ON THE USE OF SIMULATION IN THE DESIGN OF EMBEDDED ENERGY SYSTEMS.

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ABSTRACT

A reduction in the emissions arising from urban activities demands a combination of energy efficiency measures and a move away from fossil fuel sources. Progress may be enabled by the use of advanced materials and control systems and the adoption, where possible, of renewable energy conversion technologies. A major challenge is the incorporation of such systems in a manner which preserves the architectural heritage of the district. This paper describes the modelling approach used when assessing the renewable energy systems to be deployed within a demonstration project in Glasgow, UK.

INTRODUCTION

The Lighthouse Building, designed by Charles Rennie Mackintosh, is the centrepiece of Glasgow's celebrations as UK City of Architecture and Design 1999. This refurbished city centre building is of major architectural significance. The project team comprised of Glasgow City Council, Oscar Faber, Page and Park, the Energy Design Advice Scheme and ESRU. Funding came from a number of agencies, including the Millennium Commission and EC DGXII. This refurbishment presented the city with an opportunity in relation to the ongoing EC RE-Start project (Burton et al 1996). A specially configured portion of the building serves as a showcase for state-of-the-art technologies that demonstrate the integration of complimentary passive and active renewable energy components at the urban scale.

This paper describes the design process undertaken and the system configuration adopted to achieve:

i) lowest practical energy demands (without compromising building functionality),
ii) sizing of the embedded micro-scale generation systems to match a significant portion of these demands, and
iii) appraise the options for electrical power supply.

RENEWABLE ENERGY SYSTEMS

Implementation of renewable energy systems at the local level can be fraught with technical problems. When undertaking such tasks within an urban environment adds additional problems to a project such as impact on building aesthetics and most importantly, planning requirements which impair system performance. After careful consideration, the renewable energy systems deemed suitable and chosen for this demonstration were categorised as follows: type (i) are those that reduce energy demands and type (ii) are those that generate electricity to meet some of these demands. The 3 passive (type i) components were:

1) advanced glazings, including a triple glazed, double low-ε coated, argon filled component, a light redirecting component and a variable transmission component;
2) daylight utilisation through illuminance based luminaire control; and
3) transparent insulation with integral shading.

The 2 active systems (type ii) consisted of:

1) facade-integrated photovoltaic cells with heat recovery; and
2) roof mounted, ducted wind turbines with integral photovoltaic aerofoils.

Based on detailed energy simulations using the ESP-r system (Clarke 1985), it was concluded that the passive components had the potential of reducing annual energy demands by up to 64%, relative to an initial best practice compliant design hypothesis. It was also concluded that the active components had the potential to match a significant portion of the residual demand. This refurbishment is the subject of an extensive energy and power quality monitoring campaign with the results being reported under the RE-Start project.

EVALUATION METHODOLOGY

The evaluation procedures adopted adheres to a standard performance assessment method [PAM]

(Clarke et al 1996) whereby computer simulation is used to determine the multi-variate 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 both passive and active renewable technologies, applied separately or jointly, may be assessed and the different possible permutations compared.

ENERGY DEMAND REDUCTION TECHNIQUES

The initial design concept for the Lighthouse Building 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.

A number of 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 standard double glazing with low ε coated, argon filled triple glazing, with a centre pane U-value of 0.8 W/m^2 K. This resulted in a 58% reduction in annual heating energy and a 31% reduction in overall energy requirements (heating plus lighting). Further reductions were achieved using daylight responsive lighting control. The addition of a south facing transparent insulated (TI) thermal mass wall reduced the duration of the heating season, with the TI wall supplying the building's heating requirements during the transitional seasons, while auxiliary heating was 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, 59% reduction in lighting energy and a 51% reduction to the overall annual energy demands.

A detailed examination of the simulation results 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 the halogen 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. Figure 2 details the energy savings and capacity reductions achieved when undertaking the various permutations adopted within this study.

Implementing the above measures not only achieved a high level of demand-side energy reduction without compromising the building's thermal and visual comfort levels, but increased the effectiveness of the deployed active renewable energy systems in meeting the remaining energy demands.

EMBEDDED RENEWABLE ENERGY SYSTEMS

Two electricity generating renewable energy technologies were appraised and subsequently accepted for incorporation within the building. These were a photovoltaic (PV) component operating in hybrid mode to give both power and heat outputs; and ducted wind turbines (DWTs) with an integral photovoltaic aerofoil section. The hybrid PV system was incorporated within the south-facing facade, while the DWTs were positioned along the south and west facing roof edges; south-westerlies being the predominant wind direction in Glasgow. To maximise electricity generation, a high efficiency monocrystalline silicon component was chosen for both the hybrid PV and DWT systems. Figure 3 summarises the final performance results in the form of an IPV as produced by ESP-r.

PERFORMANCE OF ELECTRICITY SUPPLY SYSTEMS

The next stage in the project was to evaluated the options for maximising the efficiency of electrical supply and the resulting impact on power Quality. Three circuit types were identified as being suitable, these included:

- a dedicated low voltage direct current (DC) supply,
- an alternating current (AC) supply from the PV and DWTs via battery storage connected to a DC to AC power inverter system,
- and an alternating current (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 DC supply circuits showed that although the overall efficiency of electrical power utilisation can be high since no power conversion is required e.g. DC to AC. System costs are considerably more expensive due to the following:

a) The requirements for a parallel AC supply circuit to satisfy high power loads.
b) A requirement to use cable with higher current ratings to minimise power losses associated with low voltage, high current supply networks.
c) Higher costs associated with specialised low voltage appliances.

The option favoured for this installation was an AC supply, as shown in Figure 4, powered from a battery storage system via a DC to AC power inverter. The reasons for the choice of this type of installation were governed by both the following technical and economic issues:

a) Minimised circuit and appliance costs were achieved since only one supply circuit type is required, operating at the standardised supply voltage (240 V). This enables non specialised high efficiency electrical appliances to be used.
b) Supply of all electrical loads via DC/ AC power conversion ensures complete segregation between the renewable supply systems and public electrical supplier. This prevents any distortion or interruption to the electrical supply network resulting from the direct connection of small renewable energy systems.
c) Since this supply option results in no physical connection between the renewable energy systems and the public electricity supply network, this eliminates the technical and policy complexities that exist for compliance with network connection.

The RE based electrical generation systems consists of 7 ducted wind turbines each rated at 90W, with integral photovoltaic aerofoils rated at 85W each and a facade mounted PV system rated at 765W. This gives an installed RE based generation capacity of 1990W. The ducted wind turbines and photovoltaic systems are connected to a 48 volt 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 in the gallery are powered from the renewable energy charged battery systems via an electronic 48V DC to 240V AC, sine wave power inverter.

This electricity supply option also eliminated the requirement of a parallel electricity supply connection. Since such connections within the UK can be costly, in both capital costs associated with approved electrical/ electronic apparatus and time associated with submitting a request for parallel connection and when this actually gets approved. When undertaking such a 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 5/3. This allow up to a 2.5% tolerance on the supply voltage, a 4% tolerance on a 50 Hz supply frequency and a 5% maximum harmonic distortion on the sinusoidal wave form.

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 low power single phase generation plant to the supply network, especially systems consisting of DC to AC power inverters as deployed in this demonstration. The acceptance of a third party's, low power, single phase connection to the network remains at the discretion of the local electricity supply company who rigidly enforce the above guides. This results in third party low power generators requesting connection to the network having to undertake a costly and inappropriate compliance appraisal exercise. This deficiency 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 single phase generation systems to the network.

RESULTS

As demonstrated, 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 out with 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 predominately during the winter period when the PV components can contribute little. Conversely, the PV components supply power predominately 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.

The choice of AC supply via battery storage and inverter systems allow the temporal electrical mismatch between supply and demand to be addressed. However, due to inefficiencies within battery systems a proportion of energy from the RE supply may be lost.

FUTURE WORK

The construction stage of the project has now been completed, with the building being instrumented and monitored throughout its first year of occupancy. Monitoring will focus on climate, energy utilisation, product performance, internal environmental conditions and electrical power demand/ supply profile matching and quality.

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. Resultant internal environmental conditions will be monitored to establish the impact the RE systems have on comfort. Finally, the power quality will be monitored to assess the influences a supply of this nature will have on the operability and durability of appliances used.

The next stage of the project will be to monitor the performance of the development over an extended period and compare these with the predictions from the simulation model to test its robustness, and establish guidelines for efficient RE based electrical power utilisation.

CONCLUSIONS

This project has demonstrated the value of simulation early in the design stage of building projects. Especially, in studying the effective integration of both passive and active renewable technologies at the urban scale. The simulation approach was used initially to minimise and temporally adjust the building's energy demand profiles and, subsequently, to size a hybrid, micro-scale, embedded photovoltaic and ducted wind turbine facility to meet the residual demand.

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Burton S, Doggart J and Grace M (1996) “Community Planning for Glasgow” Renewable Energy Strategy in European Towns Report, EC DG XII, Brussels.

Clarke J A (1985), "Energy simulation in building design", Adam Hilger, Bristol and Boston.

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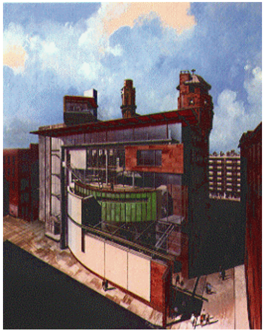
Engineering Recommendations G59/1 (1990) “Recommendations for the Connection of Embedded Generating Plant to the Regional Electricity Companies’ Distribution System” Engineering Publications, Electricity Association, UK

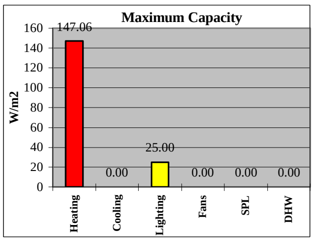
Engineering Recommendations G5/3 (1976) “Limits for Harmonics in the United Kingdom Electricity Supply System” Engineering Publications, Electricity Association, UK

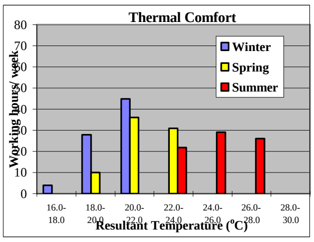
Lighthouse Viewing Gallery

Version:	Base case
Contact:	ESRU
Date:	Sep-97

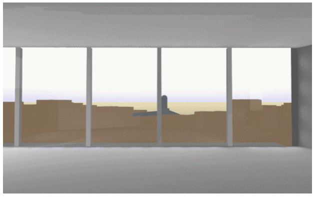


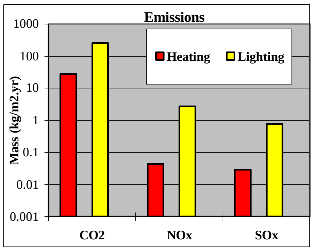
Viewing gallery base case model, double glazing in all windows.
No lighting control

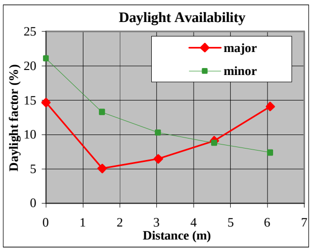


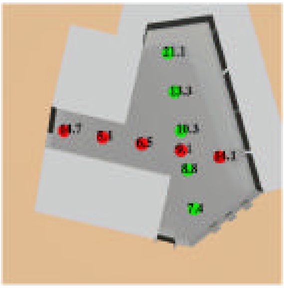


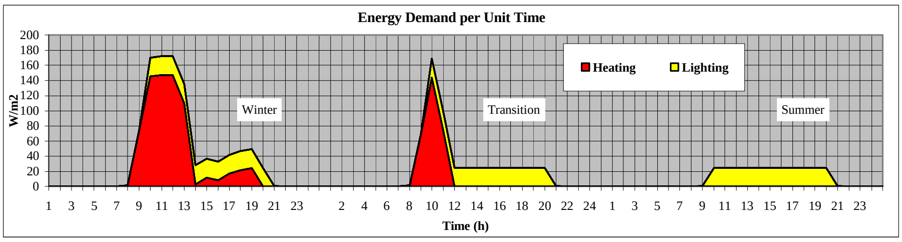
Glare Sources (cd/m^2)









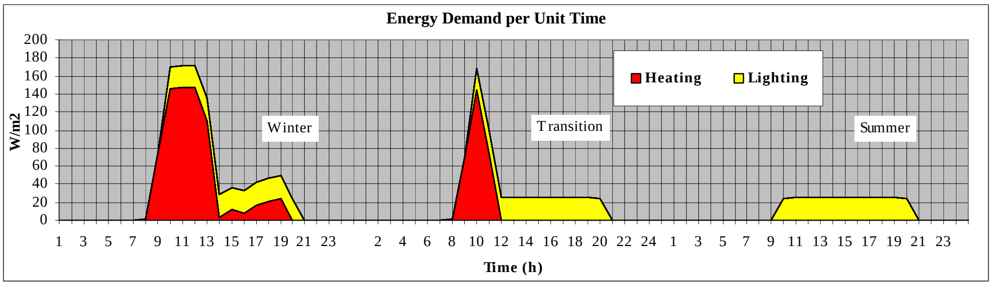


Annual Energy Performance

Heating:	118.29 kWh/m^2.a
Cooling:	0.00 kWh/m^2.a
Lighting:	100.10 kWh/m^2.a
Fans:	0.00 kWh/m^2.a
Small PL:	0.00 kWh/m^2.a
DHW:	0.00 kWh/m^2.a
Total:	**218.39 kWh/m^2.a**

Figure 1: Performance Appraisal of Initial Design

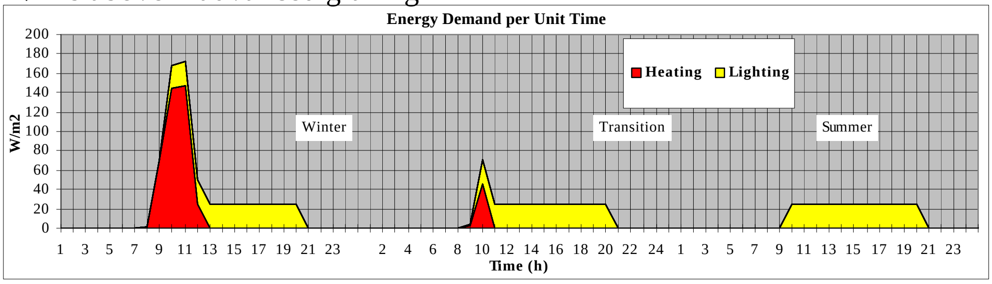
◆ Base Case



Annual Energy Performance

Heating:	118.29 kWh/m^2.a
Cooling:	0.00 kWh/m^2.a
Lighting:	100.10 kWh/m^2.a
Fans:	0.00 kWh/m^2.a
Small PL:	0.00 kWh/m^2.a
DHW:	0.00 kWh/m^2.a
Total:	**218.39 kWh/m^2.a**

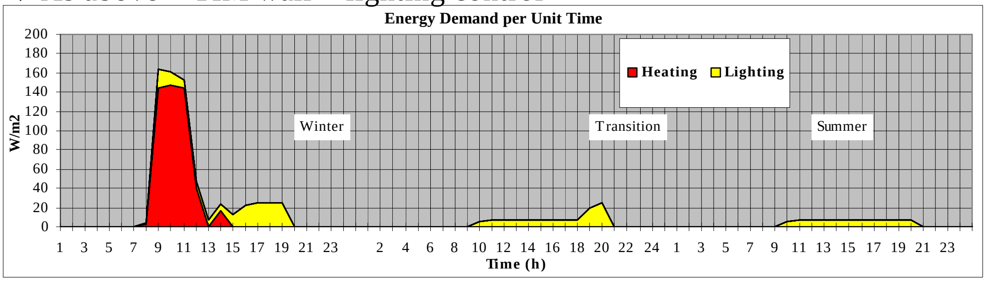
◆ As above + advanced glazing



Annual Energy Performance

Heating:	49.07 kWh/m^2.a
Cooling:	0.00 kWh/m^2.a
Lighting:	100.10 kWh/m^2.a
Fans:	0.00 kWh/m^2.a
Small PL:	0.00 kWh/m^2.a
DHW:	0.00 kWh/m^2.a
Total:	**149.17 kWh/m^2.a**

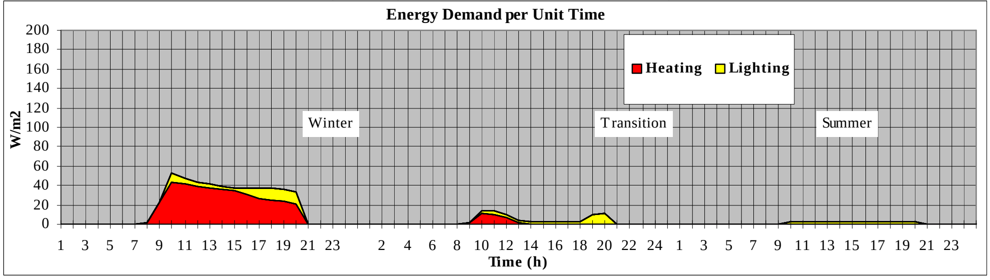
◆ As above + TIM wall + lighting control



Annual Energy Performance

Heating:	64.52 kWh/m^2.a
Cooling:	0.00 kWh/m^2.a
Lighting:	41.59 kWh/m^2.a
Fans:	0.00 kWh/m^2.a
Small PL:	0.00 kWh/m^2.a
DHW:	0.00 kWh/m^2.a
Total:	**106.12 kWh/m^2.a**

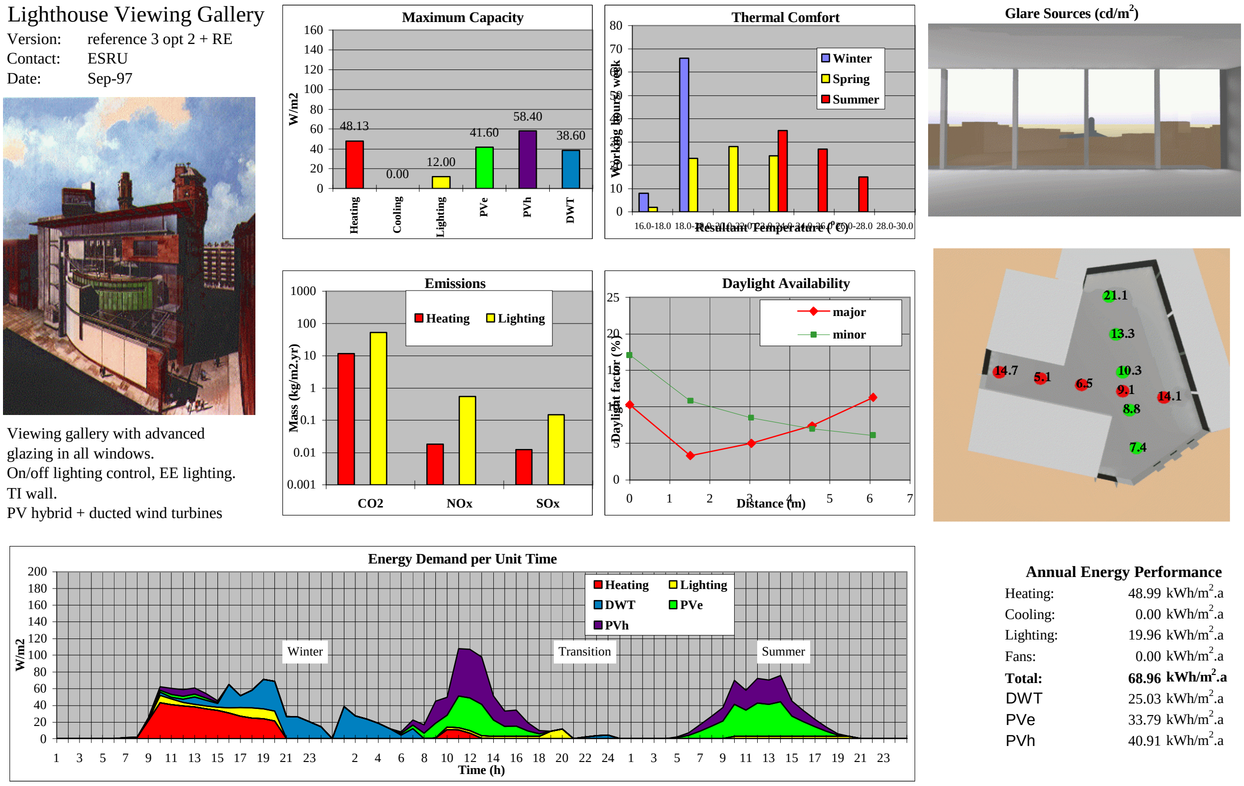
◆ As above + efficient lighting + responsive heating



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
Small PL:	0.00 kWh/m^2.a
DHW:	0.00 kWh/m^2.a
Total:	**68.96 kWh/m^2.a**

Figure 2: The energy reductions achieved by the various permutations



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 3: Performance Appraisal with Passive and Active RE Systems Applied

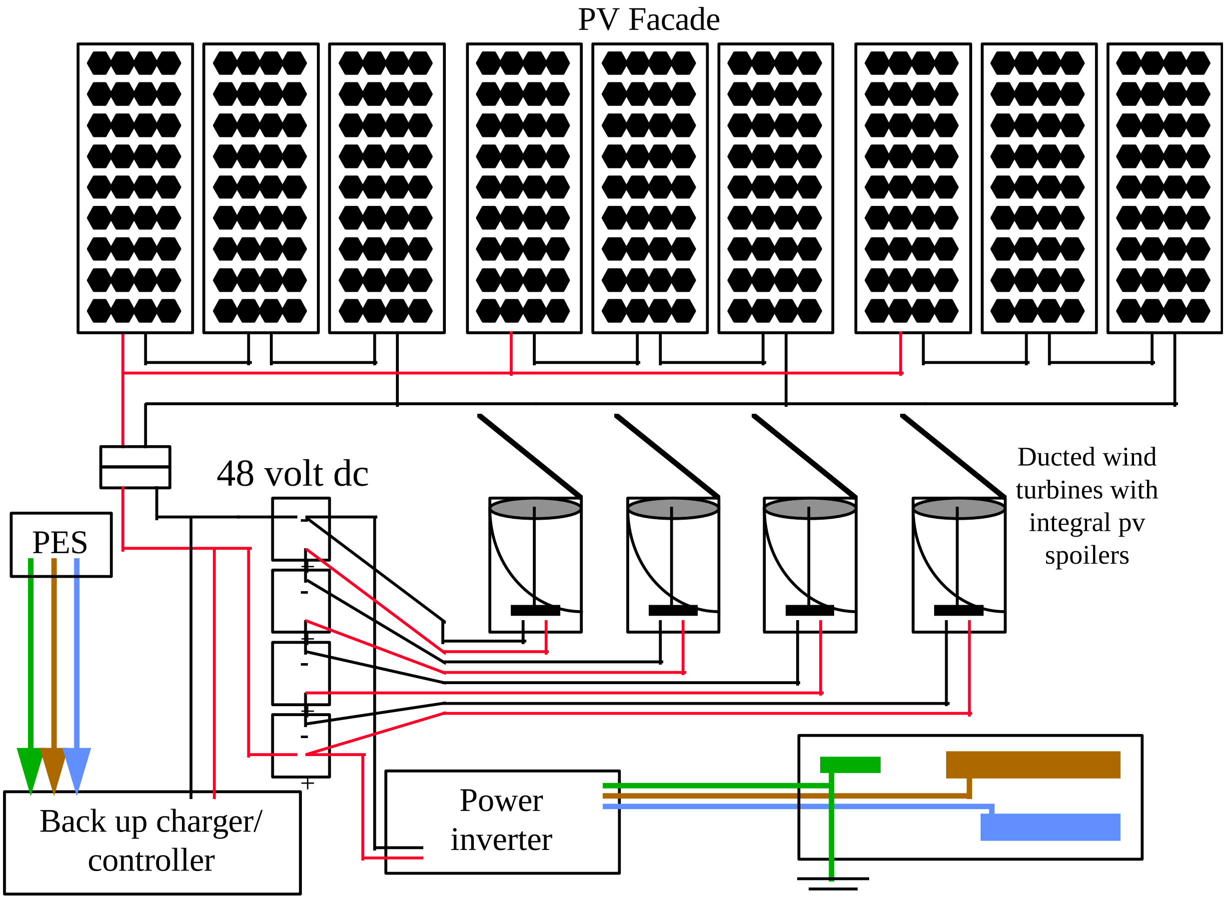


Figure 4: Electrical supply system with battery storage