Final Report for ERIF Project

Building Design for Sustainability:

Integration of Wind Power Plants for Larger Buildings

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The general goal of this project was to develop practical methods for the integration of wind power plants into the design of large buildings (``sky scrapers"). The intention is to size the power plants such that they can provide at least enough power to make the building energy autonomous on average, possibly even providing some excess energy that can be sold and fed into the public power grid, while at the same time optimizing the design subject to a number of disparate requirements. The following considerations play important roles in such projects:

- The wind turbines must form an integral part of the design of new buildings, in order to optimize performance and efficiency.
- The building with integrated wind power plant needs to be considered in the context of its climatic environment. In particular, prevailing wind directions and any neighboring structures must be taken into consideration.
- The additional noise generated by the operation of the turbine(s) must be low, such that noise levels both inside and outside of the building are not substantially increased compared to conventional building designs.
- Operation of the turbines must be safe. While this requirement is an obvious one with regard to human safety, attention should also be paid to potential dangers posed to birds.
- The turbines need to be able to operate under a wide variety of weather conditions, including varying strength and directionality of wind currents.

The research was divided into three major sections –

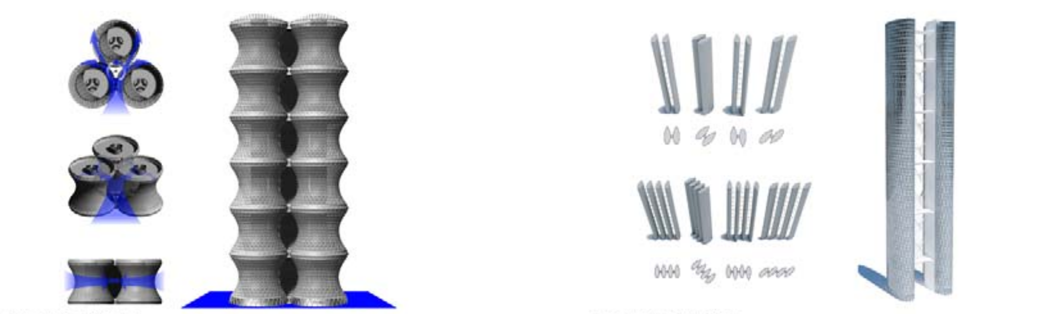
1. Continuation of concept projects with drawings and accurate physical. Ten models of basic concepts have been completed to date.
2. Optimization of concept projects for wind flow energy production. The objective is to validate, fine-tune and adjust the form concepts and dimensions,
3. Evaluation of concept projects based on wind tunnel experiments and numerical simulation.

SECTION – I.

The concepts studied can be grouped into the following four categories (see Figure 1 for examples):

a. Projects for location where wind flow may come from any direction (omnidirectional).
b. Projects for locations where wind flow may come predominantly from one direction.
c. Projects for locations where wind may come predominantly from two directions. This may be a diurnal phenomenon in certain locations.
d. Other locations with strongly predominant single wind direction.

The biggest challenge, but potentially the most rewarding, is energy output in the omnidirectional project, either as a vertical or as a horizontal structure.



a) example of an omnidirectional concept b) example of a unidirectional concept

Figure 1: Sample design concepts

SECTION – II.

From an engineering point of view, noise and safety considerations clearly favor large turbines operating at low speeds over a set of smaller, fast-rotating ones. In addition, cost, reliability and efficiency of wind turbines scale in such a way as to favor one or a few large turbines over many small ones. On the other hand, structural integrity and the safety of building designs that integrate large wind power plants present more challenges than designs that rely on smaller turbines.

The last one of the above requirements presents a number of non-trivial problems as well. While there are designs that allow wind turbines to operate independently of the direction and, within limits, the strength of the wind, integrating such designs within the large static structure of a building reduces the available design space on the one hand, while offering additional options that would not exist for stand-alone turbines on the other. In addition to traditional horizontal-axis machines that can adapt to the direction of the wind by rotating the hub, or vertical-axis designs that are omnidirectional by their nature, one can also consider optimizing the shape of the building in order to reduce or even eliminate the dependence of the efficiency to wind direction of a turbine design.

Thus, selecting an optimal design for a large building with integrated wind power plant presents a multi-faceted challenge at the intersection of civil and fluid engineering as well as architecture. The inter-disciplinary team of PIs for this proposal has collaborated on this topic over a number of years, and is uniquely qualified to further develop solutions that can successfully address the issues described above, both from the architectural and the engineering perspective.

SECTION – III.

Wind tunnel experiments and accompanying CFD analyses have been carried out for a set of six different models, and the accuracy of the CFD has been validated from comparisons between numerical and experimental data. Figure 2 shows the models that have been constructed for this project.

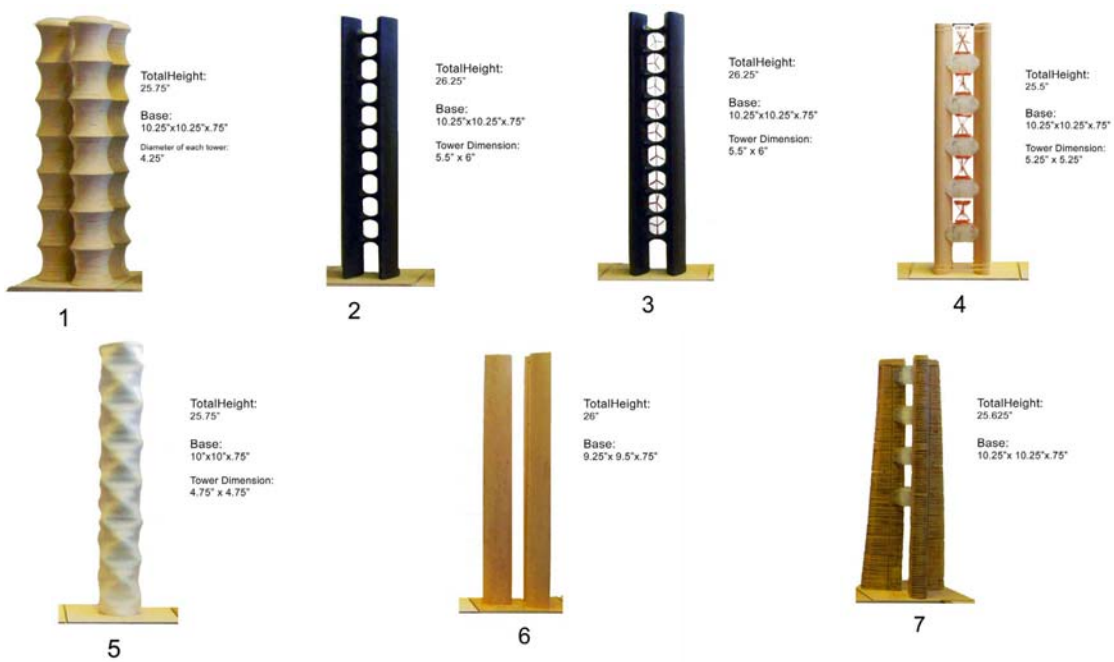
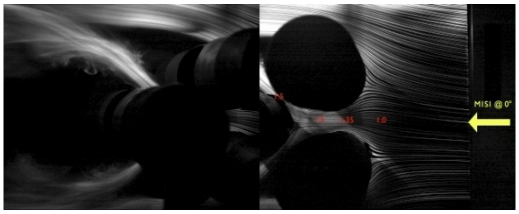
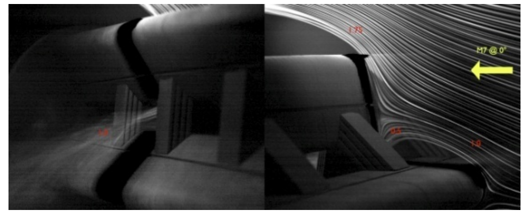


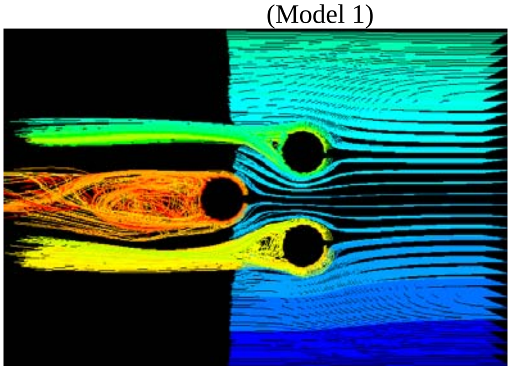
Figure 2: Completed wind-tunnel models



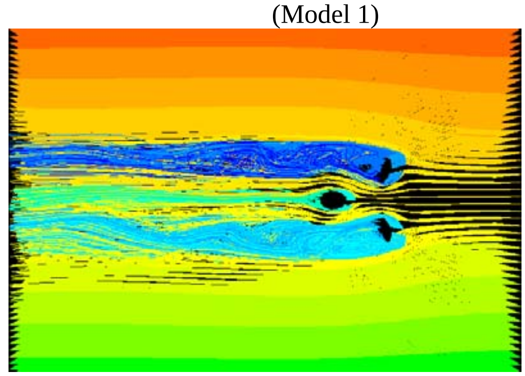
a) Wind tunnel flow visualization (Model 1)



b) Wind tunnel flow visualization (Model 1)



c) CFD flow visualization (Model 7)



d) Wind tunnel flow visualization (Model 7)

Figure 3 Visualizations for selected wind tunnel and CFD studies.

Results from wind tunnel and CFD studies are shown in Figure 3. Due to limited funds, detailed quantitative velocity information was not available from the experiments, but some point measurements were performed. These measurements indicate good agreement of the numerical simulation with experiment.

Conclusions.

Work already carried out and continuing on these unique concepts is generating original data and is in advance of similar work being initiated elsewhere. We are in the process of submitting several proposals to DOE and NSF to obtain funding for continuation and expansion of this project. We have also initiated a multi-disciplinary research program that is hosted under the WISER Institute which includes contributions from the fields of

– Fluid mechanics
– Heat transfer
– Civil engineering
– Building form
– Electrical engineering