Light bulb run-time	Duration selected randomly from within one of nine duration ranges, allocated randomly; or until active occupancy falls to zero	Duration selected randomly from within one of nine duration ranges; range specified by bulb	Nothing extra	(Nothing extra, but note different bulb ownership)
Appliance model	(a) Probability of appliance 'start' based on Time Use data (& by weekday/ weekend and by active occupancy) (b) Within the activity time use patterns, further randomness to start	Retain, but replace Time-use data with simpler representation of periods when appliances might run	Nothing extra	(Nothing extra, but note different appliance ownership)
	Appliance run time: some 'stop' for active occupancy = zero, others don't	Retain	Nothing extra	Nothing extra
	Restart delay: random variation from 0 to 2xspecified value	Retain	Nothing extra	Nothing extra
	Operating power from normal distribution	Specified mean	Operating power from normal distribution	Nothing extra
	Bespoke power profile for washing machines only	Bespoke power profile added for cooking appliances, linked to cooking diary analysis	Nothing extra	Nothing extra
Cooking energy	No link between active occupancy and energy for cooking	Occupancy at meal time defines initial pre-heat period.	Probabilistic variation around the energy used per person	Nothing extra

In summary:

- the baseline model of one household type includes some variation in how a specified set of appliances are used, within a specific occupancy pattern. Multiple runs of the baseline model will yield a representation of the typical load profile for this household.
- diversity within that household type is represented by different occupancy patterns, different power ratings of the specified appliances and different energy use for cooking. Multiple runs will yield a representation of the aggregate load profile of a collection of households of this type.
- diversity between different household types is achieved by changes to many of the parameter values used in the baseline model. Multiple runs will yield a representation of the aggregate load profile of a collection of households of the different types.

6 Further detail on the Treatment of cooking

The original CREST model treats cooking appliances like any other, and in particular does not allow linkage between the number of active occupants and the energy used to cook for them. A new cooking tab was created that contains 4 elements:

1. The key time periods for the household: wake-up and bed time; breakfast, lunch and dinner meal periods. The meal periods are user defined but are currently set to reflect the earliest and latest meal times recorded in cooking diary studies relevant to the household under study
2. The energy use per meal, based on the cooking diaries: number of people cooked for, the energy use per capita, the proportionality of energy use and numbers cooked for
3. The appliances used for each meal: proportion cooked with electricity; of that, the proportion cooked with each of up to 3 appliances (from a set of possible appliances, currently limited to hotplates and EPCs); whether each appliance is used for each meal for a 'quick' or 'long' cook
4. The assumptions for each appliance: power rating for preheat period and for the re-heat periods; the on-time and dwell period for each re-heat cycle; the number of such cycles, for quick and long cooks, and the proportion of energy for an overall cooking cycle that is expended in the pre-heat period.

For an appliance used to cook a meal, the duration of the pre-heat cooking period is calculated based on the energy needed for that meal (from energy per capita multiplied by the number of people and the proportionality factor) and the proportion of appliance energy expended in the pre-heat period (typically 75%). The inputs at (4) above define the rest of the appliance's load profile for the meal.

The model will use a random draw for each minute to decide whether to start each of the cooking appliances, within the relevant meal period, and once started it will operate with the specified load pattern.

The measured data from the cooking diaries on energy use per meal are therefore used to calibrate the operating assumptions for the appliances and can later be used to validate the model outputs. The cooking energy results for any one model run won't precisely match the cooking diary data, as according to the probabilistic basis of the appliance model, in some cases an appliance will not actually 'start' for a particular meal; in other cases (and depending on the specified restart delay) an appliance could be used twice.

7 Illustrative model outputs

At time of writing, the basic model has been completed and has been tested with example data. These data are of the right order of magnitude to represent the sort of households that MECS might work with to introduce electric cooking, but they do not represent any coherent user story. An initial set of user stories are currently being selected and data assembled, and analysis of those will be undertaken and reported in a later working paper. The charts below are intended to illustrate the nature of the model outputs, and the sort of analysis that they can support.

When the lighting and appliance models are run, the key output is the electrical demand for the one household in each minute of the 24-hour period. Figure 2 shows one such set of results, for a household type characterised using the Kenyan cooking diary study (Leary et al. 2019).

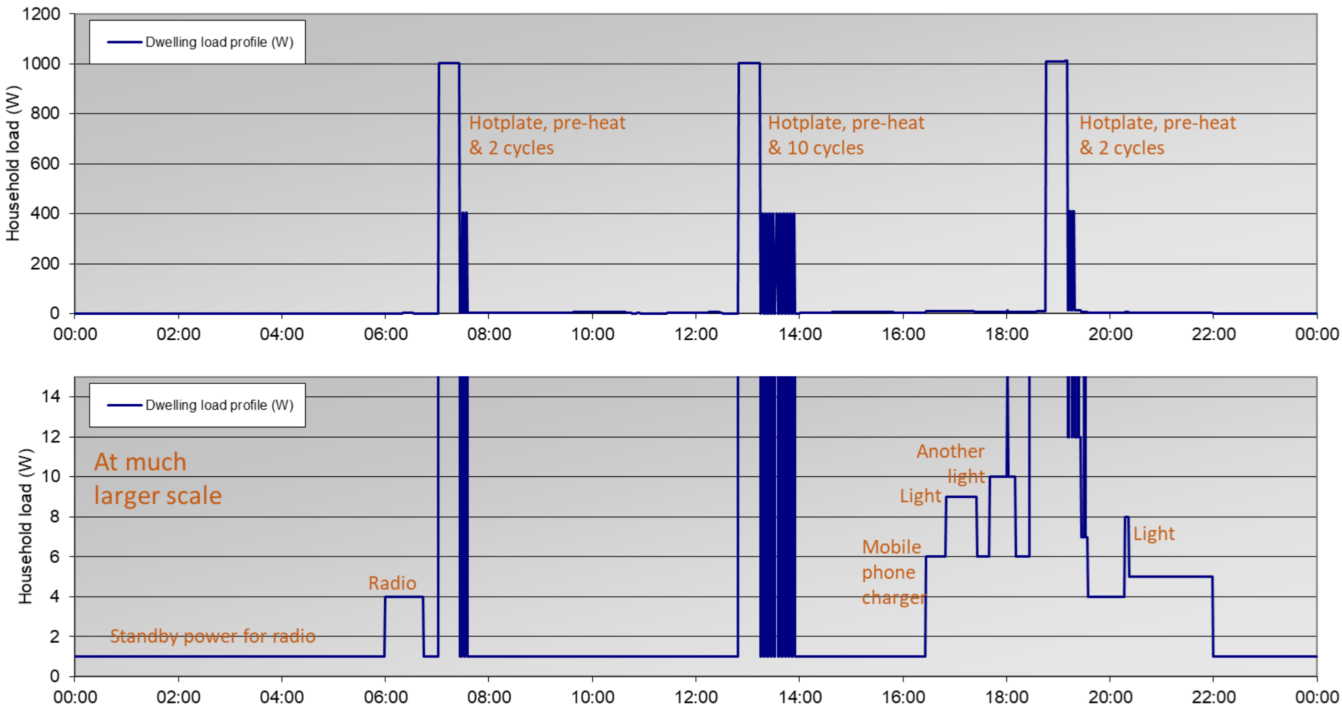

Figure 2 Example load profile outputs: one household for one 24-hour period

By resorting the results by total load level per minute, load-probability charts can be constructed. Figure 3 shows curves for three points in the day that might be expected to have high loads, as they fall within typical meal preparation times. This, or similar, results could be used to show the probability that loads exceed some threshold.

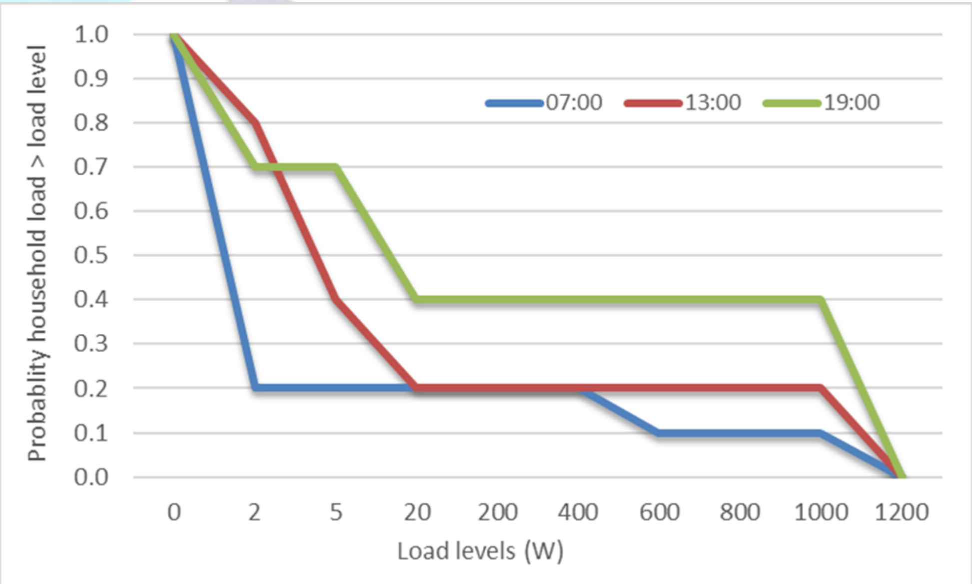

Figure 3 Load probability curve for one household

The loads for one household may be of less interest than the loads for multiple households, either to explore the diversity in load patterns, or to look at he aggregate load shape of the group. Figure 4 shows the time profile of loads for ten runs of the model using the same basic data. As in Table 1, this could be used to represent diversity within the activities of the one particular household (eg reflecting the fact that any one household may cook at varying times of the day) or diversity between different households within the same household type.

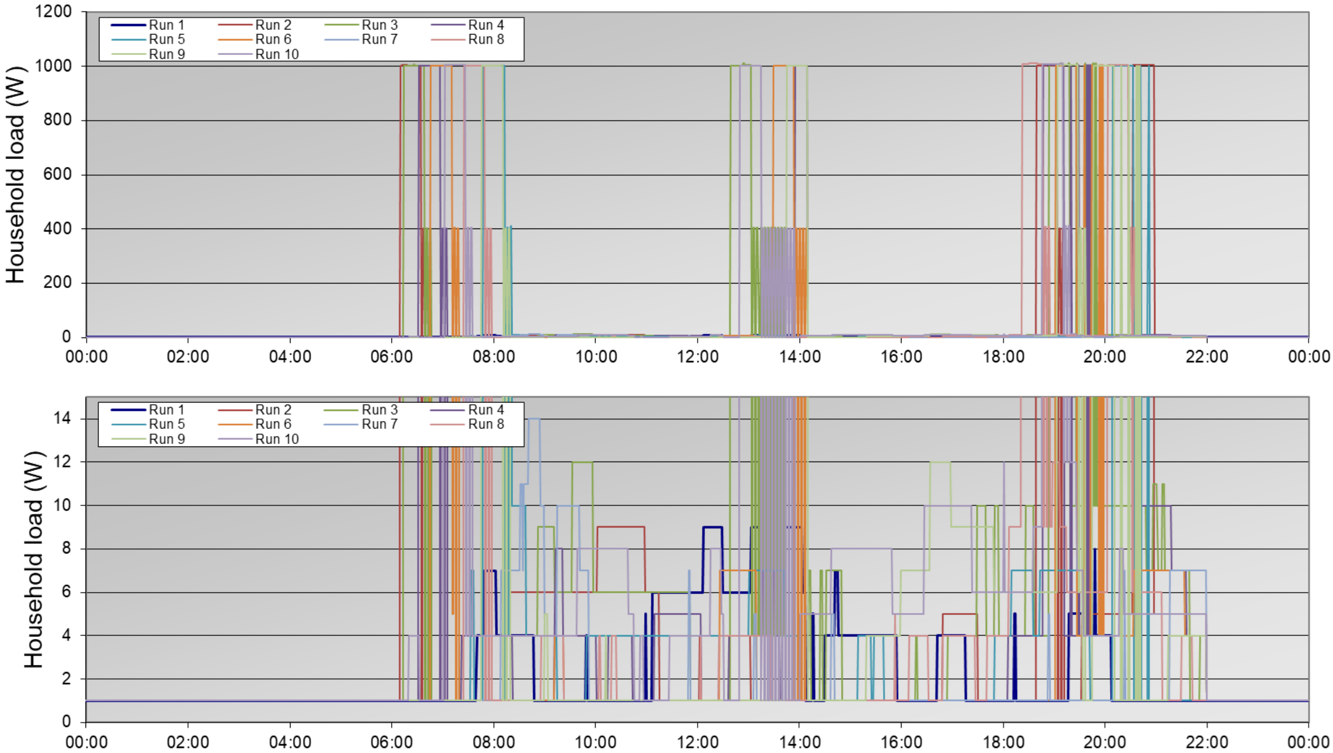

Figure 4 Example load profile outputs: ten households for one 24-hour period

The spread of cooking times is evident from the top chart. It becomes difficult to pick out individual appliances from the lower chart.

Figure 5 shows the aggregate of the loads for the ten model runs. The peak load of 5.4kW occurs just after 7pm. This demonstrates that as expected the maximum diversified demand is considerably lower than the simple sum of the ten individual maxima, which would be approximately 10kW.

The lower half of the figure shows that the maximum diversified demand of non-cooking loads for the group of households is less than 50W. In this simple example, introducing cooking would increase the peak load o the supply network by two orders of magnitude.

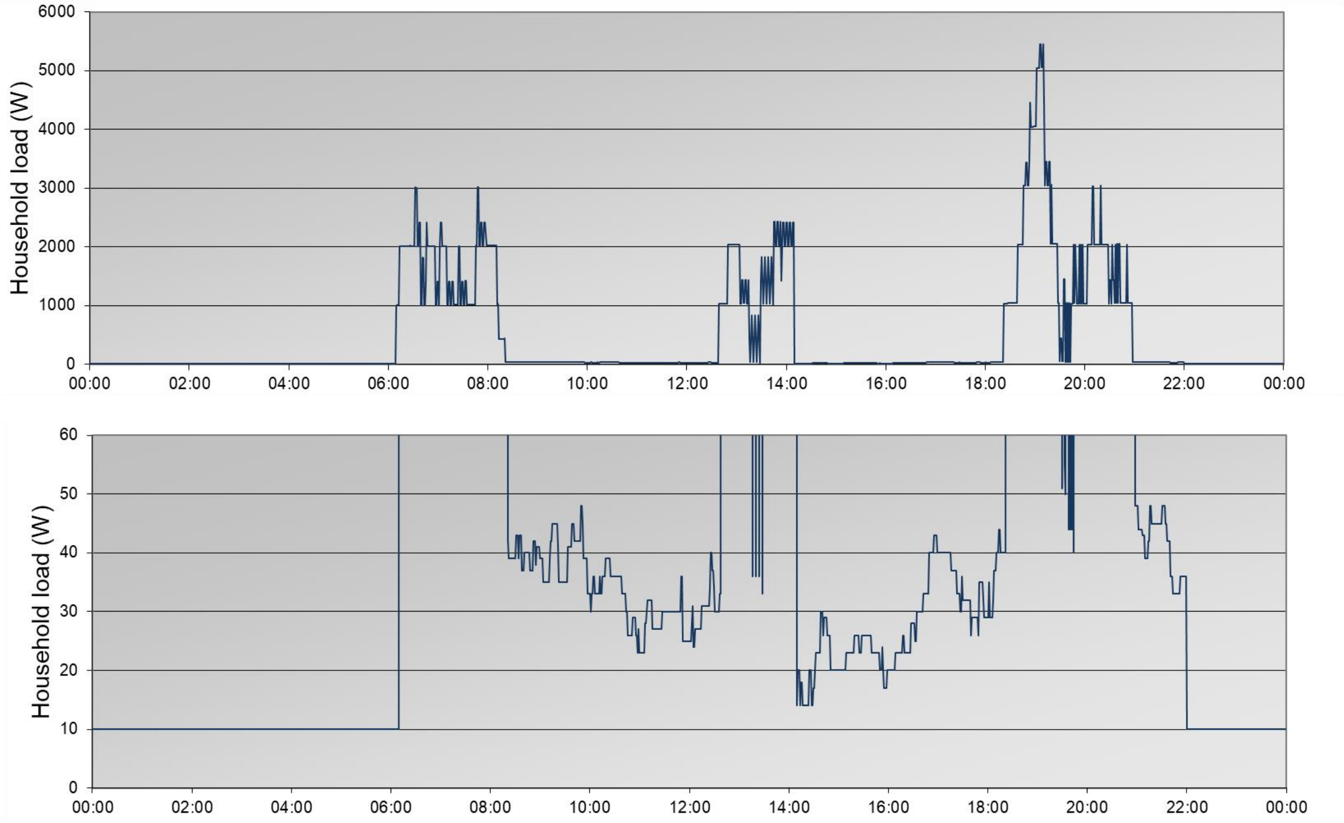

Figure 5 Example load profile outputs: aggregate of ten households for one 24-hour period

8 Conclusions and next steps

This working paper reports on the development of the MECS household electricity demand model, building on an early iteration of the CREST demand model. The model is able to make use of detailed evidence on how individual households cook, and to integrate that with simulations of the household's use of other electric appliances. The various probabilistic functions in the model can be tailored and applied to reflect different uncertainties and diversity between households, and the minute-by-minute results produced can be processed to produce different representations of overall loads.

The paper only includes some results to illustrate the types of outputs produced. The next stages in the research are to assemble the data needed for description of households in specific user stories, and then to model them. It is likely that some further model development will prove necessary, as some of the parameter values needed may reveal aspects of the original CREST model coding that need correction, or there may be appliance types that don't fit the current list. Once the model is working well with this first set of 'real' data, the resulting aggregate load profiles can be linked into the network modelling undertaken at Strathclyde, such that analysis of network issues for the uptake of electric cooking can be connected directly to the growing MECS evidence base on household cooking. A further working paper will be produced to include the first full results, and it is anticipated that the model itself will be made available.

9 References

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