INCREASING WIND POWER UTILIZATION USING ELECTRIC HEAT PUMPS FOR DOMESTIC HOT WATER, THERMAL STORAGE AND SPACE HEATING

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INTRODUCTION

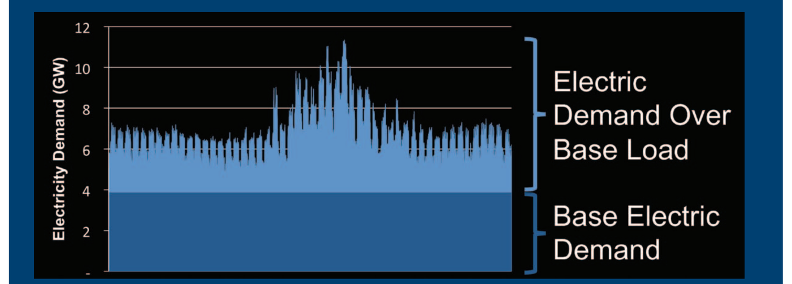
Dense urban areas are often considered energy efficient because individuals tend to use less energy than is common for residents of suburban and rural areas. However, the cumulative effect in New York City (NYC) and other urban areas is a large, concentrated energy demand. With 50% of the world population now living in cities and the benefits of reduced dependence on fossil fuels well established, addressing the challenge of providing urban areas with energy from alternative resources is essential. The potential for in-zone renewable energy is limited in urban areas due to high energy demands relative to geographical size, shading from buildings and limited space for equipment installations. Therefore, integration of renewable energy into the electricity grid is likely required to offset urban fossil fuel usage. Renewable energy resources, such as wind and solar, are intermittent: supply profiles do not necessarily align with demand profiles. As such, large-scale energy storage is generally required to increase the utilization of the electricity generated [1]. This can be costly and render large-scale renewable energy deployments infeasible. These conclusions ignore the dominant energy demands in many cities: Space heating and domestic hot water (DHW), particularly in residential buildings, which typically depend on natural gas and other fossil fuels. They also assume additional equipment will be required to meet energy storage needs.

Strategies to better align supply and demand profiles and to reduce the need for additional storage are desired. The aim of the research presented here is to evaluate the effects of coupling large-scale wind power installations with increased use of electric heat pumps to meet a portion of DHW demand. Further, the DHW tank volume provides a potential energy storage medium when wind-generated electricity exceeds demand. The effects of using electric heat pumps for space heating were also evaluated in combination with various levels of DHW heat pump penetration.

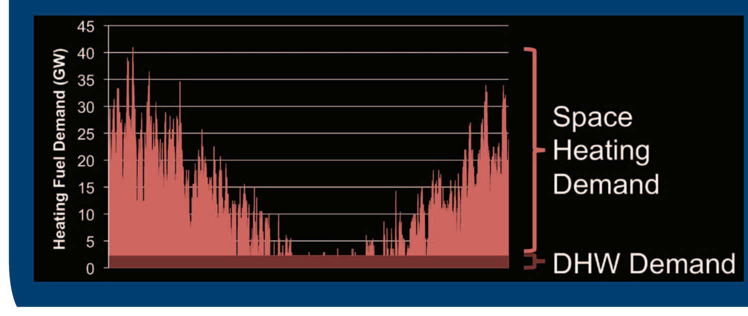
METHODOLOGY

A model was developed for an annual hourly analysis (8760 hours total) based on the hourly NYC electric demand [2], annual NYC heating fuel demand [3] and hourly wind speeds for a New York State site [4]:

Electric demand is split into base load and demand over base load:

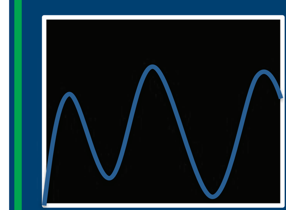


Total annual heating fuel demand is split into constant DHW demand and hourly space heating demand based on NYC fuel use splits [5] and hourly heating degree hours from weather data [6]:

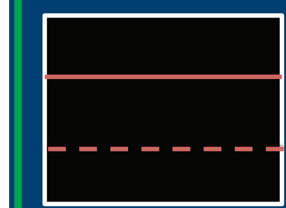


At each hour:

1. Wind power output is calculated based on wind speed, the performance curve of a commercially available 3.0 MW wind turbine and the total number of wind turbines.

2.  Wind power first serves electric demand over base load.

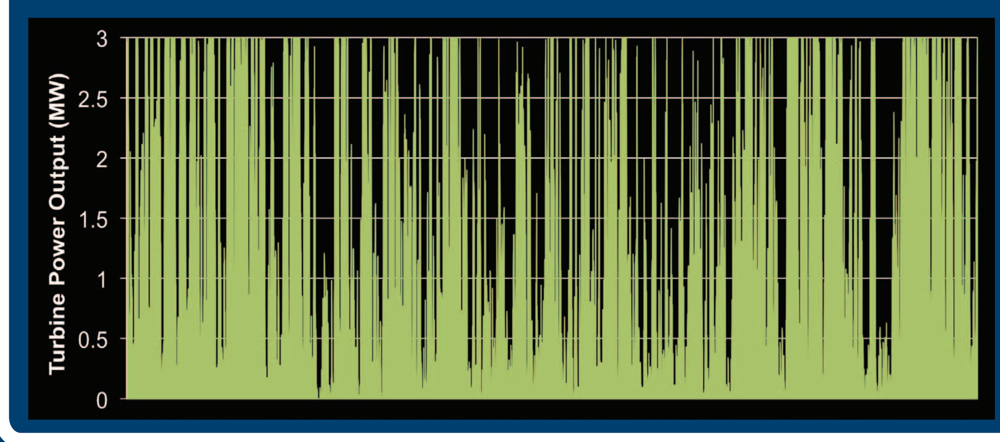
3.  Wind power available after Step 2 serves a portion of space heating demand if HPs are present.

4.  Wind power available after Step 3 serves a portion of DHW demand if heat pumps are present. Excess wind power is stored as thermal energy in water tanks until energy storage capacity is reached. Wind power is "dumped" if storage is at capacity and wind power is available.

RESULTS

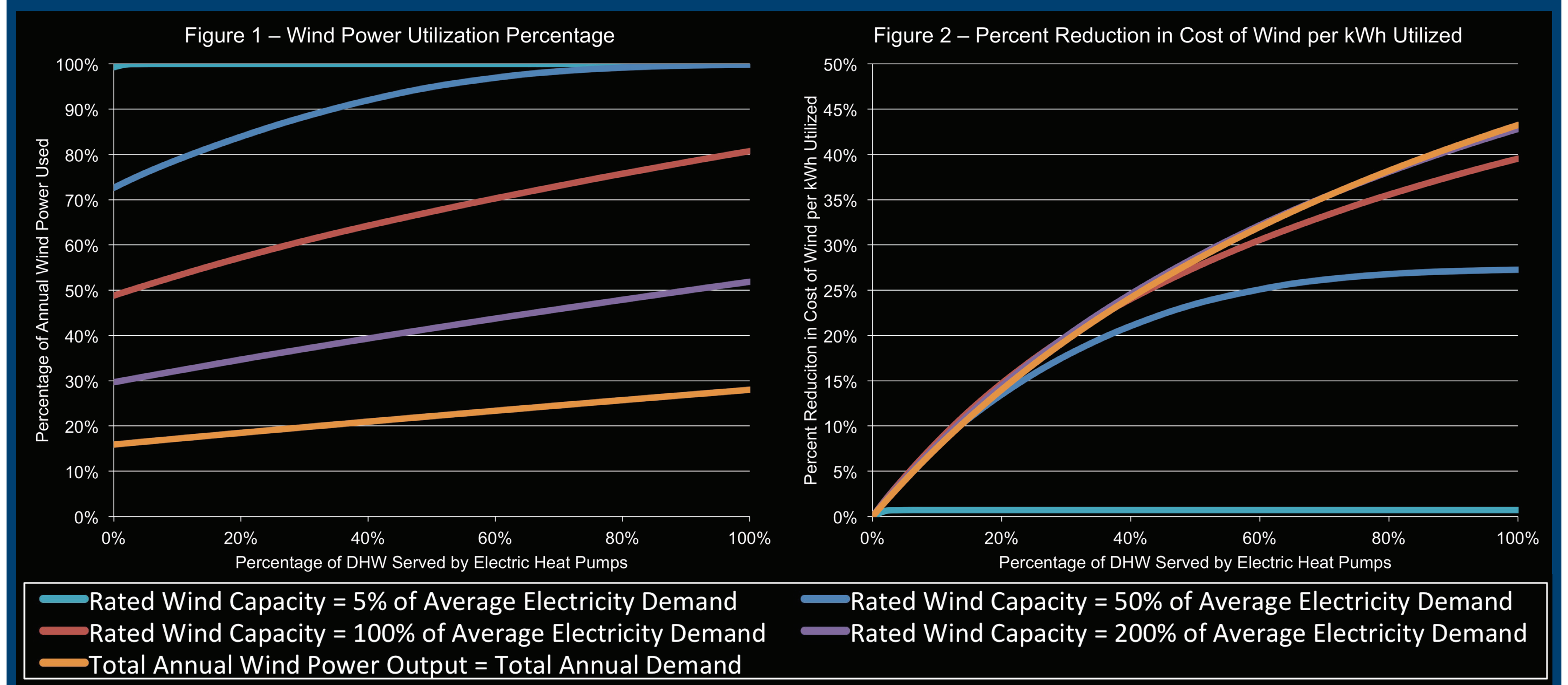
The model was analyzed for cases in which only DHW-serving heat pumps were considered and in which a combination of heat pumps for DHW and heat pumps for space heating were evaluated for their effects on wind power utilization and the resulting effects on wind power cost per unit energy utilized. Utilization calculations were based on the modeled power output of the wind turbines, which accounts for the Capacity Factor of the wind turbines at the location analyzed. Cost savings are relative to the cost of wind power under the base case (no heat pumps for DHW or space heating) for the total rated wind power capacity analyzed.

Wind Power Output



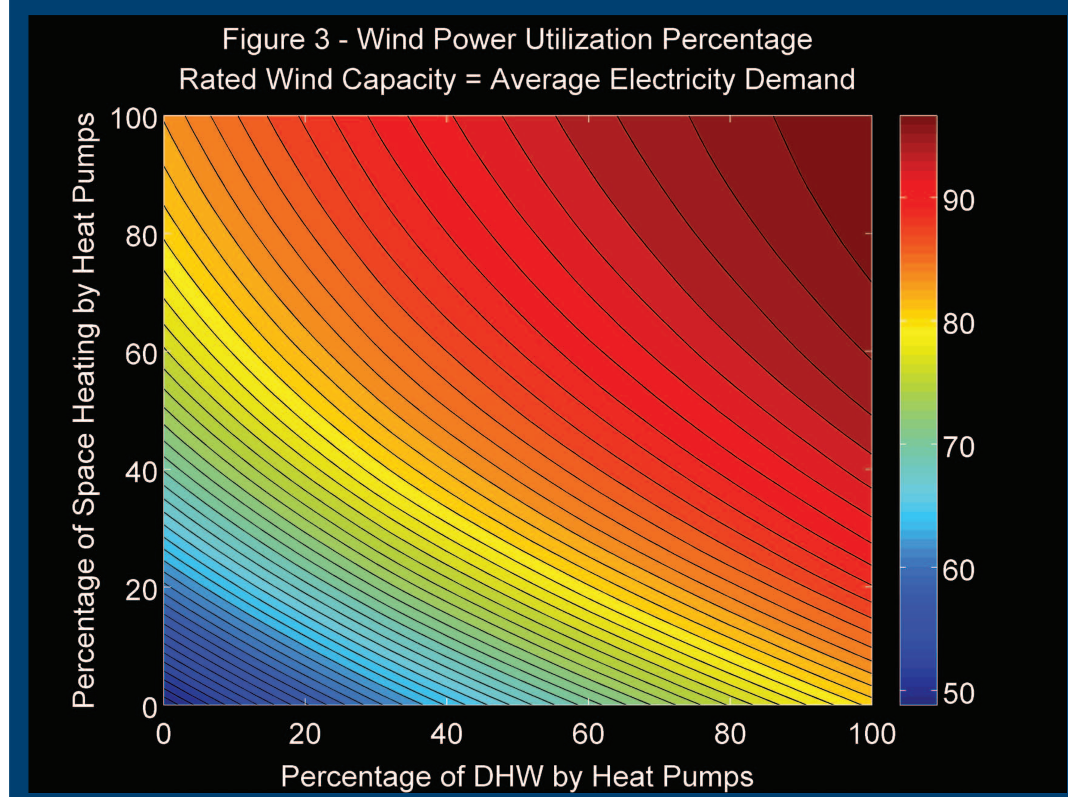
Wind speeds vary over the course of a day and due to seasonal effects. As such, the annual power output of wind turbines is less than the rated power output. The Capacity Factor is defined as the total annual energy output divided by the annual rated energy output (the rated power output multiplied by 8760 hours). For the wind turbines and site evaluated for this analysis, a Capacity Factor of 0.385 was calculated.

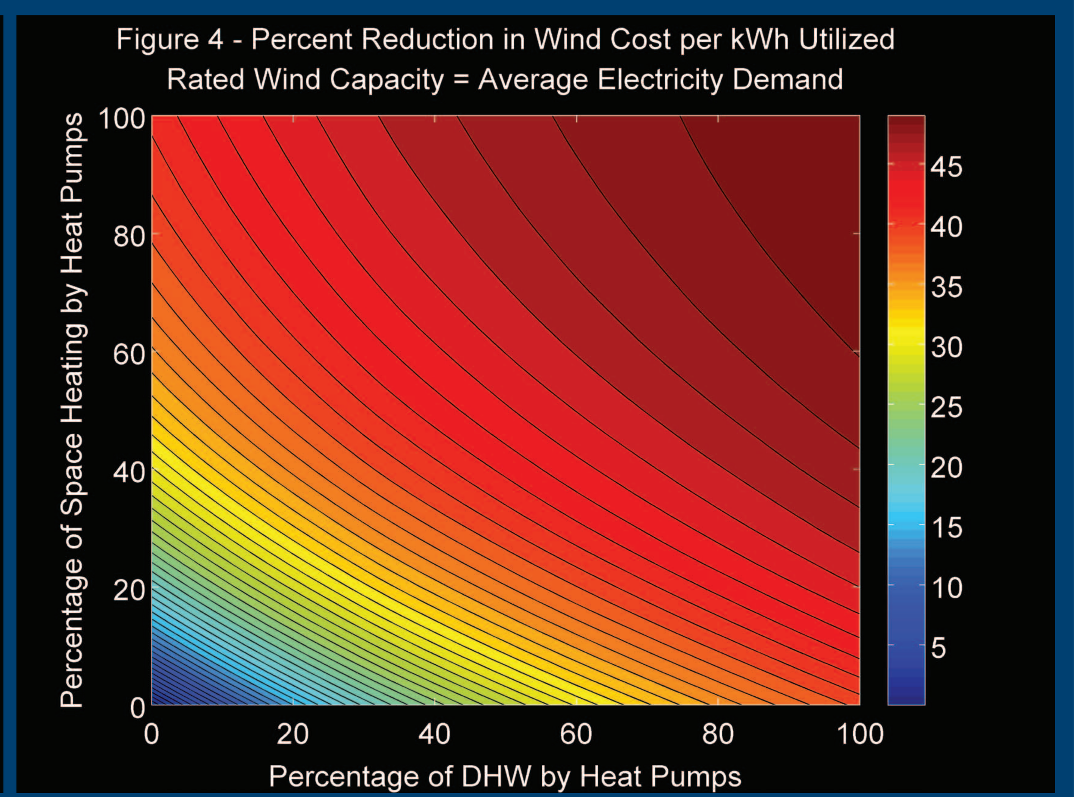
Domestic Hot Water Analysis



The implementation of HPs for DHW significantly increases wind utilization. The wind utilization rates remain higher for smaller wind power capacities, but the relative effects are greater for larger wind power capacities. The cost of wind power decreases with increasing utilization. With wind power capacity equal to average electric demand and 50% of DHW served by HPs, wind cost per unit energy used is reduced 28%.

DHW and Space Heating Analysis





Including HPs for space heating further improves wind power utilization and reduces costs, requiring less penetration of HPs to realize equivalent effects. At 50% usage of HPs for both DHW and space heating:

- Wind power utilization is 87%, compared to 49% in the base case.
- Wind power cost per unit energy utilized is 48% less than the no-HP case.

REFERENCES

[1] Carrasco et al, 2006. *IEEE Transactions on Industrial Electronics.*

[2] NYISO, 2006. *Integrated Real-Time Load Data.*

[3] City of New York, 2010. *Inventory Of New York City Greenhouse Gas Emissions.*

[4] NREL, 2006. *Eastern Wind Integration and Transmission Study.*

[5] Howard et al., 2012. "Spatial Distribution of Urban Building Energy Consumption by End Use", *Energy and Buildings.*

[6] NOAA, 2006. Surface Data, Hourly Global, NYC Central Park.

ACKNOWLEDGEMENTS

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CONCLUSIONS

- Introducing heat pumps to meet domestic hot water demands and using water storage tanks for thermal energy storage significantly increases utilization of large-scale grid-integrated wind power.
- The increased wind power utilization associated with heat pumps and thermal energy storage significantly reduces per unit costs of wind-generated electricity.
- Using heat pumps for both space heating and DHW has significant effects with lower total penetration of heat pumps into the overall system.