DELIVERABLES FROM IEA TASK 21

The Task will establish a comprehensive resource of knowledge on the integration of daylight in building design for various climates and sky conditions. Building design practitioners, lighting engineers, builders, product manufacturers, building owners and managers will find practical means and valuable guidance in the deliverables of IEA Task 21. The main deliverables from the Task will be:

Design Guide/Source Book

A system specific Design Guide on daylighting systems and lighting control systems. The Guide is to be used at the earliest stages of the design process, as the crucial decisions of daylighting design is concerned with the initial conception of the building envelope, the location of openings, their size and shape together with their systems for solar and daylighting control. The Guide will provide recommendations on systems integration and performance data on overall energy savings potential.

Daylighting Design Tools

A set of Daylighting Design Tools that markedly improve the designers' ability to predict the performance of daylighting systems and control strategies under real weather conditions and to evaluate the impact of daylight integration in the overall design concept. The types of tools developed in Task 21 varies from simple, hand calculation methods to very advanced (but user-friendly) computer tools.

Case Studies Report

The Case Studies Report will document daylighting performance and energy consumption of 15 buildings under the various climatic conditions of the IEA community. In five of the Case studies the performance assessment includes user appraisals of the visual environment which is crucial for the realization of energy savings by enhanced utilization of daylight.

IMPACT OF TASK 21

It is hoped that the results of Task 21 eventually will contribute, world wide, to overcome the barriers for integration of daylighting aspects in the building design practice. Briefly, this perspective can be expressed in three simple statements, stating that from the year 2000:

- Daylight will be an integrated design consideration in major design practices in the IEA Community
- Daylight substitutes 30-50 per cent of artificial lighting in new building design
- Daylight is recognized as a prime design consideration for occupants' well being

MORE INFORMATION

The planned work of IEA Task 21 is further described in an 8-page brochure, which can be provided by the author (kjj@sbi.dk). More information on IEA SH&C Programme at http://www.iea-shc.org/ .

ACKNOWLEDGEMENTS

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RENEWABLE ENERGY

INTEGRATED MODELLING OF LOW ENERGY BUILDINGS

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ABSTRACT

A reduction in the emissions arising from urban activities can be achieved by a combination of energy efficiency measures and a move away from fossil fuels. Progress may be enabled by the deployment of new materials and critical control within buildings, and the adoption of building-integrated renewable energy conversion technologies. This paper describes the integration of cooperating passive and active renewable energy technologies within a major building refurbishment in Glasgow. It also describes a method for the assessment of replication potential.

KEYWORDS

Passive and active renewable energy, building design, city integration.

1. INTRODUCTION

As the centrepiece of Glasgow's celebrations as City of Architecture and Design in 1999, a city centre building of architectural significance is being refurbished: the Lighthouse Building designed by Charles Rennie Mackintosh and constructed in 1896. The building has several unique design features: the use of natural resources such as daylight, the use of thermal capacity to minimise overheating risk, the use of air ducts to transport heat, and an early example of IT in the form of a tower used to relay messages by carrier pigeon to and from the newspaper company who occupied the building.

Funding has come from a number of UK agencies, including the Millennium Commission. This refurbishment has presented the city with an opportunity in relation to the ongoing RE-Start project (Burton et al 1996) funded by the European Commission's DG XVII. A specially configured portion of the building will serve as a showcase for state-of-the-art technologies that demonstrate the integration of passive and active renewable energy components at the urban scale. The systems will be monitored and the outcomes relayed to a Renewable Energy Advice Centre being established within the City (McElroy and Kane 1998). In this way, the Lighthouse will serve as a live demonstration of urban renewable energy use.

Design studies were undertaken using the ESP-r energy simulation system in order to establish the optimum mix of passive and active renewable energy (RE) technologies. Detailed appraisals of the thermal and electrical performance of the building were undertaken, firstly, for a base case model compliant with current best practice design and, secondly, for a series of reference models defining applicable RE-integrated scenarios.

This paper describes the simulation results and outlines a method by which the replication potential of beneficial outcomes can be assessed.

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2. RENEWABLE ENERGY SYSTEMS

The renewable energy systems chosen for this demonstration include 4 passive and 2 active components:

- advanced glazings, including a triple glazed, double low-ε coated, argon filled component, a light redirecting component and a switchable component;
- daylight utilisation through illuminance linked luminaire control;
- transparent insulation with integral shading;
- photovoltaic cells in both standalone and facade-integrated modes, with heat recovery in the latter case;
- roof mounted, ducted wind turbines.

Based on detailed energy simulations using the ESP-r system (http://www.strath.ac.uk/Departments/ESRU), it was concluded that the passive components have the potential to reduce the annual energy demand by 64%, relative to the initial, best practice compliant, design hypothesis. It was also concluded that the active components have the potential to match a significant portion of the residual demand. The refurbishment will be subjected to a monitoring campaign throughout 1999 with the outcomes reporting under the RE-Start project.

3. MATHEMATICAL MODELS

The simulation of a building incorporating such technologies requires a program which is able to address the non-trivial energy interactions that exist between, for example, daylight and luminaire switching, transparent insulation and wall temperature distribution, photovoltaic power and heat recovery, and local wind regime and ducted wind turbine performance.

While the ESP-r system is well founded in most respects (Clarke 1996), it required refinement in relation to local wind power production in order to meet the needs of the current project.

3.1 Wind Flow Around Buildings

The pattern of air flow around a tall building is dependent upon the velocity gradient of the approaching wind. For the atmospheric boundary layer, it is common to assume a power-law velocity profile, of the form

$$\frac{v}{V} = \left(\frac{y}{\delta}\right)^{1/n}$$

where n is about 3 in urban conditions. In practice, the nature of the approaching wind will be greatly affected by the presence of neighbouring buildings.

When the wind blows at right angles to the face of a tall building, stagnation will occur at about two-thirds of the total height. Below this level, a rolling vortex is formed; above it, the air rises to pass over the roof. If the roof is flat, it will separate from the upwind edge, possibly reattaching some distance downstream. The ducted wind turbine is designed to draw air from the high-pressure region on the upwind face of the building and exhaust it into the low-pressure region above the flat roof. The static pressures over the upwind face of the building are close to stagnation over much of the area, but fall significantly near the edges. The duct inlet located just below the roof must be carefully shaped to capture the upward moving air. The exhaust is likely to be no more than a metre downwind from the edge of the roof; in the upwind region of the separation bubble where static pressures are very low. Low pressures will be maintained for a wide range of wind direction (±45° or more) by the phenomenon of vortex lift: a rolling vortex above the roof and roughly parallel to its edge when the wind approaches from an oblique direction.

3.2 A Ducted Wind Turbine Model

Ideas for wind energy conversion in an urban environment have ranged from the simple notion of placing a wind turbine on top of a building, to proposals for dedicated buildings profiled to direct the wind through turbines embedded within the structure, such as the Tornado concept of Yen (1976). In the first case a combination of technical (building-generated turbulence) and institutional (concerns over safety and visual impact) problems conspire to make this an unattractive idea; the second is unlikely to be effective on a cluttered urban site and would be extremely costly in relation to the quantities of energy produced.

An alternative lies in the use of a small, modular ducted unit developed at Strathclyde University. Designed to be integrated into the roof of large buildings, it is simple and therefore potentially cheap to produce, and compact enough to be retro-fitted to existing structures. It is also unobtrusive, the moving parts being enclosed within a duct. The

ducting has the beneficial effect of damping out turbulence in the airstream, which can be a serious problem when large buildings are in close proximity. A price to be paid is that the device is directional: it will operate efficiently over about a 60° range of wind directions but for winds outwith this sector the performance falls away rapidly. It is therefore most effective on sites with a strong prevailing wind direction. Testing of wind tunnel models and field trials of prototypes have refined the design and determined the performance parameters of the system (Grant et al 1994).

A conventional wind turbine's output is characterised by the equation

$$P = 0.5 C_P \rho \pi R^2 V^3 \quad . \tag{1}$$

in which the power P is related to the wind speed V, the rotor radius R and the air density ρ. The power coefficient C_P is a measure of the effectiveness of the turbine rotor; for a given turbine, C_P is a function of the tip speed ratio λ, where

$$\lambda = \frac{\omega R}{V} \tag{2}$$

ω being the rotor's angular velocity. A similar type of characterisation is appropriate for the ducted wind turbine, with an additional equation to describe the dependence of C_P upon the wind direction.

Most conventional grid-connected wind turbines are constrained to turn at constant angular velocity, so as the wind speed varies the value of λ (and hence the value of C_P) will change. The ducted turbine, being a small unit for autonomous use, is unlikely to be connected to the electrical grid and so can operate in variable-speed mode. It would be desirable to operate at a constant (optimum) value of C_P for much of the time. A constant C_P implies a constant value of λ. Combining eqns 1 and 2 gives

$$P = T\omega = \frac{0.5 C_P \rho \pi R^2 \omega R}{\lambda^3} = K\omega^3 \tag{3}$$

where K is a constant and the torque T at the rotor shaft follows a quadratic characteristic, $T = K\omega^2$. In practice it is a simple matter to control the generator to produce a quadratic torque characteristic at the rotor shaft, and so a near-constant value of C_P may be achieved.

This mode of operation will be abandoned in high wind speeds, where it is necessary to limit the power produced to some maximum value. Here, the electrical load on the generator should be increased, reducing the rotor speed, stalling its blades and reducing C_P to the required value. And at low wind speeds (below about 5 m/s), the power output will fall below the values indicated in eqn 1 as a result of disproportionate mechanical losses and low generator efficiency.

On a typical urban site, rapid fluctuations in wind direction may be expected. Given the directional sensitivity of the ducted wind turbine, some impact on its performance will result. A wind which is nominally favourable in direction may produce slightly less energy than expected over a period of time, while a nominally unfavourable wind might deliver more than anticipated. Overall, the effect might be a reduction in the apparent directional sensitivity of the system.

4. EVALUATION METHOD

The evaluation procedure adopted in the project adheres to a standard performance assessment method (Clarke et al 1996) whereby computer simulation is used to determine the overall performance of an initial model of the building (in this case corresponding to current best practice design). The multi-variate performance data are then presented in the form of an integrated performance view (IPV) as shown in Figure 1. The model is then modified by incorporating one of the renewable technologies and the overall performance re-assessed. In this way, the contribution of the passive and active renewable technologies, applied severally or jointly, may be assessed and the different possible permutations compared.

4.1 Energy Demand Reduction Techniques

The initial design concept for the Lighthouse refurbishment consisted of an insulated steel clad facade, insulated lead sheet roof, extensive use of double glazing and a slate covered concrete floor slab with external insulation. The building services comprised embedded floor heating, halogen display lighting and natural ventilation from vented slot windows. Various reference models were developed to assess the contributions from alterations to glazing systems, the adoption of critical control strategies and the incorporation of various passive and active renewable energy technologies.

The first reference model replaced the double glazing (north and east facing) with low-ε coated, argon filled triple glazing, with a centre pane U-value of 0.8 W/m^2K. A switchable liquid crystal component was added to the south facing windows to control overheating and a prismatic components was added to the north facade to enhance daylight penetration. These measures resulted in a 58% reduction in annual heating energy requirements and a 31% reduction for required energy overall (heating plus lighting).

To reduce energy demands further, daylight responsive lighting control and a south facing transparent insulated (TI) thermal mass wall were added. This resulted in a reduction in the duration of the heating season, with the TI wall supplying the building's heating requirements during the transitional seasons and auxiliary heating being confined to the winter period. In comparison with the initial design hypothesis, the cumulative effect of the advanced glazings, lighting control and TI facade resulted in a 45% reduction in annual heating energy demand, a 59% reduction in lighting energy demand and a 51% reduction in the overall annual energy demand.

From a detailed examination of the simulation results, it was concluded that further energy demand reductions were possible. The next evaluation case replaced the underfloor heating system with a fast response, critically controlled, convective heating system and replaced the lamps with high efficacy luminaires. In comparison with the original design hypothesis, this reference case resulted in a 58% reduction in annual heating energy demand, a 67% reduction in heating plant capacity, an 80% reduction in lighting energy demand and a 68% reduction in overall energy demand.

Taken together, the above measures implement a high level of demand-side energy reduction without compromising the building's thermal and visual comfort levels.

4.2 Embedded Renewable Energy Systems

Two active renewable energy components were appraised and subsequently accepted for incorporation within the building. The technologies chosen were:

- a photovoltaic (PV) component operated in hybrid mode to give power and heat output;
- ducted wind turbines (DWTs) with an integral photovoltaic fairing panel.

The hybrid PV system was incorporated within the south-facing facade, while the DWTs were mounted on the south- and west-facing edges of the roof; south-westerlies being the predominant wind direction in Glasgow. The use of a photovoltaic component as the aerofoil for the DWT units increases the power density by 70%, giving an installed capacity of 450 W/m^2 of roof area. To maximise electricity generation, a high efficiency monocrystalline silicon component, with laser grooved buried grids, was chosen for both the hybrid PV and DWT systems.

Figure 1 presents the final performance results in the form of an IPV as produced by ESP-r. As can be seen, the active RE systems, in conjunction with the passive RE technologies, are capable of meeting the demands of the building during the spring, summer and autumn seasons. In winter, the active RE systems are capable of supplying a significant proportion of the energy demands. However, an electrical storage system is required to cater for the temporal mismatch between RE supply and demand since the former is largely available outwith the times of building operation.

The combination of DWTs and PV components proved to be a successful matching of RE systems to meet the seasonal energy demands. The DWTs produce electricity predominantly during the winter period when the PV components can contribute little. Conversely, the PV components supply power predominantly during the summer period when the winds are light. The combination of the two systems gives rise to an embedded RE approach which is well suited to the climate of Glasgow.

6. ASSESSING REPLICATION POTENTIAL

To facilitate an assessment of the replication potential of such low energy technologies, the ESP-r system has been connected to a fuel information management and analysis program, EnTrack, and linked to a Geographical Information System (GIS). Details on the EnTrack-ESP system are given elsewhere (Clarke et al 1998).

As depicted in Figure 2, EnTrack supports the storage and analysis of fuel consumption data, while ESP-r offers simulation capabilities for demand- and supply-side assessments. The GIS module supplies scoping data to EnTrack in support of its assessments and receives back the results for display alongside other relevant data types (such as land designation or individual RE scheme/building locations). Overall, the system provides the following functionality.

- Quantification of energy demand by fuel type, sector and time.
- Ranking of alternative building energy efficiency measures.

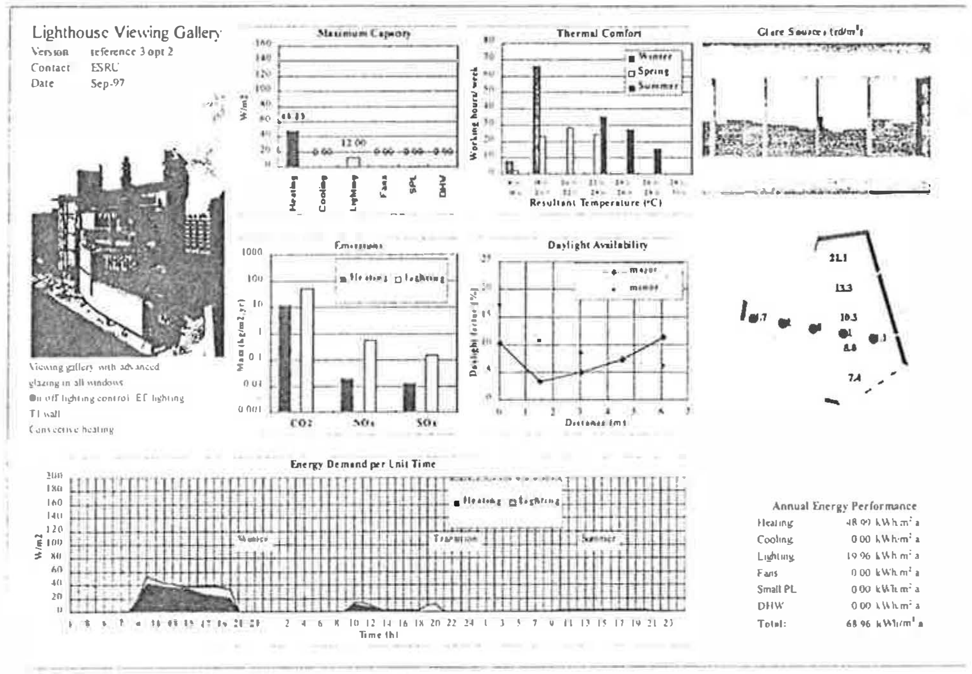

Figure 1: Final IPV for the Lighthouse building study.

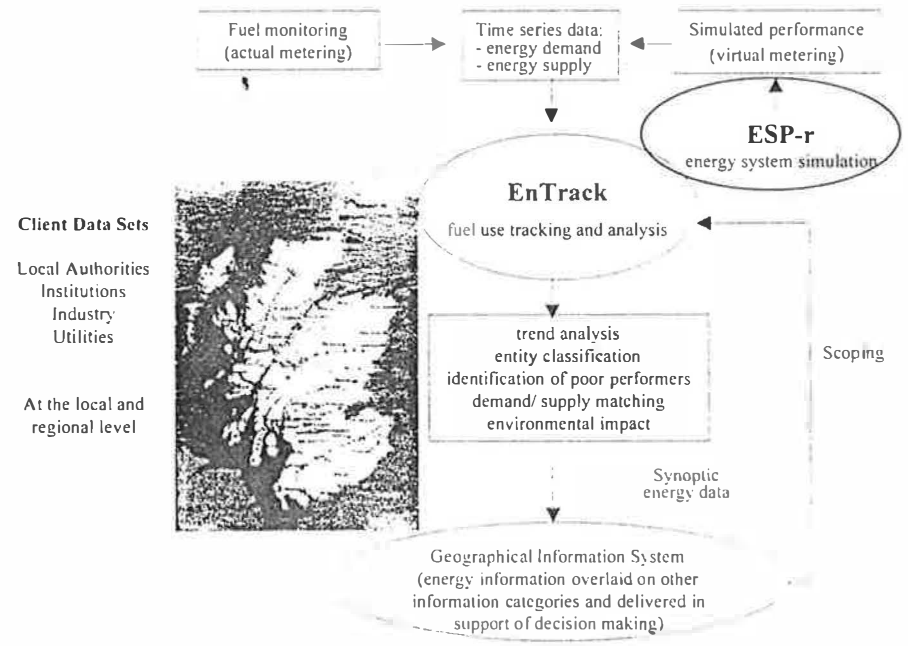

Figure 2: The EnTrack-ESP system for city-scale fuel tracking and assessment.

- Assessment of autonomous (e.g. photovoltaic facade) or grid connected (e.g. wind farm) renewable energy schemes from a standpoint of technical feasibility and planning acceptability.
- Imposition of environmental and socio-economic impact considerations.
- Correlation of energy supply with demand, on a spatial and temporal basis, for a single entity or at the institutional/regional scale.

Within the scheme, modelling may be used in situations where energy demand data are sparse to create 'virtual meters', which give data at the required temporal and spatial resolution. It is also possible to use simulation to develop generic models, or prototypes, which represent hypothesised systems. By this means, the replication potential of beneficial simulation outcomes can be determined.

5. CONCLUSIONS AND FUTURE WORK

The construction stage of the project has now commenced and the Lighthouse building will be instrumented and monitored throughout its first year of occupancy. Monitoring will focus on climate, energy utilisation, product performance and internal environmental conditions.

Climate monitoring will comprise site wind conditions, incident beam and diffuse solar radiation and wet and dry bulb temperatures. These data will be used to quantify the available local resource. Energy utilisation monitoring will cover both the demand and supply streams and will be used to determine the resource utilisation potential in terms of seasonal load matching. The operational states of each passive and active component will be monitored to establish their performance and durability. Finally, internal environmental conditions will be monitored to establish the impact of the RE systems on comfort.

By feeding these data into the EnTrack fuel database being established for Glasgow, it will be possible to study the impact of alternative city-wide replication scenarios.

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RENEWABLE ENERGY

REALISTIC VALUES OF VARIOUS PARAMETERS FOR PV SYSTEM DESIGN

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ABSTRACT

The principle of energy production evaluation of PV systems is explained and parameter definitions are given at first. Then, a new method is proposed to verify detailed system parameters from ordinary, monitored data. Data acquisition system is used for the evaluation of long-term energy performance. Monitored data are normally utilized to calculate input radiant energy, output electrical energy, system yield (equivalent operated hours), system performance ratio and so on. The author has developed sophisticated verification procedures (SV method), where system performance ratio K, power conditioner efficiency K_C, temperature factor K_{PT}, shading factor K_{HS}, load matching factor K_{PM} and other array parameter K_{PO} can be identified from only 4 monitored points with other externally available information. Especially, time series data verification process can produce more realistic results of shading and mismatch losses respectively. As a realistic example, SV method is applied to data taken from 71 systems in the Japanese Field Test Project.

KEYWORD

Phtovoltaic system; PV system; sizing; design parameter; system monitoring; performance ratio; shading factor; load matching factor; MPPT loss; incident angle.

INTRODUCTION

Although the conversion efficiency of a photovoltaic cell can clearly measured according to standard test procedures, it does not mean operational ability under outdoor conditions. Meteorological conditions vary from place to place. At least, irradiation and ambient temperature have to be known when one wants to evaluate output energy to be generated by a PV system at a certain site. In addition, conversion efficiency may be reduced to a certain level because of various site conditions and system specifications. In fact this might have been troublesome problems. The author clarifies theoretical background to define system parameters and proposes methods to verify various realistic parameters from ordinary operational data. Actual field examples are also given for better understanding of system performances.

PARAMETER DEFINTIONS

Table 1 gives fundamental equations necessary for system sizing and evaluation. The first equation (1) shows energy balance between generated energy and consumed one. The right-hand side is given by incident

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