THE DEPLOYMENT OF PHOTOVOLTAIC COMPONENTS WITHIN THE LIGHTHOUSE BUILDING IN GLASGOW

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ABSTRACT
This paper reports the integrated appraisal method used in the design and deployment of passive solar, wind power and photovoltaic technologies within the Lighthouse building in Glasgow. This Charles Rennie Mackintosh designed building was refurbished to celebrate Glasgow’s selection as UK City of Architecture and Design 1999. The incorporation of renewables was undertaken, as part of EC DGXII's RE-Sart project, to demonstrate that renewable technologies can be effectively deployed in an urban context. The key to successful deployment of active renewables proved to be the concurrent deployment of demand reduction measures thus ensuring a better supply-to-demand match.

Keywords: Building Integration – 1; Storage – 2; Off-Grid – 3.

1. INTRODUCTION

The Lighthouse Building was the centrepiece of Glasgow's celebrations as UK City of Architecture and Design 1999. This Category A listed building is of major architectural significance. Its refurbishment set out to combine traditional architectural values with modern energy efficient performance. The project team comprised Glasgow City Council, Oscar Faber, Page and Park and the University of Strathclyde's Energy Systems Research Unit (ESRU). Funding came from a number of agencies, including the Millennium Commission, EC DGXII and the UK's Energy Design Advice Scheme. The refurbishment also presented the city with an opportunity in relation to the ongoing EC RE-Start project [1] which aimed to demonstrate the potential benefits of deployment renewable energy technologies at the urban scale. A specially configured portion of the building served as a showcase for state-of-the-art technologies that demonstrate the integration of complementary passive and active renewable energy components. This paper describes the performance assessment methodology and the outcomes as used to:

i) reduce energy demands;
ii) size micro-scale, renewable generation systems to match a significant portion of these demands; and
iii) effect grid co-operative electrical power delivery.

2. ENERGY REDUCTION TECHNIQUES

The combination of high power demands of urban life styles and low power densities associated with renewable energy systems typically makes renewable energy deployment in the urban environment non-favourable because large capture areas are required facilitate matching. The feasibility of small scale embedded generation can be improved by the adoption of demand reduction and management measures. In certain cases such measured can be used to ensure that the scale of any renewable energy technology deployment is practical in relation to the spatial limitations imposed by a building's geometry and its relationship with the surroundings. To attain this state requires demand reductions well beyond that implied by present UK best practice targets of around 220 kWh/m^{2}yr [2]. Table 1 presents a scenario to illustrate the improved prospect for supply/ demand matching after the implementation of demand reduction measures.

Early in the Lighthouse refurbishment project, various demand side reduction measures were simulated to assess the impact on energy saving. The philosophy adopted was to use passive renewable energy technologies to displace conventional HVAC plant, thus reducing the energy demands; and then deploy active renewable energy systems to meet the majority of the residual demand. The appraisal methodology was based on an integrated simulation approach employing the ESP-r system [3]. Simulations were undertaken for several passive technologies when deployed severally and jointly. In this way the optimum combination of technologies were identified.

Table I: effect of demand reduction measures on supply/demand matching.

<table>
<tr><td colspan="2">Typical demand case = 50W/m^2 (300kWh/m^{2}yr) equates to a façade power intensity of ~100W/m^2
Demand reduced case = 12W/m^2 (70kWh/m^{2}yr) equates to a façade power intensity of ~24W/m^2</td></tr>
<tr><td>Photovoltaics example</td><td>Small scale wind power example</td></tr>
<tr><td>South facing surface, 45° inclination, mean annual irradiance, I, = 150 W/m^2 (Eskdalemuir).
Availability = 0.5
PV efficiency, η, of 13%</td><td>Mean annual wind speed, v, = 5 m/s (Eskdalemuir).
Availability = 0.45
Coefficient of performance, Cp, of 0.3</td></tr>
<tr><td>Mean power production = $I\eta$ = 19.5 W/m^2</td><td>Mean power production = $0.5\rho CpAv^3$ = 22.5W/m^2</td></tr>
</table>

A 'base case' model was established corresponding to current UK Building Regulations [4]. This was then simulated to establish the energy performance and comfort conditions against which all subsequent appraisals could be benchmarked. The base case assessment showed that the design would compare favourably with UK Best Practice, achieving a rating of 218 kWh/m^{2}yr. The next step was to reduce this rating to a level conducive to the deployment of active renewable systems. The results from the base case highlighted the potential for reductions in the energy demands associated with space heating and lighting. Several options were subsequently simulated and a sub-set decided upon: advanced glazings comprising low emissivity coatings and inert gas fillings; daylight linked luminaire control; energy efficient lighting; transparently insulated walls; and occupant responsive heating system regulation. The combined application of these systems improved the energy rating of the building to 70 kWh/m^{2}yr as depicted in Figure 1. An overall 68% energy saving was achieved, corresponding to a 58% saving in heating energy demand, an 80% savings in lighting energy demands, a 70% reduction in CO_2 SO_x and NO_x emissions, and a 52% and 67% reduction in installed lighting and heating plant capacity respectively. The deployment of these technologies had no negative impact on thermal comfort, with the risk of summertime overheating being reduced by 42%. An additional major benefit was the creation of a more renewable energy friendly energy demand profile, which allowed the active renewable energy systems to be of a lower installed capacity, with minimal back-up required to service demands in the event of low/ no renewable energy availability.

3. RENEWABLE ENERGY SUPPLY TECHNOLOGIES

The technical and planning restrictions associated with the city centre location of the Lighthouse building limited the size and technology types that could be used. An investigation identified suitable technologies as photovoltaics (PV) and wind turbines. Planning considerations required that the rotors of the wind turbines be concealed from public view: ducted wind turbines (DWT) were therefore designed and fabricated [5]. The south and west facing exposure of the Lighthouse meant that a combination of these technologies could be deployed on the façade and roof edge. The ducted wind turbines supplies the majority of the electricity demands during the wintertime when the predominant south-westerly winds have their highest availability factor and solar exposure is at its lowest. In the summer, the photovoltaic technologies supply the majority of the electricity demands when solar radiation exposure is at its highest and the wind availability is low. By incorporating PV within the aerofoil section of the DWT the power density of the device was increased. The DWTs were deployed along the south and west facing roof edges, while the PV components, consisting of a ventilated south facing façade system and a south and west facing DWT attached system, were installed at a 40° pitch from the horizontal.

The 7m^2 south facing photovoltaic façade comprises high efficiency monocrystalline modules installed in a ventilated configuration. This was intended to induce natural convective cooling on both the front and rear sides of the module, enabling operation at lower temperatures and hence higher efficiencies when compared to sealed façade systems. Monitoring of performance is underway to quantify the benefits associated with this type of installation and the temperature and mass flow rates of the vented cavity air for use in a related study of PV-based ventilation air pre-heat.

The 5.4 m^2 of south and west facing roof edge mounted PV are installed at a 40° pitch from the horizontal. These enable the south facing PV to maximise solar capture in the transitional and summer seasons. The use of PV as aerofoils for the DWTs improves the performance output of these modules because the turbulent air induces a wind chill effect, enabling the modules to operate at lower temperature.

4. ELECRICAL POWER SUPPLY

Because the power outputs from the PV and DWT systems are non-homogeneous (pure DC from the PV components and a rectified AC supply from the DWTs), studies were undertaken to determine ways to maximise the efficiency of the electrical power supplied to the loads while minimising any impact on power quality. Three electricity supply options were studied:

i) a dedicated low voltage DC supply;
ii) a standalone AC supply from the PV/ DWT generators via a battery storage system connected to a DC-to-AC power inverter; and
iii) a network connected AC supply allowing the renewable systems to co-operatively work in parallel with the local electricity supply network via an integral power conditioning and inverter system.

The appraisal of option i.) showed that although the overall efficiency of electrical power utilisation can be high, since no losses are experienced during DC to AC power conversion, the system costs are expensive due to:

i) the requirements for a parallel AC supply circuit to satisfy high power loads;
ii) a requirement to use larger cables with higher current ratings, minimising power losses associated with low voltage/ high current power supply; and
iii) the higher costs associated with specialised low voltage DC appliances.

The option favoured for this installation was ii.), an AC supply powered from a battery storage system via a DC-to-AC power inverter. The reasons for this type of installation being favoured are due to the following technical and economic issues:

i) low circuit and appliance costs, since only one supply circuit type is required and operating at the standardised supply voltage enables non-specialised, high efficiency electrical appliances to be used;
ii) supply of all electrical loads via DC/ AC power conversion ensures complete segregation between the renewable power supply systems and the public electricity supply network, preventing the risk of renewable energy induced distortion or interruption of the electrical supply network; and
iii) since this supply option results in no physical connection between the renewable energy systems and the public electricity supply network, this eliminates compliance with the technical and policy complexities that currently exist for parallel network connection.

This choice of a standalone electrical supply eliminated the requirement for a parallel connection to the public electricity supply network, as in option iii). Such connections within the UK can be costly, in both capital associated with the purchase of approved electrical/ electronic hardware, and in the effort/ delay associated with submitting a request for connection. When opting for this type of connection, stringent guidelines and regulations must be adhered to so that no disruption occurs within the electricity supply network due to a third party’s connection. The recommendations concerned with the connection of small, embedded generation systems into the public electricity supply network, and the limits of their impact on the quality of electrical power, are set out in Electricity Council Guides 59/1 and 5/4. These guides were primarily developed for the connection of balanced 3 phase AC rotary generation plant greater than 5kVA. At present there are no specific recommendations covering the connection of small, single-phase generation plant to the supply network using DC to AC power inverters, as deployed in this demonstration. This is currently being addressed with the development of Electricity Council Guide 77, specifically aimed at developing new standards and tolerances for the direct connection of a sub 5kVA inverter based single-phase generation systems to the network.

The renewable energy based electrical generation systems consists of 7 DWTs rated at 90Wp each, integral PV aerofoils rated at 85Wp each and a facade mounted PV system rated at 765Wp. This gives an installed generation capacity of 1990Wp. The DWTs and PV components are connected to a 48V/ 220Ah battery bank via electronic charge controllers/ regulators. The battery unit has an auxiliary charging system connected to the local electricity supply in the event of insufficient power delivery from the RE systems. The electrical supply circuits powering the loads are powered from an electronic 48V DC to 220V AC, sine wave power inverter.

5. CONCLUSIONS

This project has demonstrated the value of undertaking integrated performance appraisals at an early design stage in order to install passive renewable components to reduce demand so that active RE systems may then be more effectively deployed. The combination of passive solar, PV and DWT technologies allowed the building's energy demands to be met during the spring, summer and autumn seasons. In winter, an additional energy input is required. A battery/ inverter power supply caters for the temporal mismatch between RE supply and energy demand, avoiding the need for the importing or exporting of power.

The combination of DWTs and PV has proved successful in the Glasgow. The former technology produces electricity predominately during the winter period; the latter predominately during the summer period. Their combination gives rise to an embedded RE approach that is well suited to the climate of Glasgow.

6. REFERENCES

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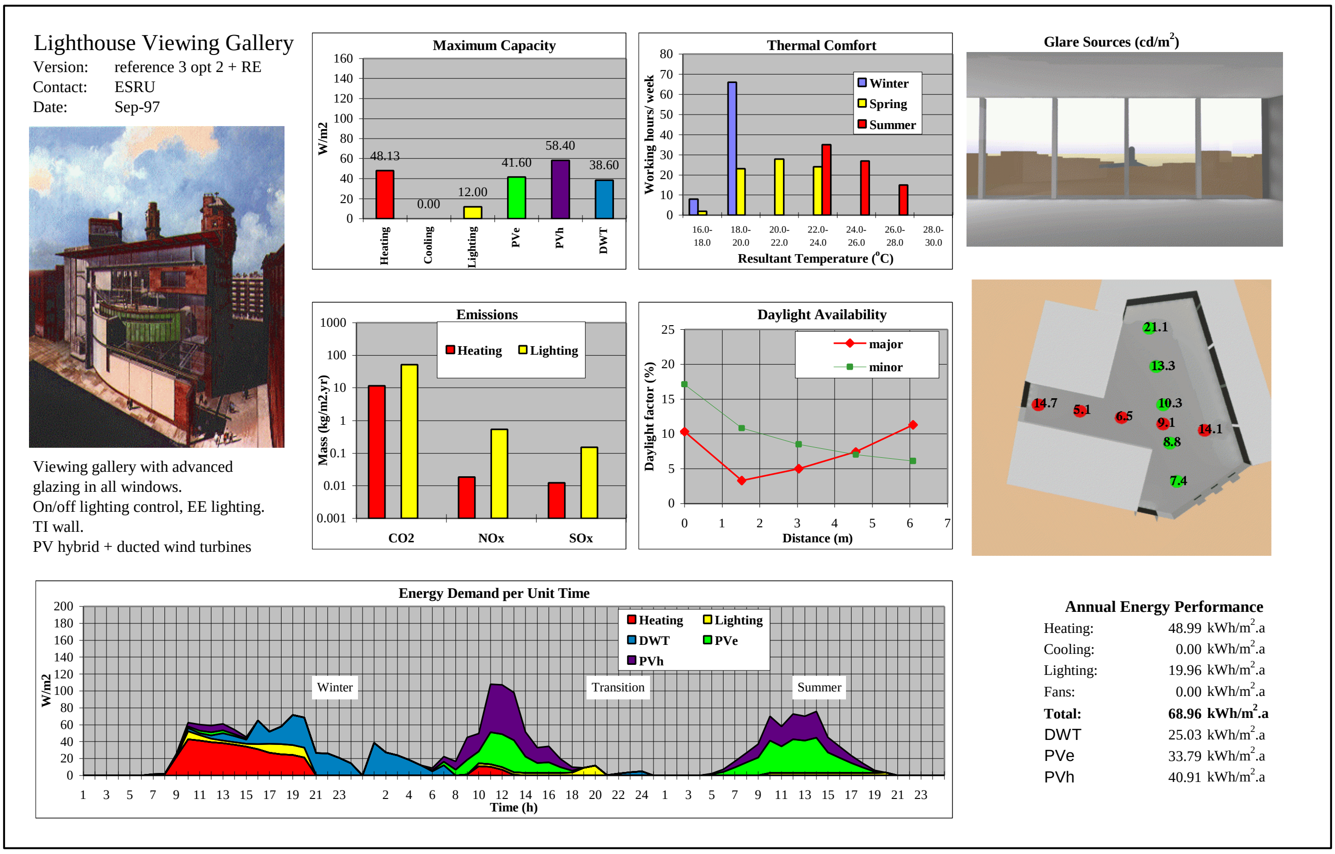

Lighthouse Viewing Gallery

Version: reference 3 opt 2 + RE
Contact: ESRU
Date: Sep-97

Viewing gallery with advanced glazing in all windows.
On/off lighting control, EE lighting.
TI wall.
PV hybrid + ducted wind turbines

Annual Energy Performance

Heating:	48.99 kWh/m^2.a
Cooling:	0.00 kWh/m^2.a
Lighting:	19.96 kWh/m^2.a
Fans:	0.00 kWh/m^2.a
Total:	**68.96 kWh/m^2.a**
DWT	25.03 kWh/m^2.a
PVe	33.79 kWh/m^2.a
PVh	40.91 kWh/m^2.a

Figure 1: Performance appraisal of passive and active RE systems.