POWER CONVERTER AND APPLIANCE POWER PROFILE SIMULATOR – Version 9

A Tutorial (July 2014)

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1. *INTRODUCTION*

1.1 *Need for Detailed Minute Data*

In order for the detailed analysis of embedded generation systems and other energy-efficiency measures such as Demand Side Management (DSM) in domestic households to be reliable and accurate, precise information on the host domestic electric load profile [1-4], is required. Depending on the type of analysis being conducted such detailed analysis may often require minute resolution domestic load profiles. Creating such detailed minute resolution domestic load profiles is not an easy task and researchers often rely on complex stochastic models in conjunction with electricity end-use measurement campaigns[1] and Time-Use Surveys to create these profiles [5-9].

1.2 *Nature of Domestic Load Profiles*

Domestic electric load profiles are characterised by a series of individual factors such as those presented by Mansouri *et al* [10] which render the profile highly unpredictable and continuously fluctuating. Occupancy, time of the day, month or year, behavioural attitude of the occupants, ownership of a particular appliance, and climatic conditions are all factors which contribute to shape an individual household electric profile. Combined, these factors result in a profile which therefore fluctuates seasonally, is highly intermittent in nature, with long stretches of time where the load is equal or just below the daily average and short intense pulses of high power peaks.

1.3 *Research done so far*

Considering such an extensive list of variables and possibilities, researchers have proposed a number of ways on how to create detailed domestic load profiles [2, 5]. One way which has been proposed is that of considering the total load profile of a specific household as being the aggregate of the instantaneous load demand (both continuous and intermittent) required by the different appliances [8, 11, 12]. This to a certain extent makes things easier since the electric power profiles of individual appliances can be in simplistically divided into two categories [8], namely:

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[1] End-use measurement campaigns usually involve direct measurement of power consumption from selected household domestic appliances, operating under real life conditions. Typically measurements are either taken using power meters connected individually to separate appliances, from which a total for the whole household is then calculated by aggregating all values for the separate appliances or else, by direct measurement across the main switchboard.

- **'Simple Profile'** appliances, whose power profile is a square pulse indicating an ON/OFF state varying between zero power during its OFF state and the steady-state operating power during its ON state; and

- **'Complex Profile'** appliances, whose profile is a combination of the power demand profiles of the different components constituting the appliance.

In the former case a variation which includes stand-by power consumption also exists.

Using this assumption, power *versus* time profiles can be created fairly easily using simple mathematical equations such as those described later on in this tutorial.

2. *PROGRAM DESCRIPTION*

2.1 *Scope of Program*

The ***Power Convertor and Appliance Power Profile Simulator*** makes use of a series of equations and assumptions based on the knowledge of the operating behaviour of certain appliances to provide a tool, coded using Visual Basic for Applications [13], whose aim is to assist and facilitate students and researchers alike in creating fine temporal precision profiles for pre-defined and custom based appliances. Although a number of domestic load profiles creating models and programs are already present [2, 5, 7, 9] and indeed are very useful, such models and programs mostly rely on the underlying principle of predicting the instantaneous minute load demand in households based on background field measurement datasets which the program uses to calculate the desired profiles. These datasets tend to be applicable only for specific locations having been measured, designed and constructed based on that location specific data. This to a certain extent leaves little flexibility to other users to use these programs and models in their desired location, with their specific data.

The simulator's main function is not to predict the total power consumption, but to provide a tool whereby hourly data contained in end-use measurement datasets can be converted into appliance active time for eventual creation of power *vs.* time minute profiles. The tool can therefore be used in conjunction with any end-use measurement research data to create detailed electric profiles which can be used to analyse the performance of individual appliances or to create aggregate domestic load profiles based on the individual appliances present in a particular household. The program makes use of hourly power consumption data of individual appliances to create data related to the active time of the appliance, minute by minute load profiles, information on the total power consumption and other data necessary for a detailed analysis of a specific appliance. The full list of features available in the program is listed in Section 2.2.

2.2 *Features Available*

The features available in the program include:

- Calculation of active time and of the total daily power consumption of the selected appliance;

- Availability of a number of pre-defined appliances steady-state operating power ratings or possibility of defining own custom based power ratings;

- Creation of power *versus* time profiles having a minute resolution for both 'simple profile' and 'complex profile' appliances; and

- Disaggregation of a daily power consumption value in hourly power consumption values.

3.   *TUTORIAL*

3.1   *Aim of Tutorial*

The aim of this tutorial is not limited simply on how to operate the ***Power Convertor and Appliance Power Profile Simulator*** but also to explain the methodology, calculations and assumptions used by the program for the different features available. Therefore, before each feature description, the tutorial gives a short account of the methodology used by the program to perform such a calculation or operation and also lists any assumption used.

3.2   *Starting off the Program*

The program is divided into parts:

- An excel worksheet where results and charts are listed and plotted respectively; and

- The interface between the user and the simulator.

To start the program open the Excel Workbook and press the CALCULATE button at the top part of the worksheet. The main menu of the program, shown in Figure 1, immediately appears. **Before clicking the button make sure Macros are enabled!!**

Figure 1 - Main Menu of the Power Convertor and Appliance Power Profile Simulator

3.3 Calculating the Active Time of an appliance

3.3.1 Methodology

One of the main features of the simulator is the capability to convert hourly power consumption data into time duration. This is the first step leading to the creation of the minute load profile. This feature can be used with all types of **'simple profile'** appliances, both for the pre-defined appliances contained in the "Appliance selection Box" and for user custom defined appliances. The methodology used in creating such data assumes that a finite amount of energy consumed by a particular appliance over an hour can be re-modelled using a known energy utilisation pattern for that particular appliance. As discussed, for appliances which follow the 'simple profile' pattern, it is reasonable to assume that the pattern is a simple square varying between zero power during its OFF state and the steady-state operating power during its ON state. The appliance switching-on transients are ignored as these are for the most part only seconds long and not influent on a minute duration profile [14].

Therefore, for an appliance k having a steady-state operating power $\mathbf{P_{on\text{-}app}k}$ in Watts (W), whose power consumption during Hour i was $\mathbf{P_{Cons(Hour\ i)}}$ in Watt-Hours (Wh), the active time in minutes, $\mathbf{min_{on\ (Hour\ i)}}$, for that appliance can be represented mathematically using the following equation:

$$\frac{P_{Cons(Hour\ i)}\ x\ 3600}{P_{on-appk}\ x\ 60} = min_{on(Hour\ i)} \qquad \text{- (1)}$$

The total daily active time in minutes is the addition of all minute values for all hours, whilst the total daily power consumption $\mathbf{P_{Cons\ (Daily)}}$ is similarly the addition of the individual hourly values of power consumption, equations (2) and (3) respectively.

$$\text{Total Active Time in minutes} = \sum_{i=1}^{n=24} min_{on(Hour\ i)} \qquad \text{- (2)}$$

$$\text{Total Daily Power in (kWh)} = P_{Cons\ (Daily)} = \sum_{i=1}^{n=24} P_{Cons(Hour\ i)} \qquad \text{- (3)}$$

If for any Hour i, part of the power consumption is due to stand-by consumption, equation (1) is modified into equation (4) below to include a stand-by power consumption, $\mathbf{P_{Stand\text{-}By}}$ in Watts, during the time in which the appliance is not active.

$$\frac{\left(P_{Cons(Hour\,i)} - P_{Stand-By}\right) x\,3600}{\left(P_{on-appk} - P_{Stand-By}\right) x 60} = min_{on(Hour\,i)} \qquad\qquad - (4)$$

3.3.2 Using the program with pre-defined values

In order to find out the number of active time in minutes of a particular appliance for a specific hour, insert the hourly values for the power consumption in Watt-Hours (Wh) in the corresponding power consumption boxes for each hour. If the desired appliance is one of the pre-defined appliances listed in the appliance selection box shown in Figure 2, select it by clicking the corresponding check box. Once ready from the selection and the inputting of the hourly values press the CALCULATE button situated at the bottom left corner of the main menu. The results for each hour, that is, the active minutes for each hour will appear in the corresponding boxes on the left hand side as shown in Figure 3.

Figure 2 - Pre-defined appliances listed in the Appliance Selection Box

The pre-defined appliances listed in the appliance section menu enable the user to select amongst a range of pre-defined steady-state operating power values for different appliances. The assumed power rating for the selected appliance is shown in the Assumed Power Rating Box. Figure 2 shows a selection carried out for the analysis of a refrigerator with an assumed power rating of 80 Watts. Table 1 shows the power values assumed by the program for the listed appliances in the Appliances Selection box.
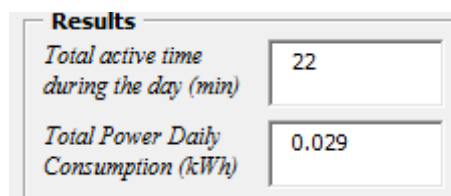

Figure 3 – Results of a calculation performed

Table 1 - Typical power consumption ranges for selected appliances

Appliance	Typical Steady-State Operating Power	Pre-defined Steady-State Operating Power value assumed by program	Comment

	Range ($P_{on\text{-}appk}$) (Watts)	(Watts)	
Refrigerator, Fridge Freezers and Freezers	80 - 250	80	Power depends on the cooling power of the appliance [15].
Television (CRT)	32 - 185	84	Power depends on size television. Active stand-by may account to a maximum of 12 Watts [16].
Television (LCD)	31 - 421	130	Power depends on size television. Active stand-by may account to a maximum of 18 Watts [16].
Microwave (Defrost)	200 - 300	N/A	Typical power used during defrosting operations [5].
Microwave (Cooking)	700 - 1,300	900	Typical power used for short length cooking and heating operations. Typical peak power is of 900 Watts although variations including rotary turntables and other accessories exist which might increase the power consumption to 1,300 Watts [5].
Electric Oven	1,000 - 3,000	2,000	Power varies depending on the type of oven used and whether or not it has hobs etc. [5, 8].
Electric Water Heater	1,000 - 3,000	2,000	Power depends on size of water heater which in itself depends on the size of the dwelling and the number of occupants presents in the household [5].
Hi-Fi	4 - 40.6	15	Power depends on type of Hi-Fi. Active stand-by may account to a maximum of 37.6 Watts [16].
Laptop	40 - 100	40	Power depends on type of type of Laptop. Different active stand-by and hibernation mode make it difficult to establish a single stand-by power consumption. Indicative figures for the two modes of stand-by mentioned are 40 and 20 Watts respectively [16].
Kettle	1,000 - 4,000	2,000	[5]

Together with the active minute values of each individual hour, the program also calculates the total daily active time of the appliance and the total daily power consumption of the appliance. The box **Results** at the top right end corner of the main menu shows the results as shown in Figure 4.

Figure 4 – Results showing total active time during the day in minutes and the total daily power in kWh of a calculation performed

3.3.3 Using the Program with User Defined Power Rating

If instead of the pre-defined values the user wants to input a custom defined steady-state operating power, $P_{on\text{-}appk}$, such as in the case of a lighting unit or an appliance not listed in the appliance selection box, activate the

custom defined power rating function by pressing the $\boxed{\textbf{USER DEFINED POWER RATING (W)}}$ button and insert the desired value in Watts (W) of the desired custom appliance in the corresponding box.

3.3.4 Adding Stand-By Consumption

Stand-by consumption for both pre-defined and custom defined appliances can be added before the calculation is performed by simply clicking the include stand-by consumption check box, shown in Figure 5, and adding the desired stand-by consumption power rating in Watts. The program will automatically subtract the amount of power required for stand-by power consumption in order to create the continuous stand-by consumption profile. The program includes this in the calculation by awarding a continuous stand-by power consumption during all the non-active minutes for that specific hour only. The sequence used by the program is to first award the power to the stand-by consumption then whatever amount remains is awarded to the active power consumption.
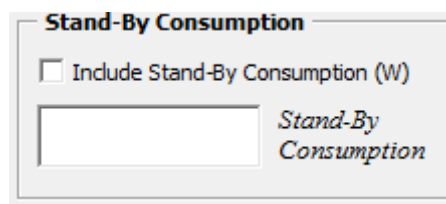

Figure 5 – Stand-by selection box

3.3.5 Exporting results to the Excel sheet

Results for these hourly values can be than exported to the accompanying excel sheet using the $\boxed{\textbf{EXPORT}}$ button. The results will appear in the excel sheet under the corresponding heading (part marked in red) and the chart will immediately update showing the number of active minutes per hour as shown below in Figure 6.
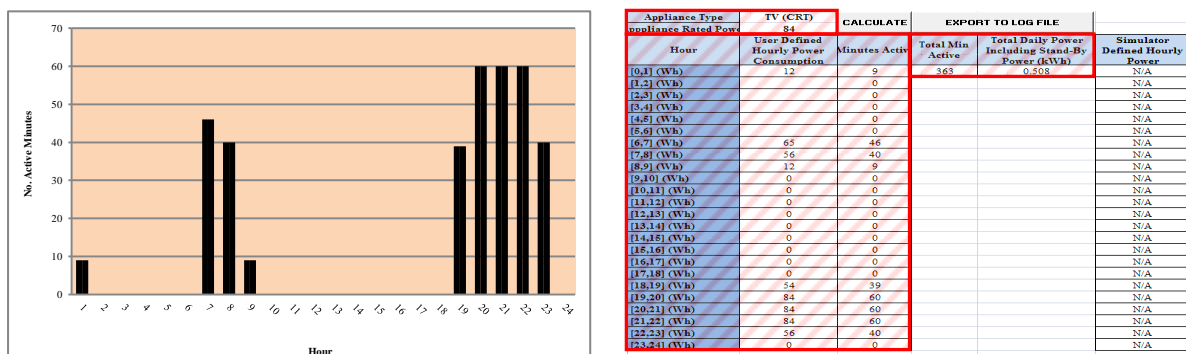

Figure 6 – Chart showing the number of active minutes per hour (left) and listed results (right)

3.4   Creating the Minute Profile

Once the active minute values have been calculated as described in the previous section, one can create the minute resolution profile by pressing the CREATE POWER vs. TIME PROFILE button which is found in the main menu of the program[2]. The program will automatically create the profile in the excel sheet by listing the power for every minute in the relevant column (part marked in red) and plotting the value on the corresponding chart as shown in Figure 7.
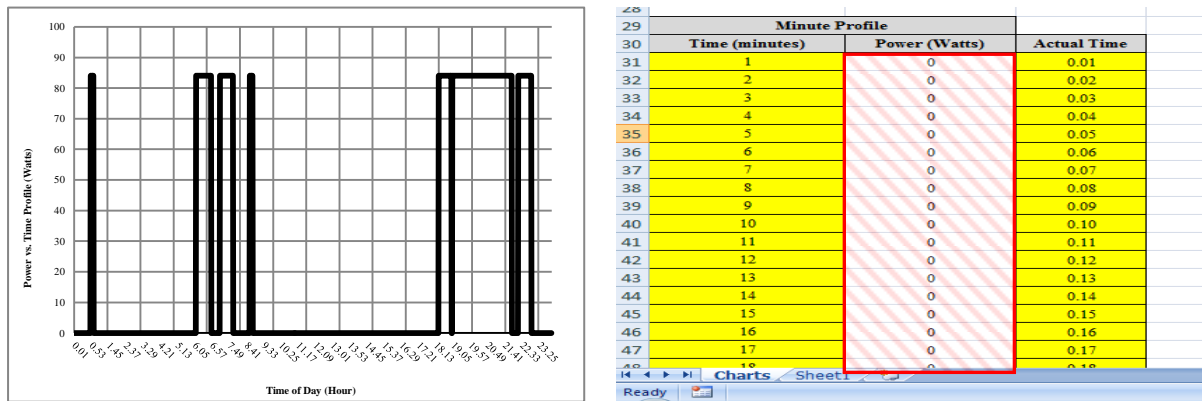

Figure 7 – Chart showing the a power vs. time profile created using the program (left) and listed results (right)

The starting time which signals the triggering of an event for a particular hour is chosen independently for every hour using a uniform distribution random number generator.

3.5   Creating Complex Profiles

3.5.1   Starting the complex profiles appliance menu

What has been described so far is valid for 'simple profile' appliances. For 'complex profile' appliances the program offers also a facility whereby the user can create minute resolution profiles for 'complex profile' appliances such as washing machines, dishwashers or electric vehicle battery chargers. To start this feature and open the complex profiles appliance menu shown in Figure 8, press the CREATE COMPLEX PROFILES button present in the main menu of the program.

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[2]   To create the minute resolution profile from the calculated active minutes the user must perform this request before exiting the main menu. Otherwise, the information will be lost, even if the active minute have been exported to the excel sheet.
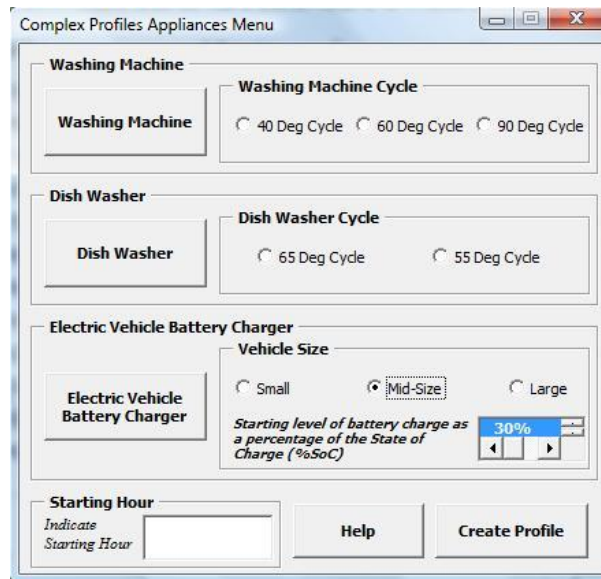
Figure 8 – Complex Profiles Appliance Menu

3.5.2 *Dishwashers and Washing Machines*

To find the load profile for a washing machine or a dishwasher simply select the desired appliance, that is, either a dishwasher or a washing machine by clicking on either of the respective buttons and after selecting the desired cycle, indicate the starting hour of the cycle. The starting hour must be an integer between 0 and 23 hours. Finally press the [**CREATE PROFILE**] button for the program to automatically create the profile and export it to the excel sheet[3]. The total power consumption of the selected cycle is also listed in the corresponding box for the total daily power consumption. The profiles created by this program are based on research done by Stokes [5].

3.5.3 *Electric Vehicle Battery Charger*

By selecting the electric vehicle battery charger option the user can find the load profile for three different types of electric vehicles sizes, based on battery capacity. There program offers three possible options:

1. *Small vehicle* refers to a vehicle having a battery capacity of 10 kWh, a range of 100 km and a rated charger power of 2.2kW;

2. *Mid-Size vehicle* refers to a vehicle having a battery capacity of 20 kWh, a range of 130 km and a rated charger power of 4.4kW; and

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[3] The CREATE PROFILE button within this menu will automatically calculate and export results to the excel sheet so there is no need for the user to press the CREATE POWER vs. TIME PROFILE in the main menu.

3. ***Large vehicle*** refers to a vehicle having a battery capacity of 35 kWh, a range of 180 km and a rated charger power of 7.8kW.

To use this option select the option electric vehicle battery charger by clicking on the electric vehicle battery charger button, select the type of vehicle and the charging starting time, which again must be an integer between 0 and 23 hours. For this specific case the user must however also specify the initial charge present in the battery by selecting a percentage from the *starting level of battery charge* box. This indicates to the program what level of charge is already present in the battery as a percentage of State of Charge[4] (SoC). Such that if the selected percentage is 40%, then it means that the battery is already 40% charged. Obviously, if the user selects a state of charge of 0%, it implies that the battery is completely discharged. Finally press the CREATE PROFILE button for the program to automatically create the profile and export it to the excel sheet. The total power consumption of the selected cycle is also listed in the corresponding box for the total daily power consumption.

Profiles are based on data and research presented in [17, 18].

3.6   *Create Hourly Values*

Often the hourly consumption of an appliance is not known, for this reason the ***Power Convertor and Appliance Power Profile Simulator*** offers an additional feature which creates hourly values from single daily values for the power consumption. This feature is available by accessing the Hourly Values Creator Menu, shown in Figure 9. This menu is accessed through the main menu of the program.

3.7.1 Methodology

This particular feature of the program makes use of step functions which assign a ratio to every individual hour indicating the share that each hour has from the total daily power consumption. The total daily power consumption is the addition of the individual ratios of all hours.

These step functions can be set either manually by the user using the sliders in the menu or automatically using the options offered by the program in the appliance prediction box.

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[4]   State of Charge (SoC) refers to the level of charge present in a battery.

Mathematically the process carried out by the program in conducting the analysis is the following:

Recall that the total daily consumption of an appliance is defined by $P_{Cons\ (Daily)}$, and that the power consumption of any one Hour i is defined by $P_{Cons\ (Hour\ i)}$:

$$P_{Cons\ (Daily)} = \sum_{i=1}^{n=24} P_{Cons\ (Hour\ i)} \qquad\qquad - (5)$$

Now let $P_{Cons\ (Hour\ i)} = a(S_i)$ - (6)

Where   **a** is a scaling factor; and

       S_i is an $\in (0,1)$, equal to the value of the step function selected for Hour i.

Substituting Equation (6) in equation (5) the following equation, equation (7) is obtained:

$$P_{Cons\ (Daily)} = a(\sum_{i=1}^{n=24} S_i) \qquad\qquad - (7)$$

Since $P_{Cons\ (Daily)}$ is known and the user defines S_i for all the 24 hours, the program automatically calculates the value of **a**, hence the value for $P_{Cons\ (Hour\ i)}$.
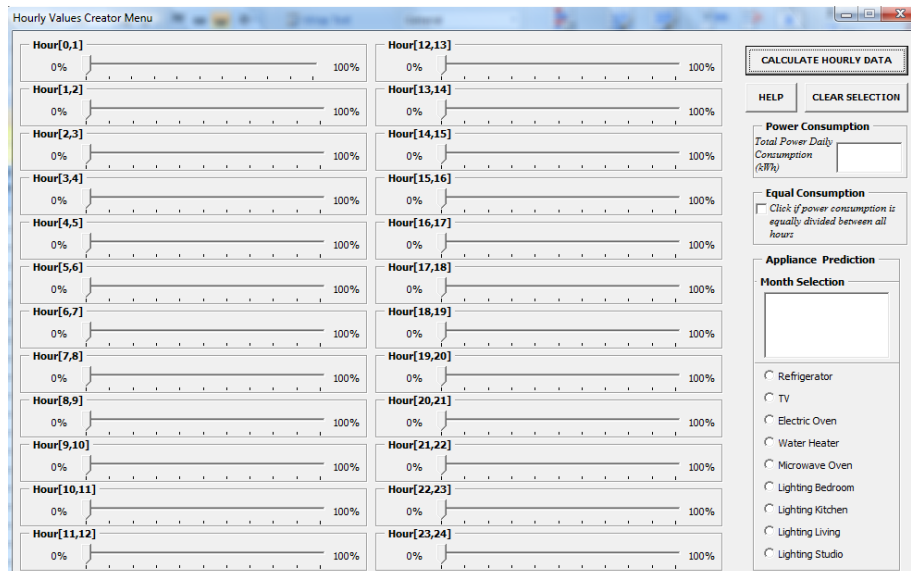

Figure 9 – Hourly Value Creator Menu

3.7.2   Using the program to find the hourly consumption

3.7.2.1   Manual setting

To manually calculate the hourly power consumption of an appliance from a known daily power consumption value, insert the daily power consumption value in (kWh) in the Total Daily Power Consumption Box situated in the middle upper part of the menu, then move the sliders for each hour accordingly to indicate the share each hour has from the total daily consumption. Press the CALCULATE HOURLY DATA button once ready and the program will automatically calculate the power consumption for each individual hour. Results are automatically exported to the excel sheet and listed under the corresponding heading as shown in Figure 10 (part marked in red).

Figure 10 – Results created by the Hourly Value Creator Menu

If the power consumption is divided equally between all hours, such that the power consumption is equal for all hours, the program can automatically calculate this by simply ticking the equal consumption box before performing the calculation.

3.7.2.2   Automatic Prediction

This menu also offers the user the possibility to select amongst a list of pre-defined appliances and domestic lighting units which are based on *by location* type. The program has an in-built dataset (for the appliances listed in the Appliance Prediction Box) which includes the probability that an event occurs for a specific hour and month. By using this feature the program automatically sets the hourly share of power consumption for the selected appliance and month. The datasets used is based on research done in Italy presented in two energy end-use measurement campaigns, [19, 20].

To utilise this feature, click on the Month Selection menu and then tick the desired appliance box as shown in Figure 11 and follow the same procedure as before, that is, insert the daily power consumption in the

corresponding box and press the [CALCULATE HOURLY DATA] button.
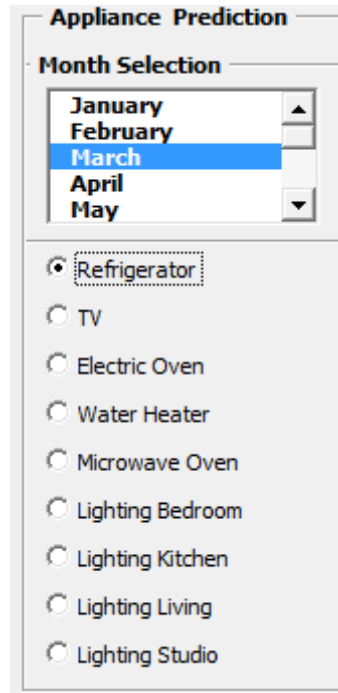
Figure 11 – Appliance Prediction Facility

After calculating the probability that an event occurs, the program awards that hour a specific share of power consumption based on the in-built datasets. The program re-calculates the probability that an event occurs each time the command is used by the user.

3.8   *Export Data to Log File*

Finally the program also offers the user the possibility to export all results into separate log files for further use with other programs, such as building simulation programs. To perform this task and create the individual log files press the [EXPORT TO LOG FILE] button present at the top end of the excel sheet and a new window, as shown in Figure 12 will appear.

The Export Data facility enables the user to export three types of files namely:

- **Active minutes and data on appliance performance** which as the name implies lists down the time during which an appliance was active for all 24 hours, the total daily power consumption and the total daily active time;

- **Power vs. Time Minute Profile** which lists down the minute resolution profile created; and

- **Simulator Defined Hourly Power Consumption**, which lists down the hourly values created using the hourly values creator menu.

To create the desired file, select which type of data file is required by selecting the desired dataset from the drop down menu and insert the desired text file name and location path in the appropriate box. Once ready press the

| Create |

button and the program will create the file in the location indicated.
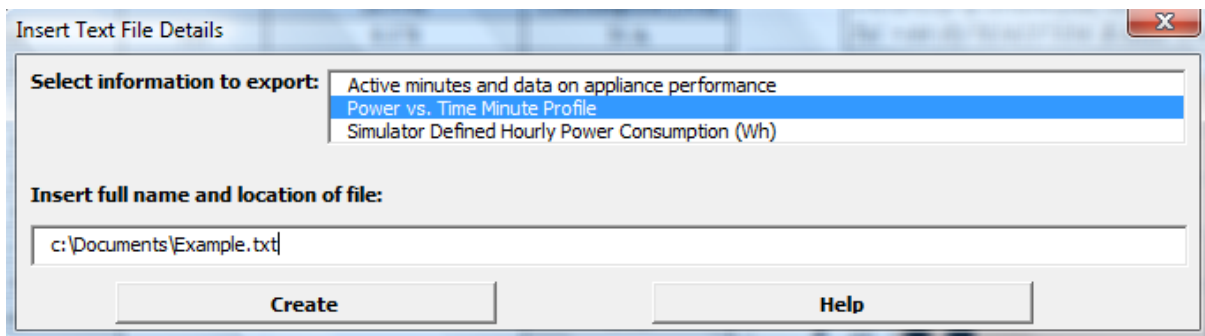
Figure 9 – Window to specify text file name and path of file

IMPORTANT: The file name and path must be specified as follows:

c:\MAIN_FOLDER_NAME\SUB_FOLDER_NAME\LOG_FILE_NAME.txt

e.g. if you want your file to be named Example and located in the Documents folder write:

c:\Documents\Example.txt

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