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SIMULATION-BASED DESIGN PROCEDURE TO EVALUATE HYBRID-RENEWABLE ENERGY SYSTEMS FOR RESIDENTIAL BUILDINGS IN KOREA

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ABSTRACT

Energy and environment issues such as the reduction of greenhouse gas emissions and ecological-friendly buildings are increasingly of interest in the Korean housing market. A number of technologies are considered appropriate in the Korean context, including roof-top gardens, low energy underfloor heating and renewable energy (RE) systems. To successfully adopt such technologies into domestic buildings, it is important to identify suitable technology types and capacities at an early design stage and effectively to integrate them in the building. In the study reported here, a procedure was established to enable a design team to evaluate the feasibility of new technologies using a simulation-based decision support system. The procedure was applied within a case study involving a multi-family residential building type being established within a major development programme termed 'PLUS 50'. This paper presents the design procedure and the results from the case study.

INTRODUCTION

The requirement for environment friendly and energy efficient domestic buildings is growing in Korea. While significant effort has been directed towards energy efficiency, the feasibility of integrating RE systems within the domestic sector is a new concept. A recent survey highlighted the cause of this slow progress to be related to the lack of design integration appraisal procedures (Yun *et al* 2001). The survey stressed the significance of collaboration between architects and energy system specialists, which is particularly weak within the Korean construction industry as evidenced by the Zero Energy Solar House project (Yun et al. 2003).

The basic approach to the deployment of RE systems within the built environment is to reduce energy demands to levels that present favourable aggregate load profiles to the available RE system combinations (Born *et al* 2001). In such an approach, it is important to identify appropriate technology types and capacities on the supply side, and to adopt suitable demand management techniques and energy efficiency measures on the demand side. To this end, an integrated evaluation method is required in which all aspects of building performance are considered together.

The purpose of the present study was to investigate the feasibility of establishing an integrated method for the evaluation of the performance of RE components in the context of multi-family residential buildings. The method is based on simulation and employs network data management to support collaborative decision making between design team members.

EVALUATION PROCEDURE

In the proposed procedure, simulation was used to assess the energy performance and thermal comfort of design options while resolving any inherent conflicts (e.g. between a PV façade and daylight utilisation). Simulation modelling tools exist at various levels of abstraction ranging from conceptual to detailed (Hensen 1995). As the level moves towards the latter, the number of input parameters increases and more user knowledge and effort is necessary. In practice, the non-availability of input data and lack of user knowledge presents a formidable barrier to the use of simulation. The approach adopted here was to progress from simple to more comprehensive tools as the level of detail increased. Figure 1 illustrates the approach.

First, a feasibility test is implemented at the early design stage where the design team usually acts to

- evaluate site and local conditions and establish the building's functional requirements;
- meet prescriptive standards;
- consider building geometry, envelope, systems and energy sources; and
- integrate energy features into the architectural design.

At this stage a simulation model is constructed to investigate variants of some base case design. Appropriate new and RE systems are considered along with actions that are likely to result in favourable adjustment to the demand profile. At this stage, certain conflicts may also be resolved. For example, certain RE systems may imply radical architectural changes, which are unacceptable from an aesthetic viewpoint. The design team can then use the model to locate a best compromise. At this stage, the modelling technique employed should be adequately simple, with the required information being readily accessible.

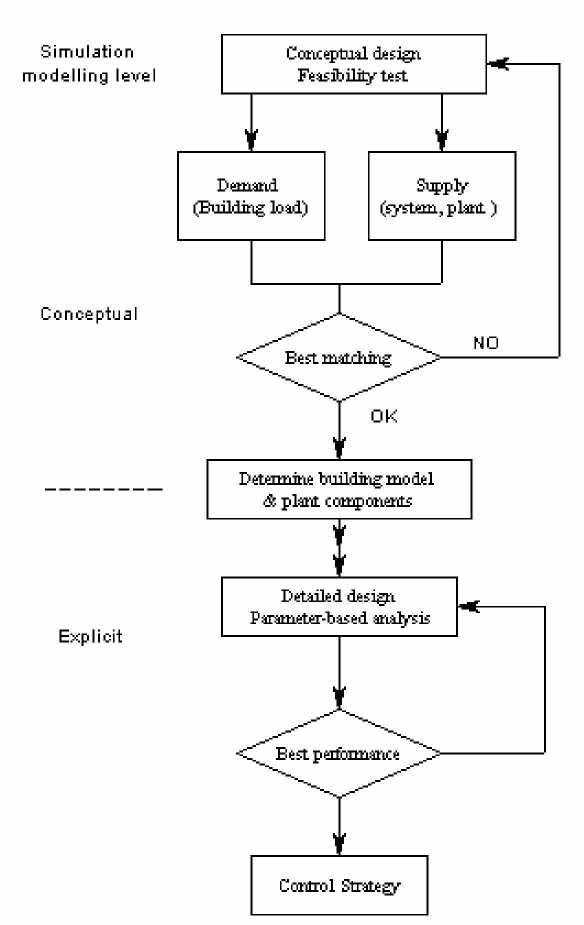


Figure 1: Schematic procedure for RE-integrated building assessment.

Once an appropriate RE system/design parameter combination has been identified, sensitivity analyses can be undertaken in order to determine the robustness of the proposed solution in terms of the many uncertainties that are inherent in the design. The important point is that the building and RE systems are dealt with in an integrated manner so that the essential interactions are fully considered. At this stage, more detailed systems modelling may be undertaken in order to inform design decisions and explore specific issues such as power quality and the demand/supply match.

DESCRIPTION OF DECISION SUPPORT TOOLS

The approach used in the procedure involves three co-operating programs: *EnTrak*, *Merit* and *ESP-r* (Figure 2). *ESP-r* (Clarke 2001) is used to model the proposed design in order to generate virtual demand profiles corresponding to the building's environmental control systems. *EnTrak*, an energy use information management tool (Kim 2004), is used to store the demand profiles from *ESP-r* alongside monitored data (i.e. real and virtual data are combined within the same data model) and to enable the data to be retrieved by other associated programs (e.g. *Merit*) via communication streams. Finally, *Merit* (Born et al 2004) is used to determine the match between supply and demand in order to make informed decisions about the suitability of certain supply mixes for particular applications.

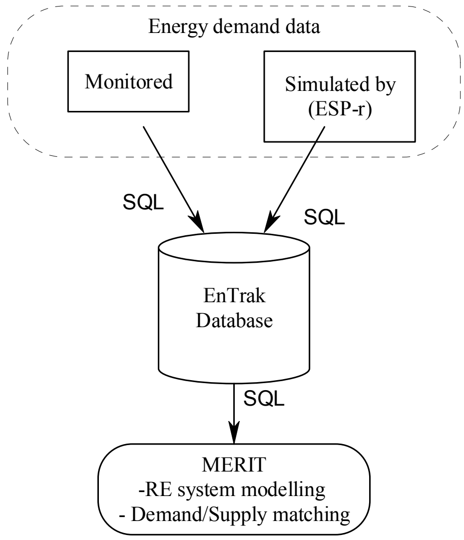


Figure 2: Structure of the decision support system.

After appropriate technologies have been identified using *Merit*, an integrated performance assessment is undertaken using *ESP-r*. In addition to modelling the heat and mass transfers within the building and RE systems, this assessment will also model the electrical systems because:

- RE systems straddle the thermal and electrical domains;
- RE systems interact with the building's fabric, plant, lighting and control systems through the electricity vector; and
- the dynamic effects of climate, occupant interaction and control action will affect the operational state of the RE systems and the ability to utilise the produced electricity.

Of course, such modelling sophistication requires detailed input data as the complexity of the computer model grows. Such issues are not considered here.

The data connectivity of these co-operating programs is established via an on-line communication protocol (i.e. SQL). The network-based decision support system allows the design team to efficiently share extensive data collected from various data channels. For example, the weather data, the technical specifications of RE systems and the energy demand data are held in a central database of *EnTrak.* This information can be accessed by *Merit* for analysing the supply/demand mix, with the results delivered to individual members of the design team who are not necessarily equipped with relevant expertise in RE systems or modelling techniques.

CASE STUDY

Plus 50 project

This case study was implemented as a part of the PLUS 50 project launched by the Korea Institute of Construction Technology (KICT). The purpose of the PLUS 50 project is to develop technologies of design, construction structure, materials and energy systems for residential buildings which prolong building life by 50% and reduce environmental impact by 50%. A demonstration building will be constructed in a urban area of Seoul in Korea during the course of the project. In terms of ecological and environment friendly design aspects, a number of element technologies are considered such as green roof and wall systems, a low energy under-floor heating system, and RE-embedded hybrid energy systems. The low energy under-floor heating system is an innovative heating system (e.g. pre-fabicated pannel structure, high radiation emissivity surface, low supply water temperature etc) developed by KICT aiming to improve the energy performance of a conventional under-floor system. The proposed design procedure was employed to support the design team in the early design stage.

Step 1: Climate analysis

ESP-r weather data for Seoul (37.34˚N, 8.42˚E) corresponding to 1983 was employed for the case study. According to the degree days (DD) analysis, the cooling DD (204.6 at 23ºC) is less than 10% of the heating DD (2637.4 at 17ºC), i.e. the heating load comprises the majority of the total load. While solar energy resources are readily available throughout the year (Figure 3), the annual wind speed distribution is mostly lower than necessary for effective wind energy generation (Figure 4). Considering wind speed reduction factors due to the location of the building, the feasibility of wind turbines is questionable.

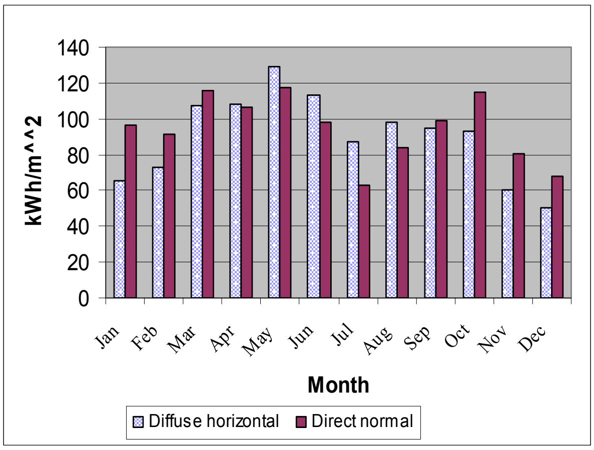


Figure 3: Monthly solar radiation.

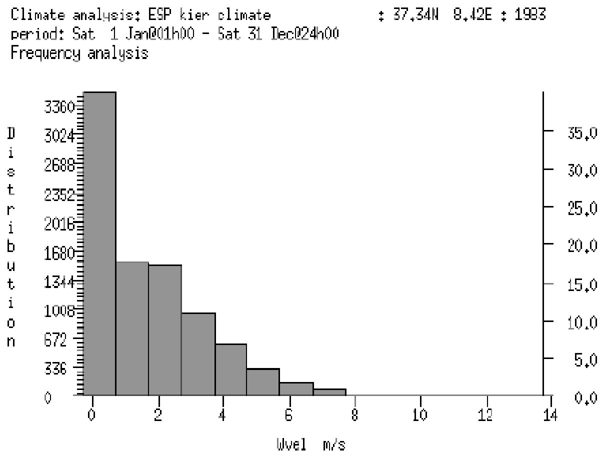


Figure 4: Frequency histogram of annual wind speed.

Step 2: Demand profile of electricity and domestic hot water via monitored data

As domestic hot water (DHW) and electricity demand are generally associated with occupant life styles rather than climatic factors, monitored and statistical data are used. Typical DHW and electricity demand profiles were obtained from on-site measurement. Based on typical daily demand patterns, whole year profiles were generated using *Merit*'s Profile Designer. To increase or decrease the magnitude of the profile, whilst maintaining its shape, a daily demand modulus was applied to the profile for different time periods throughout the year and for different days of the week. In the same way, an annual DHW profile was generated on the basis of typical DHW demand data. Figure 5 illustrates typical DHW profiles by season (winter, transition and summer) assuming that the profiles of weekdays and weekend are identical. A generated weekly DHW demand profile is shown in Figure 6. The generated data were then imported into the *Entrak* database to be used in the matching analysis.

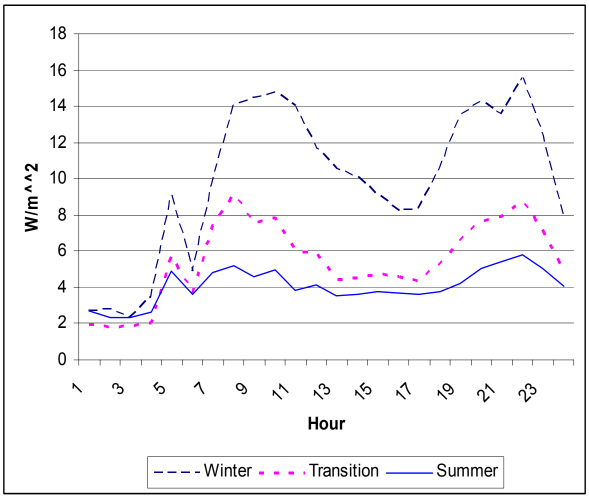


Figure 5: Typical DHW profiles by season.

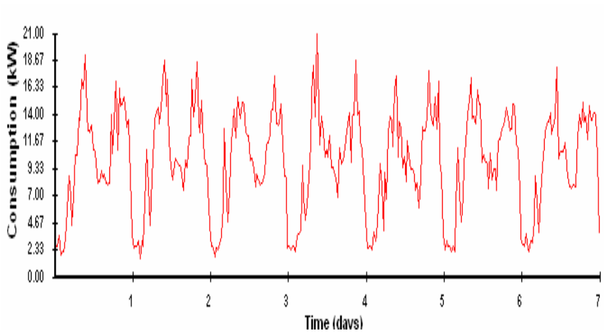


Figure 6: A generated weekly DHW demand profile (3^{rd} week of January).

Step 3: Demand profile for heating/cooling via simulation

The heating/cooling load profile is dependent on the building design and is directly related to climate factors. A detailed simulation technique is adopted to create the load profiles. To this end, a reference model was created based on an initial design for the Plus 50 project. Figure 7 shows the building appearance. The construction corresponds to a typical Korean multi-family dwelling equipped with an under-floor heating system.

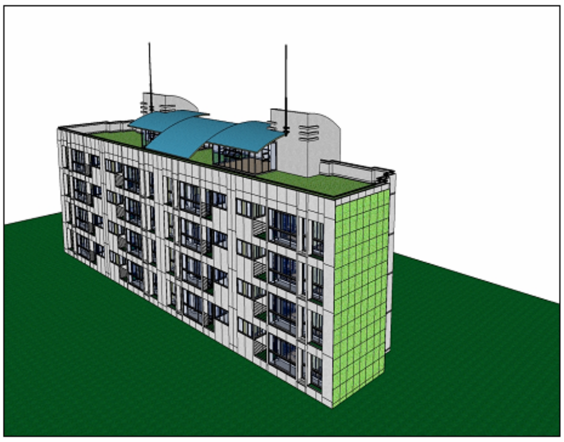


Figure 7: Appearance of the Plus 50 building.

The model focuses on a column of apartments in the building in order to identify the thermal characteristics of apartments located vertically due to variations in solar gain and the heat exchange between floors associated with the under-floor heating system. Figure 8 shows the ESP-r reference model. Apartments consist of three zones: room, front balcony and back balcony. To model the under-floor heating system, an energy supply zone is introduced beneath each apartment. This zone is controlled by a multi-sensor controller that supplies energy in response to apartment temperatures. The simulation results indicate that this model reasonably represents the thermal characteristics of an apartment with the under-floor heating system. Based on this reference model, various design scenarios were explored (e.g. conventional under-floor heating versus low energy under-floor heating system). The simulation results were then imported into *EnTrak* for inclusion in a subsequent matching study using *Merit*.

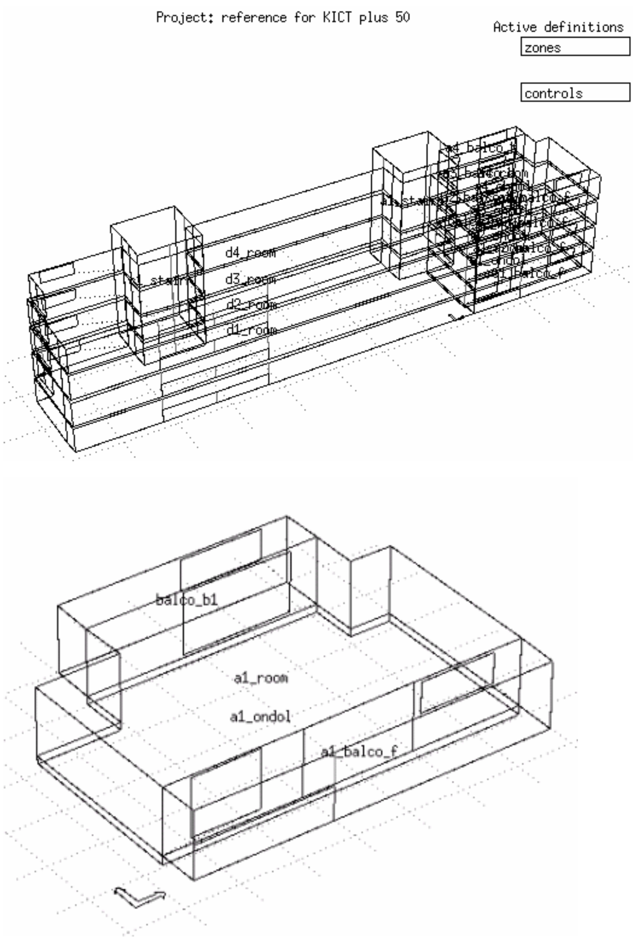


Figure 8: ESP-r model of the PLUS 40 building.

According to the simulation results, there is a high possibility of overheating in some zones, particularly on the first and second floors in the reference model equipped with the conventional under-floor heating system. As a result, the peak heating load is high. In contrast, the magnitude of the peak load is reduced in the case of the low energy under-floor heating system. Although the low energy under-floor heating system is more favourable due to the shape of the demand profile and lower required heating capacity, improved insulation must be introduced at the top floor roof. Otherwise, the top floor cannot be maintained at the required temperature set-point. The roof-top garden, which is one of elements of the PLUS 50 building concept, will be helpful in this respect by providing additional insulation.

Step 4: Renewable energy system options

Ruling out the wind turbine option through the climate analysis which showed that the wind resource is unfavourable, solar collector, PV and heat pump systems were selected for consideration. The specification of the solar collector system used within the matching analysis is illustrated in Table 1. The PV system is dedicated to the domestic electricity demand and incorporates a battery to improve the match. The specification of the PV system is shown in Table 2. The capacity and COP of the heat pump system is 10 kW and 3.8 respectively for heating, and 10kW and 5.5 respectively for cooling. Assuming the heat pump system is operated by an on/off control, the supply from the heat pump system is essentially constant because it does not depend on climate but on ground temperature (at a 70-100m depth), which is steady at around 13ºC in winter and 15ºC in summer.

A number of system options were defined according to the structural conditions of the Plus50 building type. The installation of the solar collector and the PV system is restricted by the building structure in terms of position and area, leaving two candidate positions for installation: at the front balcony (6.15m^2) and roof (32.7m^2). The balcony and roof areas will accommodate a solar collector or PV component for an individual apartment. To examine the impacts of building orientation on thermal demand and RE system supply, alternative ESP-r models were defined and used within the matching analysis.

Table 1: Solar collector with storage tank.

Parameter	Value
Collector length (m)	2.49
Collector width (m)	1.323
Collector depth (m)	0.095
Plate thickness (m)	0.0005
Plate length (m)	1.17
Plate longwave emissivity	0.95
Plate solar absorbance	0.95
Plate conductivity (W/mK)	380
Number of tubes	11
Spacing between tubes	0.0114
Storage tank:	
Volume of storage tank (m^3)	300
Wall conductivity of storage tank (W/mK)	0.03
Wall thickness of storage tank (m)	0.05
Surface area of storage tank (m^2)	320
Initial temperature of storage tank (ºC)	25
Return temperature of storage tank (ºC)	30
Room temperature of storage tank (ºC)	0

Table 2: PV system.

Parameter	Value
Manufacturer	Siemens
Cell type	Monocrystalline
Nominal power (W)	110
Maximum power point current (A)	6.3
Maximum power point voltage (V)	17.5
Short circuit current @ STC(A)	6.9
Open circuit voltage @ STC (V)	21.7
Standard test condition (STC) temperature (ºC)	25
Standard test condition (STC) insolation (W/m^2)	1000
Panel height (m)	1.32
Panel width (m)	0.66
Number of cells in parallel	1
Number of cells in series	72

Step 5: Matching analysis

The demand profiles for thermal and DHW were used to construct demand side options with a solar collector and heat pump system. Figure 9 shows the matching analysis facility of *Merit* where 5 demand side options and 4 supply side options are defined. Each demand option consists of a set of sub-demand profiles. For example, the low energy under-floor heating option aggregates thermal load profiles from 4 under-floor heating zones simulated by ESP-r. On the other hand, a supply option represents the prediction of the energy generation simulated by *Merit.* For example, 'solar_roof_south_5' in the supply side option in Figure 9 has a supply profile generated by the solar collector installed on the roof with 5 panels and south orientation. When making the matching analysis, every possible combination of demand/supply options as well as individual demand/supply matches are assessed to identify the best overall match in terms of user-selected match statistics.

Through the auto-search matching analysis in *Merit*, the best match was obtained by matching the heating demands for the 4 apartments with a roof-installed solar collector and a heat pump. As can be seen in Figure 9, the graphical result indicates the demand/supply combination and displays the matching profile. As the heat pump determines the base-line magnitude of the supply profile, a recommended capacity of the heat pump can be determined with the storage tank of the solar collector system.

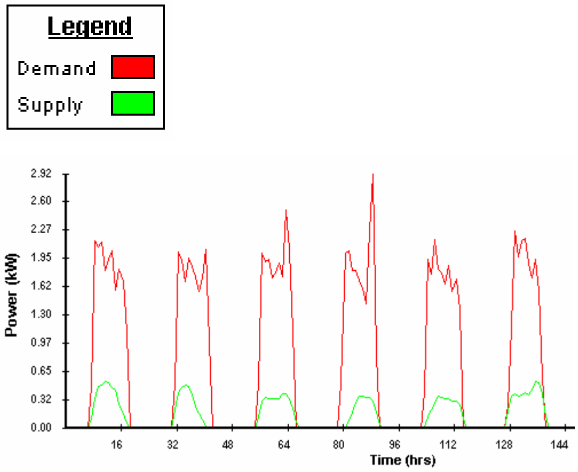
To match the DHW demand, the aggregate supply from the solar collector is more effective than individual supplies. Since the DHW profile is based on statistical data, thermal demand plays a major part in determining the match. It implies that if DHW demand can be controlled so as to adjust the shape of profile to a supply profile, a better match will be achieved.

As a demand side load, the typical domestic electricity use pattern was used after adjustment to relate to the area (96.1m^2) of the zone in the ESP-r model. Four PV installation options were considered according to position and orientation: balcony south, roof south, roof east and roof tracking. Since the power generation from the PV system is too small to meet the electricity use of the household, it was assumed that the night-time electricity demand was matched with electricity imported from the grid.

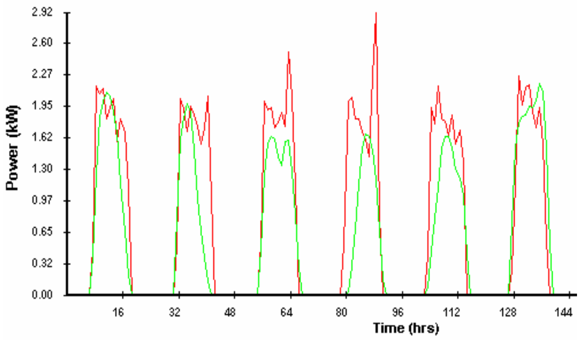
Statistics from the auto-search matching analysis are given in Table 3 where the indices of matches are described in a previous study (Born et al 2004). As presented in the table, the best match was obtained from the combination of ‘balcony south’ and ‘roof tilt tracking’. If the battery system is utilised, the match can be increased from 74% to 77%. A flat roof location is better than the tilted roof for the case where the building is oriented east. No significant improvement will result from adding a battery in the case of an east-facing, roof-installed PV system. Overall, roof mounted PV systems make reasonable matches except for the 45 degree tilt east oriented PV system.

Although a good match is obtained from the combination of ‘balcony south’ and ‘roof tilt tracking’ (or ‘roof mounted’), it may not be acceptable to install both systems in the building. The design team can decide their preference for the location for the PV installation.

The decomposed graphic results of the matching analysis for ‘balcony south’ and ‘roof tilt tracking’ are displayed at a) and b) respectively in Figure 10. In the case of the balcony installed PV system, the correlation is as high as for the roof mounted PV system although the inequality is not good (i.e. it has a high value). It implies that the match can be improved by either increasing the number of PV panels or matching the current supply with small demands. The former case is unrealistic due to the limitation of the available façade area (especially with a balcony-installed PV system). Matching with small demand profiles implies that the total household demand must be divided into its components (i.e. by appliance).



a) Balcony south.



b) Roof tracking.

Figure 10: Graphic results of matching analysis for PV options (8/4-13/4).

Step 6: Identifying design considerations

The case study focused on a PLUS 50 building, concentrating on a demand/supply matching analysis. In relation to RE installation position and system combinations, the following issues were identified:

- There are constraints in installing RE systems because the roof-top garden is considered as a key design element of the PLUS 50 building (although this is the favoured position for the PV system or solar collectors).

- Adopting the low energy under-floor heating system results in more favourable load profiles when compared to a ground-source heat pump. However, there is a high risk of energy supply shortage on the top floor due to the thermal loss through the roof where improved insulation levels are required.

Design conflicts exist between the key elements of the PLUS 50 building – the low energy under-floor heating system, green envelopes and RE systems. This conflict can only be tackled in an integrated manner. This requirement provided the rationale for the present study.

The study gave information that may be used to assist with decision-making on building design to accommodate RE integration. The study also identified the design parameters that should be considered significant at the next design stage. To tackle potential problems, RE plant operation and control strategies should be studied together with possible demand side measures. Such a parameter-based analysis should focus on the following issues.

- complex effects of hybrid PV systems (e.g. insulation, thermal supply and power generation);
- effect of shading by adjacent buildings on PV power generation and passive solar heat gain;
- thermal effects of roof-top gardens (e.g. insulation in heating season and evaporation in cooling season);
- other demand side measures (e.g. low emissivity glass, double façades, ventilation strategy *etc*); and
- interactions between thermal and power demand/supply and between different new and RE systems (e.g. integration of heat pump and PV systems).

CONCLUSIONS

An approach to the evaluation of integrated RE systems was investigated, including consideration of heat and power demand profiles, necessary climate data, supply-side options, and strategies for matching supply and demand. The procedure entails a two-stage process: a feasibility study followed by a parameter-based analysis.

An integrated software environment was proposed and its use demonstrated through a case study. The procedure employs an integrated building energy simulation program (*ESP-r*), a new and RE modelling and matching tool (*Merit*), and a fuel use information management program (*EnTrak*). This network-based decision support system allows a design team to exchange information within a collaborative framework.

Based on the requirements identified in this study, new analysis facilities will be integrated in *Merit* such as the demand profile decomposing algorithms and demand side control (DSC) algorithms. DSC is a function of user-imposed criteria or demand side management measures (e.g. improving the energy efficiency of appliances or changing the pattern of energy use). Different control strategies can be simulated by setting the various DSC parameters (e.g. priority, methods and periods) for a certain demand profile. The new facility will be used to identify a demand/supply control strategy which optimises the match between supply and demand.

REFERENCES

Born F, Clarke J and Johnstone C, 2004, Development of a Simulation-Based Decision Support Tool for Renewable Energy Integration and Demand-Supply Matching, *Proc. eSim 2004*, pp205-12, Vancouver.

Born F, Clarke J, Johnstone C, Kelly N, Burt G, Dysko A, McDonald J and Hunter I, 2001. On the integration of renewable energy systems within the built environment, *Building Services Engineering Research and Technology*, V22, N1, pp3-13.

Clarke J, 2001, *Energy Simulation in Building Design* (2nd Edn), Butterworth-Heinneman, London.

Kim J, 2004, Integrated Information System Supporting Energy Action Planning via the Internet, *PhD Thesis*, University of Strathclyde.

Hensen J, 1995, On System Simulation For Building Performance Evaluation, *Proc. Building Performance '95*, pp259-67.

Yun J, Back N and Yu C, 2001, An Overview of R&D in the Field of Solar Building and System in Korea, *Journal of Korea Architectureal Institute,* Chungnam, Deajeon.

Yun J, Back N and Yu C, 2003, Design and Analysis of KIER Zero Energy Solar House, *Proc. ISES Solar World Congress*, Goteborg, Sweden.

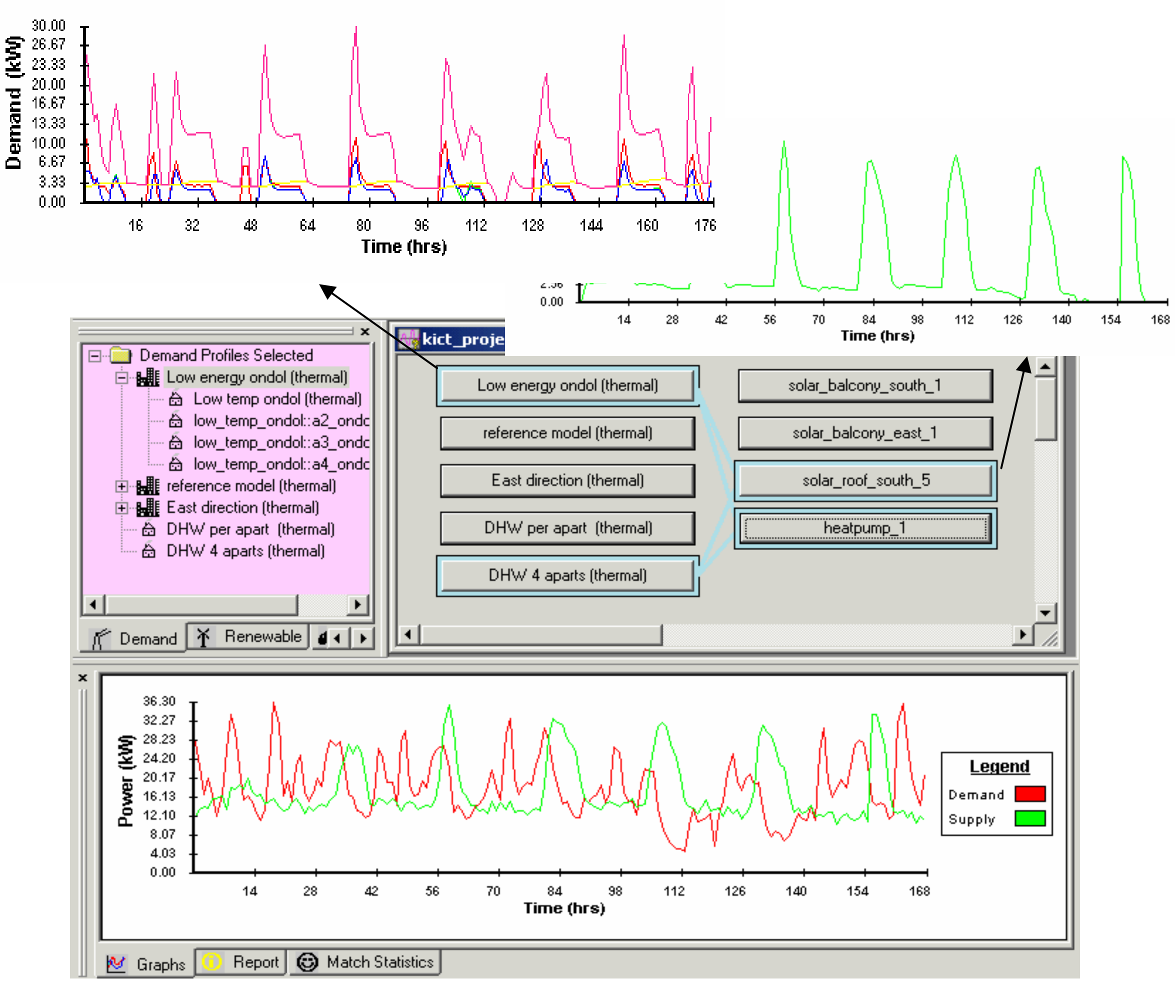


Figure 9: Auto-search match of heating and DHW demand to solar collector and heat pump outputs.

Table 3: Matching analysis statistics (daytime-only domestic electricity demand, one month 1/4-30/4).

PV option	Total supply (kWh)	Match	Percentage Match*	Inequality Coefficient	Correlation
Balcony south + roof tilt tracking	480.4	Good	74	0.26	0.79
Roof tilt tracking	388.46	Good	71	0.29	0.79
Roof south, 45° tilt	334	Reasonable	67.9	0.32	0.78
Roof south, 5° tilt	327.45	Reasonable	67.37	0.33	0.79
Roof east, 5° tilt	321	Reasonable	67.07	0.33	0.79
Roof east, 45° tilt	255.18	Poor	59.01	0.41	0.73
Balcony south	91.94	Very bad	27.7	0.72	0.79
Balcony south + roof tilt tracking + battery	469.04	Good	77.37	0.23	0.84
Roof east, 5° tilt + battery	323.38	Reasonable	67.67	0.32	0.8

* Percentage match = (1 - Inequality) x 100