

WIND ENERGY FOR THE BUILT ENVIRONMENT (PROJECT WEB)

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ABSTRACT: While rapid development of huge on- and off-shore wind farms continues, examples of integration in the urban environment, closer to prime consumers of energy such as buildings, remain scarce. Successful integration will require developers to fully address the concerns of planners, pressure groups and the public as to the necessity and environmental impacts of such schemes. Turbines should (be sized to) produce a significant proportion of the annual electricity demand of the building in which they are housed or of neighbouring buildings. These buildings must be energy-efficient, otherwise the turbines risk becoming a purely aesthetic feature.

The focus of Project WEB (funded under EC JOULE III) has been the development and demonstration of wind enhancement and integration techniques, which improve the annual energy yield per installation by concentrating the low to moderate wind speeds (2-5 m/s) typical of most urban areas in Europe. This has involved balancing and reconciling aesthetic, aerodynamic, architectural, environmental and structural constraints.

Suggested acronyms for the technology developed are 'Urban Wind Energy Conversion Systems' (UWECS) and 'Building Augmented Wind Turbines' (BAWTS). These principles have been successfully demonstrated by the field-testing of a 2-storey prototype building with integrated turbine. Conceptual design guidance has also been produced.

Keywords: Wind Turbines(HAWT), Innovative Concepts, Environmental Aspects, Buildings.

1 INTRODUCTION

Project WEB (JOR3-CT98-0270) brought together 4 academic and SME partners from the construction and wind energy industries (Figure 1) on a 2-year EC research project completed in September 2000.

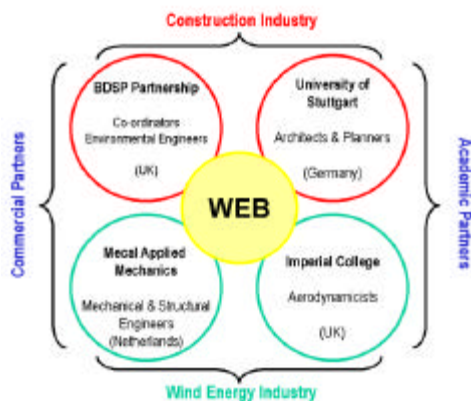


Figure 1: The Project WEB Team

Highly engineered integration of wind turbines into the built environment poses some formidable problems, e.g. the turbines will be in close proximity to people and property, and mean wind speeds are lower in urban areas.

The focus of the project was therefore on the development and demonstration of wind enhancement and integration

techniques that could potentially solve these problems, without degrading the local environment.

A number of recent publications suggest that interest in wind energy for buildings is indeed growing [1].

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2 INTEGRATION STRATEGIES

Three generic integration techniques are available in the urban environment:

- Full integration, such that the wind turbines (WTs) drive the architectural form (see Figure 6 below);
- Retro-fitting wind turbines onto existing buildings (Figure 2);
- Siting (landscaping) stand-alone wind turbines in urban locations (Figure 3).

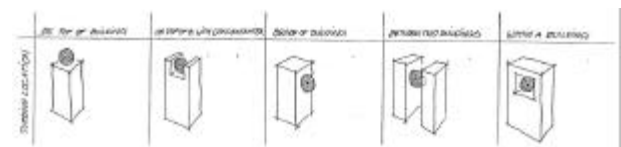


Figure 2: Methods for Suspending WTs from Buildings

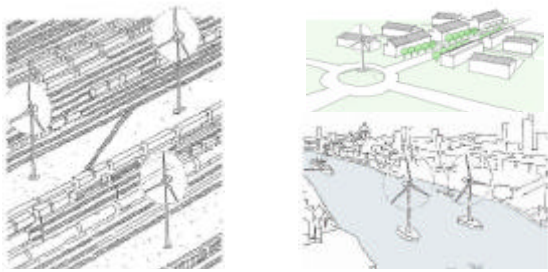


Figure 3: Possible Categories of Urban Location for the Placement of Stand-Alone Wind Turbines

Due to limitations of space, this paper will focus primarily on the innovative subject of full integration of wind turbines into buildings. It should be noted, however, that the potential cumulative impact of retro-fitting and landscaping wind turbines into the built environment would be expected to be greater.

3 AERODYNAMIC/ENERGY OPTIMISATION

Good wind enhancement over a wide range of angles of wind incidence is essential for fully-integrated turbines, since in general neither they nor the building will be able to yaw to face into the prevailing wind. Rarely in urban areas does the wind blow strongly from a single direction for the majority of the year and, in any case, the possible building orientations may be limited by the constraints of the site.

In order to assess the potential for fully integrating (and retro-fitting) turbines into buildings, the aerodynamic performances of a wide range of building forms were assessed using Wind-Tunnel Testing and Flow Visualisation Techniques on Scale Models and CFD (Computational Fluid Dynamics) Simulations.

The building shapes studied ranged from conventional ,non-aerodynamic' square block shapes (Figure 2) through to optimised three-dimensional (3-D) shapes designed to concentrate wind flow (Figure 4).

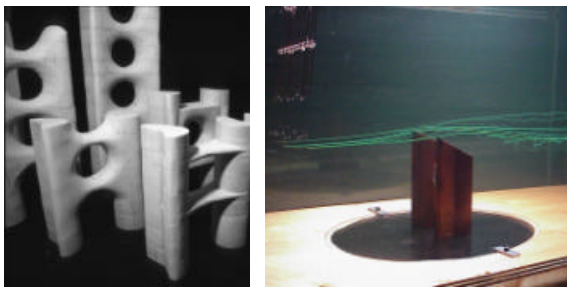


Figure 4: Prototype Architectural Models used in the Wind-Tunnel Testing and Flow Visualisation Studies

The key findings of these energy studies were that:

- Optimum performance is obtained for smooth, rounded, fully 3-D building forms;
- Towers with 'Kidney' or 'Boomerang' footprints produce the best wind enhancement (Figure 5);
- Aerodynamic wings or 'infills' connecting towers and creating a close fitting 3-D aerodynamic duct shape (hole) around the turbine are highly effective,

preventing flow separation and loss of wind enhancement;

- Good wind enhancement can be obtained for angles of incidence up to 40°-50°, and appreciable flow through an aerodynamic ducted hole can occur at very acute angles.

As for Diffuser Augmented Wind Turbine technology [2], the level of power enhancement will be proportional to the increase in mass flow rate through the swept area of the turbine (i.e. to the mean wind speed rather than its cube). The maximum instantaneous power enhancement is likely to be less than a factor of 2.

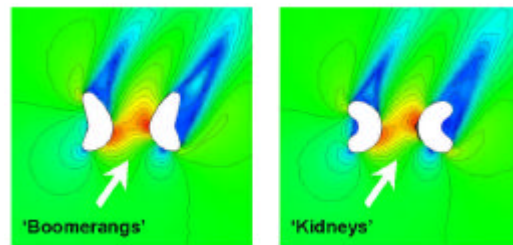


Figure 5: CFD Results showing Wind Enhancement for ,Boomerang' and ,Kidney' Twin Towers

4 ARCHITECTURAL, STRUCTURAL AND ENVIRONMENTAL INTEGRATION

Conceptual architectural designs for several full-scale buildings incorporating single/multiple turbines were completed during the project. Detailed architectural and computer models have been created and analysed.

Aerodynamically optimal designs may prove sub-optimal in terms of economic organisation of space. Neither will they necessarily produce energy efficient buildings, particularly if they contain deep floor plates where daylighting and natural ventilation are impossible.

Space adjacent to the turbines will inevitably be less attractive (and valuable) due to concerns over noise transmission, flickering of rotating blades, electromagnetic interference with electronic equipment.

A sensible means of spatial organisation would therefore be to place intermittently used or service areas (i.e. lifts, stairs, cores) adjacent to the turbine(s), as they have less demanding requirements than normal (office) space and can provide a buffering role. The interiors of infills linking twin tower buildings can be used as exciting transitional spaces or 'sky lobbies' (Figure 6).

Structural optimisation of UWECS is very important. Methodologies and prototype designs (based on Finite Element Method analysis) have been developed to tackle the unique design problems posed, e.g.:

- Stiffening of the building structure;
- Streamlined turbine suspensions from buildings;
- Providing safety meshes to enhance public safety (*and* perception of safety) in the event of a failure of the turbine or turbine suspension (Figure 7);
- Solving the ,Blade Pass Frequency' vibration problem (caused by the continuous movement of the blades past the turbine suspension and building).

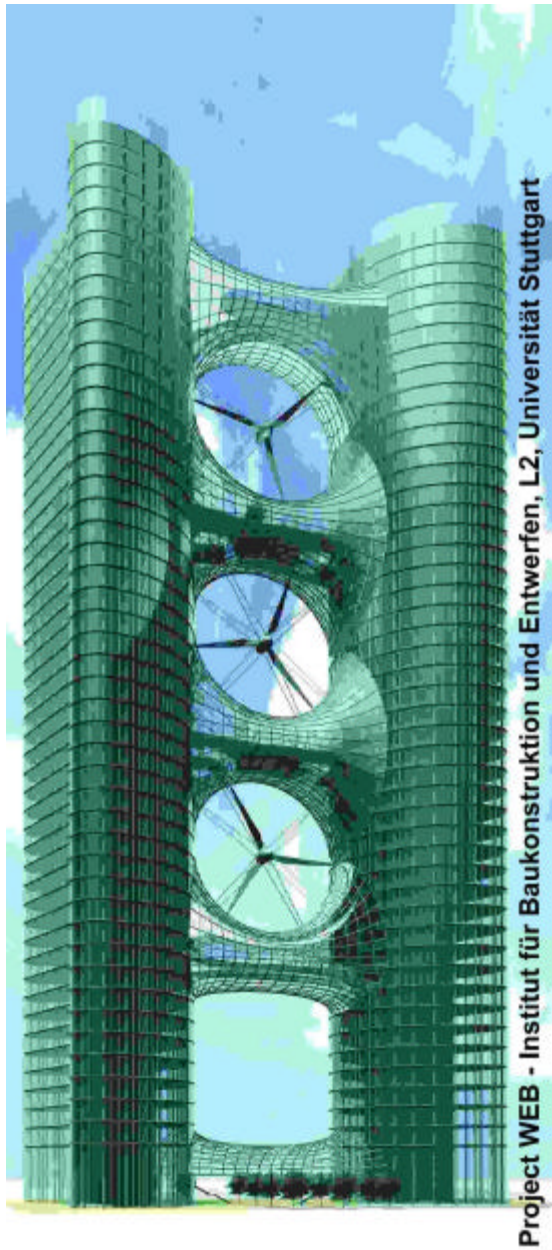
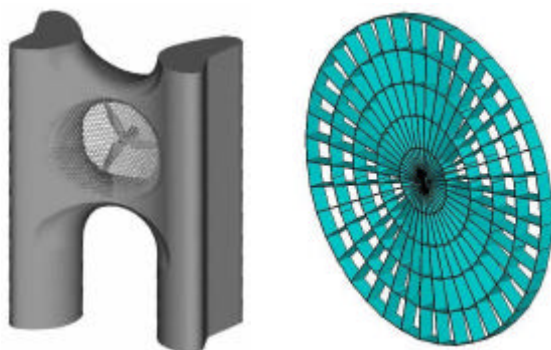


Figure 6: Conceptual Architectural Design of a Twin-Tower Building with 3 Integrated Ø35m HAWTS



Position of Safety Meshes Radial Safety Mesh

Figure 7: Illustration of the Design and Deployment of a Prototype UWECS Safety Device

Assessments of key environmental factors such as visual impacts and noise emission/propagation have been made by building on existing best practice.

The massive scale of multi-MegaWatt turbines is unsuitable for many urban locations, which require smaller machines that may be older and less efficient. Many architects also seem to instinctively favour the aesthetics of (the less widely produced) VAWT designs as opposed to the propeller-like HAWTS.

Acoustic computer modelling has been used, for example, to study the application of acoustic insulation materials on the surfaces of the infills linking twin-tower UWECS buildings, i.e. the effect on Sound Pressure Levels (SPL) perceived by nearby pedestrians (Figure 8).

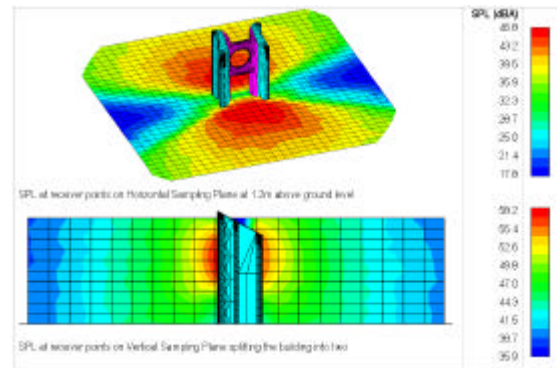


Figure 8: Acoustic Modelling of a UWECS Design

For a multi-turbine twin tower building (e.g. Figure 6), providing that techno-economic and environmental constraints can be satisfied, the integrated turbines could provide at least 20% and up to 100% of the annual electricity demand of the building (i.e. lighting; computers; plant and equipment).

Figure 6 represents a demonstration of how the concept of integrating wind energy into buildings (UWECS) might ultimately be expressed. The same principles could be utilised on a more modest scale or in the form of 'energy or wind towers' – i.e. unoccupied structures used to generate electricity that could be placed on- or off-shore.

5 PERFORMANCE OF UWECS PROTOTYPE

A prototype of one of the most promising UWECS designs – an aerodynamic twin-tower building with a 'boomerang' footprint - was built and successfully field-tested. This design evolved through architectural, aerodynamic and structural studies involving all partners.

MECAL executed the final structural design of the 1/7th scale prototype, which was fabricated in the Netherlands by Xkwadraat (X²), shipped to the UK and erected at the Energy Research Unit at the Rutherford Appleton Laboratory (RAL), near Oxford (Figure 9).

The energy yield of both a Horizontal Axis Wind Turbine (HAWT) and a Vertical Axis Wind Turbine (VAWT) was measured outside and inside the prototype building by RAL (with and without infills).

Placing the wind turbines inside the building/concentrator produced considerably more power compared to when they were conventionally mounted at the same height on an open site.



Figure 9: Photograph of the Prototype UWECS Building (Wind Concentrator) during Field-Testing

Specifically, for the HAWT testing:

- The concentrator effectively increased the wind speed seen by the turbine by a significant 1 m/s;
- The integrated turbine produces enhanced power output for a wide range of incident wind angles (+/- 75degs) onto the building;
- The addition of the infills further enhanced concentrator performance (particularly at acute wind angles).

Extrapolating the results, using a calculation method developed during the project, suggested that a scaled-up building with an integrated HAWT would produce at least a 25% increase in annual energy yield in a typical urban setting over a freely yawing stand-alone machine. Further gains could be realised if the turbine(s) could be safely mounted higher from the ground, thereby benefiting from higher atmospheric wind speeds.

Testing at a larger scale with bigger, higher inertia wind turbines will be required to confirm these findings.

6 DESIGN GUIDANCE

Design guidance has been produced, which attempts to draw upon and extend existing best practice [3]. The guidelines cover the conceptual design process and include methodologies for predicting energy yield, and categorising and assessing environmental impacts and economic costs. There will be both external and internal environmental impacts for UWECS.

If the project (whether the WTs are fully-integrated, retro-fitted, or stand-alone machines connected into the building via the local electricity sub-station) is feasible, i.e. there is sufficient wind at the site and no serious planning or environmental restrictions, then it is possible to move onto an iterative design process (Figure 10). Here, the

UWECS design is optimised by continually updating and improving the level of design information.

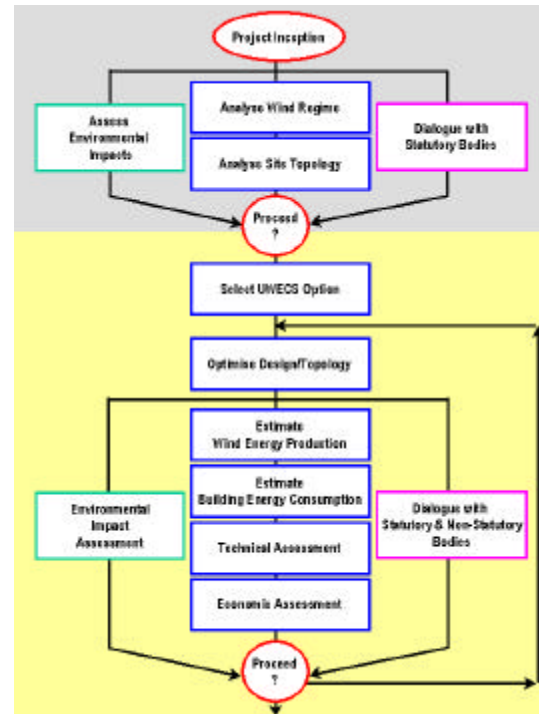


Figure 10: The UWECS Design Process

Ultimately, if the project makes technical and economic sense and the environmental impacts are acceptable, planning permission will be granted (with conditions). The cycle will move onto detailed design (the solution of primarily technical design issues, i.e. the turbine suspension design), construction and operation. Environmental monitoring and consultation will continue throughout the operating lifetime until eventual decommissioning, replacement and/or demolition.

The nature, size and location of the proposed development will govern the real design process. This will depend on attitudes/policies of many actors – national/regional governments, investors, developers, planners, architects, engineers, electricity utilities, insurers, environmental groups, general public - which will vary from country to country. The potential cumulative contribution from integrating wind power into the built environment (on a national or international scale) is therefore difficult to assess at the current time.

7 REFERENCES

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