Designing the Pentagon for Performance

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ABSTRACT

The 59-year-old Pentagon is undergoing an eight-year renovation that includes stripping the building down to its structural members and reconstructing all new systems in Wedges 2 through 5. The renovation will be completed in phases, one phase per 1-million square-foot building wedge. This paper provides an overview of the design process for the renovation of Wedge 2, which is currently underway.

Renovation of Wedges 2 through 5 is being done using a design-build delivery method. This contrasts to the normal design-bid-build scenario used in Wedge 1 and historically favored by the federal government; a process that compromises the search for coordinated solutions to incorporate energy efficiency into the completed project. Besides improving on project coordination, the design-build approach also lowers the administrative overhead for the Pentagon.

A key feature of the Wedge 2 through 5 renovations is that the design-build team, meet a specified energy performance target. The energy budgets range from 68-100 kBtu/ft^2/year and account for all energy crossing each wedge's boundaries. Budgets vary because of differences in tenant composition. Actual Pentagon energy use is estimated to be 131 kBtu/ft^2/year at the wedge level. As an incentive for the contractor to meet the target, monetary award fees are offered and linked to the team's commitment to efficiency and achieved performance, as well as other contract goals.

For the Wedge 2 renovation, the distribution system design selected is an innovative fan-powered induction system. The DOE-2 computer simulation program was used to demonstrate that this system could meet the specified budget. The system design uses less above-ceiling space, allowing the architects more space and freedom in designing the building's interior. A plan for the measurement and verification (M&V) of energy performance was developed as part of the design package. Meters included in the wedge electrical design (i.e., circuit board monitors) and the energy management and control system (EM&CS) are used to meet M&V requirements and to demonstrate compliance with the energy performance budget.

Introduction

The Pentagon building, built in 1943 and housing nearly 25,000 people, had never undergone a major renovation until recently. In 1998, the above ground renovation of the Pentagon started with Wedge 1 and included gutting the building to its structural members and reconstructing new systems. The Wedge 1 renovation was about one month away from completion when part of the wedge was demolished by the September 11, terrorist attack. Currently, Wedge 1 is being rebuilt, and the renovation of Wedge 2 is underway.

Due to the magnitude and duration of the project, the Pentagon Renovation Office (PenRen) was created to manage the renovation for the Government. In January 2001, PenRen invited three contractors to respond to a request for proposal (RFP) to renovate Wedges 2-5. PenRen selected one of the proposals and entered into a contract agreement with the contractor in September 2001 to complete the renovation of Wedge 2.

The project approach taken by PenRen includes two important features aimed at reducing construction and operational costs, and increasing energy efficiency. These features include: 1) the use of a design-build (DB) approach (instead of the design-bid-build (DBB) approach used in Wedge 1 and historically favored by the federal government) and 2) the requirement that the installed systems meet a specified energy performance budget.

For DBB projects, a bid is made to build a system that meets pre-defined design drawings and specifications. This approach usually results in many change orders and cost over runs. In the DB process, the contractor proposes a system design to be built to meet specified performance and usability requirements within a fixed budget. Thus, the DB process encourages coordinated solutions and cost management. In addition, the DB approach also lowered the administrative overhead for the Pentagon. For example, 3,500 pages of technical specifications were required for Wedge 1, but only 16 pages for Wedges 2-5 (Turpin 2000b, 78; PenRen 2000).

The overall goal of the Pentagon renovation, as stated by PenRen, is to upgrade the Pentagon into a modern, flexible and safe office environment that will endure for the next 50 years. Some renovation objectives to support this goal include: 1) providing reliable and readily serviceable building systems having the lowest life-cycle costs (LCC) to the Government over 50 years and 2) providing a sustainable-design facility supporting national goals in energy and environmental awareness, compliance, cleanup, and conservation. Project requirements put forth by PenRen to meet the above objectives are listed below and briefly explained.

Energy efficiency performance requirements. The energy performance requirements are set through the imposition of an *energy budget* for each wedge that specifies the maximum acceptable level of annual, normalized energy consumption (kBtu/ft^2 year). The budget figure comprises all energy use for the wedge, including energy for HVAC systems (fans, pumps, chilled water, hot water), lighting, receptacles, elevators, motors, water heating, and miscellaneous loads.[1] The Wedge 2-5 budgets are 100, 100, 73, and 68 kBtu/ft^2/year, respectively. The budgets vary because of the different energy use intensities of the tenants comprising each wedge. PenRen also set the wedge budgets for later renovations to be slightly more aggressive, anticipating some technology improvements in future project years.

Design evaluation requirements. A comprehensive performance evaluation, accounting for system interactions, is required. The performance evaluation must be based on the system or technology meeting the performance criteria specified by PenRen in the RFP.[2] An LCC analysis is required for making design choices for major building systems.

[1]The energy budget includes all energy that crosses the wedge boundary. Chilled water and steam are delivered to each wedge and produced in the Pentagon heating and cooling plant. Both of these energy loads are included in the wedge budget with no adjustment for efficiency/COP or auxiliary power used in their generation or delivery.

[2] For example for the HVAC system: setpoints, outdoor air ventilation rates, and operating schedules are specified for each building space type.

Building system commissioning. To ensure fully functioning facility systems that meet design intent and performance specifications, PenRen requires that the contractor develop and execute a wedge-specific Commissioning Plan and Procedures Manual concurrent with design and construction.

Energy performance measurement and verification requirements. To demonstrate compliance with the energy budget, the actual energy performance of each wedge is verified through permanent sub-metering of electricity, chilled water, steam, and other utilities as appropriate.

The renovation construction schedule for Wedge-2 spans two years. During the construction period, the contractor is responsible for design, construction, and system commissioning. The third year of the project (the first year of occupancy) is termed the "warranty" period. During this period, the contractor is responsible for servicing, conducting measurement and verification (M&V) of energy performance, and meeting the energy budget.

The project contract includes an award provision with the purpose of incentivizing the contractor to achieve superior performance based on the contract goals. Throughout the project, the contractor's performance will be continually monitored and evaluated. Based on the evaluation, an award amount is decided. The maximum award fee available is 10% of the value of the contract.

The amount of award fee earned is determined every three months over the three years. For each period, the contract defines evaluation factors having highest importance. For example during early construction phases, the important factors involve: design and construction quality of work and cost control, a commitment to energy efficiency and sustainable design, and commissioning effectiveness. The evaluation factors for the warranty period include: effectiveness of M&V activities and success rate in meeting the energy budget. The 10% maximum award is broken down between the construction and warranty phases as 9.5% and 0.5%, respectively. For perspective, the maximum award fee available during the warranty period is about equal to the anticipated expense for performing the project building simulation modeling and M&V activities.

Designing for Performance

Because of the energy performance requirements and the award fee incentives, efficiency is continually being considered as part of the design process. The areas impacting efficiency that the contractor can influence include: the HVAC distribution system, the lighting system, and the building envelope.

It is difficult to evaluate the performance improvement mandated for the project by comparing the energy budget to recent utility billing data. The decommissioning of Wedge 1 commenced in 1998. Prior to that, the Pentagon central plant was renovated. In addition, several facilities are served by the Pentagon central plant and none are submetered. Also, to estimate a value at the wedge level, the efficiency of the plant equipment must be considered. Taking these factors into account and using utility data over a 3-year period that encompasses the plant renovation, results in a rough value of 131 $kBtu/ft^2$ year. This can be compared to the average Wedge 2-5 energy budgets, equal to 85 kBtu/ft^2 year. Thus, the rough estimate indicates that substantial improvements to the existing systems are required.

In this section, the impact the efficiency considerations have had on the project during the design process is described. The design process has classically been broken into discrete stages, as outlined in Table 1. Those stages and how they relate to the Wedge 2 renovation are presented in the table. To date, the contract team (team) has completed the schematic design, design development, and construction document stages.

Table 1. Wedge-2 Renovation Design Stages

Stage	Wedge 2 renovation description	Status
Predesign	Building programming/space allocation and system performance requirements defined as part of RFP development.	Completed by PenRen 1/01
Schematic Design	Basic design completed as part of proposal submitted to PenRen. Preliminary evaluation of Wedge-2 energy use was completed using a DOE-2 building simulation analysis.	Completed by team 5/01
Design Development	Design finalized. Building elements given dimensions. Measurement and verification plan developed.	Completed by 1/02
Construction Documents	Detailed drawings and specifications prepared. Documents presented to PenRen in form of 35%, 75%, 95%, and final construction documents.	Partially complete by team 5/02
Construction	On-site renovation work.	Underway

Schematic Design

For conditioning the building, the Pentagon previously relied on induction units located underneath the windows for space heating with various air conditioning systems added over time. The building was never intended to have horizontal ductwork. It also wasn't designed for full electrical and computer interconnectivity. With just over an eleven-feet floor-to-floor height and limited ceiling space, meeting electrical, communication, and outdoor air requirements are a major design challenge. Other design constraints include the need to provide a highly flexible office environment and special function spaces, fully supportive of all tenant requirements.

In its initial evaluation of possible HVAC distribution systems, the mechanical team qualitatively reviewed ten systems, five conventional and five innovative.[3] (One of the ten evaluated is a variable-air-volume system, which was installed in Wedge 1 as part of its renovation.) The highest ranked was the fan-powered induction system. In this system, 100% outdoor-air central fans supply ventilation air to fan-powered induction units (FPIU), which are located at the zone. The FPIU consists of a cabinet, a sensible-only cooling coil, an efficient electronically commutated motor (ECM) and a pressure independent air valve with actuator. The air valve allows a discrete constant-volume of conditioned outdoor-air (OA) to be supplied to the zone. The outside air quantity can be monitored and reset from the EMCS. The outdoor air is cooled to a design dewpoint temperature of 48 ^{o}F and delivered at 52 ^{o}F due to fan reheat. At the zone terminal, the OA and the fan-induced recirculated air pass over a cooling coil. This sensible-only cooling coil uses an elevated chilled water temperature to

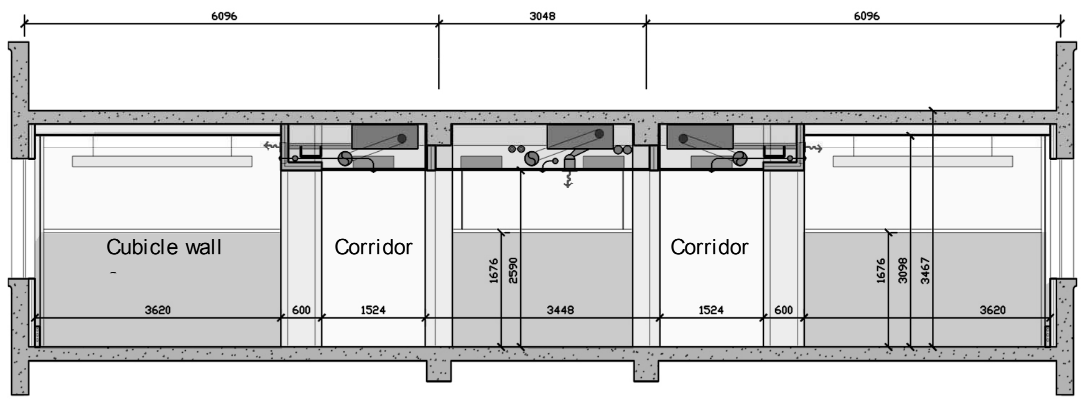
[3] Conventional systems include: induction air, variable air volume, fan coils, constant volume with reheat, and water source heat pumps. Innovative designs include: low temperature air, raised floor air distribution, chilled ceilings, chilled beams, and fan-powered induction system.

avoid condensation at the zone. Exterior zones are heated by a fin-tube hot-water radiation system, which has its controls integrated with the FPIU.

The FPIU system showed significant advantages over other evaluated systems. The main advantage being; most of the cooling is done by chilled water instead of air. This reduces duct space requirements. For example, for a typical branch duct capable of delivering 10 tons of cooling: a VAV system requires about a 20” duct while the FPIU requires a 10” duct (for supplying OA only) and two 1-1/2” pipes for the chilled water.

The additional ceiling height made available by the FPIU design was well used by the architectural team, as shown in Figure 1. They placed the plenum spaces (holding ducts, piping, electrical, and communication cables) predominately over corridors and other core spaces. This allowed the full, 11 feet of exterior walls and windows to be exposed at the wedge perimeter. In addition to opening up the perimeter offices and improving space quality, it affords greater daylighting opportunities. This design contrasts to the Wedge 1 interior layout that has plenums throughout, resulting in an 8’ ceiling height and partially blocked windows.

Figure 1. Cross-Sectional View of Wedge-2 Interior Layout (dimensions in millimeters)



As part of the assessment of the proposed design, a comprehensive analysis was completed to determine energy performance of the system to determine if the proposed design would meet the energy budget and be as efficient as a conventional VAV system. To complete the assessment, the DOE-2 computer simulation program was used to model the system and meet the space requirements outlined by PenRen.

As part of the renovation specifications, twenty-three different space types were defined and located on color-coded plan drawings. In addition, hours of occupancy, set point temperatures, outdoor air requirements, occupants, lighting power, and equipment power were defined for each space. These data, as well as assumptions about plug load diversity factors (DFs), provided the input needed to develop the DOE-2 model.

A VAV system with economizer was also modeled using the same input data. However, a VAV system can not exactly meet the wedge OA requirements as the FPIU can. The VAV system (with a fixed OA aperture) has a fixed OA fraction. As the total supply air volume is reduced, the outdoor air flow is reduced. Thus if fan operates at a 50% turndown, the outdoor air flow fraction must double to achieve the same outdoor air flow as at design conditions. Therefore, in the proposal analysis, the OA flow for the VAV system was set at

30% to maintain the required ventilation rates (as outlined in the RFP and consistent with ASHRAE Standard 62) at all times.[4] For the FPIU, the OA flow rate for the building is 14%.

The results of the DOE-2 analysis are presented in Table 2. The runs have substantial diversity factors applied to the design plug load values specified by PenRen. The design values were provided to represent the worst-case scenario and were used for mechanical and electrical designs.

The end-use breakdown shows the dominance that the chilled water load has on the total budget. Of next importance are the plug loads and lights. The FPIU zone fan energy use is 5.3 kBtu/ft^2 year of the total fan energy reported. This value is low due to a recently available fan motor technology. Electronically Commutated Motors (ECMs) efficiency (70-80%) is much better than the Permanent Split Capacitor motor (PSC) efficiency (30%) that are typically used in zone terminals.

Table 2. Energy Budget Evaluation

System	Energy Use (kBtu/ft^2 year)							
	Lights	Plug	Pumps	Fans	Heat load	Cool load	DHW load	SUM
VAV w/econ	16.4	17.2	0.0	7.4	14.2	39.1	1.2	95.4
Fan Powered Induction	16.4	17.2	0.5	8.9	3.9	45.0	1.2	93.0

The results in Table 2 show that the Wedge-2 performance with the FPIU system is slightly better than that with the VAV system. A LCC study was completed to compare the two systems on a long-term economic basis. Based on a 20-year, life-cycle period and considering capital, energy, and maintenance costs, the study results estimate a 2.5% reduction in operating expenses and a 6% reduction in net present value costs for the FPIU system. Given this and the other benefits previously described for the FPIU system, the FPIU system design was proposed by the team for the Wedge 2 renovation.

For the Wedge-2 lighting system, the PenRen design specifications included a minimum light level and maximum power density for each space type. For example, for the office spaces in the wedge, the light level requirement is 450 lux direct and 350 lux indirect at the work plane and the maximum allowable lighting power density is 1.0 W/ft^2. For comparison, the latest ASHRAE standard allows a lighting power density of 1.3 W/ft^2 for offices (ASHRAE 1999). To satisfy the design requirement, the system proposed by the team is a combination of 8-foot indirect suspended fixtures and 2x2 recessed fixtures. The indirect fixture is equipped with 2 – 48” F32T8 low mercury content lamps per cross section and 2 electronic ballasts. The direct fixture is equipped with 2 – F31 U-lamps.

For the building envelope, the proposed design met the design specifications required. These specifications are consistent with ASHRAE Standard 90.1 1999 (ASHRAE 1999) in terms of thermal resistance, light transmittance, and solar heat gain.

[4] A more sophisticated analysis could have been done and other VAV control strategies could have been considered. Completing the simplified evaluation was achievable within the proposal timeframe and proved to be sufficient for PenRen.

Design Development

The project design-development stage followed the award of the contract to the team. During this stage, the general design concepts outlined in the proposal were developed into complete design specifications. Efficiency considerations were an underlying influence in the development of many of the design details. Several examples of how efficiency influenced design choices are cited below:

- In general, system specifications used in the schematic design that significantly impact the wedge energy budget were strictly upheld in the design development.
- To uphold the HVAC system specifications and achieve acceptable energy performance, specific design choices were made as part of the design development. Some of these choices include:
  - The primary chilled water piping was oversized to minimize pressure drop and eliminate the need for primary booster pumps since chilled water from the central plant is available to the wedge at only a 20 psi differential at the point of connection.
  - An exhaustive selection process was followed to choose an optimum FPIU design, including the following parameters:
    - fan and motor of the highest possible efficiency;
    - coils that could meet the air pressure drop and load specification; and
    - custom box designed to hold the custom-tailored components.

Additional efficiency analyses that were not evaluated during the schematic design phase were considered during design development. These studies include evaluating:

- the impact that plug-load diversity factors have on the energy budget estimates;
- the use of lighting occupancy sensors; and
- the sensitivity of the energy budget to envelope characteristics.

Studies not yet completed but required by PenRen are listed below. It is anticipated that PenRen will enforce the requirement for these studies:

- the use of dimmable ballasts with integrated occupancy controls and
- the use of daylighting controls.

The design development process was also influenced by meeting project objectives other than the energy budget. In an effort to meet the contract sustainability objectives, the team is engaged in a U.S. Green Building Council (USGBC) Leadership in Energy and Environmental Design (LEED) evaluation for the project. According to USGBC, a green design includes design and construction practices that significantly reduce or eliminate the negative impact of buildings on the environment and occupants. The project has been accepted as a LEED EB (existing buildings) pilot project (USGBC 2002). The goal of participating is to become LEED certified. The level of certification has yet to be determined.

Another project requirement is measurement and verification (M&V) of performance. To meet this requirement, the team is developing the project M&V approach and metering plan. The M&V will be carried out after construction of Wedge 2, during the warranty period.

While building commissioning is a requirement, it is just beginning to be a project concern. Currently, securing the commissioning firm to join the team is under way.

Construction Documents

During the construction documents stage, reference documents are produced that will be used during construction. One type of document are construction drawings, which reflect the efficiency choices made in the earlier design stages. For Wedge 2, drawings are submitted by HP to PenRen at several points of completion. They include 35%, 75%, 95%, and 100% construction documents (CDs).

Presently, the 35% and the 75% drawings have been submitted. Following each submittal, an extensive review process followed. PenRen comments were posted on the Internet. HP responded with explanations or changes, which were also posted on the Internet. All comments and response were tracked to ensure no issues were neglected.

Two other required reference documents are the Commissioning Plan and the M&V Plan. The Commissioning Plan will be developed with advisory oversight from the Government's Commissioning Specialist and guided by an existing, draft, plan and procedures manual developed for Wedges 2-5. Development of the Commissioning Plan will commence once commissioning activities for the project begin.

The initial draft of the M&V Plan has been completed for the project. The purpose of the M&V Plan is to develop a methodology to measure and meaningful compare actual and baseline energy use. The main components of the Pentagon M&V plan for Wedge 2 are listed below:

- The definition of the baseline building conditions associated with the Wedge-2 target energy budget put forth by PenRen;
- The development of methods for adjusting the target energy budget to account for deviations from baseline conditions; and
- The development of a plan for metering of utilities/end-uses and other parameters needed to measure actual energy use and make target budget adjustments.

Defining baseline conditions is the starting point for quantifying changes that impact the target energy budget and making adjustments. Thus, both PenRen and the team must agree upon the baseline definition and adjustment methodologies. Since the underlying assumptions supporting the Wedge-2 energy budget were not disclosed by PenRen, the baseline conditions were not defined as part of the contract agreement. PenRen and the HP team are currently discussing baseline issues.

Discussion

The change in delivery method from Wedge 1 to Wedge 2, from DBB to DB, has resulted in many changes in design approach. The Wedge-2 method encouraged greater team cooperation, increased focus on efficiency, and included whole-building performance analysis. It also integrated sophisticated analysis tools (such as the DOE-2 computer simulation program) and M&V activities into the project. While these tools are well known and used by the Government, their interactive application during the design process is relatively rare. These changes in design approach underlie the anticipated success for achieving the aggressive performance savings goals set for the project.

Much of the performance analyses, performed for the project, have been related to the mechanical system. This is explained by the fact that HVAC system, relative to lighting and envelope, most heavily impacts the budget in this project. Thus, justifiably, it was the mechanical firm that identified the need to subcontract services to an energy engineering consulting firm with simulation modeling and M&V experience. The mechanical firm was aware of the work entailed in an energy-performance driven contract due to past experience with performance contracting. However in future efforts, having the energy-consulting firm be a full-team member (instead of a subcontractor to the mechanical firm) may help coordinate analyses, ensure consistency in building characterization, and bring powerful energy analysis tools to all parts of the project.

Currently, PenRen and the team are resolving the definition of the baseline conditions. As explained earlier, these conditions underlie the target energy budget and are the basis for making adjustments to it. After performing sensitivity studies using the simulation model, the team realized the large dependence the estimated budget had on the plug load assumptions. This is because the design values of plug loads provided by PenRen are worst-case scenarios. Using these value in the Wedge-2 model put the energy budget over 300 kBtu/ft^2 year. Thus, substantial DFs were applied in the model in order to approach the target budget and be consistent with rough estimates of historical utility energy use data. Because of the large impact plug loads have on the budget, the team would prefer that the plug load component be specified by PenRen. This will enable the contractor to focus on the systems it can impact and remove large uncertainties in defining the baseline.

Conclusions

The design-build approach taken by PenRen and the efficiency-related contract requirements has benefited the project in many ways. Some of the benefits of PenRen's approach are listed below.

- It led to the evaluation and subsequent specification of an innovative system relying on newly available technologies that met performance requirements and reduced plenum-space requirements.
- It encouraged coordinated solutions across specializations to meet contract objectives. Examples are as follows:

    - Architects coordinated with mechanical engineers to utilize larger interior volumes to improve space quality and daylighting opportunities and
    - Meters included as part of the electrical design and energy management computer system (EMCS) were utilized to fulfill M&V requirements.

- It kept efficiency considerations a high priority during all stages of the design process.

The change in delivery method has also resulted in new procedures that can benefit from lessons learned thus far in the design process. The team highly recommends that, in future contracts, PenRen specifies the plug load component of the energy budget. This will enable the contractor to focus on the systems it can impact and remove large uncertainties in defining the baseline. In addition, it is believed that the energy performance evaluation studies will improve if the energy specialist is held as a full team member.

In summary, the benefits to the Wedge-2 project design approach are numerous. Combining a contract DB delivery method with specifications for an energy budget, commissioning, and M&V is an effective approach for achieving aggressive performance improvements in Government buildings.

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