DEVELOPMENT AND DEMONSTRATION OF A RENEWABLE ENERGY BASED ENERGY DEMAND/ SUPPLY DECISION SUPPORT TOOL FOR THE BUILDING DESIGN PROFESSION

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ABSTRACT

Future cities are likely to be characterised by a greater level of renewable energy systems deployment. Maximum impact will be achieved when such systems are used to offset local energy demands in contrast to current philosophy dictating the grid connection of large schemes. This paper reports on the development of a software tool, MERIT, for demand/ supply matching. The purpose of MERIT is to assist with the deployment of renewable energy systems at all scales. This paper describes the procedures used to match heterogeneous supply technologies to a set of demand profiles corresponding to the different possible fuel types.

INTRODUCTION

Considerable attention is being given to the accelerated deployment of renewable energy (RE) in an attempt to reduce the environmental impact associated with traditional energy supply systems and meet obligations emanating from the Kyoto Summit and Montreal Protocol. Until now this attention has focused on renewable deployment at the strategic level with the construction of hydro stations, bio-gas plant and wind farms generating electricity to be used within a national supply network. This approach introduces additional complexities in network management, which (under current operation) will limit RE deployment to an estimated 25-30% [EA 99] of installed capacity. These limitations are a due to the intermittent nature of the renewable resources requiring reserve capacity and energy storage to maintain network stability and power quality during periods of fluctuating outputs.

To further the expansion of RE beyond this threshold requires the adoption of a new deployment strategy, which uses RE at the local level in the form of building integrated systems to minimises the quantity of energy imported from the electrical network. This approach is seen as the most effective to maximise the use of RE to meet ever-increasing building energy demands while minimising the negative impacts associated with existing network integration. The successful integration of RE systems within buildings requires careful consideration at all design stages to ensure that the selected technologies are well suited to the application.

SYSTEM DEVELOPMENT

To successfully integrated RE systems within buildings, it is crucial that appropriate technology types and capacities are identified and integrated within the building. The philosophy being adopted is to utilise demand side management techniques to reduce energy demands to magnitudes that present a favourable load for the RE systems being targeted. The technologies to be employed therefore fall into two categories:

- *demand reduction systems*: mainly passive in nature and used to reduce peak demands and reshape the demand profile, e.g. advanced glazing systems to maximise daylight capture and distribution, smart control to eliminate waste, and solar thermal collectors to offset heating capacity.
- *power supply systems*: mainly active renewable technologies which converted captured energy into electrical power (and heat) used to meet the building's reduced demand.

The MERIT system has been established to assist practitioners to identify the suitable demand reduction and supply technologies, and to ensure the effective operation of these technologies when deployed together. To support the range of possible site technology combinations, the system has several key features:

- in-built databases containing demand profiles for various sectors and against variable time resolutions;
- the ability to import site specific data as (as metered or predicted);
- a simulation engine to predict the impact of possible demand reduction measures;
- models of the different possible supply technologies;
- and a mechanism to automatically match heterogenous supply to demand.

SYSTEM OPERATION

To provide a user-friendly interface and maintain flexibility, MERIT was coded in Visual C++. The tool uses a structured navigating path to enable users to specify the problem being investigated (in terms of a family of demand profiles) and the energy supply options for possible utilisation [Born 2001]. Figure 1 describes the tool's modular components, whereby the user enters the program through the central program manager and continues through a series of dialog modules typically followed in the clockwise order depicted. Figure 2 shows the initial specification window.

The first task is to specify the climate context of the appraisal and the simulation period. This is achieved by selecting from a database of standard climates or by importing site specific weather data.

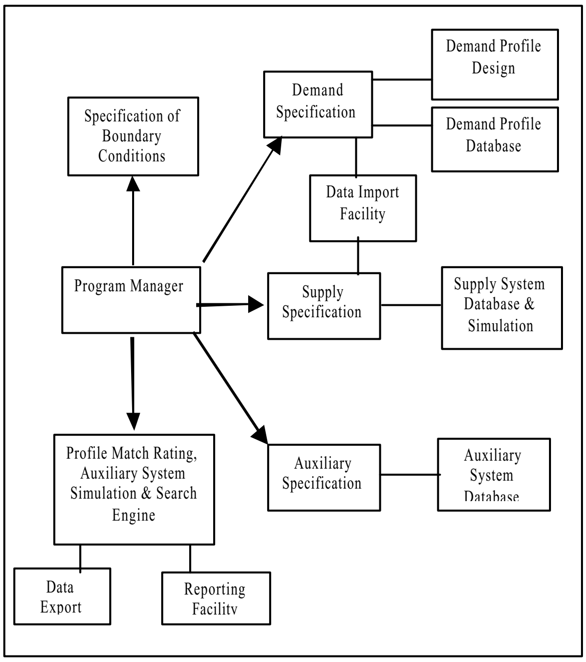

Figure 1: Components of MERIT

SPECIFYING DEMAND PROFILES AND SUPPLY TECHNOLOGIES

The second stage in the definition process is to establish the demand profile set for the problem of interest. This set can be established at any scale: a room, a building, a city portion, a region, national etc. Large scale sets may be produced by combining specific profile types after manipulation to reflect the scale. For example, a multiplying factor can be applied to the heating or power demand profile for a single house to obtain the corresponding profile for a community. Or a reduction factor can be applied to reflect the application of some energy efficiency measure. Where a monitoring programme has produced appropriate demand data for a specific site, this can be imported.

Figure 3 highlights the demand profile construction process. The individual profiles are graphed along with the combined profile for the problem under investigation. The example shown correspondins to a community comprising domestic and commercial premises and street lighting.

The next stage of the specification process requires the user to select a range of possible supply technologies to meet either the demands in whole or part. This specification is undertaken in two steps.

First, RE systems are selected from a model library or, where performance data exists for a specific technology, this can be imported. Each technology can be held individually or combined with other types to make up a combination supply. For each technology type the user specifies the required parameters. Figure 4, for example, shows the parameters required for a photovoltaic component.

Second, a back-up supply system may be selected. This may comprise battery storage, a connection to the local power supply network or a back-up generator. Where a local network connection is specified, a specific tariff may be selected from a list or, where a custom tariff applies, the relevant data can be defined and the new tariff added to the list.

When the supply options have been specified, an initial inquiry may be made to ascertain the expected output capacity and energy delivery potential. Figure 5 shows the individual and combined supply potentials for a

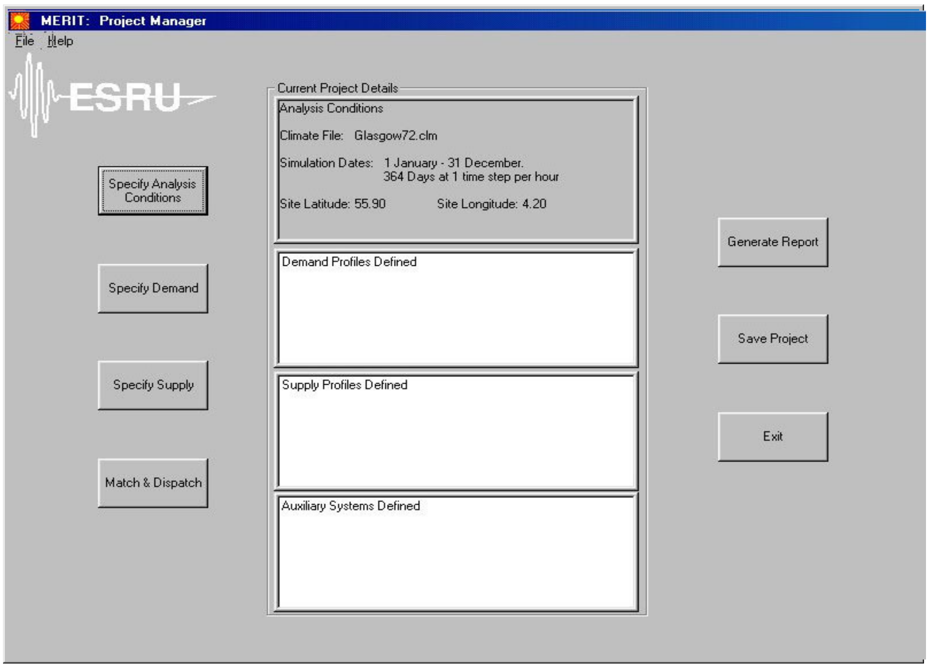

Figure 2: Initial specification window.

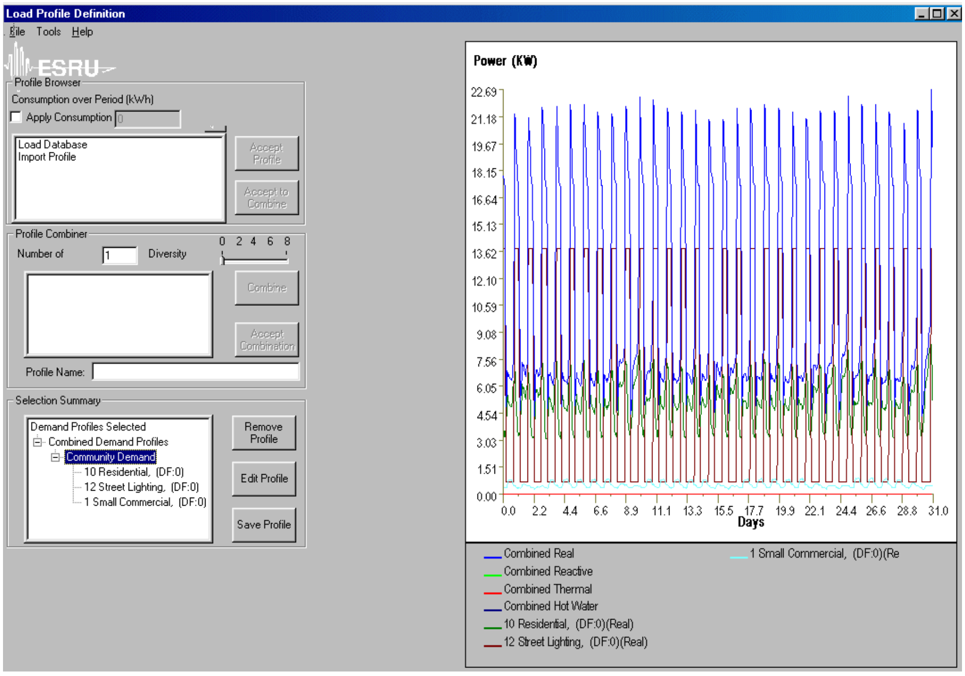

Figure 3: Example problem demand profile.

specification comprising a 15kW wind turbine and a 17kW photovoltaic system.

At this stage, the user direct the matching of individual supply options to combinations of demand profiles, perhaps in order to explore the extent to which RE technologies can satisfy demand and identify the capacity of reserve plant required for auxiliary power. Where the user has specified a large number of supply options, MERIT has the facility

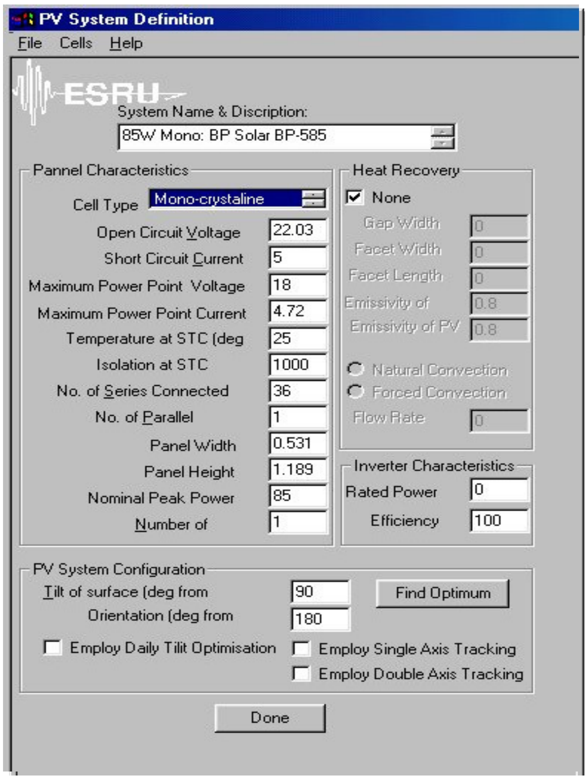

Figure 4: Specification of a photovoltaic

to conduct an automated search in order to identify those combinations that best match user specified search criteria as shown in Figure 6. In this way, a user can call for the identification of the best supply match per individual demand or best supply match overall. The automated search facility activates data processing techniques, which numerically assess the demand and supply, excluding auxiliary systems data streams, in order to performance benchmark each match via a *Match Assessment* before being evaluated by a *Search Ordering* process which presents possible matches in order from best to worst.

AUTOMATED DEMAND/ SUPPLY MATCHING

The *Matching Assessment* within the automated matching process is conducted using the Spearman's Rank Correlation Coefficient [Scheaffer and McClave 1982] to establish the phase matching between the demand and supply streams and an inequality coefficient described by Williamson [1994] to ascertain the magnitude of match. The Spearman's Rank Correlation Coefficient describes the correlation between the demand and supply variables by calculating the degree to which the variables fall on the same least square line. Calculation of this coefficient will always result in a value between -1 and 1. A result of 1 indicates perfect positive correlation and -1 perfect negative correlation, i.e. as one variable tends to increase the other will decrease at the same rate. A value of zero denotes no correlation between the variables. Within MERIT, the correlation coefficient, CC, between a demand and a supply profile, is calculated as described by eqn 1.

$$CC = \frac{\sum_{t=0}^{n} (D_t - d)\cdot(S_t - s)}{\sqrt{\sum_{t=0}^{n} (D_t - d)^2 \cdot \sum_{t=0}^{n} (S_t - s)^2}} \qquad (1)$$

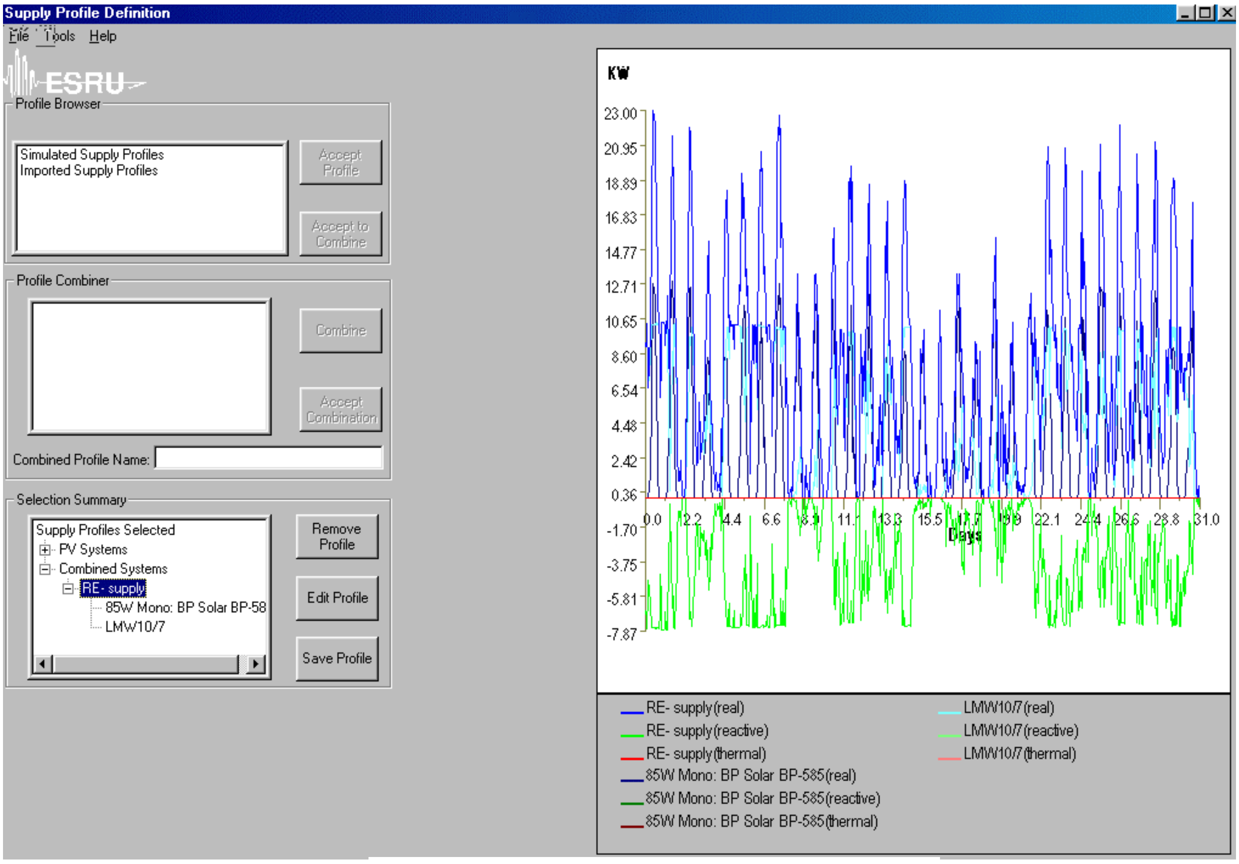

Figure 5: Estimation of supply potentials.

where D_t is the demand at time t, S_t the supply at time t, d the mean demand over time period n and s the mean supply over time period n.

The coefficient is used to describe the trend between the time series of two data sets and does not consider the relative magnitudes of the individual variables. Thus, if a supply system were doubled in size the correlation coefficient would remain the same even though the excess supply would be far greater.

Additionally, two profiles perfectly in phase with one another, but of very different magnitudes, would result in a perfect correlation, but not a perfect match.

Nevertheless, it provides a measure of the potential match, which could exist given changes to the relative capacities, i.e. through energy efficiency or altering the size of the RE system.

The inequality coefficient is used to validate prediction models used in thermal performance. The Inequality Coefficient, IC, describes the inequality in the magnitude domain due to three sources: unequal tendency (mean), unequal variation (variance) and imperfect co-variation (co-variance) as described by eqn 2. The resultant coefficient can range in value between 0 and 1, with 0 indicating a perfect match and 1 denoting no match. This metric is well suited to establishing bands of match, where matches resulting in inequalities between 0 and 0.1 could be termed good and bad matches are those resulting in values between 0.9 and 1.

$$IC = \frac{\sqrt{\frac{1}{n}\cdot\sum_{t=0}^{n}(D_t - S_t)^2}}{\sqrt{\frac{1}{n}\cdot\sum_{t=0}^{n}(D_t)^2} + \sqrt{\frac{1}{n}\cdot\sum_{t=0}^{n}(S_t)^2}} \qquad (2)$$

A *Search Ordering* process is conducted to identify which profile combinations are best. This is undertaken, firstly, by initiating a search for the best overall. This search includes every possible combination of demand and supply profiles and outputs an optimal result, which could include both multiple supplies and demands. Secondly, a demand led search finds the optimal supply profile combination for each demand scenario. The best overall match search involves obtaining the match statistics for all the possible supply and demand combinations. Single demand profiles are matched with single supplies according to eqn 3. . Single demand profiles are matched with single supplies according to eqn 3. The large C denotes the combinatorial order, and eqn 3 infers that every individual supply profile, s, out of a vector of possible supplies, S, is combined with every individual demand profile, d, out of a vector of possible demands, D.

$$M_{1D} = C_i^s\left(S_i + C_j^d D_j\right) \qquad (3)$$

Where M_{1D} is the match order for single demands, s the number of supply profiles, S_i the ith supply profile, d the number of demand profiles and D_j the jth demand profile.

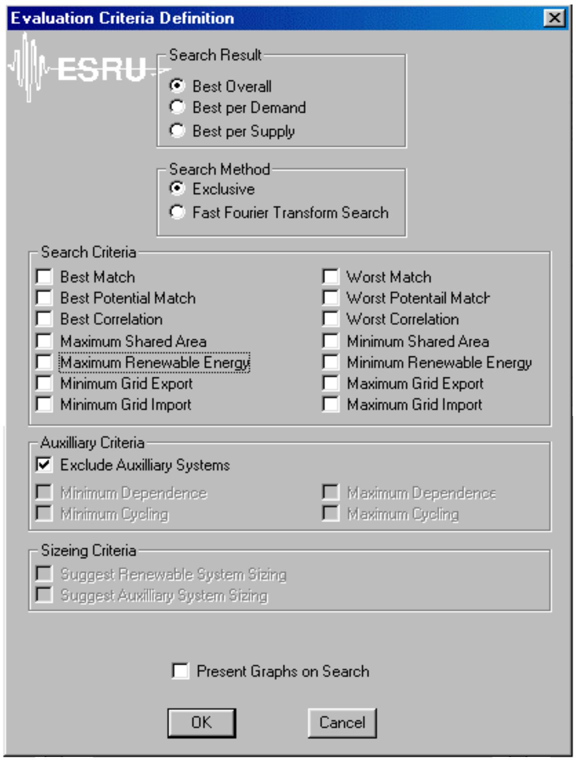

Figure 6: Search criteria for automated matching of supply to demand.

Following the single demand profiles, coupled demand profiles are matched with single supplies as described by Eqn 4. Again, the large C represents the combinatorial order. The equation ensures that every individual supply profile is combined with every possible set of paired demand profiles.

$$M_{2D} = C_i^s\left(S_i + C_j^d\left(D_j + C_k^d D_k\right)\right) \qquad (4)$$

Where M_{2D} is the match order for coupled demands, and k begins at j+1, ensuring that a supply is not combined with a multiple of the same demand. Thus S_i is the ith supply profile of a supply vector of s supplies, D_j the jth demand profile of a demand vector of d demands, and D_k the kth demand profile which is always greater (in order) than j.

The match order for three demands, M_{3D} and that for four, M_{4D}, is described by eqns 5 and 6. This pattern of matching is continued until the number of demands in combination, matched to the individual supplies, is equal to the total number of demands. For example, with eight demand profiles, each individual supply profile would eventually be matched with all eight demands.

Once single supplies and multiple demands are matched, the procedure is reversed and multiple supplies are combined with individual demands, with the match statistics noted after every combination. Thereafter, multiple supply and multiple demand profiles are combined. Eqn 7 describes how two supplies are matched with two demands. This equation is expanded until all demands are combined with all supplies and every possible match statistic is obtained. A limit incorporated into this search procedure is that multiples of the same profile are never used, otherwise the search would be infinite.

Demand led searches are modified versions of the best overall search, but only include single profiles of the search type, i.e. a demand led search will only evaluate a single demand profile in combination with every possible amalgamation of supply profiles. Such a search will find a solution for each priority ‘A’ profile made up of a single or set of priority ‘B’ profiles, where priority ‘A’ profiles lead the search. This reduces the number of possible combinations and increases the results set, enabling the identification of a field of focus for profile types. A demand led search identifies the types of supply best matched to each demand, from which more detailed studies for each demand scenario can be initiated.

During MERIT’s search procedure, the definition classes involved in a given combination are activated for the duration required to obtain the search results and then deactivated, i.e. put into storage. Minimising memory requirements promotes fast calculations and helps to ensure that the program can run on machines with limited memory. Each of the search results (correlation coefficient, shared area, inequality metric, net excess etc) is stored in an indexed array. This array is then passed into an array sorting class, which filters the array for the condition variable. If the ideal condition is not met by any of the possible combinations of profiles then the accepted interval range is iteratively extended until a combination or a set of combinations satisfies the condition. Where multiple variables are used, the same iterative procedure is employed for each variable and the index(es) of the combinations are compared until at least one combination can satisfy each variable condition.

$$M_{2D+2S} = C_i^d\left(D_i + C_j^d\left(D_j + C_k^s\left(S_k + C_l^s S_l\right)\right)\right) \qquad (7)$$

$$M_{3D} = C_i^s\left(S_i + C_j^d\left(D_j + C_k^d\left(D_k + C_l^d D_l\right)\right)\right) \qquad (5)$$

$$M_{4D} = C_i^s\left(S_i + C_j^d\left(D_j + C_k^d\left(D_k + C_l^d\left(D_l + C_m^d D_m\right)\right)\right)\right) \qquad (6)$$

REPORTING OF A DEMAND/ SUPPLY MATCHING STUDY

Following an appraisal, user is presented with a performance-reporting window as shown in Figure 7. For each demand/ supply combination identified, the total energy demands for the period are displayed together with the total energy supplied from the RE systems and the capacity of the auxiliary/ backup power supply system. The match statistics governing the phase matching of the demand/ supply streams, and the magnitude of match prior to the use of an auxiliary system, are presented as the correlation and inequality coefficients respectively. Match ratings on a scale of 1 to 10 are presented for the demand/ supply streams, again prior to an auxiliary power system being incorporated. Where a value of 1 is presented this indicates a poor match, while a value of 10 indicates a perfect demand/ supply match. Where an electrical network connection is chosen as the auxiliary power supply, the costs associated with the network connection and the power imported to meet the deficit are displayed in the auxiliary system performance section.

CONCLUSIONS

MERIT allows energy managers, planners and designers to appraise the potential for RE deployment at an early stage in the design process. Site specific technologies can be identified and their installation capacity established. Where physical constraints associated with building integrated systems limit technology deployment, e.g. the surface area available for photovoltaic deployment, further appraisals can be undertaken to establish the impact of applying demand reduction measures.

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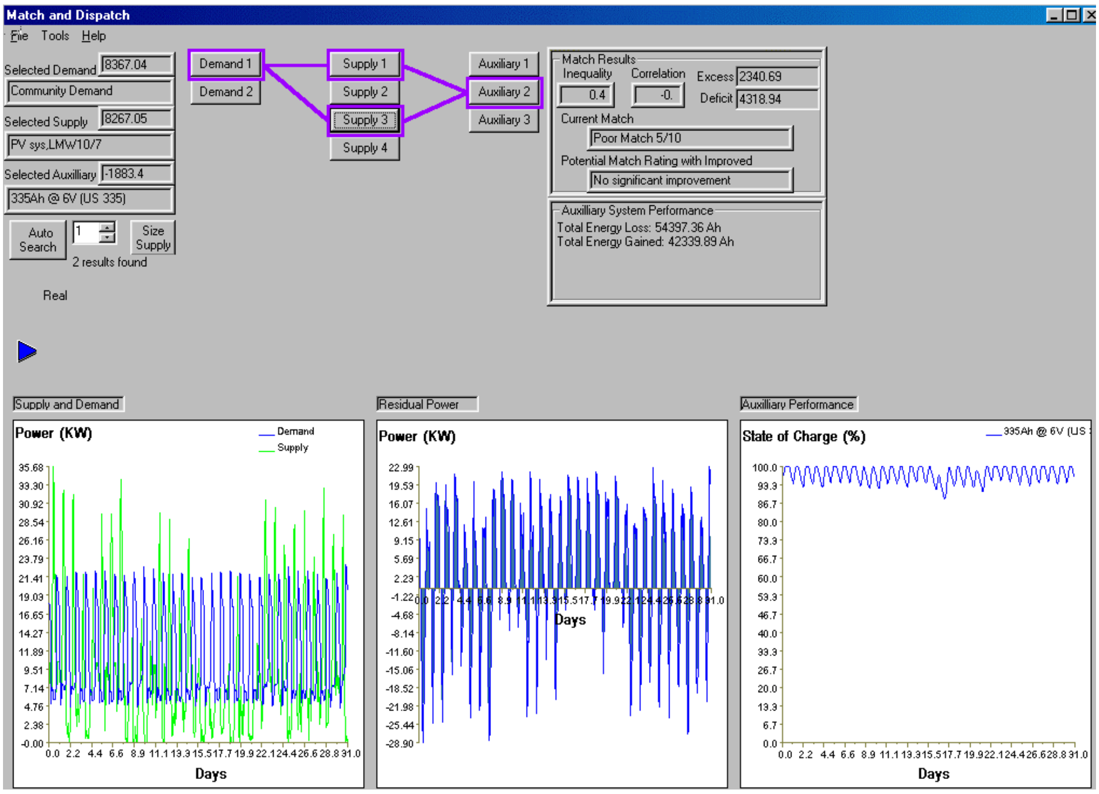

Figure 7: Example of the demand/ supply performance reporting window.