Session 2333

NEW PARADIGMS IN ENERGY CONSERVATION and POWER GENERATION FOR THE WORLD'S TALLEST BUILDINGS

(Part 1)

Francis A. Di Bella, PE
617-373-5240 (fdibella@coe.neu.edu)
Assistant Professor, Northeastern University, Boston, MA. 02115
School of Engineering Technology
and
Garen Gregorian, PE
Gregorian Engineers (617-484-3565)
Consulting Structural Engineers
Belmont, Ma.

ABSTRACT

The development of advanced building materials seems to be progressing as fast as the creativeness of architects who demand them for use in their latest creations. Architects often spur onward the development of building materials in order to "push the envelope" of building size, height and form. In 1956, the famous architect Frank Lloyd Wright once envisioned a skyscraper that would be 5,280-ft. tall (500 stories). Wright's contemporaries are still looking to build the Grand Design Skyscraper- some with as many as 210 stories or approximately 3,000 ft. tall. Many contemporary architects see the research for stronger, lighter, corrosive free building materials as the Holy Grail that promises that their modern buildings will live, not only after them, but also through many generations of full usefulness.

Their grandiose life goals are not simply a test of their ingenuity and their ability to get the job done. A very tall skyscraper does serve to solve a very critical dilemma in the business and private world to day: the need for ever expanding office space in a shrinking or stagnant supply of open areas within attractive urban settings. According to Dr. James Trefil ("A Scientist In The City", Doubleday Publishers, 1994),
a 200-story building would have about 20 million square feet of floor space; enough office space for 30,000 workers in a commercial environment or 50,000 occupants living in an ultra-high rise apartment.

In order to be able to compete successfully for the privilege of getting a commission for the Grand Design, architects are constantly looking for the competitive edge; a modern design that would make such buildings more functional and certainly more attractive economically. The fact that futuristic buildings can reach ever increasing heights never before conceived enables innovative and heretofore uneconomical concepts for energy

generation and recovery to be viable or certainly at least worth a serious study. A skyscraper that extends 1,000 ft. or more into to atmosphere enables energy generation schemes that can take advantage of all the natural elements, literally: wind, fire (solar energy and lightening!) and rain.

This paper will explore the energy generation and conservation options that are available for use with the tallest of high-rise buildings. The paper will examine the limits of what are possible and the paybacks for those who are as economically adventuresome as they are entrepreneurial in their architectural designs.

INTRODUCTION

The word ‘skyscraper’ was first penned in Chicago in the 1880’s to describe buildings that were beginning to exceed the 100 ft. level! Since then their increasing majesty has been available for all to witness as the true embodiments of ‘Art plus Science’. Even those pedestrians who are afraid of heights can observe with awe the artistic splendor and appreciate, or at least, wonder at the engineering achievement (the ‘Science’ part of the endeavor) that a skyscraper compels. The world’s tallest man-made structure as of this writing is the Petronas Tower in Malayasia which stands 1,482 ft; only surpassing the Sears Tower in Chicago by 28 ft. as a result of the pinnacles used to cap the Petronas Towers. A more complete list of the world’s 10 tallest buildings is given in Table I for further reference.

TABLE 1. WORLD’S 10 TALLEST BUILDINGS
(ref.: Advances in Tall Buildings;Council on Tall Buildings; Van Nostrand)

BUILDING	City	Ht.	# of Stories	Use	Year.	Matl.
PETRONAS TOWER	MALAYASIA	1482	110	OFFICE	1996	STEEL
SEARS TOWER	CHICAGO	1454	100	OFFICE	1974	STEEL
WORLD TRADE	N.Y.	1386	110	OFFICE	1972	STEEL
EMPIRE STATE	N.Y.	1250	102	OFFICE	1931	STEEL
STANDARD OIL	CHICAGO	1136	80	OFFICE	1973	STEEL
JOHN HANCOCK	CHICAGO	1127	100	MULT.	1968	STEEL
CHRYSLER BLDG.	N.Y.	1046	77	OFFICE	1930	STEEL
BANK OF CHINA	HONG KONG	1031	71	OFFICE	1988	MIXED
TEXAS COMM. PLAZA	HOUSTON	1002	75	OFFICE	1981	MIXED
ALLIED BANK PLAZA	HOUSTON	970	71	OFFICE	1983	STEEL

The extreme heights of these buildings are already large enough to excite the interest of energy engineers to wonder if these heights can be utilized to generate power with power generation options that may not have been considered viable at lower elevations. As more futuristic buildings get commissioned the result will only be to have these heights grow taller still. What is the limit? Perhaps, Mr. Frank Loyd Wright’s image of a building that could be built 1 mile high is a bit (even by 21 st Century standards) optimistic. The engineer’s engineer (i.e. the Left-Brain dominant personality) will quickly point out the physical limitations that a building that grows above 2,000 ft would need to contend with. That engineer quickly identifies the geometrically (with height above the ground) higher wind velocities and hence higher dynamic forces on the building. The need to pump water up to the 2,000 ft level necessitates heavier thickness pipes to sustain the hydrodynamic forces. The sway motions caused by the aforementioned dynamic loads on the buildings would require dampeners that would try to negate sways of over 4 ft. The need to devote more vertical tubes for elevators to provide for transporting the increased number of people to the top floors in a reasonable (less than 2 minute) time requires more non-income generating space. Any attempt to install wind generators on the top of the buildings must consider the increased lateral loads on the building as well as transmitted vibrations. Certainly the enhanced environmental and fire fighting engineering would dictate that the mechanical and electrical systems in the building would need to be integrated better and thus would require enhanced computer controls that would make the buildings virtually fail safe, perhaps requiring advanced computer algorithms.

All of these engineering concerns are valid and now that they have been stated to satiate the appetite of the engineer's engineer, they **will not** be mentioned again in this paper! The purpose of this paper to answer the "What if..." questions that are often first posed by the Artist-Engineer (i.e. the Right-Brain dominant individual) who is not disposed to having such physical constraints stop the flood of possibilities. Thus the principal question that is asked in this paper is: Can a high-rise building's height contribute to the viable generation of power? This first part of a series of papers on this subject will hopefully answer this question.

Energy Generation Options

Once the flood gates are chocked open to new possibilities then the number of power generation opportunities that become available for high-rise building, primarily due to their taller heights is considerable. The power generation options studied for this introductory paper are listed in this section of the paper, along with the relevant equations and assumptions used in the analysis. Based upon these equations and assumptions a set of nominalized parameters were determined and used in a spreadsheet analysis that calculated the power generation and/or energy storage capability of the concepts that were considered. This method of analysis serves two important purposes. First, the parameters are easily presented to all reviewers in order to judge the validity of the results and, second, the parameters may be changed as necessary for either parametric analysis of the options studied or to easily correct any errors in the values of the parameters in future studies. In general, thus, the results presented in this paper should be considered to be a first order analysis with the primary objective being to quickly discern the most attractive energy generation options that would qualify them for further study.

All of the options studied may be quickly identified by observing Figure 1. This figure also serves to indicate how one or more of these power generation systems could be configured to form a complete, integrated power generation system. Thus, Figure 1 indicates that the principal power generated is envisioned to be D.C. electric power which could be stored in an array of state-of-the-art batteries and/or hydraulic storage. The energy stored in this manner would be used as required by first inverting the D.C. current to A.C. This method assures that the power generation options are always active and the power recovered whenever there is a potential energy source available even if the energy is not instantaneously used.

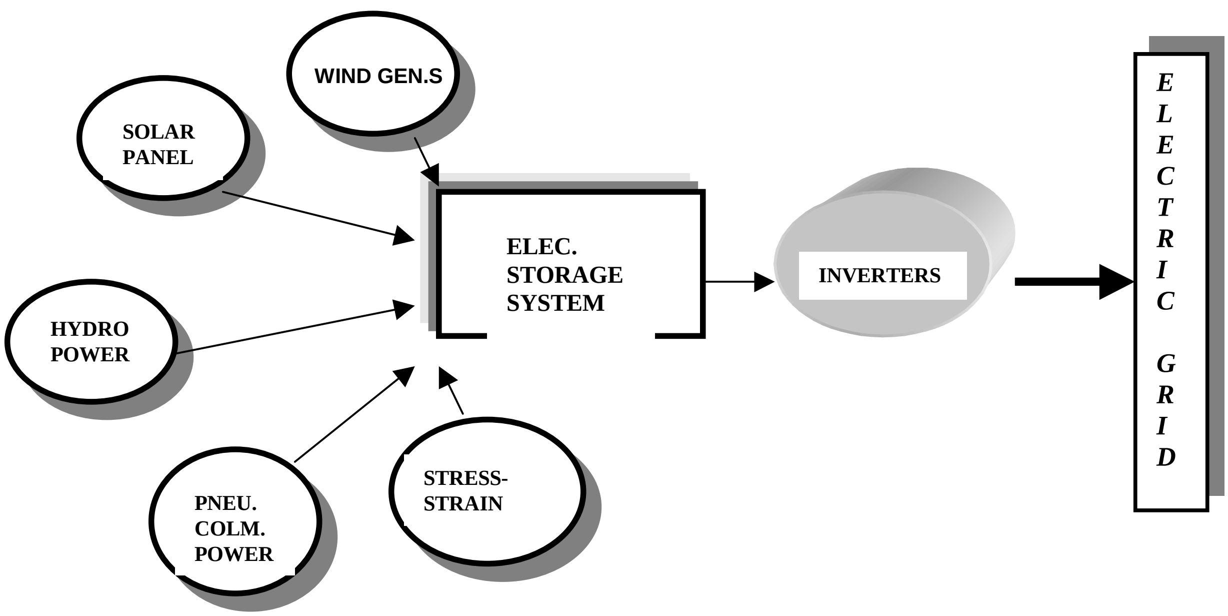


FIGURE 1. ELECTRIC POWER RECOVERY, STORAGE AND DELIVERY SCHEME

This method also provides an interesting complimentary feature that is particularly useful when dealing with tall buildings that need damping to counter the dynamic forces that cause the building to sway. The need for batteries and/or hydro-storage (as will be outlined in this paper) can be used secondarily in place of the massive weights required to provide mass damping in the tallest buildings. Dampening masses of 400 to 600 tons are not uncommon in buildings that range in height from 1000 to 1,450 ft. (ref. 3). Such weights can be used to store enormous amounts of potential energies, as will be demonstrated. For example, a state-of-the-art Sodium-Sulfur (battery) electrical energy storage system can store 320,000 WH/m^3 and has been used in Japan at an electrical substation to provide 6 MW of power for up to 8 hrs. Similarly a zinc-bromide battery has been demonstrated to deliver 1 MW of power for 4 hrs. (ref. 11) in an electric substation.

Wind Power Recovery

It is known that wind velocities increase geometrically with height above the ground. (ref. 3 and 9). Thus, in any study of power generation opportunities at high elevations, it becomes essential to consider the use of wind turbines to generate a continuous amount of power. The choice of the correct type or design of the wind turbines is the only engineering decision to be made. The typical multi-bladed vertical axis type is an option. The Savonius Rotor and Darrieus Rotor (vertical axis) geometries should also be considered. All three types of wind generators have been studied in great detail by various private and governmental sources. The typical efficiencies for such wind turbines between 20 and 30% depending upon their final installation. In fact, it is very common to have these "laboratory efficiencies" compromised by local air disturbances and frequent changes in wind direction. The result is that these efficiencies are seldom obtained on a continuous basis and a utilization effectiveness must be assigned to more accurately determine how many hours in the day the wind generators are actually performing at or even close to their design point efficiencies.

This paper is proposes the use of a multi-directional, helical rotor type that has been designed and studied extensively by Prof. Alexander Gorlov (College of Engineering, Northeastern University, retired). A photo of a small Gorlov wind turbine is given in Fig. 2.

The Gorlov turbine is able to have a vertical axis turbine installed that will enable the wind energy from any direction be recovered at efficiencies that have been measured in open fields to be 30%. The vertical turbine design also lends itself to be packaged in cost-effective modules that can be installed around the periphery of the building's roof and/or, for a very large device, on the pinnacle of the skyscraper. For a pinnacle rotor, its installation would take the place of the traditional aerial antenna. This author believes that such a pinnacle would be an attractive and productive cap for the world's next tallest building.

The vertical axis orientation is also thought to minimize any vibrations that may otherwise be induced into the building's super structure which is a common limitation when a typical horizontal, multi-bladed wind turbine is used for power generation on buildings. The vertical axis turbine also minimizes the thrust (lateral) loading that would be exerted by a conventional horizontal axis machine.

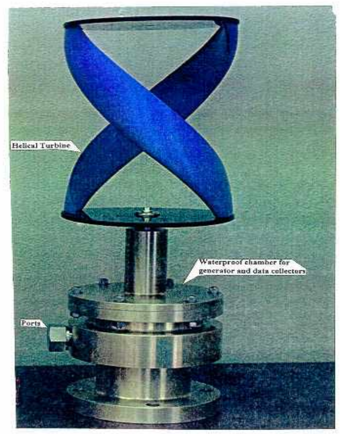


Figure 2 Double-Helix Turbine with electric generator for underwater installation

Fig.2 Gorlov Turbine Rotor and Motor Assembly

The Gorlov wind turbines used in this analysis will be assumed to be 26 ft. tall (or approximately the length of two skyscraper stories). It is also assumed that they will be installed along the perimeter of skyscraper's roof with a spacing that is determined by a fixed ratio: a Turbine Dia.-to-Axial Displacement =50%. This ratio also accounts for turbines that are in line with each other in the direction of the wind and thus may interfere with each turbine receiving the full strength of the wind stream that is available at the roof line. It is also assumed that the velocity of the wind at an elevation (h, ft) varies according the following relationship (derived by the author using information from ref.s 3 and 9).

$$\textbf{Wind Vel. (ft/s)} = 18.3 \times (h/32.8)^{0.166341} \qquad \textbf{Eqn. 1}$$

The wind kinetic energy will be recovered in the conventional manner: kinetic energy converted to rotary mechanical converted to electrical power (via gear box) at conversion efficiencies of 30% and 80%, respectively.

Of particular interest in a future study will be the use of a matrix of vertical axis turbines that are installed in a three dimensional pattern from the top 4 floors of the building. This turbine field will be used to recover the von Karman vortices that are shed from the building due to the wind streams flowing around the building. The von Karman vortices are known to contain considerable amounts of energy that are focused in small areas, making their recovery more effective with a minimum number of wind generator modules.

Solar Panels

The use of roof mounted and/or skin mounted solar panels is an obvious choice for power generation on skyscrapers. The efficiency of photovoltaic solar panels is expected to reach their true design efficiency of 15% and not be compromised by the natural obstructions that are commonly found on or near ground level. Thus, at elevations above 1,000 ft. one would not expect either natural objects such as trees or man-made objects such as neighboring buildings to obscure the sun light from obscuring the solar panels. It is also possible that such periodic occurrences such as clouds, fog or urban smog and haze will less often effect the solar view factor for panels that are elevated above the ground. Clearly, a solar panel that is installed at higher elevations has a maximum utilization effectiveness. For this analysis it will be assumed that the last two stories (26 ft.) of the building will have solar panels installed and that 75% of the roof surface can be utilized for installing solar panels. A solar constant of 300 Btu/hr/ft^2 was used in the analysis with a collection efficiency of 15%. A daily effectiveness of 70% was chosen to account for variations the solar constant during the day light hours of use.

Hydro Turbine Power Generation

The celebrated Hoover Dam, one of the largest in the world, is 725 ft. tall. The world's tallest building is almost 2 times this height. It thus seems only natural that the ability to generate power using hydro turbines be studied. But what is the source of the water at these extended elevations. The obvious answer is rain water. The less obvious but even more continuous supply is the water that must be pumped to each floor of the skyscraper in order to provide lavatory water (as well as any commercial water supply needed for penthouse restaurants, etc.).

Pumped hydro storage also becomes of increasing interest when elevations exceed 1,000 ft. The later requirement is not uncommon at ground level where many electric utilities and private companies are saving electrical utility costs by pumping water to high elevations when the cost of electricity is cheap (during the evening and early morning hours) and then recovering the stored energy during the day-light hours. The savings in demand costs alone is often enough to justify the engineering expense to construct, install and operate such a system. The use of a pumped storage system for sky scrapers does have merit when one also considers the existing need for large masses in the penthouses for dampening the sway induced in the tall buildings caused by dynamic (wind) forces. The consideration for providing an emergency supply of water for fire fighting is also an added benefit.

A significant engineering consideration is again the choice of the hydroturbine that can operate robustly with a fluid source that will not only be at very high speeds (falling from 1,000 + ft.) but also not be simply liquid. If energy from sanitary water is to be recovered then the mechanical system must be designed to contend with particulate matter as well as high velocity fluid flow.

The amount of water that can directed to the hydro turbines will be directly proportional to the number of occupants working in the tall rise building. For this study it was assumed that the maximum number of people that will occupy the building is based on an occupancy of 100 ft^2 per person (ref. 6). The amount of floor space for a generic skyscraper is given by:

$$\mathbf{A_{floor} = h/(ht.\ of\ each\ story) \times (A_{base}/2) \times (1 + A_{roof}/A_{base})} \qquad \textbf{(Eqn. 2)}$$

where : $\mathbf{Abase = (300 \times h/1450)^2}$

$\mathbf{A_{roof}/A_{base} = 0.6}$ **; ht. of each story =13; h = Building height, ft.;**

$\mathbf{A_{effec.\ floor} = (-.0002x(h-500)+0.8) \times A_{floor}}$

These relationships are based on a very generic model of a skyscraper whose basic shape is a slender, four sided, regular pyramid and thus whose base is always larger than its roof area. The areas obtained from this equation have also been rounded up to allow only 2 significant digits. This is thought to be adequate for the very generic model used in this analysis to represent a futuristic skyscraper that can only have generic (indeterminate) design features at this time.

For purposes of determining the total daily waterfall, it is assumed that each occupant of the building will consume 2.5 gal.s of water within the building during a 12 hour (business) day. More specifically it was assumed that 80% of this water would be delivered to the hydro. turbine outfall piping during three concentrated, 1 hour periods during the normal business hours. It has also been assumed that the average water-fall height is one-half of the building height for all of the water consumed during the day.

The choice for the turbine is again the Gorlov turbine. This turbine is seen to be robust enough in design as to allow particulates to not interfere with its mechanical operation. In fact, its original design specifications considered the need to be able to pass live (fish) as well as inanimate objects (tree limbs, silt, etc.) when first considered for use in recovering energy from rapid river currents as well as hydro dams. The efficiency for this turbine is taken as 30% with respect to the input kinetic energies.

Air-Vent Power Recovery

It is known that one of the natural results of building taller buildings in the atmosphere is the need to control the internal and external air flows. Presently, for example, air flow control is required for maintaining proper ventilation for not only the occupants (at 15 - 25 cfm/person, ref. 14) but also the electrical (heat generating) equipment (approx. 0.8 cfm/sq.ft. (ref. 12) for 2 to 3 W/ft^2, ref. 6).

It is also known that a 1,000+ ft. conduit extending into the atmosphere will have its top opening at lower atmospheric pressure and temperature than the opening at ground level. The difference is caused by the changes in the weight of the air column at the two different heights. The formula for the change in pressure is given here (and assumes a constant gravitation acceleration, g_g =32.2 ft/sec.^{2}, for the heights to be considered in this paper (i.e. less than 3,000 ft)).

Dp (psi)=14.696 x (1- exp(- h x 32.2 x 28.966/ (32.2 x 1545 x To) Eqn. 3

where: To= 520- .5 x 3.6 x h/1000; To= amb. temp. R at bld.g height, h; h= ht. of the building (ft.);

If a pressure differential (Dp) of this magnitude could be maintained then an air flow will be induced through such a conduit. This phenomenon has not been utilized for power generation; until now! For the purposes of this analysis it will be assumed that an induced air flowrate can be controlled through one or more of the elevator shafts that may be not in full operation during the non-rush hours. Certainly, a more complicated but equally valid energy conservation options would be for the air draft to assist the lifting of the elevators, thus saving some of the power required to raise the elevator to the top floors. This will be left for a later time and Part 2 of this paper[1].

A patent disclosure has been prepared by the author to identify a modification of this effect as summarized above. The disclosure recognizes that the induced air flow can be affected by increasing the temperature of the air within the air shaft. Increasing the air temperature, decreases the density of the air column achieves the desired effect: that of establishing more of a pressure differential across the inlet and outlet of the pneumatic conduit. The addition of heat certainly is an energy consumption unless, as the disclosure claim states, it can be recovered from the building's otherwise wasted energy sources. For example, the air conditioning within the building must include cooling, heating as well as ventilating. The waste energy from the building's HVAC system as well as from the pieces of conventional electrical office equipment as well as people (250 & 200 Btu sens. & latent heat loading, ref. 12, and heat from a myriad of other commercial sources for which Q_{waste}= 10 to 20 Btu/hr/ft^2 , ref. 5) can be directed to an air conduit that has been specifically designated for the Pneumatic Column Power Recovery (PCPR) system. An alternative method for establishing a significant pressure differential would be to use a rather large pneumatic-ejector device on the top of the building that utilizes the Bernoulli effect to draw air upward, through the air conduit, using the high velocity air streams that are prevalent at those altitudes.

For a skyscraper, the columns for the PCPR are ready-made: the unused or under-utilized elevator columns. For this study the power generation considers the use of at least one of the elevator shafts that are installed in the building during the non-rush hours. The velocity of the air was fixed at 45 mph (maximum) and the hydraulic diameter of the conduit assumes a 12 ft. x 12 ft. opening for each shaft. A calculation of the induced airflow rate[2] through this size elevator shaft found that a volume flow rate of 7,400 ft^3/s is easily maintained; corresponding to approx. 45 mph. It was also found that this

[1] The recovery of elevator, and in some instances, escalator power by using regenerative braking with induction generators is also not considered in this paper as they are already in place in some high rise buildings.

[2] An induced air velocity of 95 mph was calculated in this analysis which is comparable to an actual measurement of 70 mph that has been recorded at the Sears Tower when the revolving doors in the lobby were out of order (ref. 3)

flowrate was not a strong function of building height. Although the pressure drop increased with height it did so linearly at building heights from 1,000 to 2,500 ft. but so also does the the air flow pressure drop vary linearly with conduit height. Thus, virtually the same volume flowrate can be maintained in the same size conduit in buildings with heights from 1,000 to 2,500 ft.

The number of elevators used in a high rise building is based on the following relationship:

Nelev.s = (Afloor/100) x 0.60 x h x (SF=2)/(2 x Velev. x 0.5hr x 20 occupants/elev. x 60 min/hr) Eqn. 4

A check of this formulation with the floor space and known number of elevator shafts used in the Sears Tower (where 40 elevator shafts are known to be installed, ref. 3) reveals a very good correlation.

Once again, the Gorlov Wind Turbine is considered as the mechanical device used to recovery the induced air, kinetic energy.

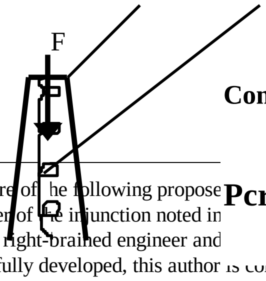
Thermal Expansion Energy

Avoiding the adverse effects of thermal expansion is essential in a properly designed skyscraper. The architects and structural engineers must contend with the adverse effects of thermal expansion when designing the skin (facade) of a high rise building to be sure that the skin members are not damaged via thermal fatigue only to become dislodged and fall on innocent pedestrians. Can this expansion energy be put to use? [3]

One potential means is storing the thermal expansion energy in a spring. As the building expands, the compressive energy is stored in a spring as shown schematically in Fig. 3 until it can be released via a mechanical or hydraulic mechanism not shown and as far as this author is aware, not yet invented[4].

For this analysis the 'spring energy'-building system shown in fig. 3 has been modeled with the following equations (eqn. 5a & b)

Fig. 3 Model of Skyscraper with Spring



Compressive Load (lbf)= α x DT x (kspring x AE)/(AE+kspring x h); $\alpha = 6 \times 10^{-6}$ in./in./F

Pcr.= π^2 x (EI)/h^2 ; (EI) $\cong$ 1 to 2 x 10^{16} (lbf-ft^2)

[3] Given the nature of the following propose… remind the reader of the injunction noted in… liberated from a right-brained engineer and…

[4] While not yet fully developed, this author is considering an hydraulic system that can store the energy not using a spring in the literal sense but an equivalent system using an hydraulic piston and fluid storage device. The system would utilize a modification of a concept conceived by a student, Mr. Edward Araujo for a building dampener.

The analysis proceeded by assuming that the building was elastic and could be treated with a single Modulus of Elasticity (E). The above formulation determines the compressive force that the building structure must support but constrained to a Euler Column critical load with a safety factor of 2. The thermal expansion is assumed to have a cycle time of 1 per 24 hours.

Stress- Strain Energy

One of the most critical factors in the design of high rise buildings is the need to avoid via dampening the sway that is caused by dynamic wind loads. Building sway must be limited to approximately 1 ft per 500 ft. of building height[5]. The stress-strain energy invested in the tall-rise building from this dynamic loading is considerable and was deemed worth considering for this study.

For this study it was also assumed that the building structure could be modeled with a single 'spring constant' (k). The wind loading on the building was assumed to be modeled by the following relationship:

Wind P_{load} on Bldg. (lbf/ft2)= 50 x (Vel. x 3,600/(100 x 5,280))^2 ; Vel. (ft/s) Eqn. 6

Net Load (Lbf) on Bld.g= 0.183 x W_{base} x 0.5 x(1+ sqrt(0.3)) x $h^{1.3323}$ Eqn. 7

Stored Stress-Strain Energy (lbf-ft.)= Load x Sway/2 x (conv. eff.= .75); Eqn. 8

Sway (ft)= (h/500) x (Wind Vel./147)^2 Eqn. 9

where: h =height of Building, ft.

The pressure loading on the building (P_{load}) is observed to geometrically increase with the wind speeds that also increase geometrically with elevation (see: Wind Power recovery section of this paper). As indicated previously, a mechanical or hydraulic mechanism for recovering this energy is not presented but certain aspects of the designs are under consideration by the author.[6]

Fossil Fuel Emissions Savings

[5] This standard is based on a conversation with Mr. Zareh Grogorian, Grogorian Engineering

[6] In fact, the use of energy absorption dampers in many skyscrapers is well known but as yet the absorbed energy is not recovered for later use.

An important aspect of the recovery of energy from the high rise buildings will be the economics of the power generation systems selected. The economic considerations will be reviewed in Part 2 of this paper.

An important environmental savings to also consider (with an appropriate economic assessment to be evaluated) is the savings in environmental pollution. It has been shown (ref.13) that a 500 kw wind generator, for example, can avoid the use of 290 tons of oil per year and thus prevent the release of 1087 tons of CO_2, 1.81 tons of NO_x and 4.8 tons of SO_2 (all per year).

Additional Building Analysis Parameters

The following list includes other building parameters that have been used in this first order analysis.

(ref.s 5, 6, 7):

Elec. power Req.s= 2.5 to 3.0 W/ft^2

Peak Elev. Power (kw)= 1130 x (h/610)

Effective Floor Util.- to - Total Floor Space= .75 to .80

Outer Facade Surface -to- Floor Area = 0.4 to 0.5

Ventilation Req.s = 5 cfm/occupant

Ref. 10

Lead/Acid Battery Rating= 30 W-H/Kg

Li/Cl_2 (at 600 C) Rating = 440 W-H/Kg

Ag/Zn Rating = 220 W-H/Kg

Ref. 11.

Lead/acid battery= 80,000 WH/m^3

Sodium/Sulfur = 320,000 WH/m^3

Zinc/Bromide= 25,000 WH/m^3

Author's Assumptions:

Height per Building Story= 13

Roof Area -to- Base Area = 0.3

Width of Building Top -to- Width of Bld.ing Bottom = sqrt (0.3)

Elevator Shaft Size= 12 ft. x 12 ft

Elevator Speed = 20 + 0.02 x (h-1500) , mph

Max. Elev. Occupants= 20

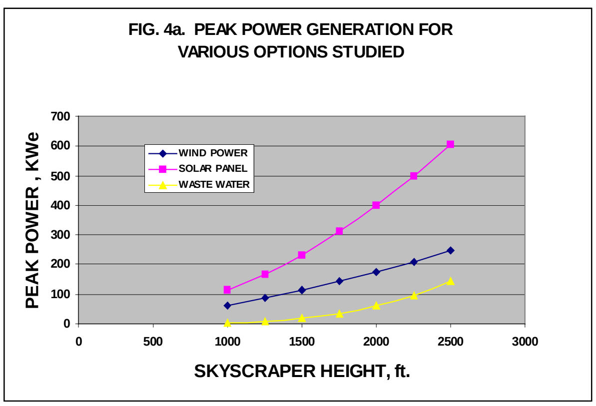
(All other assumptions are given at the top of the spreadsheet that was used for the analysis of each power recovery option **– the entries are clearly identified with a bold box around the value**

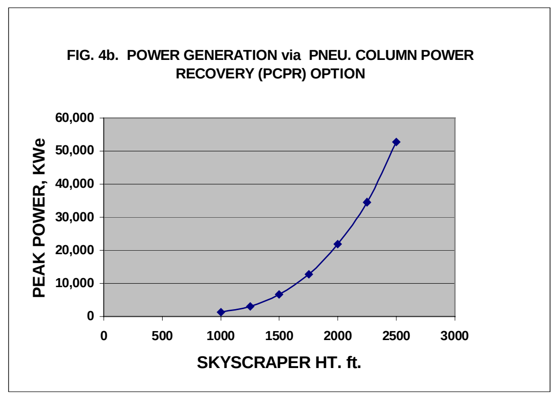
RESULTS

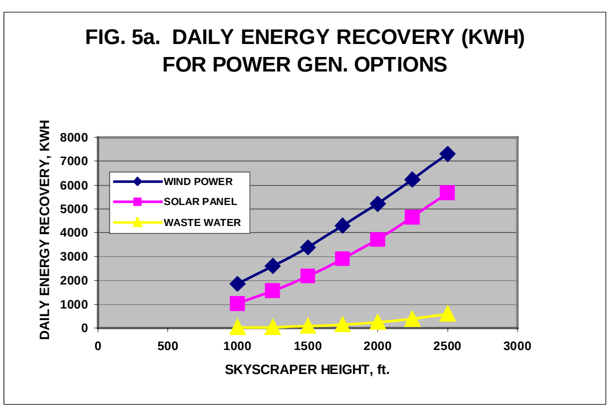
The results of the energy and power study are displayed in Figures 4 (a &b) and 5 and Tables 2, 3 and 4.

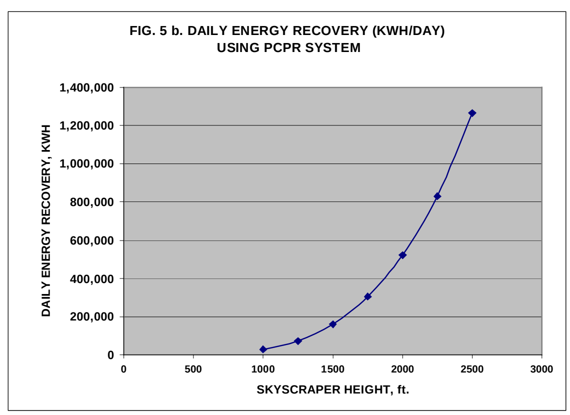
The three Tables of data identify the output directly from the spreadsheet at skyscraper heights of 1,000 , 1,500 and 2,500(!) ft. All of the assumptions made by the author (or gathered from the available references is given at the top of the Table and are enclosed with a (bold) box. The middle data range in each Table displays the calculated results based on these assumptions. The lower part of each table entitled: ***Power and Energy Results*** displays the calculated results from all of the subsequent calculations.

A more concise result of these calculations is graphically displayed in Figures 4 and 5.









The analysis reveals considerable power generation opportunity if a pneumatic column power recovery system (PCPR) is utilized to recovery the induced air kinetic energy from the skyscraper. The peak power recovery ranges from 1,200 to 53,000 Kwe for a skyscraper with a height of 1,000 to 2,500 ft., respectively.

The analysis revealed a more modest power generation opportunity if either wind turbines or solar panels are utilized at the roof line of the skyscraper. Power recovery ranged from 100 to 600 Kwe (for solar) and
from 60 to 250 Kwe for wind power recovery.

The potential for recovering the building stress-strain energy(s) is insignificant compared to these options.

Waste water, hydro. power recovery is not viable unless turbine efficiencies can be improved upon. The use of the mutli-directional, helical turbine may need to be revised to consider a more conventional hydro turbine where efficiencies above 50% are possible.

CONCLUSION:

This study has provided a first order analysis of the potential energy and power recovery available from five power generation system options that may be integrated into skyscraper buildings. The paper has revealed an interesting power generation option: a Pneumatic Column Power recovery (PCPR) that could enable skyscraper buildings to generate considerable amounts of power with no fuel consumption. The economics and design of such a system is underway by the author and will be reported in part 2 of this paper.

References:

1. “Remaking the World. Adventures in Engineering”, H. Petroski, Knopf, 1997
2. “Why Buildings fall Down”, M. Levy and M. Salvadore, Norton, 1992
3. “A Scientist in the City”, James Trefil, Double Day, 1994
4. www.the-skydeck.com; Info. on Sears Tower
5. “Advances in Tall Buildings”, Lynn Beedle, Editor-in-Chief; Council on tall Buildings and Urban Habitat
6. “Developments in Tall Buildings, 1983”, Lynn Beedle, Council on Tall Buildings and Urban Habitat
7. “Tall Buildings: 2000 and Beyond”, Nov. 5-9, 1990, Fourth World Congress; Council on tall Buildings and Urban Habitat
8. “ Tall Building System and Concepts”, Volume SC, Monograph on Planning and Design of Tall Buildings; Coordinators Fazlur Khan and John Rankine
9. “Principals of Solar Energy”, Frank Kreith and Jan Kreder, McGraw-Hill, 1978
10.”Applied Solar Energy”, A. Meinel and M. Meinil, Addison-Wesley, 1977
11. “Electrical Energy Storage Systems for Energy networks”, J. Kondah, et al, Energy Conversion and Management Journal, No. 17, Nov., 2000 , pg 1863
12. “Energy Efficient Design of Large Office Buildings”, John Radford, M. Addison, T. Smith; Energy Engineering , Vol.98, No.1, 2000

13. "Wind Energy Surveying and Technoeconmic Assesment of Identifiable WEC System Installations:, A.D.Karlis, Dermentzoglou, D.P. Papadopoulos, Energy Conversion and Management, 42 (2001), pg. 49

Biography:

Francis A. Di Bella, PE is an Assistant Professor, Northeastern University, Boston, MA.; College of Engineering , School of Engineering Technology. Mr. Di Bella's professional engineering research interests involve the practical, engineering applications of Thermo-fluid and Machine Design sciences within the Mechanical Engineering discipline.

Specific areas of interest include all aspects of energy systems including generation, storage, conservation and a variety of innovative applications of wind, solar and hydropower. Such systems and their application include gas and steam engines (reciprocating, gas and steam turbines) with steam generation and steam turbine cogeneration of ancillary power. Engine power augmentation including turbo compounding, micro-turbine power generation using turbo-charger machinery for stationary electric power generation and use. Interest extends to the thermodynamic modeling of cogeneration systems and their size vs. cost optimization. This interest is exhibited in course instruction in heat transfer, thermodynamics, fluid dynamics.

Prof. Di Bella is also involved in all aspects of creative product concept genesis, design and product development. Product development extends the gamut from systems to prevent Road Rage to emergency repair of ruptured natural gas pipelines. University application of this interest includes instruction in the following courses: Machine Design, Statics and Dynamics, Intro. to Design and Intro. to Product Design as well as student Capstone Design Projects. He is also the Faculty Advisor for the Student's Mini-Baja vehicle competition.

Mr. Garen B. Gregorian, PE, MSCE, MSME is a Project manager with Gregorian Engineers and is an Adjunct Professor at Northeastern University in the Department of Art and Architecture. He has 15 years of experience in the construction industry and is a registered professional engineer in five states.