# Preliminary Final Proposal

## Mechanical System Re-design and Breadth Topics


## Butler Memorial Hospital | New Inpatient Tower

## Butler Healthcare Providers

## Butler, PA

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# Executive Summary

The New Inpatient Tower at the Butler Memorial Hospital is a 209,000 square foot addition seated in Butler, Pennsylvania that has just been completed in July 2010. The eight story tower was built to house state of the art operating and recovery rooms.

The primary means of heating, ventilation, and air-conditioning is done through the variable air volume system with reheat at the terminal boxes and supplementary finned tube radiation heating coils at the perimeter of patient rooms. After doing extensive research, it appears that the New Inpatient Tower at the Butler Memorial Hospital is a prime candidate for a dedicated outdoor air system. The current design calls for 54,000 CFM of ventilation air; however, only 28,000 CFM of ventilation is required by AIA guidelines. By decreasing the amount of ventilation air, chiller and boiler loads will be decreased, as well as air handling units and duct sizes.

In order to supplement the dedicated outdoor air system, examining the use of chilled beam technology will be analyzed. The chilled beam technology will only be responsible for sensible loads created within the space. Two different options of chilled beams will be investigated; either an active chilled beam system or a passive chilled beam system.

In order to saving additional energy with the dedicated outdoor air system, energy recovery and water-side free cooling will also be implemented. Two different options for energy recovery from exhaust air are a runaround glycol loop or a total heat recovery wheel. Both systems have pros and cons which will be analyzed further. Water-side free cooling will utilize the cooling tower to alleviate some of the burden imposed on the chillers during temperate seasons.

An investigation will be done to evaluate the impact of the mechanical system re-design on the electrical and structural systems. Structural members on the roof will be re-sized and priced to account for lower roof loads due to smaller air handling equipment. An electrical analysis will also be done in order to tie the additional pumps and DOAS air handlers into the existing power distribution.

# Mechanical Summary

## Introduction

The New Inpatient Tower at the Butler Memorial Hospital serves as the newest attraction to the hospital, and at 209,000 square feet of space it houses much of the hospital's activity. The new tower includes many public spaces including a chapel, retail space, a café, waiting areas, and conference rooms on the main level. Below the main level is mostly mechanical space and storage; however, the focal point of the tower lies on the floor above. Eight state of the art operating rooms are the main attraction of the entire addition. The remainder of the tower is comprised of recovery rooms, critical care units, and patient rooms for those recovering from surgery.

## Design Criteria

When designing the New Inpatient Tower, engineers and architects took a very direct approach: build a patient tower that will be energy efficient, reliable, and comfortable to patients and families. When designing the HVAC systems, reliability and comfort were the two most important factors. Any HVAC system looks to provide comfortable temperature and humidity levels, which this system easily accomplishes. Every main piece of equipment within the mechanical system has inherent redundancy. Due to the loop system and other design specifications, the hospital can lose an air handler, cooling tower, primary pump, secondary pump, chiller, or boiler and is still able to meet the majority of loads under normal operating conditions. It should be noted that there were no design influences based upon the site, rebates, or tax relief.

Due to the nature of the hospital, a great deal of the thermal and energy loads are a direct effect of lighting and hospital equipment operation. Both of these areas are essential for the tower to function and are fairly constant loads unable to be altered. Variable loads which occur are due to infiltration, conditioning of ventilation air, solar gain, and mechanical equipment loads.

Designers oversized the outside air fraction to ensure proper indoor air quality providing patients and staff with high quality supply air. The building is designed for every space to receive 33% outside air at design loads. The minimum ventilation rates used by engineers also significantly exceeds ASHRAE Standard 62.1, reinforcing the fact that air quality within the tower is a large concern.

Solar gain during the cooling season is not a large problem for the inpatient tower. The hospital design is fairly conservative when it comes to fenestration, which will lower the effects of solar gain. Also, the majority of fenestration is located on the North and Northwest facades of the building with only a small portion of exterior glass occurring along the southern face.

Mechanical equipment operation accounts for a large portion of the overall energy consumption. The system could very well be sized down to become more efficient, however design engineers were more focused and reliability and redundancy than efficiency. This approach is understandable since there will be human lives in jeopardy every day, demanding certain environmental conditions for the best chance of survival.

An extremely important facet of the hospital design is linked to the (8) operating rooms on the third floor. These operating rooms are served by two identical air handlers and are 100% redundant in the case that one air handler malfunctions. The two air handlers are fed by a 120 ton scroll chiller supplying 34°F chilled water in order to keep the operating rooms at exactly 60°F year round. The system is backed up by the (2) main chillers in an emergency case. Hepa filters at the terminal boxes also ensure the highest quality air within the operating rooms.

The mechanical system also had to be designed for the overhanging floor on the third level. As a result of the third floor overhanging the second, extra thermal loads coming through the floor had to be accounted for. The perimeter of the tower is also home to the majority of patient rooms and subject to extra heating loads at the perimeter and windows. In order to give patients thermal control and to account for the additional envelope loads, designers implemented finned tube radiant coils along the perimeter of patient rooms and in the floor of the overhanging third level.

## Design Conditions

The weather data and outdoor conditions were taken from the design data within ASHRAE Fundamentals 2009 and are shown below in ***Table 1***. Indoor design conditions were taken from the design documents basis of design. The driftpoint was also specified.

| Outdoor Design Conditions | |
|---|---|
| **Location** | Butler, PA |
| **Summer Dry Bulb (°F)** | 89 |
| **Summer Wet Bulb (°F)** | 73 |
| **Winter Dry Bulb (°F)** | 2 |
| **Carbon Dioxide Level** | 400 |

**Table 1: Outdoor Design Conditions**

As depicted in ***Table 2*** below, the thermostat setpoints for the hospital vary depending upon which space we are examining. The bulk of the hospital attempts to keep the inside environment within the thermal comfort region specifying a set point 75°F in the summer and 72°F in the winter and 50% relative humidity. However, the operating rooms are under more stringent requirements and require that the environment is maintained year round at 60°F and 50% relative humidity to reduce the chance of infection and bacteria growth within the operating rooms.

| Typical Thermostat Parameter | |
|---|---|
| Cooling Dry Bulb (°F) | 75 |
| Heating Dry Bulb (°F) | 72 |
| Relative Humidity (%) | 50 |
| Cooling Driftpoint (°F) | 77 |
| Heating Driftpoint (°F) | 70 |

| Operating Room Thermostat Parameter | |
|---|---|
| Cooling Dry Bulb (°F) | 60 |
| Heating Dry Bulb (°F) | 60 |
| Relative Humidity (%) | 50 |
| Cooling Driftpoint (°F) | 62 |
| Heating Driftpoint (°F) | 58 |

Table 2: Indoor Design Conditions

## Ventilation Requirements

After analyzing the entire ventilation system of the Butler Memorial Hospital, it has been determined that every space exceeds the required amount of ventilation air according to ASHRAE Std 62.1. As noted earlier, the bulk of the ventilation is done by AHU-1, 2, & 3 which comprise a loop sytem serving every area except for the operating rooms.

The total outside air intake $V_{ot}$ = (14,366)/0.9 = 15,962 CFM according to standard 62.1. The design calls for 53,812 CFM of outside air, and 153,848 CFM of total supply air. The "as designed" outdoor airflow rate is considerably higher, likely due to engineers using an outside airflow rate of 20 CFM/person and AIA guidelines which are well above ASHRAE standards. Due to the fact that AHU-1, 2, & 3 are each 62,000 CFM resulting in a total of 186,000 CFM, the air handlers are more than capable of meeting the load. The operating rooms require a minimum of 2,307 CFM of outside air according to standard 62.1, but are designed for 9,682 CFM of outside air and 29,340 CFM of total supply air. AHU-4 & 5 are both 18,500 CFM, resulting in a combined 37,000 CFM which can easily meet the required load.

It is apparent that the designers oversized all the air handlers to ensure the best indoor air quality and to improve reliability. They coupled AHU-1, 2, and 3 to improve redundancy in case one air handler fails. They also designed the building to supply a great deal more outside air than required by ASHRAE to ensure patients receive the finest air quality. All spaces have an outside air fraction of 0.33.

## Mechanical Equipment Summary

The primary heating, air conditioning, and ventilation is performed by a variable air volume system equipped with (3) 62,000 CFM rooftop air handlers. These three air handlers comprise a loop system which serves every area of the hospital except for operating rooms and a few mechanical rooms. Due to the nature of the loop system, all 3 air handlers are coupled feeding every diffuser, there is natural redundancy built into the mechanical system. (2) 400 ton centrifugal chillers with variable speed drives provide AHU-1, 2, & 3 with cold water used for dehumidification and cooling via (2) constant volume primary chilled water pumps and (2) VSD secondary pumps. A central rooftop cooling tower serves as the primary means of cooling the condenser water which exits the two centrifugal chillers.

Rooftop air handling units 4 and 5 are located on a lower level roof (Floor 5) and provide the necessary heating, ventilating, and air-conditioning to the (8) operating rooms which are located on the 3rd floor. The operating room air handlers are serviced by an adjacent 119 ton air-cooled scroll chiller supplying 34°F water. The lower temperature system is backed up by the primary chillers in case of emergency; 45°F primary water can still be supplied. Air Handling Units 6, 7, & 8 are all smaller units which serve specific mechanical rooms with an extra need for cooling.

On the heating side, (2) 215 BHP combustion gas/oil-fired hot water boilers supply all of the heating water for the entire building: this includes heating water to the air handling unit heating coils, unit heaters used for reheat within terminal boxes, duct heating coils, radiant ceiling panels around the perimeter of patient rooms, and finned tube radiation in the soffit/plenum area above the second floor to keep the cantilevered floor warm. Two constant volume primary pumps and (2) VSD secondary pumps circulate the heating water.

# Proposal

## Introduction

As noted in previous reports the hospital has overdesigned the entire mechanical system and presents multiple avenues to explore when re-designing the mechanical system. Due to the fact that the current system is variable air volume with many of the components and designed airflows well above baseline requirements, a number of ideas have been researched to make the hospital more energy efficient, reliable, and easier to maintain. It should be noted that due to the critical nature of the mechanical system supplying the operating rooms, only the (3) primary air handlers will be altered.

The first implementation will be to eliminate the variable air volume system including the (3) main air handlers and all of the associated terminal boxes. In lieu of using a VAV system with 33% outside air, a dedicated outdoor air system will be instituted providing the hospital with 100% fresh, clean outdoor air to all spaces within the hospital.

Dedicated outdoor air systems work under the principal of conditioning the minimum requirement of ventilation air and supplying it directly to the space. Because the DOAS air handler can only remove the latent and sensible heat from the entering outside air, a parallel system will need to be implemented to account for sensible loads within the space. The use of chilled beams will be researched and discussed to account for the extra sensible load created within the space.

Inherently, a hospital exhausts a great deal of the air due to restrooms, both public and in patient rooms, as well as janitor closets, and specialty medical equipment rooms. The current design simply discharges this air into the environment. The re-design will attempt to transfer the enthalpy from the conditioned exhaust air to that of the incoming outdoor air.

Another potential savings of a dedicated outside air system with chilled beams can be achieved by the use of water-side free cooling. Water-side free cooling works extremely well with chilled beams. Water-side free cooling works as an economizer during mild or cold temperatures allowing the chiller to turn off thereby saving mechanical energy.

After all changes are implemented a Trane Trace analysis will be run to quantify the overall energy savings of the redesign. First costs of the current system as well as the re-designed system will also be evaluated. After analyzing the first cost and operational costs of both designs, a payback period analysis will be performed. Throughout the process, feasibility studies and integration will be incorporated to ensure that the final product is comprehensive and constructible.

## Dedicated Outdoor Air System

After analyzing the Trane Trace energy model it is clear that a great majority of the heating and cooling load within the hospital is a result of conditioning the ventilation air. The amount of ventilation air being introduced into the hospital is well above the minimum requirements set forth by AIA guidelines. As designed, the hospital supplies 53,812 CFM of outside air; however the minimum requirements set forth by AIA requires only 28,036 CFM of outside air be supplied for ventilation. Therefore the overall amount of ventilation air can be cut by almost one half, which will also greatly reduce the load imposed on the cooling and heating systems.

The hospital is currently transporting roughly 154,000 CFM of supply air through the duct work. By switching to a dedicated outdoor air system, only 28,036 CFM of outdoor air will need to be supplied therefore greatly reducing the amount of fan energy required and duct sizes within the hospital. As depicted in ***Figure 1*** below, almost 20% of the overall energy usage within the hospital is due to the supply fans. By decreasing the airflow, the size of the air handlers and supply fans will also be minimized which will save energy and money during operation and first cost.

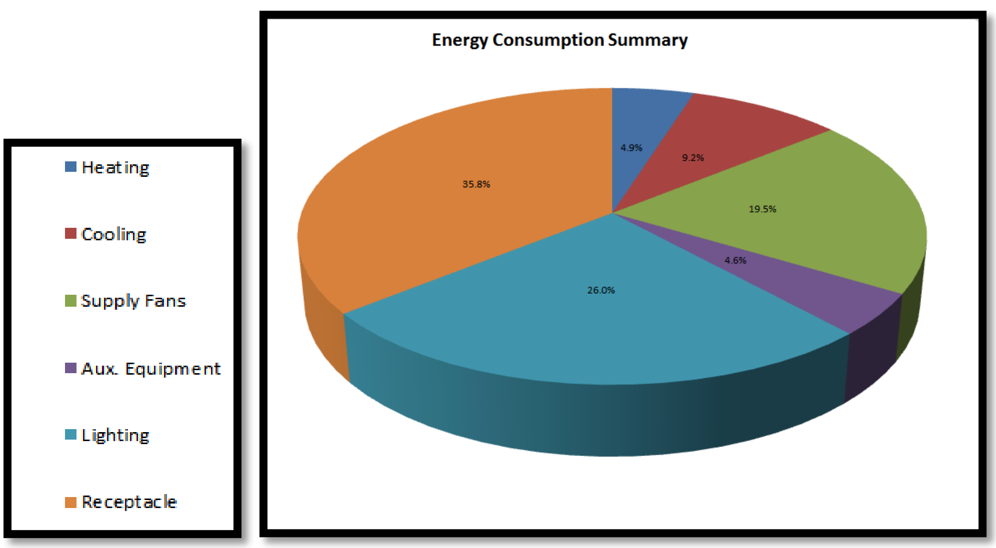


Figure 1: Energy Consumption Summary

A common problem among variable air volume systems is the failure to deliver adequate amounts of ventilation air at part loads. Because the dedicated outdoor air system is a constant volume system and always supplies the same amount of ventilation air, this problem is avoided and indoor air quality remains high.

## Chilled Beams

A DOAS air handler will condition the ventilation air by removing sensible and latent heat from incoming outdoor air during the summer and adding sensible and latent heat to the outdoor air during the winter. With this being said, although the DOAS air handler can meet the entire latent and sensible load from the outside air, a parallel system must also be installed to meet the demand of sensible loads created within the space.

In order to meet the added demand for sensible heat transfer, the implementation of chilled beams will be studied. There are two types of chilled beams, active and passive. As depicted in ***Figure 2*** an active chilled beam is much like a cooling coil which induces high velocity supply air through it and then delivers the air to the room. Referencing ***Figure* 3**, a passive chilled beam is simply a radiant panel located in the ceiling decoupled from the ventilation system operating solely on radiation principles.

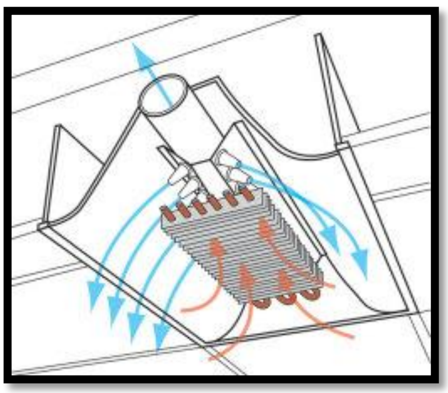

Figure 2: Active Chilled Beam

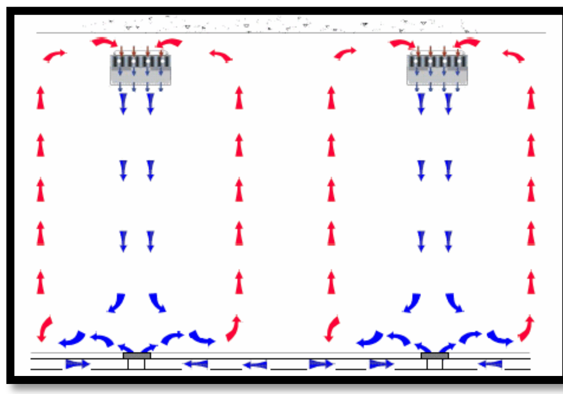

Figure 3: Passive Chilled Beam

Chilled beams can be used for both supplemental heating and cooling purposes. This can be done with a variety of piping arrangements. The two arrangements that will be studied include a 4 pipe system which contains a supply and return line for both heating and cooling, and a 2 pipe changeover which will allow the same piping to carry either heating water or cooling water depending on the season.

Potential advantages of chilled beams is the elimination of wasteful terminal reheat boxes, better air mixing within the space, and better utilization of heat transfer. As a comparison 1 cubic foot of water has a heat capacity of 20,050 J. One cubic foot of air at STP has a heat capacity of 37 J K. After accounting for differences in density it is apparent that a 1” diameter pipe can carry the same amount of energy as an 18” x 18” duct. Using water instead of air to heat or cool a space is much more efficient, not to mention space savings due to reduced duct sizes and hydronic piping.

## Exhaust Energy Recovery

As specified in ASHRAE Standard 90.1, any mechanical system using 100% outside air must have some means of energy recovery. In order to account for this and to save energy, a few different options will be analyzed when looking at energy recovery. The hospital currently exhausts a great deal of air due to the abundance of restrooms, janitor closets, and medical laboratory spaces. The current design simply discharges all exhaust air to the atmosphere.

One of the options analyzed for heat recovery will be a glycol filled run-around loop. This system works well for exhaust ducts which are not in close proximity to supply ductwork, which is the case in the New Inpatient Tower. However, because the loop is distributed throughout the building and relies on heat exchangers in both airways, it lacks in efficiency and performance. Another method of heat recovery is via a total heat recovery wheel. A heat recovery wheel can transfer latent and sensible heat from one airway to the other with much higher efficiency. The only downfalls of the heat recovery wheel are proximity restrictions between the two airways and possible contamination of supply air from the exhaust air. An example of an energy recovery wheel operating in the summer is shown below in ***Figure 4.***

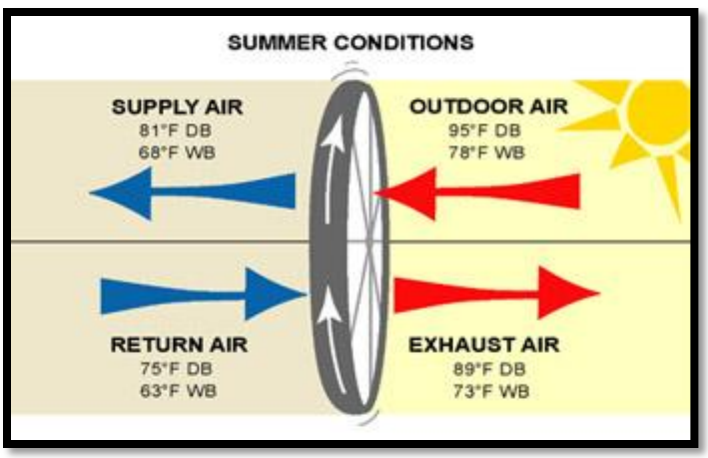


**Figure 4: Heat Recovery Wheel**

## Water-Side Free Cooling

Water-side free cooling is an economizer method which should work very well with the DOAS chilled beam system. Water-side free cooling refers to using the cooled condenser water from the cooling tower as a chilled water source to cool a load, therefore eliminating the need for a chiller. Water-side free cooling works best when the outdoor wet bulb temperature is around 40°F for typical applications that desire to produce average chilled water temperatures. However, a chilled beam uses water temperatures between 55°F and 58°F which is much higher than typical applications. Because the chilled beam uses higher temperature water, water-side free cooling will be available for a greater portion of the year which should reduce the amount of chiller hours and save energy.

# Breadth Topics

## Electrical

An electrical breadth topic will be investigated to determine the impact of the new mechanical system on electrical distribution. Because some of the equipment will be downsized or eliminated and other equipment added, a new inspection of the power distribution will need to be analyzed. Over current protection, feeder sizes, and feasibility issues will need to be examined and resolved. A revised single line diagram will be laid out to aid in the conceptual schematic of the new design.

## Structural

A structural breadth will also be scrutinized to determine the effects of the mechanical re-design on the structural support system. The (3) main rooftop air handlers will be greatly reduced in size, and perhaps even eliminated in some cases. Due to the reduced load on the roof, an analysis of the structural system will be performed to resize roofing members and distinguish any cost savings that may be a result of the re-design.

## MAE Breadth

Throughout the final report, a number of references will be made to items pertaining to the MAE curriculum. Calculating lifecycle costs and payback periods will be performed, which is a direct correlation to the material learned AE 558 Central Heating. Water-side free cooling is a topic discussed in AE 557 Central Cooling and will be an integral part of the final thesis presentation. Lastly, the improvements in indoor air quality as a result of the DOAS system ties in nicely with AE 552 Indoor Air Quality.

# Summary

In conclusion, an overall mechanical system re-design will be implemented by removing the current variable air volume system and designing a new dedicated outdoor air system with a parallel chilled beam secondary system to account for sensible loads within the space. Either a heat recovery wheel or runaround glycol loop will be utilized to recovery energy from the exhaust air. The new system should result in lower utility bills, more plenum space, smaller duct work and air handlers, and ultimately a reduction in costs and energy usage.

An examination of the mechanical system will allow further analysis into the impact that the mechanical re-design has on the electrical and structural components of the building. New designs for both will be implemented to account for the change in the mechanical design. Overall costs and energy savings or surpluses will be provided at the end of each analysis.

# Appendix A: References


1. Mumma, PhD, PE, Stanley. "Dedicated Outdoor Air Systems."February 2001. The Pennsylvania State University DOAS. 7 Dec. 2010 http://doas.psu.edu

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6. Barnet B.. "Chilled Beams for Labs: Using Dual Energy Recovery". ASHRAE Journal. (December, 2008).

# Appendix B: List of Tables and Figures

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## List of Figures

# Appendix C: Spring Schedule