THE NEW YORK TIMES BUILDING

620 EIGHTH AVENUE
NEW YORK, NEW YORK 10018

TECHNICAL REPORT THREE: ALTERNATIVE SYSTEMS EVALUATION

AE 481W-Comprehensive Senior Project I
Building Mechanical & Energy Systems Option
IPD / BIM Senior Thesis

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EXECUTIVE SUMMARY

The New York Times Building (NYTB) is located on the west-side of Midtown Manhattan in New York City, New York. This 52-story building is 1.6 million square feet and offers high end office space and ground level retail. An energy analysis and existing conditions evaluation of the NYTB was performed and reported in technical assignments one and two. This technical report presents three research studies that were performed to investigate the building's mechanical system. These three studies focused on topics including façade redesign, energy sources and finally, alternative air distribution systems. The goal of these studies was to identify areas in which the design could be altered in order to optimize overall performance in areas such as energy use, sustainability, operating costs and maintainability. It also investigates the mechanical engineer's role in a project which utilizes Building Information Modeling (BIM) and the Integrated Project Delivery (IPD) method.

The façade of the NYT Building is one of the most notable architectural design features and also one of the most significant contributors to the building's energy load profile. An analysis was performed to determine the weight of different variables in façade design and their effect of the building's heating and cooling loads. It was concluded that a decrease in the glazing's shading coefficient and percent glazing independently produce reduction in heating and cooling loads.

The energy sources study investigates current energy consumption and how the design can improve on the baseline consumption. In technical report one and two, it was established that the utility costs were unnecessarily high. Improving the energy utilization will most certainly provide long-term savings for the owner and future tenants. The study concludes that it would be cost effective to increase the size of the cogeneration plant. It also establishes solar-thermal technology as the most viable renewable on-site energy resource. For a more in-depth analysis, see the Energy Sources Study section and Appendix 1.

The third study focuses on the HVAC air distribution system. More specifically, a comparison was done between the existing underfloor air distribution system and an alternative chilled beam system. Both active and passive chilled beams were analyzed in this study, and results concerning energy use and operating costs were tabulated. The advantages and disadvantages of each type of system were also tabulated to assist in the comparison. A hybrid system using both underfloor air distribution and radiant heating and cooling was also analyzed in this way. However, an energy simulation of this hybrid system could not be done due to the limitations of the Trane Trace software. The results show a slight decrease in overall energy use with a chilled beam system. A chilled beam system could also help increase indoor air quality and comfort. In addition, it was found that a hybrid system could potentially help improve the electricity demand profile and thus allow for further optimization of the cogeneration system.

The final design must emphasize energy efficiency and maintain or exceed criteria for occupant safety, health and comfort, while preserving the architectural integrity of the building and the desires of the owner. The performance of all three of these systems is affected by the other two, and all contribute heavily to the overall building performance. Ultimately, the results of this research will lay the groundwork for the redesign that will happen during next semester.

Façade Study

The building facade presents what is most likely the highest point of concern in respect to building performance. With a high window to wall ratio and the use of highly transparent glazing, the exterior walls become a heat sink during the cooling months and a poor insulator during the heating months.

An analysis in Trane TRACE was performed investigating the performance of the existing façade system. The curtain wall is comprised of 76% glazing with an aluminum spandrel across the plenum space. The glass used was likely a custom hybrid of curtain wall materials so the properties used in the simulation were assumed given product specifications. For the existing façade system simulation, a glazing U-value of 0.625 Btu/ft^2-F along with a shading coefficient of 0.75 was used. The glazing makes up 76% of the curtain wall and the remaining material consists of the spandrel with a U-value of 0.08 Btu/ft^2-F. Figure 1 shows a section of the curtain wall and respective materials. Analysis performed on the eighth floor of the tower only with these material properties produced a peak cooling load of 62.8 tons and a peak heating load of 564.6 MBh. The total envelope loads made up 58% of the total building loads. This is a significant percentage, therefore optimization of the envelope can provide significant energy savings for the building owner and provide a better experience and space for occupants.

a. Recessed 3/16" Aluminum Spandrel Panel sealed within raised perimeter frame
b. 1-5/8" Diameter Ceramic Tubes
c. 1" IGU Vision Lite – Clear with Low e (Double Pane – Aluminum Frame)
d. 2-1/2" Rigid Insulation

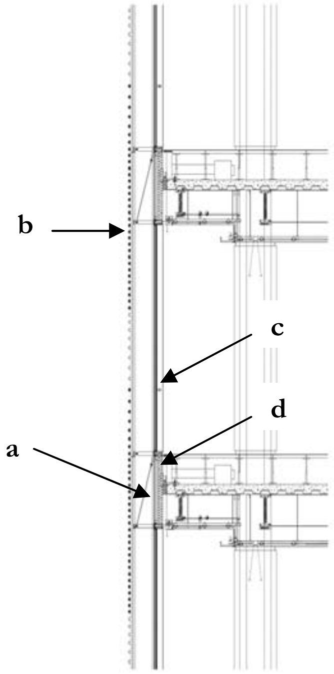


Figure 1

Multiple analyses were performed investigating the effects of variables in the façade design on heating and cooling loads in the space. Specifically, the adjustment of the shading coefficient and the percent glazing was analyzed. The shading coefficient (SC) is the ratio of the solar heat gain through a glazing system under a specific set of conditions to the solar heat gain through a single sheet of double strength glass under the same conditions. It is effectively a measure of shading effectiveness of a particular glazing product. With the reduction of the glazing's SC from 0.75 to 0.65, the peak cooling load was reduced to 59.2 tons, a 6% reduction. The peak heating load was also reduced 5% to 540.1 MBh. While the space does not gain as much solar heat in the winter, the shading properties of a glass with a lower SC allow the internal heat to become trapped, therefore taking advantage of the internal heat gains of an office building. Optimizing the shading ability of the glazing and the architectural desire for a transparent façade provides a challenging opportunity in the building's façade redesign.

A second analysis was performed reducing the percent glazing of the façade. This was done by increasing the existing aluminum spandrel 1 FT above floor level, minimizing architectural impact. Figure 2 shows the area of existing spandrel height and Figure 3 shows the addition of 1ft of aluminum spandrel height. In doing this the overall U-value of the envelope decreased, reducing conductive heat transfer between the exterior and interior of the building. The resulting peak cooling and heating loads were 51.1 tons and 446.3 MBh, respectively. This was a roughly a 20% decrease in peak loads by just a small reduction in the amount of glazing. The analysis helps provide a baseline for further façade investigation and shows the significance of the façade design on energy factors.

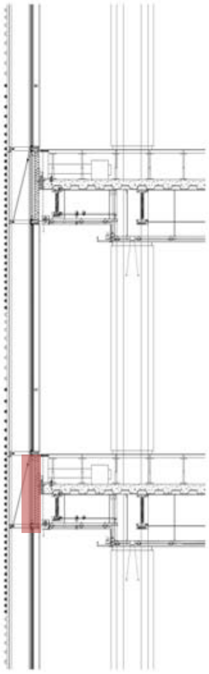


Figure 2

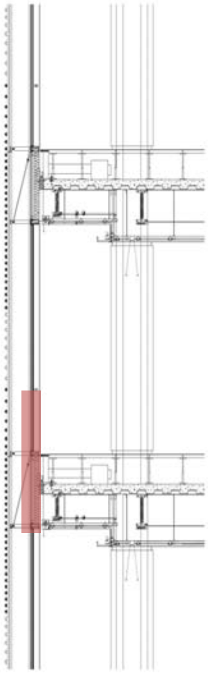


Figure 3

The building envelope is a complex system with multiple performance and functional requirements. With any redesign of this system it will be important to address the structural implications of the weight of materials. Also, water penetration, air infiltration, and condensation will need to be addressed. Acoustics also becomes a factor, especially for a high rise in a dense urban environment. Safety, durability and maintenance are also significant factors in the façade redesign.

ENERGY SOURCES STUDY

The existing systems use a variety of energy sources to heat, cool and power the NYTB. The facility has a 1.4 MW cogeneration, or combined heat and power (CHP) plant and is located on the 5th floor roof of the podium building. With an efficiency of 85%, the plant burns natural gas and provides 40% of the power needs of the New York Times Company. The plant waste heat is used in an absorption chiller to pre-cool the chilled water for the electrical chiller plant. Waste heat is also used to produce perimeter heating hot water in the winter months. The CHP plant's primary purpose is as an uninterrupted power supply for critical spaces such as the New York Time's data center. The CHP plant is not connected to the grid for re-metering, but the site is backed up by on-site diesel generators.

The NYTB burns natural gas in the CHP plant for perimeter heating, but the plant does not produce enough heat to meet all the loads on the building. Purchased steam is used for humidification, space heating in the outdoor air units, and it also supplements any perimeter heating that cannot be accomplished through the CHP plant's hot water loop. The third major energy source in the existing building is electricity drawn from the local utility (Consolidated Edison). Electricity is used for occupant activities (i.e. lighting, plug loads, miscellaneous equipment) as well as MEP systems (pumps, fans, chillers and BAS controls).

In order to optimize building performance, an economic and energy consumption analysis was performed. CHP plant alternatives were studied in order to produce an optimal total building solution. At first glance, the NYTB consumes a lot of two very expensive energy sources, steam and electricity. A utility investigation was performed to explore opportunities to reduce operating costs and primary energy usage over the lifetime of the building. Finally, renewable energy technologies were researched in the pursuit of greatly reducing the NYTB's fossil fuel consumption.

The analysis includes a brief overview of each research area followed by an analysis comparing the performance of the proposed alternative compared to the existing baseline building. This analysis provides raw data combined with a recommendation on the feasibility of each alternative. However, the final proposed system alternative is not a decision for the mechanical engineer alone. Any design alternatives should be aligned with the scope and goals of each design team as a whole.

UTILITY INVESTIGATION

Table 1 - Utility rates

Utility	Yearly $/Unit	Reference
Natural Gas	$1.392/Ccf	New York State Public Service Commission
Electric	$0.249/kWh	New York State Public Service Commission
Steam	$18.36/Mlb	Consolidated Edison
Water	$2.31/per(748gals)	New York City Water Board

Smart Grid Initiatives

A smart grid refers to a power grid which allows two-way communication between the utility and the customer. Demand response (DR) programs can be implemented so that both the utility and the customer can benefit. With the help of the smart grid, a DR program allows the utility to send a signal to the customer to cut-back on electricity in times of high-demand. This helps the utility because is flattens the load profile that they must meet. From the perspective of the consumer, they know in real-time when electricity is in times of peak demand. Utility rate structures are based on peak utility usage, among other things. Reduction of peak demand typically leads to lower rates. For larger buildings, a DR program becomes more economical because they are a larger consumer and have more of a potential to save energy.

To implement a DR program, no additional controls are necessary. Standard DDC controls can be used with the addition of a few lines of control logic. The additional cost will be in a "smart meter", which are becoming more common and will eventually become a standard. For the NYTB, it is recommended that a building energy manager be on staff during all occupied hours, which will increase operating costs. However, the demand response program will reduce energy cost at peak times. Further research can be done to explore local utility smart grid initiatives and programs. Interdisciplinary coordination for this particular issue should occur with the mechanical, lighting/electric and construction management disciplines.

Minimize Utility Usage

There are many benefits to reducing utility usage. First, when a consumer reduces their peak energy consumption they are placed in a lower rate structure and they will see savings on their total utility bill. Also, by reducing dependence on the grid, a customer is less susceptible to the volatility of some energy markets. Finally, on-site energy most often produces fewer pollutants than grid energy because it does not suffer from the inefficiencies of outdated electric generation systems and transmission losses.

Other than implementing DR programs, utility usage can be minimized by using on-site energy generation systems. The NYTB could see substantial economic beniefits by reducing their utility usage. Their two largest purchased energy sources (electricity and steam) are very expensive considering the national average. Solar, wind and other renewable sources are already available on-site and can be utilized if they are properly captured. Not all of these solutions will work; some technologies are site specific, not reliable and will generate variable amounts of energy. These systems have increased initial costs and require more maintenance and operational costs than the baseline systems. In order to implement these systems, a payback period must be established on a case-by-case basis. Interdisciplinary coordination for this particular issue should occur with the mechanical, lighting/electric and construction management disciplines.

COGENERATION PLANT ANALYSIS

The sections below summarize the research of alternatives for the cogeneration plant. A copy of the complete cogeneration analysis can be found in Appendix 1. These results are a preliminary feasibility study and do not reflect different prime mover configurations. Options such as fewer, larger generators or many smaller prime movers to operate more efficiently at part load conditions must be looked at on a case-by-case basis. The two prime movers studied in depth were gas turbines and internal combustion generators. Further research could involve evaluating the use of micro-turbines and other prime movers.

Separate Heat and Power (SHP)

The current CHP plant exists to supplement the building's electrical demand and as an emergency power system for the data center. The same emergency power can be supplied with a diesel generator or similar system. Removing the CHP plant will simplify the MEP systems and reduce operating costs if operation of the plant is not economically feasible. A reduction in maintenance staff would be possible because the proposal is to downgrade the complexity of the system.

Removal of the CHP plant will reduce the initial cost because the building is already connected to the grid. Purchased steam and electricity are very expensive in New York City and according to our analysis, operating costs would increase significantly. The SHP alternative would use more primary energy because the utility is less efficient than CHP. Interdisciplinary coordination for this particular issue should occur with the structural, mechanical, lighting/electric and construction management disciplines.

Larger CHP plant

A larger CHP plant will decrease the steam and electricity purchased from the utility and decrease primary energy usage. CHP will always produce fewer emissions, but an economic analysis must be done to evaluate whether the plant will save on operational costs. The proposal to increase the size of the CHP plant will not require any major changes to the existing maintenance staff.

For initial cost, a larger CHP plant would be more expensive than removing the plant all together (SHP). According to our research, the high price of purchased steam and electricity makes it possible to reduce the operating costs of the larger CHP plant. Each design team's total building proposal must be factored into the cost analysis to find the payback period for the larger CHP plant. Interdisciplinary coordination for this particular issue should occur with the structural, mechanical, lighting/electric and construction management disciplines.

Chart 4

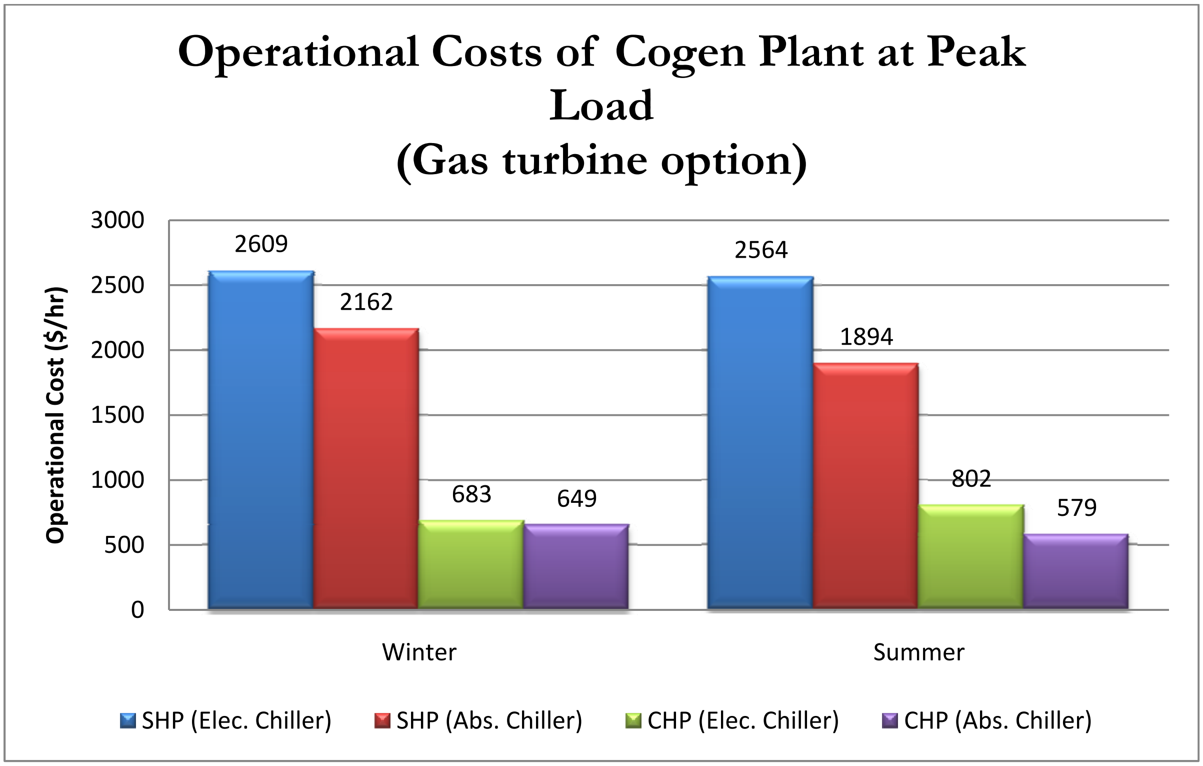
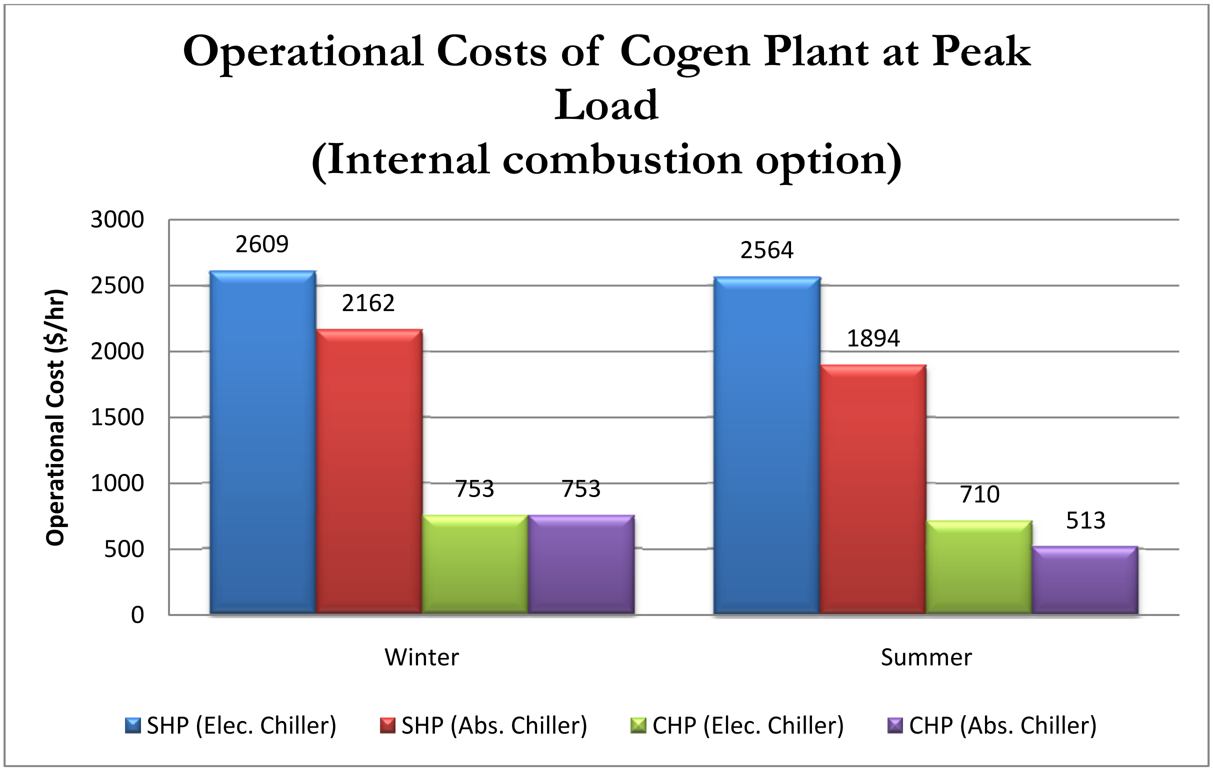


Chart 5



RENEWABLE ENERGY SOURCES

Solar-Thermal Systems

The concept behind solar-thermal systems is to collect solar radiation and use it to heat water or another working fluid. According to the Energy Information Administration the Concentrated Solar Power Resource Potential is 3-4 kWh/m^2/day for New York State. The solar power varies with the time of day and the weather. For space heating purposes, medium temperature solar-thermal collector types such as flat plate or evacuated tube are the most practical for heating hot water. The system will produce hot water using a renewable energy source, which reduces primary energy use by the building. An installed solar-thermal system will not require extra maintenance staff. However, the system will involve adding more heat exchangers and will require the use of a more complex controls system. Further investigation could involve researching other buildings with solar-thermal systems in urban environments (preferably in New York City) to find reasonable estimates for energy savings.

Photovoltaics

Sunlight is collected on Photovoltaic (PV) panels to produce electricity. PV's are anywhere from 12-26% efficient (depending on the panel type). The solar power varies with the time of day and the weather. The performance of the PV array will depend on how much direct sunlight reaches the panels. Careful consideration should be used when selecting the location and size of array because the surrounding buildings may change in size and orientation. Power production can be improved year-round if PV's actively track with the sun. Typical installation costs are $3.50 per installed Watt. Operating costs are around $0.20 per kW. Primary energy usage and emissions will be reduced because solar energy is a renewable resource. Further investigation could involve researching other buildings with PV's in urban environments (preferably in New York City) to find reasonable estimates for energy savings.

Wind Energy Systems

Small scale electricity generation can be accomplished with wind turbines. Wind speed in an urban environment is dynamic and unpredictable without a site specific wind study. Wind patterns could also change when new buildings are constructed near the NYTB. Furthermore, small scale wind power operates at around 20% efficiency. Vertical helical wind turbines are best suited for the gusty nature of the wind seen on the sides of tall buildings in an urban environment. Horizontal axis bladed turbines are more applicable in cases where wind is at a consistent speed and coming from a predictable direction.

Typical wind plants have a cost of $0.50 per installed Watt. Operational costs are typically around $0.06 per kWh. Furthermore, the electricity produced is through a renewable energy source, so there will be reduced primary fuel consumption and emissions. If a large enough wind plant is installed, short-term storage or re-metering devices can be used. Wind turbines have moving parts which will eventually need repair. A slightly more experienced maintenance staff is required to operate the wind plant. Further investigation could be researching other buildings with wind power in urban environments (preferably in New York City) to find reasonable estimates for energy savings.

Bio-Fuels

In this instance, bio-fuels refer to the production of methane through anaerobic digesters in landfills or from other organic waste. This methane can be used as a fuel in a combustion process to generate heat and/or electricity. On-site digestion of organic waste is not viable and it would be very costly to run a natural gas pipeline from an outside source of gaseous bio-fuel. The alternative is to purchase renewable energy credits (REC). The RECs exist because the current utility grid cannot guarantee the delivery of renewable energy. Although REC's cannot ensure that every Btu or kW of "green" energy purchased gets delivered to the buyer's building, it certifies that the energy was indeed produced. An estimated 20-30% premium will be added onto the electricity cost for REC's. Bio-fuels will use the same amount of prime energy, but their use can be thought of as approximately carbon-neutral.

Bio-Mass

In the case of this research, bio-mass refers to organic materials which are used for combustion in a boiler to produce steam for space heating purposes. Similar to the bio-fuels, this system is not that viable because it requires a lot of organic waste to be produced and stored on-site. If enough organic waste is produced, this will require an ongoing waste capture program which will incur more operating costs. Furthermore, the fuels utilized will most likely be of poor energy density compared to what can be purchased from the local utility. Bio-mass will use the same amount of prime energy, but their use can be thought of as approximately carbon-neutral.

Legend	
Improvement of Baseline	🟩
Same as Baseline	🟨
Worse than Baseline	🟥

Table 2 –Renewable Energy Sources Evaluation

	Solar-Thermal	Photovoltaics	Wind Energy	Bio-Fuels	Bio-Mass
Initial Cost	🟥	🟥	🟥	🟨	🟥
Life-Cycle Cost	🟩	🟨	🟩	🟥	🟥
Primary Energy	🟩	🟩	🟩	🟨	🟨
Emissions	🟩	🟩	🟩	🟩	🟩
Feasibility	Yes	Maybe	Maybe	No	No
Trades Involved	All	All	All	CM, M, L/E	CM

AIR DISTRIBUTION STUDY

The existing air distribution is achieved via variable air volume boxes for interior zones and fan powered boxes with heating coils for exterior zones. The floors occupied by the New York Times utilize a UFAD system. Swirl diffusers were installed to provide occupant control, while in high occupancy spaces perforated floor tiles provide a more visually pleasing layout. A traditional overhead ducted system was implemented on the Forest City Ratner floors. Demand controlled ventilation is achieved via carbon dioxide and VOC sensors located in the return ducts for each floor. Outdoor air is brought in through outdoor air units in the two mechanical penthouses on the 28th and 51nd floors, and then is distributed throughout the building.

In order to optimize building performance this system was compared against both an active and a passive chilled beam system. However, because of the magnitude of the heating and cooling loads, passive chilled beams do not appear to be a viable source of cooling and heating. Active chilled beams do seem to be a viable alternative solution to the current UFAD system. A reduction in air movement and mechanical equipment size could help achieve reductions in energy use and life cycle costs. Smaller ducts and the lack of an underfloor plenum could also help achieve lower floor to floor heights, which could ultimately lead to additional floors and more rentable space for the owner.

Though a hybrid system presents increased complexities in design several new building designs have utilized this concept successfully. Decoupling the heating/cooling and ventilation loads also presents both advantages and disadvantages. One of the clear advantages of using a hybrid system is the opportunity for electricity demand profile optimization, which is one of the best ways to increase cogeneration efficiency.

The analysis below shows advantages, disadvantages, energy use distribution and operating costs for each system. Further analysis is necessary to determine which system will provide the best building performance when coupled with other building systems. With an integrated project delivery approach, a decision on the air distribution system will be made through much coordination with not only other mechanical systems, but also through interdisciplinary coordination.

SYSTEM ADVANTAGES AND DISADVANTAGES

Under Floor Air Distribution

Advantages:

- Flexible floor plan
- Occupant controlled heating and cooling
- Higher chilled water and lower hot water temperatures

Disadvantages:

- Deep plenum space
- Indoor air quality issues
- Condensation in plenum

Chilled Beams

Advantages:

- Decreased fan energy
- Decreased air handled to 25-50% of all-air system
- Smaller AHU on each floor
- Decoupled heating and cooling / ventilation
- Higher chilled water and lower hot water temperatures

Disadvantages:

- Increased water use
- Increased pumping energy
- Humidity and condensation issues.
- Higher initial costs

Combined Chilled Beams/UFAD

Advantages:

- Improved electricity demand profile
- Improved thermal comfort (10 am-6 pm)
- Reduced HVAC energy use during cooling months

Disadvantages:

- Increased summer morning heating
- Reduced comfort in early morning (7am-9am)
- Increased size of cooling tower (50%)

ENERGY USE AND COST SUMMARY

Under Floor Air Distribution

Table 3 - UFAD Energy Breakdown

Heating	814986	47%
Cooling	455743	26%
Auxiliary Fans/Pumps	126680	7%
Lighting	256644	15%
Receptacle	98009	6%
Total	1752062	(kBtu/yr)

Chart 3: UFAD Energy Breakdown

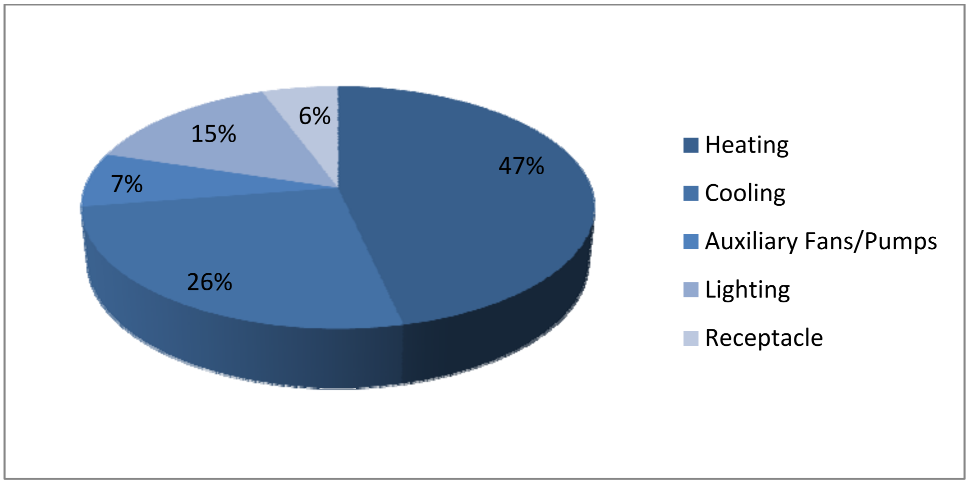


Table 4 - UFAD Cost Summary

Function	Utility	kBtu	Kwh	$/kwh	Mlb	$/Mlb	Cost ($)
Heating	steam	814300			681.9933	$18.36	12521.40
Cooling	electricity		133533	0.249			33249.72
Aux. Fans/Pumps	electricity		37117	0.249			9242.13
Lighting	electricity		75196	0.249			18723.80
Receptacles	electricity		28716	0.249			7150.28
					Total		80887.33

Active Chilled Beams

Table 5 – Active Chilled Beam Energy Breakdown

Heating	557693	32%
Cooling	589649	34%
Auxiliary Fans/Pumps	218835	13%
Lighting	256644	15%
Receptacle	98009	6%
Total	1720830	(kBtu/yr)

Chart 4: Active Chilled Beam Energy Breakdown

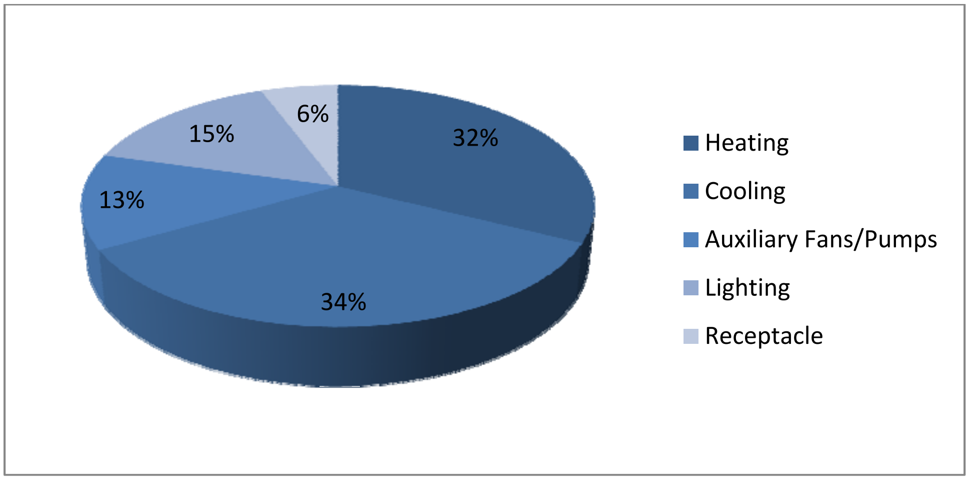


Table 6 - Active Chilled Beam Cost Summary

Function	Utility	kBtu	Kwh	$/kwh	Mlb	$/Mlb	Cost ($)
Heating	steam	557693			467.0796	$18.36	8575.58
Cooling	electricity		172767	0.249			43018.98
Aux. Fans/Pumps	electricity		64118	0.249			15965.38
Lighting	electricity		75196	0.249			18723.80
Receptacles	electricity		28716	0.249			7150.28
					Total		93434.03

Passive Chilled Beams

Table 7 – Passive Chilled Beam Energy Breakdown

Heating	461031	31%
Cooling	530742	36%
Auxiliary Fans/Pumps	145368	10%
Lighting	256644	17%
Receptacle	98009	7%
Total	1491794	(kBtu/yr)

Chart 5: Passive Chilled Beam Energy Breakdown

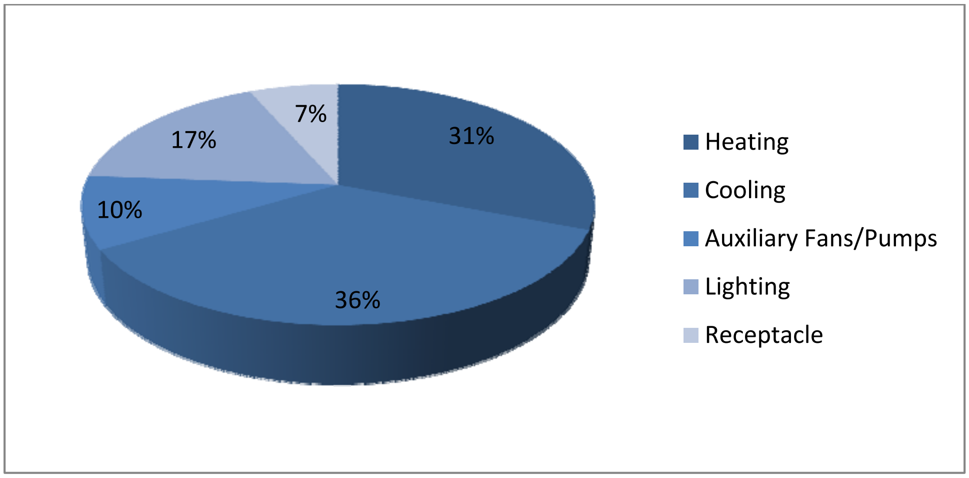


Table 8 - Passive Chilled Beam Cost Summary

Function	Utility	kBtu	Kwh	$/kwh	Mlb	$/Mlb	Cost ($)
Heating	steam	461031			386.1231	$18.36	7089.22
Cooling	electricity		155508	0.249			38721.49
Aux. Fans/Pumps	electricity		42592	0.249			10605.41
Lighting	electricity		75196	0.249			18723.80
Receptacles	electricity		28716	0.249			7150.28
					Total		82290.21

OVERALL EVALUATION

The NYTB is a flagship building for the New York Times Company. It is iconic for the New York City skyline and it will be so for many decades. While the building's systems were well engineered, the mechanical team has found room for improvement in several areas. Alternative designs will most likely involve aspects from all of the research areas discussed in this report. The façade is an interdisciplinary challenge that will need to be solved with an integrated approach by the entire design team. The energy sources are a key factor into the building's operating costs and will need to be addressed with the entire building in mind. Both of these design alternatives will factor into deciding which HVAC systems are most appropriate for each team's redesign.

Mechanical engineers have a growing role in the construction industry due to shifts in owner and building requirements. Within the IPD/BIM environment, mechanical designers have extended their services earlier in the design process through tools like energy modeling software and 3D building modeling. Future team proposals are encouraged to include the exploration of the roles of all disciplines in the design process.

In general terms, the mechanical systems in the NYTB are quite complex. The designers implemented a wide variety of unique systems in their pursuit of a high performance building that would become an icon for the New York Times Company and provide a benchmark for future sustainable high-rise projects. With such a variety of complex systems, which use untested technologies, it can be difficult to determine the actual effectiveness of the overall system. Also, without any information on building operating history it is nearly impossible to know how the building is performing in regards to energy consumption and operating costs. However, the analysis done in this report will help each BIM/IPD team to develop new design concepts in pursuit of a building that performs at a higher level.

APPENDIX 1: CALCULATIONS FOR COGENERATION PLANT

The following tables are from the original calculation worksheet for evaluating the effectiveness and the economics of a cogeneration system.

Table 1A - Building Parameters

Building Area (ft^2)	1065645
Boiler Efficiency	N/A
COP $_{\text{elec chiller}}$	4.65
COP $_{\text{abs chiller}}$	0.75

Table 2A - Building Seasonal Load Intensities of Building Estimates

Season	Occup. Activity	Cooling Load	Aux Cooling	Space Heating	Hot Water
	W/ft^2	ft^2/ton	kW/ton	Btu/hr-ft^2	Btu/hr-ft^2
Summer	5.7	300.0	0.25	0.0	10.0
Winter	5.7	450.0	0.15	25.0	10.0
Fall	5.7	400.0	0.20	15.0	10.0
Spring	5.7	350.0	0.20	10.0	10.0

Table 3A - On Site Generation (Electric Chiller)		
Heat Rate GT Prime Mover	Recoverable Exhaust (+ Jacket) Enthalpy	
Btu Fuel/kW-hr	0.80 for GT and 0.65 for I.C.	
13648.0	Btu recov (exhaust, jacket)/Btu Total Reject	
Heat Rate IC Prime Mover	GT Exhaust (Btu/kWhr)	IC Exh + Jack (Btu/kWhr)
Btu Fuel/kW-hr	8188.8	2710.6
7582.2		
Site Characteristics		
Design Peak (kW)	9651.2	9651.2
Potential "Exhaust" (Btu/hr) Rec.	79,031,365	26,160,845
Potential Fuel Enthalpy Used @ Site	111,961,100	59,090,580
Potential FU efficiency %	85.0	80.8
lbm CO2 e/ hr Nat. Gas utilized	1.65E+04	1.00E+04
lbm CO2 e/ yr Nat. Gas utilized	1.44E+08	8.78E+07

Table 4A - On Site Generation (Absorption Chiller)		
Heat Rate GT Prime Mover	Recoverable Exhaust (+ Jacket) Enthalpy	
Btu Fuel/kW-hr	0.80 for GT and 0.65 for I.C.	
13648.0	Btu recov (exhaust, jacket)/Btu Total Reject	
Heat Rate IC Prime Mover	GT Exhaust (Btu/kWhr)	IC Exh + Jack (Btu/kWhr)
Btu Fuel/kW-hr	8188.8	2710.6
7582.2		
Site Characteristics		
Design Peak (kW)	6962.2	6962.2
Potential "Exhaust" (Btu/hr) Rec.	57,012,178	18,872,087
Potential Fuel Enthalpy Used @ Site	80,767,252	42,627,161
Potential FU efficiency %	85.0	80.8
lbm CO2 e/ hr Nat. Gas utilized	1.19E+04	7.23E+03
lbm CO2 e/ yr Nat. Gas utilized	1.04E+08	6.34E+07

Table 5A – Utility Use and Economic Analysis with Gas Turbine Option

SHP vs. CHP utility use and economic analysis (Gas turbine)	SHP with electric chillers		SHP with absorption chillers		CHP with electric chillers		CHP with absorption chillers	
	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer
Heat required (Btu/h)	37297575	10656450	37297575	10656450	37297575	10656450	37297575	10656450
Elecricity required (kW)	8222	9651	6429	6962	8222	9651	6429	6962
Resulting CHP heat rate (Btu/h)	-	-	-	-	49093668	57627037	46621969	41571380
Purchased steam usage (Mlb/h)	30.6	8.7	30.6	8.7	-	-	-	-
Grid electricity usage (kW)	8222	9651	6429	6962	-	-	-	-
Natural gas usage (Ccf/h)	-	-	-	-	491	576	466	416
Purchased steam rates ($/h)	561	160	561	160	-	-	-	-
Grid electricity rates ($/h)	2047	2403	1601	1734	-	-	-	-
Natural gas rates ($/h)	-	-	-	-	683	802	649	579
Total operational costs ($/h)	2609	2564	2162	1894	683	802	649	579

Table 6A – Utility Use and Economic Analysis with Internal Combustion Option

SHP vs. CHP utility use and economic analysis (Internal Combustion)	SHP with electric chillers		SHP with absorption chillers		CHP with electric chillers		CHP with absorption chillers	
	Winter	**Summer**	**Winter**	**Summer**	**Winter**	**Summer**	**Winter**	**Summer**
Heat required (Btu/h)	37297575	10656450	37297575	10656450	37297575	10656450	37297575	10656450
Elecricity required (kW)	8222	9651	6429	6962	8222	9651	6429	6962
Resulting CHP heat rate (Btu/h)	-	-	-	-	54081484	51041090	54081484	36820365
Purchased steam usage (Mlb/h)	30.6	8.7	30.6	8.7	-	-	-	-
Grid electricity usage (kW)	8222	9651	6429	6962	-	-	-	-
Natural gas usage (Ccf/h)	-	-	-	-	541	510	541	368
Purchased steam rates ($/h)	561	160	561	160	-	-	-	-
Grid electricity rates ($/h)	2047	2403	1601	1734	-	-	-	-
Natural gas rates ($/h)	-	-	-	-	753	710	753	513
Total operational costs ($/h)	2609	2564	2162	1894	753	710	753	513

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