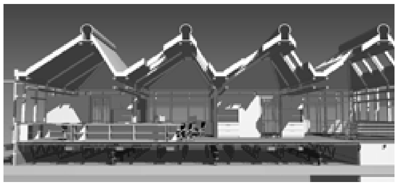

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Sustainable Development Alternatives for Speculative Office Buildings:

A Case Study of the Soffer Tech Office Building

Final Report
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1.0 Introduction

This report documents the analysis of sustainable design alternatives for the Tech Office Building - a two-story, 64,000 sq.ft. speculative office building developed by the Soffer Organization in Pittsburgh, Pennsylvania (figure 1). The architects are Garder+Pope, and the mechanical/electrical consultant is RAY Engineering. The attached drawings show the plans, sections, elevations and system details of the building. The purpose of this study was to assess alternative enclosure, HVAC and lighting design options in terms of their environmental performance and cost-benefit justifications.

Figure 1. The Tech Office Building is a two-story 64,000 sq.ft. speculative office building.

Acknowledgement:
This study was made possible with funding support from The Heinz Endowments. The study was undertaken in partnership with the Green Building Alliance (GBA), a Pittsburgh based, non-profit organization that educates the market about the benefits a green building approach to development. The research and findings contained in this study will be used by the GBA, Carnegie Mellon University and its authors for education purposes.

2.0 Overview

Significant quality gains have been made in almost every building subsystem in the building sector. However, first cost and fast track decision-making has stifled implementation of these advances. The Center for Building Performance and Diagnostics at Carnegie Mellon, with Gardner+Pope Architects and RAY Engineering have identified numerous advanced alternatives in enclosure, HVAC, networking, interior and lighting components that can be applied to the Tech Office building. These alternatives were then evaluated in terms of their performance benefits and life-cycle costs.

In the case of speculative office buildings, it is important to distinguish the cost-benefit factors for the building owner from those of the tenants. Although this can vary based on the leasing agreement, typically the cost benefit factors may be categorized as follows:

Owner	**Tenant**
First costs	Energy
Facilities management	Individual productivity
Technological churn	Organizational productivity
Organizational churn	Health/absenteeism
Reuseability/waste	
Taxes/litigation/Insurance	
Attraction/marketing	
Image gains	

Appendix A contains a description of these cost-benefit factors.

To identify viable sustainable alternatives to "standard" speculative office building design, the project team worked with the Soffer Organization. For each system/component, the standard option and more sustainable alternatives were identified as shown in Table 1. This table also identifies the quantitative and qualitative life-cycle benefits of this set of design/engineering alternatives, while Table 2 gives the specific values. Section 3.0 discusses in further detail the major alternatives for sustainable design in speculative office buildings. The final recommendations for the Tech Office building are described in section 4.0.

Table 1. Sustainable alternatives and their life-cycle benefits

System	Standard/ Alternatives	First costs gains	Facilities management	Technological churn	Organizational churn	Reuseability/waste	Taxes/litigation/Insurance	Attraction/marketing	Image gains	Energy	Individual comfort/prod.	Organizational prod.	Health/absenteeism
Facade Glazing	Standard1: Sungate w/ grey tint (SC=0.33, U-value = 0.29, Vis Trans = 0.41)												
	Standard2: Dark reflective glass (SC=0.22, U-value = 0.42, Vis Trans = 0.10)												
	Alternative1: High-visibility, low-e, argon filled glass with 25% reduced glass area							●		●	●		●
Facade Shading	Standard: No shading												
	Alternative1: 3-layer light redirection device (3 ft. effective overhang) on south, east, west facade							●	●	●	●		●
	Alternative2: Internal light-redirecting venetian blinds							●	●	●	●		●
Roof Insulation	Standard: R-14 rigid insulation on metal deck												
	Alternative1: R-20 rigid insulation on metal deck									●			
	Alternative2: R-30 rigid insulation on metal deck									●			
Roof Color	Standard: Black/dark EPDM surface												
	Alternative1: White/light surface	●								●			
Lighting	Standard: direct lighting fixtures with parabolic louvers, rated at 1.6 $W \cdot ft^{-2}$												
	Alternative1: Split task ambient lighting, rated at $1.1 W \cdot ft^{-2}$ ($0.8 W \cdot ft^{-2}$ ambient + $0.3 W \cdot ft^{-2}$ task)		●		●	●		●		●			●
	Alternative2: Daylight-based dimming with continuous dimming ballasts (dimmable to 0 power)		●	●						●			●
HVAC	Standard: Ceiling-based VAV with terminal reheat												
	Alternative1: Floor-based supply plenum with relocatable diffusers	●	●	●	●	●		●		●	●		

Table 1. Sustainable alternatives and their life-cycle benefits

System	**Standard/ Alternatives**	**First costs gains**	**Facilities management**	**Technological churn**	**Organizational churn**	**Reuseability/waste**	**Taxes/litigation/Insurance**	**Attraction/marketing**	**Image gains**	**Energy**	**Individual comfort/prod.**	**Organizational prod.**	**Health/absenteeism**
Networking	Standard: Ceiling plenum cable trays with poke-throughs to floor above												
	Alternative1: Structured Power/data/voice with relocatable boxes	●	●	●	●	●		●				●	●
Office equipment	Standard: No energy-saving strategies												
	Alternate1: Use strategies such as EPA's EnergyStar program									●			
Partitions	Standard: Drywall on metal frame												
	Alternative1: Relocatable modular walls			●	●								
Furniture	Standard: Non-modular furniture with minimal ergonomic adjustability												
	Alternative1: Modular furniture with full range of ergonomic adjustability			●	●						●		
Finishes	Standard:												
	Alternative1: Recyclable, environmentally benign fabrics, paints, adhesives							●					●

Table 2. Cost-benefit data for sustainable alternatives

System	**Standard/ Alternatives**	**First Cost**	**Life-Cycle Benefits**	**Sources/Notes**
Facade Glazing	Standard1: Sungate w/ grey tint	base		
	Standard2: Dark reflective glass	$30,000 over base		Project bids
	Alternative1: High-visibility glass w/ 25% reduced area	($18,000) saving over base	$341/year energy savings Increased daylight/views	Simulations, Project bids
Facade Shading	Standard: No shading	base		
	Alternative1: 3-layer light redirection device	$340,000 total $5.32/ft^2	$3151/year energy savings Glare control	Simulations, CMU IW, Project bids
	Alternative2a: Internal fixed light direction	$42,540 total $0.6//ft^2	Increased daylight/ Glare control	Project bids
	Alternative 2b: Inverted 1" mini blinds	$16,173 total $0.25//ft^2	Increased daylight/ Glare control $400/year energy savings	Simulations, CMU IW, Project bids
Roof Insulation	Standard: R-14 rigid insulation on metal deck	base	-	
	Alternative1: R-20 rigid insulation	$5231 over base	$1024/year energy savings	Simulations, Project bids
	Alternative2: R-30 rigid insulation	$17,500 over base	$1586/year energy savings	Simulations, Project bids
Roof Color	Standard: Black/dark EPDM surface	$37,000 base	-	
	Alternative1: White/light surface (acrylic top coating)	$11,200 over base	$1898/year energy savings	Simulations, Project bids
Lighting	Standard: direct fixtures, rated at 1.6 $W \cdot ft^{-2}$	$255,600 base $4.0/ft^2		
	Alternative1: Split lighting, rated at 1.1$W \cdot ft^{-2}$ (Does not include task lights)	$171,200 total $2.68/ft^2	$11,857/year energy savings User Control	Simulations, Project bids
	Alternative2: Daylight-based dimming	$187,900 over base $2.94/ft^2	$7291/year energy savings	Simulations, Project bids
HVAC and Networking Infrastructure	Standard: Ceiling-based VAV, poke-throughs	base		
	Alternative1: Raised floor system - Floor-based air supply w/ relocatable diffusers; structured wiring and relocatable boxes	$0.27/ft^2 (incl. $5.03/ft^2 raised floor cost)	User Comfort & Productivity $4.66/ft^2 savings per churn $875/year energy savings	Simulations, Project bids

Table 2. Cost-benefit data for sustainable alternatives

System	Standard/ Alternatives	First Cost	Life-Cycle Benefits	Sources/Notes
Office equipment	Standard: No energy-saving strategies			
	Alternate1: Energy saving strategies		$1\ W\cdot ft^{-2}$ reduction = $18000 energy save	Simulations
Partitions	Standard: Drywall on metal frame (9’ high)	$43/lf		General Contractor
	Alternative1: Relocatable modular walls (9’ high)			
Furniture	Standard: Non-modular, non-ergonomic furniture	$2500 each user		Furniture dealer
	Alternative1: Modular/ergonomic furniture	$500 over base	User comfort	Furniture dealer
Finishes	Standard:	base		General Contractor
	Alternative1: Recyclable, benign finishes	No/minimal additional cost over base		General Contractor

Notes:

1. See Appendix B for detailed cost break down of Raised floor

2. See Appendix C for DOE-2 Simulation technical report

3.0 Discussion: Sustainable Design Alternatives

3.1 Orientation

Orient the building to face north and south predominantly.

Buildings that face predominantly north-south have a greater potential for effective solar control - particularly with the use of overhangs and light shelves on south-facing facades, which minimize solar gain in summer and maximize it in winter. Orientation is particularly important in perimeter dominated buildings with large aspect ratios. In the case of the Tech Office building, the orientation had a minimal impact, given its aspect ratio and core-dominated geometry.

3.2 Facade Glazing

Use high visible transmission - low shading coefficient glass.

Throughout the US, both speculative and owner-occupied office buildings have been built with highly reflective glass for the window areas. This darkly tinted, reflective glass (with shading coefficients of 0.40 or less) has been specified to reduce solar loads that contribute to cooling demands. However, the dark glass also drastically reduces daylight and leaves the occupant with darkly "tinted" views. This in turn requires that electric lighting must be on throughout the day, and even results in a secondary reflected glare from the electric lights off of the dark glass.

In cooling-load-dominated buildings, the major issue with regard to glazing is the tradeoff between lowering the shading coefficient to reduce solar gain and increasing the visible transmittance to provide daylight and views. New developments in glazing materials allow designers today to specify glass with visible transmissions of greater than 50% while having shading coefficients that are no greater than the conventional reflective glass used in commercial office design today. These new high visible transmission - low shading coefficient glazing materials can be specified at a marginal cost differential, to be justified by gains in marketing and individual health as well as gains in daylight contributions to reducing lighting electricity use.

The effectiveness of high visible transmission glass for perimeter daylighting in the Tech Office building allowed the designers to reduce the glazing area by about 25% (from 8'8" to 6'8" glazing height) and still provide ample daylight with clear views. (If light redirection/diffusion devices can be considered this additional glass area would be retained to provide greater daylighting into the interior). With the reduction of glass area, the cost of improving the performance of the glass for daylighting and views actually reduced first cost as well as providing annual energy savings - a no lose proposition.

While the $350 dollars of energy savings a year may seem minor, other benefits of daylight are major - marketing, worker health, and worker attraction/retention. First of all, in an experiment with skylighting in "big box" retail buildings, Walmart has found greater sales in a daylit portion of a major store than in an electric-only area (Romm and Browning 1994). It is our belief that the marketing of daylit tenant office space will reflect similar benefits to the "consumer" in rental speed, to be evaluated with the Soffer Organization over time. Secondly, a CBPD/DOE study has shown that health complaints in daylit office areas are 23% fewer than those in internalized workplaces (ABSIC/DOE 1994). With poor daylight access, some occupants suffer from clinical sunlight deficiency syndrome, while others complain of depression, conditions that result in lost productivity and health costs for a lessee. The recovery of daylight and clear views for the office worker is a benefit that can be marketed to prospective tenants. Finally, tenants who have clear views of landscaped areas and people activities are less likely to leave leased space for poorer quality alternatives, increasing tenant retention - another financial benefit to be tested with the Soffer Organization.

In short, the shift from highly reflective, tinted glass to high visible transmission - low shading coefficient glass offers first cost savings, energy savings, and yet-to-be-measured savings in tenant attraction and retention.

3.3 Facade Shading

Introduce window shading and, if possible, light redirection.

To reduce first cost, the conventional speculative office building has no exterior overhangs, awnings, or shading devices. The ideal approach to managing solar heat and glare would be to use dynamic shading devices that can control the sun based on time of day and season. However, such facades tend to be expensive and typically cannot be cost-justified on energy alone.

Consequently, fixed overhangs were considered for the Tech Office building, as a lower-cost alternative to dynamic external shading devices (see figure 2). These overhangs are effective in reducing solar gain in summer while allowing more solar gain in winter when sun angles are low. Although horizontal overhangs are most effective on southern orientations, they were also considered for the shorter east and west facades of the Tech Office building. A three foot deep horizontal overhang could reduce energy costs by about $3150 per year. Alternatively, the same impact can be achieved by a 3-layer overhang of one foot depth, that could also act as a light-redirecting device to improve the depth of effective daylighting in the office areas (see again figure 2). However, the additional first cost for these overhangs ($350,000) cannot be justified by energy costs alone.

Beyond cooling energy benefits, the overhangs are also effective in reducing glare in the perimeter areas by obstructing the upper part of the sky. This improves lighting benefits when combined with better electric lighting controls, and takes advantage of the marketing and health benefits of daylight in the workplace (described above). Moreover, these exterior shading elements provide a more modern image to the speculative office, in keeping with the aesthetics of high profile office buildings today with their linear overhangs and the lights and shadows they create.

Figure 2. External view of 3-tier 1 ft. deep external shading devices proposed for Tech Office building

3.4 Roof Insulation

Increase the roof insulation to R30, with HCFC foam.

Conventional tenant office buildings are built with code minimum roof insulation which is R-14 in Pennsylvania. The benefit of additional roof insulation, however, is measurable in reduced heating and cooling loads. These benefits can result in annual energy savings, in reduced peak loads (at peak power rates) and possibly in reduced equipment sizing at the outset.

For the Soffer Tech Office building, both R-20 and R-30 rigid insulation alternatives were studied, with careful selection of insulation materials that have low or no CFCs. Compared to the basecase, an R-30 insulation saves over $1600 per year in heating and cooling bills. At an increased first cost of about $17,500, it would take about 11 years for the better roofing to be amortized. R-20 was chosen for the Tech Office Building.

3.5 Roof Color

Select a light roof color.

Roofs are one of the major contributors to the cooling loads in office buildings. Standard black roofs increase cooling loads by acting as solar absorbers. Moreover, black roofs also increase the ambient temperature of the micro-climate causing the office park to be hotter overall. The cost of a white roof depends on the type of roof. An acrylic coating on a standard black roof has an additional first cost of $11,200. A white membrane roof is substantially more expensive ($60/sq.ft just for material). Substituting a white or light colored roof onto the Tech Office building will reduce energy costs by about $1900 per year. In addition, the selection of a light roof will reduce peak loads which impact peak energy prices and the initial sizing of equipment. In future projects, green/ planted roofs should be considered for both their energy and environmental contributions.

3.6 Lighting

Shift from direct lighting to indirect with task lights.

High-performance lighting is one of the most cost-effective ways of reducing energy loads. Conventional lighting in office buildings relies on multi-lamp 2 x 4 troffers in the ceiling (sometimes with parabolic lenses rather than flush lenses) to provide combined task-ambient lighting at a rated power of about 1.6 $W \cdot ft^{-2}$. This uniform array of fixtures is typically designed to deliver 50 footcandles of task illuminance on any horizontal surface that is introduced. However, this uniform array provides too much light for computer work and too little light when there is interference from high panels and hanging cabinets. This uniform array is typically combined with large zones for switching, such that almost all lights must be on if any one person is working. Moreover, the appearance of the overall space is often dim and undifferentiated with the introduction of parabolic lenses.

In contrast, next generation offices are beginning to introduce split task and ambient lighting systems with ambient light provided by a soft (30 footcandle) uplighting system that washes ceilings, walls and coves. Combining this ambient light system with high efficiency task lights can reduce the rated power demands to 1.1 watts per square foot (0.8 $W \cdot ft^{-2}$ ambient and 0.3 $W \cdot ft^{-2}$ occupancy-based task lighting). This translates into an energy savings of $11,900 per year with a first cost savings of $84,400 (excluding the cost of task lights). In addition, the indirect ambient lighting will not need to be reconfigured as often since the task lights will move with the worksurfaces to ensure the appropriate light distribution with organizational churn.

A split lighting systems is also advantageous with regard to visual comfort and health, since users can set the task environment to their preferences and tasks. Cornell studies have shown higher user satisfaction with uplighting than with conventional downlights, especially with parabolic louvers (Hedge et al. 1989). This satisfaction should translate into prospective tenant interest as they enter the office spaces, especially if the uplighting system enhances the aesthetics. In the Tech office building, the lighting system will be chosen by the tenant.

Introduce high efficiency dimming ballasts for the light fixtures with individual controls, including daylight responsive controls.

Even in uplighting systems, first cost often drives inexpensive lighting ballasts with few controls. However, the introduction of high efficiency ballasts with dimming control for every fixture has numerous benefits. First of all, variations in light levels can be introduced that correspond to functional differences such as circulation, waiting areas, computer workstations, conference rooms, etc. - adding visual interest and saving energy. Secondly, daylight-based dimming can be introduced for perimeter workspaces to take advantage of daylight and reduce reflected glare from the windows. Finally, tenant fit-outs and changes can be more readily accommodated since lighting and switches do not need to be rewired every time walls or partitions move.

In the Soffer Tech Office building, the use of high-efficiency electronic ballasts with daylight-based dimming in the perimeter areas will reduce overall energy costs by about $7300 per year on an additional first cost investment of $187,900. Even if automatic daylight-based dimming is not used, high-efficiency ballasts will improve user control and energy savings by allowing users to dim the lights based on task requirements and daylight availability. In addition to the annual energy savings, these individually ballasted and controlled fixtures will save significant dollars in tenant fit-out and modifications - especially if the fixtures are relocatable with plug and play connections. One additional recommendation that would help to support the purchase of higher quality fixtures rather than least-first-cost, is purchasing lighting density on an as-need basis rather than all at once. This just-in-time approach to lighting density would allow first budgets to be used for quality fixtures with additional lighting needs met as they arise through the plug-and-play connections.

3.7 Energy recovery

Introduce heat/coolth recovery for the HVAC air handler.

Speculative office buildings normally do not have energy recovery systems. The perception is that these systems have higher first costs. RAY Engineering has found desiccant recovery wheels typically have a negative (first cost is less) to a two year pay back. The recovery system works by allowing incoming ventilation air to go through one side of a desiccant wheel and the exhaust air to go through the other side of the wheel. As the desiccant wheel turns both sensible and latent heat passes from one air stream to the other. Incoming winter air is heated and water molecules are transferred from the exhaust air stream to the entering air stream. The reverse occurs in summer. The effect is outside ventilation air has the feel of spring and fall rather than summer and winter under the most severe conditions.

For the Tech Office building, the rooftop cooling units were manufactured by AAON with desiccant recovery wheels within the units. These wheels are 81% efficient and allowed the building cooling load to be reduced from 185 to 150 tons. The reduced cooling tonnage and cost of the units exactly offsets the added cost of the wheels. Therefore, there was no premium to use energy recovery wheels. In addition, taking into account the smaller wire, breaker, and duct sizes, using energy recovery wheels is less expensive.

3.8 Mechanical Zoning and Control

In conventional office buildings air is delivered overhead at 55ºF to cool the space. Many buildings the size of the Tech Office building use one variable air volume (VAV) box for each 1500ft^2 of space. Downstream of each VAV box is a hard duct and a series of flexible ducts to ceiling diffusers. The VAV boxes open and close via wall thermostat to maintain space conditions.

For the Tech Office building, medium pressure ductwork is routed below the 18" high raised floor. One VAV box is connected to the duct for each 2,000 ft^2. The VAV box opens and closes to allow air to enter the plenum based on the room thermostat. There are no ducted connections between rooms to have precise control of the space if walls extend below the floor. Air delivered from the floor is between 60ºF to 65ºF. As a result, the air side economizer has a longer period to operate, up to 65ºF outside air temperature rather than 55ºF for conventional buildings.

Another important control factor in the Tech Office building is that discharge air temperature from the rooftop units vary based on variable speed drive output. If the drive is at 90% of full speed this indicates many VAV boxes are wide open and calling for cooling. Therefore, the discharge air temperature is set at the lowest point, 60ºF, to get VAV boxes to start closing. If the drive is at 40% of full speed this indicates many of the VAV boxes are closed and are not calling for cooling. Therefore, the discharge air temperature is raised 65ºF to get VAV boxes to start opening. By raising and lowering discharge air temperature better comfort levels can be maintained with more consistent air flows.

3.9 Raised Floor for HVAC and Networking

Install a raised floor for floor-based HVAC and networking.

Speculative office buildings invariably use ceiling-based infrastructure for HVAC (heating, ventilation and air conditioning) and networking, consisting of a ducted VAV system for HVAC and "poke-throughs" for networking. Despite first cost savings, the inadequacies of these systems are well known. Poke-through modifications require interruptions of the occupied floor below, with dust and measurable disruption of activities. They also result in surface mounted or partially embedded outlet boxes that are non-relocatable and safety hazards. The cost of relocation is charged out at about $400 a box, until the number of holes puts the structural integrity of the slab in question, after which they cost up to $800 a box (so that structural patching can occur). At the same time, ceiling-based HVAC with the typical hard ducting and fixed zone sizes also has performance weaknesses. Over time, the mismatch between functional layouts and HVAC zones and diffuser locations becomes a serious concern (Tu 1997). The resulting occupant complaints about "too hot/too cold" and "too stuffy/too drafty" are well documented throughout the U.S. (CBPD/PacifiCorp 1995, Harris 1992, IFMA 1991) and lead to significant facilities management costs. The Soffer Organization also reports that their most frequent complaints are "too hot/too cold". First cost decision-making is driving engineers to larger and larger zones (now at an average of 15-20 people, moving towards 50 sharing a thermostat), and to "blanket" diffusers that are further apart, resulting in even poorer performance of these fixed, ceiling-based approaches.

One of the most promising new approaches to delivering both HVAC and networks to the individual workstation is the use of a raised floor plenum instead of a ceiling plenum. Based on cost-benefit studies, the Soffer Tech Office building will use a raised floor for both HVAC and modular power and networking. The HVAC will use the floor as a supply air plenum, with user relocatable air diffusers. Some underfloor ducting will distribute conditioned air to redefinable zones under the floor, with air temperature controlled by thermostats and VAV dampers. These pressurized plenums allow tenant layouts and densities to change continuously, with thermal conditioning ensured by the continuous addition and relocation of VAV diffuser "pots" in the floor (see figure 3). The 18" raised floor will also support underfloor networking and relocatable outlet boxes (see next recommendation). These floor based infrastructures leave the ceiling free for creative lighting and acoustic solutions, adding interest to the workplace.

The major benefits of this system are the provision of service (connectivity, HVAC, user comfort (temperature control and air quality), and ease of reconfiguration. The floor based delivery or air can also reduce energy costs since cooling air temperatures do not need to be as cold, and air can be delivered to the occupant without having to cool the entire volume of space. In the Tech Office building, this was calculated at $875 per year for this project given - a conservative estimate due to the limitation of simulating raised floor air supply with DOE2 (see Appendix C for details). There are also significant first cost gains in the underfloor HVAC systems since a majority of the ducting can be eliminated.

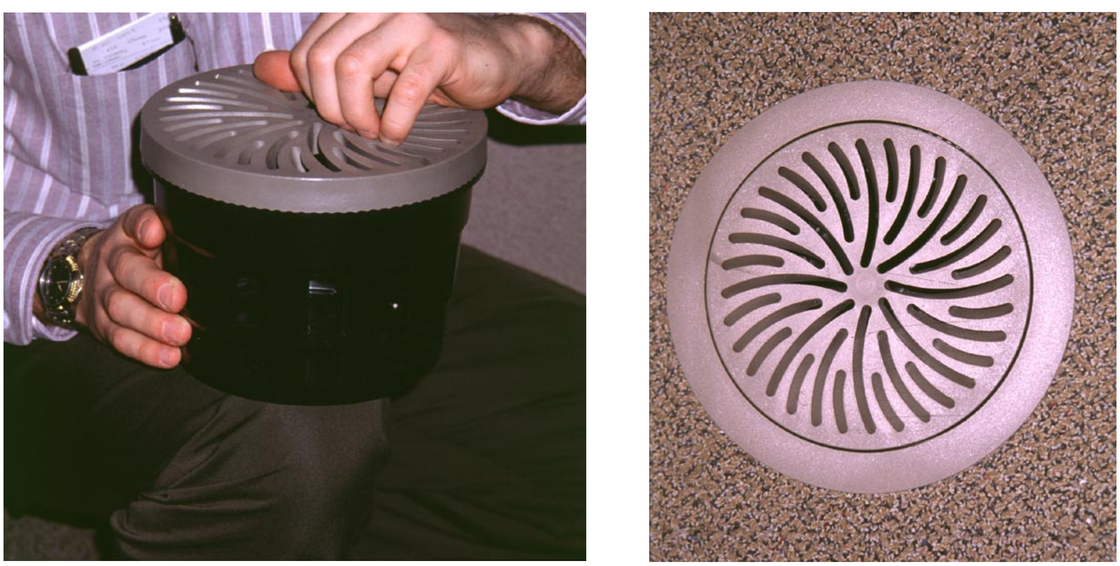

Figure 3. The Owens Corning headquarters building features an underfloor air plenum with Titus™ swirl-plate diffusers providing a flow rate between 0 and 90 cfm each.

The three part high performance package (raised floor, plenum air supply with relocatable diffusers, and structured/relocatable wiring for data-power-voice) does cost $0.27 more per square foot than conventional systems on this project. However, the facility cost savings in the first reconfiguration (churn) will yield $4.66 per square foot (7 times the additional cost investment), which will accrue with each full tenant reconfiguration (see Appendix B). The floor based HVAC has other benefits. Since the air diffusers can be open and closed (to a minimum) as well as relocated by the occupants, facility management complaints about thermal comfort and air quality will diminish. Combined with a variable frequency drive air handler, the tenants can introduce more air diffusers as needed to meet the needs of additional meeting spaces and higher density layouts (gaining the benefits of just-in-time purchasing of infrastructure rather than first cost redundancies). Since the air diffusers and the outlet boxes can be relocated, added and subtracted, waste is dramatically reduced - with tenant turnover no longer requiring base building and fit-out components to be thrown away. Finally, there is growing evidence that personally controllable air systems increases individual productivity. Combining the floor plenum air supply with such user-centered air management components such as Johnson Controls PEMs has shown as much as 2% increased productivity in the West Bend Insurance Company headquarters - justifying the cost of the individualized system in one year for the employer.

3.10 Networking

Install a structured wiring system for data, power and voice.

Along with the commitment to an accessible and reconfigurable underfloor networking strategy for data, power and voice, consideration should be given to the investment in relocatable connections for this system. Traditional wiring and cabling is accomplished with "hard-wire" connections at both ends, combined with idiosyncratic lengths of cable. This results in the need to call in tradesmen every time a data/voice or power outlet needs to be relocated or reconfigured. In addition, access to the existing cabling and boxes typically results in damage to floors, walls or ceilings as well as hours of worker disruption.

On the other hand, a structured wiring system located in a raised floor provides ease in network reconfiguration that is unmatched by existing solutions. Not only can outlet boxes be easily relocated by any facilities person, but the mix of services (between data, power and voice) can be reconfigured at each box. This is due to the development of plug-and-play connections and uniform cable lengths (whips or harnesses), that can be added/subtracted and relocated as needed.

The major benefits of structured wiring are first cost savings and "churn" or reconfiguration cost savings. In the Pittsburgh context, these factory-produced cabling packages are cost competitive if not cheaper than on-site wiring and cabling approaches. Reconfigurations can be done quickly, saving both facilities management costs and productive worker time. Moreover, there is little or no waste from this system, and there is the possibility of buying connections on an as-need or just-in-time basis to save the material costs of redundancy. Although structured wiring systems can be installed in ceilings or cable trays as well, the combination of raised floors with structured wiring and underfloor HVAC offer the best service for the individual user over time with the least disruption and waste.

Once again, the project bids for the Tech Office building showed that although the raised floor/ infrastructure system costs $0.27/ft^2$ more than the conventional system in first costs, the estimated first churn costs savings with the raised floor system is $4.66/ft^2$. Thus, the additional cost of the raised floor is more than covered within the first churn itself (Appendix B has a detailed cost breakdown and comparison).

3.11 Office Equipment

Select Energy Star office equipment.

Plug loads and the associated cooling loads from office equipment are a major part of the total energy consumption in modern office buildings (up to 20-30%). Strategies to reduce these loads, such as EPA's EnergyStar program (www.epa.gov/BuildingLabel), can significantly reduce energy use as well as peak loads.

The means to achieve this may range from tenant awareness campaigns, to recommended purchase advise from the owner, to time-based and occupancy-based automatic equipment shut-off. Simulation studies on the Tech Office building showed that reducing the equipment load by 1 $W \cdot ft^{-2}$ results in a total energy saving of about $18,000 per year (in cooling and electrical savings).

3.12 Partitions

Install relocatable walls instead of drywall.

Once the appropriate, modular, relocatable infrastructures are provided, the continuous recreation of workstations and workgroups will depend on the reconfigurability of the wall and furniture systems. It is critical to design these systems to support rapid changes between open and closed planning, between individual and teaming spaces, as well as rapid changes in occupant density, equipment density, and infrastructure/service to match these configurations. In keeping with these goals, the wall systems should:

- Provide mobile and modular space dividers, in horizontally and vertically stackable units to support shifts between open and closed workspaces.
- Support user reconfigurable levels of "closure", including support for doors
- Provide modules compatible with ceiling and floor modules for acoustic closure and for coordinated infrastructure access.
- Select dual purpose space dividers, providing storage in addition to acoustic and/or visual privacy.
- Provide relocatable components, eliminating drywall contributions to the waste stream.

3.13 Furniture

Utilize modular floor based furniture with full ergonomic adjustability.

All furniture components should be designed for user reconfigurability, with a minimum of waste, supporting just-in-time utilization, as follows:

- Provide modular and user relocatable (floor based) work surfaces to support increased surface and storage as needed.
- Provide adjustable height worksurfaces for ergonomic support.
- Provide mobile worksurfaces as needed to support individual and group reconfigurations.
- Select reconfigurable furniture systems to support relocatable service centers (pubs) and advanced conferencing facilities.

Increasing occurrences of muscular stress problems in the electronic workplace have made the introduction of ergonomic chairs a critical need in the workplace. A simple checklist for the selection of ergonomic chairs would include:

- Adjustable seat height, forward tilt of seat
- Locking mechanism
- Swivel on five caster base
- Adjustable back height/position for lumbar support;
- Footrest if worksurfaces are not adjustable
- Padding of seat and back
- Adjustable height armrests

The second half of the ergonomic equation is the design of the worksurface that supports the electronic equipment (as distinct from other worksurface needs). A simple checklist for the selection of ergonomic worksurfaces would include:

- Adjustable height/ position keyboard support
- Thin, low-impact keyboard and wrist support
- Adjustable height/ position screen support
- Typing document holder
- Worksurface adjustable height/ tilt

3.14 Finishes

Select environmentally benign fabrics, paints and adhesives.

The creation of a healthy indoor environment is advanced with the use of the right finishes. In addition to concerns for energy consumption and occupant comfort, environmentally benign finishes can reduce the introduction of harmful gases into the interior. Many conventional finishes, such as vinyl wall coverings, adhesives for carpet, wall finishes and construction elements (for gluing woods, drywall, etc.) give off gas that is potentially carcinogenic or allergenic. With the Environmental Protection Agency identifying the indoor environment as one of the top five environmental hazards for the next century, it is advisable to select finishes which are environmentally benign.

The following interior finish selections will improve the indoor air quality:

- Use of water based paints eliminates harmful solvents.
- Where upscale appearance is desired, water base sprayed on multi-color paint treatments (Zolatone™ is one such product) provide a seamless decorative appearance for a cost the same as or lower than the types of vinyl wall coverings normally used. The product is durable and washable.
- Loose laid carpet tile in 18" X 18" or 24" X 24" (to match the size of the raised floor access panels) do not need much adhesive to stay in place. The small amount of adhesive used in a grid pattern to maintain placement is low in VOC's (Volatile Organic Components).
- Acoustic ceiling manufacturers and carpet tile manufacturers are increasingly offering products made of recycled materials. There are now ceiling panels with 25-35% recycled content. Carpet manufacturers such as Interface and fabric manufacturers (for furniture system panels) such as Designtex are actively promoting products whose fibers are made of recycled content in ever increasing amounts, some up to 100%.

4.0 Recommendations

Based on the above discussion and analysis, the following are the recommendations for speculative office buildings, based on this study:

- *Facade:* Use argon filled, low-e, low shading coefficient, good visible transmission, untinted glazing with 25% reduction in glass area throughout. Also consider Azurlite™ and Evergreen™ products with higher visible clarity than Sungate™ with grey tint.

  Use interior upturned venetian blinds on south and north facades, with vertical blinds on east and west facades.
- *Roof:* Increase roof insulation to at least R-20 and ensure white (or very light) surface color.
- *Lighting:* Introduce to tenants the opportunity of modular and relocatable task-ambient lights with continuous dimming ballasts and user controls. Alternatively, introduce a split task-ambient lighting system with ambient uplighting system (appropriate to ceiling shape and reflectivity), with separate articulated arm task light.
  Select high efficiency T-5 lamps, high efficiency fixtures/reflectors, continuous dimming high energy efficiency ballasts, and user reconfigurable controls.
- *HVAC:* Introduce plenum floor based air system with distributed damper boxes, and the ability to add additional VAV zones for local requirements and tenant subdivisions.

- Energy Recovery: Use desiccant wheels in the roof-top air handling units.
- *Networking:* Introduce a structured wiring system for power, and for data/voice under a raised floor, with ability to relocate and add outlet boxes as needed.
- *Equipment Power loads:* Promote Energy Star ratings for tenants, illustrating the cost-savings from 1 to 3 $W \cdot ft^{-2}$ of plug loads.
- *Modular components:* Utilize modular, plug and play components rather than redundancies or embedded solutions for HVAC, connectivity and lighting, as well as carpets (must be same size as access floor).
- *Reconfigurable furniture:* Promote relocatable walls and horizontally and vertically stackable furniture to support tenant reconfigurations without waste.
- *Benign materials:* Promote low outgassing and environmentally responsible fabrics, carpets, acoustic ceilings. Avoid paints and adhesives.

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Appendix A:

Cost-Benefit Factors for Office Buildings

Excerpted from:
Loftness, V., Ries, R., Shankavarm, J., Gurtekin, B., Aziz, A:
"Cost benefit Analysis of Intelligent Workplace Technologies", Research Report to the Advanced Building Systems Integration Consortium. June 1998.

There are at least ten major cost-benefit factors to be considered in evaluating high-performance, sustainable design options for office buildings (Loftness et al. 1997). Each of these factors could fully justify better quality products and systems in very short time periods. The cumulative value of these cost factors over a 3-7 year time period could justify buildings of twice the initial investment with significantly longer design-engineering studies, typical of other industrialized nations. The resulting buildings also offer better organizational, environmental and technological quality for the end-user as well as being sounder solutions for a global environment.

1. *First Costs*

   Although high-performance systems typically have higher first costs than standard construction, there is substantial evidence that multi-disciplinary solutions may lead to greater building performance at equal or less cost. First cost savings have been shown to accrue through effective systems integration, including the merging of mechanical heating systems with facades, raised floors for networking with HVAC distribution, sunshading and orientation of facades with HVAC sizing and configuration. Although this first cost benefit is the easiest sell in the boardroom, it is the hardest sell to the professionals who must work together and maintain their confidence in integrated solutions in the face of litigation

   Another strategy for generating first cost savings with increased performance is replacing redundancy with accessibility when planning for change. Many building lighting and networking systems are designed with planned redundancy in the event of expansion. Thus 10-50% additional products are installed to support estimated long term demands, investments that often remain untapped due to the fixed nature of the redundant systems in the face of real organizational and technological changes. Reduced first cost investments in quantity of products can be traded for quality and reconfigurability of products.

2. *Operational Cost Savings: Energy, Maintenance and Repair*

   The second cost-benefit area is in operational cost savings, including energy, pollution mitigation, maintenance staffing and repair cost savings. Since energy costs are often well known by a building owner, substantial recommendations for innovation are often seriously considered if payback is less than 1-3 years. Beyond this time frame, however, few decision makers believe in the predictions of the cost energy, or that they will still own the building and still be accruing savings from the innovation.

   Compared to energy savings, maintenance and repair cost savings are less successful promoters of "innovations for quality" because there are very incomplete records on causes of M&R costs, and what M&R savings (including manpower costs) would be offered by various design/engineering solutions. At present, HVAC operations and maintenance costs are presumed to be roughly 2-5% of current plant value.

3. *Individual Productivity:*
   Speed, Accuracy, Effectiveness, Creativity, Impairment, Absenteeism

   Since a majority of the annual employee and workplace costs is for salaries (as much as 60%), any innovation that will clearly increase productivity will royally pay back investments in quality products and systems. However, measuring productivity in the "gold collar" environment is difficult. Productivity must be studied independently for skill-based, rule-based and knowledge-based jobs (Rasmussen 1990), to include such variables as speed, accuracy, individual and collaborative effectiveness, and creativity. Two indices could be readily available to evaluate investments in quality buildings - self assessment of productivity and absenteeism. An additional indicator that could also be more readily explored than "output" is observed downtime for modifications, complaints, and interruptions.

4. *Organizational Productivity:*
   Time to Market, Profit, Company Value (present and future)

   While individual productivity can be measured for some job descriptions, other knowledge-based jobs will have to evaluated through measures of organizational productivity. Time to bring product to market (design, engineer, manufacture), profit, as well as present and future stock value are all indices that can be used to cost-justify investments in quality built environments.

5. *Health Costs: Medical Costs, Litigation Costs, Compensation, Study, Remediation*

   After salary, the second major annual cost of an employee is benefits, including medical and insurance costs as well as workman's compensation. Again, measured reductions in these costs would justify investment in better quality environments. The most dramatic health related costs are tied to "sick building syndrome" mitigation including health costs of employees, field study costs, litigation costs, remediation costs, and building down-time costs. Due to poor nation-wide records, the fact that the many serious down-time costs have occurred in new sealed buildings with all air systems still has not translated into reconsideration of design/engineering solutions or better first-cost investments in quality, accessible solutions with full commissioning.

6. *Retention Costs: Commitment, Training*

   Another aspect of the productivity cost-benefit equation is the ability to attract and keep the best workers, the time needed for training, and the commitment of those workers to unpaid overtime. Attracting and retaining the best employees can be linked to the quality of the benefits they receive, including the physical, environmental and technological workplace. Moreover, an estimated six months must be dedicated to training a new employee, such that rapid turnover (poor retention) should be considered as 6 months lost over the time spent with the company. In this way, poor retention can be translated into serious cost centers. In addition, the commitment of an employee to voluntary overtime and weekends, punctuality, and reduced break times could be linked to workplace qualities that support motivation rather than stress.

7. *Renewability Costs: Organizational Reconfigurability*

   There are significant cost benefits to investing in renewable, quality building systems, if "churn" dollars could be considered. Significant additional expenses are presently incurred in buildings to support the cost of:

   - reconfiguring working groups and individual space
   - accommodating changes in functions, densities, workhours
   - accommodating rapid changes in technologies
   - building system overload and failure

Some organizations have been working to reduce space reconfiguration costs through universal footprints, especially in back offices. On the other hand, other organizations are pursuing massive reconfigurations to support non-territorial offices, mobile workstations, micro workstations and teaming spaces in response to organizational re-engineering. At the same time, occupant density, length of workday, and technology have dramatically increased in the workplace. As a result, system overload and failure costs are now accruing beyond the already significant costs of conventional churn. The extent of these organizational churn costs are not well documented, nor the benefits of investing in quality, "renewable" solutions, resulting in a lack of support for better life-cycle decision making.

8. *Renewability Costs: Technological Reconfigurability*:
   Network, Hardware, Software, Training, Management

   The Forrester Group in Cambridge (Forrester Group 1995) has found that Fortune 500 companies spend on average $8,000 - $10,000 per worker per year keeping desktop technology current. These costs are divided between hardware and software, networking, training and staffing. Over several years, these investments far outweigh the value of the physical workspace which contributes to the success or failure of computer based productivity. The $1000 per worker per year in networking modifications alone would cost justify better tele-communications and power infrastructures. The ergonomic and environmental costs of a continuously evolving technological infrastructure must also be recorded for better life-cycle decision-making in relation to those infrastructures as well.

9. *Tax/Code/Insurance/Litigation Cost Savings:*
   Tax Depreciation, Code Compliance, Insurance & Litigation Costs

   A number of investments in quality building components and systems can be cost justified through cost-savings in taxes (rapid depreciation of movable infrastructures), code compliance (such as CFC, PCB and asbestos elimination), insurance savings (health, safety), and litigation cost savings (health, safety, waste). The building performance investments that can be achieved with savings in these cost centers have not been evaluated by most building owners and managers.

10. *Salvage/Waste Cost Savings: Organizational, Technological, Environmental Modifications, Aging & Wear, Obsolescence, Salvage Value*

    Many buildings go through continuous cycles of spatial and technological change, often with major waste. Not only do workable infrastructures often have to be destroyed and rebuilt to allow for technological changes, but waste products can often be hazardous or bulky, and are requiring increasing expenditures for appropriate disposal. Moreover, the salvage value in these products (carpets, cabling, switches, pc's) is almost always lost. Greater investment in high performance products and systems might be fully justifiable in a short time frame if these waste costs/ salvage value are fully accounted for in the decision making process. Given long term goals to reduce national consumption of rare or non-renewable material resources, the implications of salvage and waste should be fully incorporated in building investment decision making.

Appendix B:

Cost Data for
Raised Floor Infrastructure

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Tech Office Building, Pittsburgh, PA
Cost Comparisons, 63,200 sq.ft. Building
July 10, 1998

	Conventional Overhead Systems	**Raised Floor Systems**
Base Building		
Raised Floor	0	272,000
Raised Core Area	0	66,000
Reduced Building Height	17,500	0
HVAC	690,000	690,000
Electrical	245,000	245,000
Plumbing	112,000	112,000
Sprinkler	43,000	43,000
Tenant Fitout		
HVAC	243,000	51,800
Electrical		
Power	167,400	97,200
Lighting	205,200	205,200
Data/Comm. wiring	94,500	54,900
TOTAL	1,817,900	1,834,600
Cost Per Square Foot	**$28.76**	**$29.03**

Raised floor systems offer the following advantages:

Lower operating costs

Lower life cycle cost

Better indoor air quality

Better thermal comfort

Greater flexibility

Reduced building height or increased occupied space height

Reduced construction time

No need for wiring in furniture systems

Potential tax incentives

Note: Construction documents were prepared for both system types and competitively bid to contractors. Building is currently under construction using raised floors.

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Tech Office Building, Pittsburgh, PA
Cost Comparisons, 63,200 sq.ft. Building
July 10, 1998

Square Foot Costs of Conventional Mechanical and Electrical Systems vs. Raised Floor Systems

	Tenant Fitout			**Estimated First Churn Costs**		
	Conventional Systems	*Raised Floor Systems*	*Savings*	*Overhead Systems*	*Raised Floor Systems*	*Savings*
Electrical Power						
Labor	0.98	0.28	0.70	0.98	0.28	0.70
Material	1.67	1.26	0.41	0.85	0.00	0.85
Subtotal	2.65	1.54	1.11	1.83	0.28	1.55
Telephone/Data						
Labor	0.56	0.32	0.24	0.56	0.32	0.24
Material	0.94	0.55	0.39	0.53	0.00	0.51
Subtotal	1.50	0.87	0.63	1.07	0.32	0.75
Mechanical HVAC						
Labor	1.15	0.10	1.05	1.15	0.09	1.06
Material	2.69	0.72	1.97	1.30	0.00	1.30
Subtotal	3.84	0.82	3.02	2.45	0.09	2.36
TOTAL	7.99	3.23	**$4.76**	5.35	0.69	**$4.66**

Cost of Raised Floor	$ 4.30
Additonal Cost to Raise Core Area	$ 1.04
Reduce Building Height	$-0.28
TOTAL COST OF RAISED FLOOR	**$ 5.06**

Raised floor systems offer the following advantages:

- Lower operating costs
- Lower life cycle cost
- Better indoor air quality
- Better thermal comfort
- Greater flexibility
- Reduced building height or increased occupied space height
- Reduced construction time
- No need for wiring in furniture systems
- Potential tax incentives

Note: Construction documents were prepared for both system types and competitively bid to contractors. Building is currently under construction using raised floors.

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Appendix C:

Technical Report:
Energy Simulation and Analysis

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Tech Office Building Energy Analysis

Report No. 98-01-01
16 September 1998

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1.0 Introduction

This report documents the computational energy analysis of the Tech Office Building - a speculative office building located at Penn Center West in Pittsburgh, Pennsylvania. The purpose of these simulations was to assess alternative enclosure, HVAC and lighting design options in terms of their energy use and cost. This energy analysis was part of a larger study funded by the Heinz Foundation, focused on “greening” the Tech Office Building.

The simulations were carried out using VisualDOE, which is based on the DOE-2.1E hourly energy simulation program.

2.0 Building Description

2.1 General

The Tech Office Building is a two-story, 66000 sq.ft. speculative office building developed by the Soffer Organization. The architects are Garder+Pope, and the mechanical consultant is Ray Engineering. The attached drawings show the plans, sections and elevations of the building.

2.2 Enclosure

Exterior Walls:
The exterior wall assembly consists of (from outside to inside): Corrugated metal panel with white factory finish, 1/2” GWB sheathing, metal frame with 6” fiberglass insulation, 1/2” drywall. The R-value of this assembly is 15.12 $ft^2 \cdot hr \cdot F \cdot BTU^1$, and the solar absorptance is 0.2.

Interior Walls:
The interior wall assembly consists of metal stud wall with drywall

Internal Floor/Ceiling:
The floor is made of a 4” concrete slab over 1 1/2” metal decking. There is a raised floor of 1 1/2 ft. No ceilings are assumed for the simulations.

Ground Slab:
The ground slab is made of a 4” concrete slab. Since the elevation of this slab is 1 1/2 ft. below grade, the effective heat transfer through it is assumed to be 0, according to the procedure defined by Winkelmann 1998.

Roof:
The roof construction is composed of (from outside to inside): Black EPDM surface, 2” rigid insulation on metal decking. The R-value of this assembly is 15.29 $ft^2 \cdot hr \cdot F \cdot BTU^1$, and the solar absorptance is 0.8.

Glazing:
The specified glazing is Sungate 1000 Grey. The corresponding glazing type in the DOE-2 glazing library has U-value = 0.29 $BTU^{-1} \cdot ft^{-2} \cdot hr^{-1} \cdot F^{-1}$, shading coefficient = 0.33, visible transmittance = 0.41).

2.3 Lighting Systems

The building is assumed to have combined task-ambient fluorescent down lighting, with a power density of 1.6 $W \cdot ft^{-2}$. The lighting operation schedule is indicated in table 1. No dimming is assumed.

Table 1. Lighting day schedules - % of peak lighting power density for different days

Day	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Weekday	5	5	5	5	5	10	10	30	90	90	90	90	80	90	90	90	90	50	30	30	20	20	10	5
Saturday	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Sun/Holiday	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5

2.4 Occupancy Loads

The office areas are assumed to have a density of 150 ft^{-2} per person. Table 2 indicates the occupancy schedule.

Table 2. Occupancy day schedules - % of peak occupancy for different days

Day	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Weekday	0	0	0	0	0	0	10	20	95	95	95	95	50	95	95	95	95	30	10	10	10	10	5	5
Saturday	0	0	0	0	0	0	5	5	5	5	5	5	5	5	5	5	5	5	0	0	0	0	0	0
Sun/Holiday	0	0	0	0	0	0	5	5	5	5	5	5	5	5	5	5	5	5	0	0	0	0	0	0

2.5 Equipment Loads

Equipment loads are assumed to be 2 $W \cdot ft^{-2}$ in office areas. The schedule for the equipment loads is the same as that for the lighting loads.

2.6 HVAC Systems

The office space has a floor-based HVAC system, using the raised floor as a supply plenum. Conditioned air is ducted to different parts of the plenum from 4 packaged roof-top air handling units. The air supply into the different parts of the plenum is modulated by VAV dampers. The supply air temperature is assumed to be 62°F. A 5th rooftop AHU is dedicated to the core and lobby areas. The perimeter heating is done through hot-water baseboard heaters, located in the plenum. A 10 ft. perimeter zone is assumed in the open office areas.

The rooftop air handlers are cooling-only units, with enthalpy controlled economizer and variable frequency drives. The integrated desiccant wheel in the air handlers was not modeled, since the desiccant wheel models in DOE-2 do not adequately match the given specifications.

A gas-fired boiler supplies the hot water for baseboards and domestic hot water. There is no plant equipment for cooling (rooftop air handlers are packaged units).

The HVAC system is operated from 6 am to 10 pm on weekdays only. During on-hours the heating setpoint is 70°F and the cooling setpoint is 76°F (see note below). During off-hours, the heating set-back temperature is assumed to be 55°F, and no cooling is assumed.

Note on cooling set point: DOE-2 assumes perfect mixing of the air within each zone, and as such cannot model the temperature stratification inherent in a floor-based air supply system i.e. a floor-based conditioning system allows the occupied zone (4-6 ft.) to be conditioned to comfort levels (typically 72°F) while allowing the upper part of the room to be at higher temperatures (80-84°F). The actual temperature gradient within the room will vary based on the type of diffuser. To model the energy implications of this effect in DOE-2, an equivalent mixed air temperature of 76°F was assumed for the zone cooling set point. (Section 3.6 of this report documents the energy implications of this effect, contrasting it to a conventional ceiling-based system, which assumes perfect mixing i.e. no temperature stratification.)

2.7 Utility Rates

The electric utility rates were obtained from Duquesne Light Company, and are as follows: fixed charge of $5527 per month, $0.038/kWH energy charge, $13.98 demand charge per KW over 300 kW.

Enron gas utility rates were obtained from Soffer Organization, and are as follows: $0.364/therm, no demand charges.

3.0 Parametric Studies

3.1 Facade Glazing and Shading

Table 3. Facade System Design Options:

Glazing Type	*Basecase: Sungate w/ grey tint* *(SC=0.33, U-value = 0.29, Vis Trans = 0.41)* Glazing-1: Argon-filled low-e (SC=0.43, U-value = 0.26, Vis Trans = 0.44) Glazing-2: Dark Tint (SC=0.22, U-value = 0.42, Vis Trans = 0.10)

Table 3. Facade System Design Options:

Glazing Area	*Basecase: Window height 8'8"* GlassArea1: Window height 6'8" (~75% of basecase)
Shading	*Basecase: No Shading* Overhang-1: 3 ft. overhang Overhang-2: 1.5 ft. overhang

Table 4. Facade Options Energy Use Summary:

Case	Electrical End-Use (kWh)							Gas End-Use (Therm)		
	Light	Equip	Heat	Cool	Pump	Fans	**Total**	Heat	DHW	**Total**
Basecase	296,967	339,542	2,824	223,206	2,598	126,059	991,196	6,677	1,136	7,813
Glazing-1	296,967	339,542	2,494	223,080	2,423	137,483	1,011,989	5,908	1,136	7,044
Glazing-2	296,967	339,542	4,083	212,915	3,152	112,658	969,317	9,611	1,136	10,747
GlassArea-1	296,967	339,542	2,571	216,395	2,477	119,126	977,078	6,081	1,136	7,212
Overhang-1	296,967	339,542	2,863	213,885	2,601	115,931	971,789	6,760	1,136	7,896
Overhang-2	296,967	339,542	2,845	217,648	2,596	120,413	980,011	6,723	1,136	7,859

Table 5. Facade Options Energy Cost Summary:

Case	Electric ($)	Gas ($)	Total ($)	Savings ($)
Basecase	122,877	2,844	125,721	-
Glazing-1	125,368	2,564	127,932	-2,211
Glazing-2	119,764	3,912	123,676	2,045
GlassArea-1	120,623	2,627	123,250	2,471
Overhang-1	119,696	2,874	122,570	3,151
Overhang-2	121,202	2,860	124,062	1,659

3.2 Roof Construction

Table 6. Roof Construction Design Options

Insulation	*Basecase: R-14* Roof-Insul-1: R-20 Roof-Insul-2: R-30
Surface Color	*Basecase: Black (Absorption 80%)* White-Roof: White (Absorption 50%)

Table 7. Roof Options Energy Use Summary:

Case	Electrical End-Use (kWh)							Gas End-Use (Therm)		
	Light	Equip	Heat	Cool	Pump	Fans	**Total**	Heat	DHW	**Total**
Basecase	296,967	339,542	2,824	223,206	2,598	126,059	991,196	6,677	1,136	7,813
Roof-Insul-1	296,967	339,542	2,665	221,823	2,551	125,511	989,059	6,298	1,136	7,434

Table 7. Roof Options Energy Use Summary:

Case	Electrical End-Use (kWh)							Gas End-Use (Therm)		
	Light	Equip	Heat	Cool	Pump	Fans	**Total**	Heat	DHW	**Total**
Roof-Insul-2	296,967	339,542	2,580	221,213	2,519	125,370	988,191	6,097	1,136	7,233
White-Roof	296,967	339,542	2,903	218,335	2,647	119,522	979,916	6,861	1,136	7,997

Table 8. Roof Options Energy Cost Summary:

Case	Electric ($)	Gas ($)	Total ($)	Savings ($)
Basecase	122,877	2,844	125,721	-
Roof-Insul-1	121,991	2,706	124,697	1,024
Roof-Insul-2	121,503	2,632	124,135	1,586
White-Roof	120,912	2,911	123,823	1,898

3.3 Lighting System

Table 9. Lighting System design Options:

Fixture Type and Power	*Basecase: Combined Task-Ambient @ 1.6 W·ft^{-2}* Split-Lighting-1: Split Task Ambient @ *1.1 W·ft^{-2}* (ambient lighting @ 0.8 W·ft^{-2}, task lighting @ 0.3 W·ft^{-2})
Daylight-based Dimming	*Basecase: No dimming* Daylighting-1: Continuous dimming (50 fc set point) Daylighting-2: 3-Step dimming (50 fc)

Table 10. Lighting Options Energy Use Summary:

Case	Electrical End-Use (kWh)							Gas End-Use (Therm)		
	Light	Equip	Heat	Cool	Pump	Fans	**Total**	Heat	DHW	**Total**
Basecase	296,967	339,542	2,824	223,206	2,598	126,059	991,196	6,677	1,136	7,813
Split-Lighting-1	195,688	339,542	3,205	209,174	2,775	108,092	858,476	7,571	1,136	8,707
Daylighting-1	256,981	339,542	3,043	217,285	2,703	118,274	937,828	7,179	1,136	8,315
Daylighting-2	242,334	339,542	3,126	215,081	2,753	115,455	918,291	7,368	1,136	8,504

Table 11. Lighting Options Energy Cost Summary:

Case	Electric ($)	Gas ($)	Total ($)	Savings ($)
Basecase	122,877	2,844	125,721	-
Split-Lighting-1	110,695	3,169	113,864	11,857
Daylighting-1	117,406	3,027	120,433	5,288
Daylighting-2	115,335	3,095	118,430	7,291

3.4 Equipment Power

In order to illustrate the impact of office equipment on power use as well as space conditioning loads, the following cases were simulated:

Table 12. Equipment Power Alternatives

Office Areas Power Density	*Basecase: 2 W·ft^{-2}* EquipPower-1: 1.0 W·ft^{-2} EquipPower-2: 3.0 W·ft^{-2}

Table 13. Equipment Power Alternatives Energy Use Summary:

Case	Electrical End-Use (kWh)							Gas End-Use (Therm)		
	Light	Equip	Heat	Cool	Pump	Fans	**Total**	Heat	DHW	**Total**
Basecase	296,967	339,542	2,824	223,206	2,598	126,059	991,196	6,677	1,136	7,813
EquipPower-1	296,967	182,117	3,484	201,261	2,851	99,140	785,880	8,221	1,136	9,357
EquipPower-2	296,967	496,914	2,518	215,170	2,490	158,795	1,172,854	5,967	1,136	7,103

Table 14. Equipment Power Alternatives Energy Cost Summary:

Case	Electric ($)	Gas ($)	Total ($)	Savings ($)
Basecase	122,877	2,844	125,721	-
EquipPower-1	104,190	3,406	107,596	18,125
EquipPower-2	140,599	2,585	143,184	-17,463

3.5 Combination Options

Table indicates the parametric cases that are combinations of two or more of the options outlined above.

Table 15. Combination options

Facade Combinations	GlassArea1Glazing1: GlassArea1 + Glazing-1 GlassArea1Overhang1: GlassArea1 + Overhang1
Multi-System Comb.	Combi-1: GlassArea1 + Overhang1 + Daylighting-2 Combi-2: Combi-1 + Internal Shades Combi-3: Combi-2 + RoofInsul-2 + White Roof Combi-4: Combi-3 + Split-Lighting-1

Table 16. Combination Options Energy Use Summary:

Case	Electrical End-Use (kWh)							Gas End-Use (Therm)		
	Light	Equip	Heat	Cool	Pump	Fans	**Total**	Heat	DHW	**Total**
Basecase	296,967	339,542	2,824	223,206	2,598	126,059	991,196	6,677	1,136	7,813
GlassArea1-Glazing1	296,967	339,542	2,311	224,141	2,332	128,125	993,418	5,474	1,136	6,610

Table 16. Combination Options Energy Use Summary:

Case	Electrical End-Use (kWh)							Gas End-Use (Therm)		
	Light	Equip	Heat	Cool	Pump	Fans	**Total**	Heat	DHW	**Total**
GlassArea1-Overhang1	296,967	339,542	2,596	208,573	2,471	109,680	959,829	6,133	1,136	7,269
Combi-1	244,544	339,542	2,869	201,326	2,612	100,268	891,161	6,757	1,136	7,893
Combi-2	245,031	339,542	2,886	200,425	2,622	98,961	889,467	6,796	1,136	7,932
Combi-3	245,031	339,542	2,681	195,245	2,587	94,887	879,973	6,304	1,136	7,440
Combi-4	168,451	339,542	2,972	187,036	2,709	83,892	784,602	6,990	1,136	8,126

Table 17. Combination Options Energy Cost Summary:

Case	Electric ($)	Gas ($)	Total ($)	Savings ($)
Basecase	122,877	2,844	125,721	-
GlassArea1-Glazing1	122,974	2,406	125,380	341
GlassArea1-Overhang1	117,304	2,646	119,950	5,771
Combi-1	109,919	2,873	112,792	12,929
Combi-2	109,500	2,887	112,387	13,334
Combi-3	106,988	2,708	109,696	16,025
Combi-4	99,585	2,958	102,543	23,178

3.6 HVAC

As noted earlier, the Tech Office Building has a floor-based conditioning system, which provides for temperature stratification within the space i.e. the lower part of the room is conditioned to comfort levels while the upper parts of the room is allowed to have higher temperatures. The tables below contrast the energy use of a floor-based system with a conventional ceiling-based system.

Table 18. Specification for Floor vs. Ceiling Based HVAC

Floor HVAC (Basecase)	Supply air temperature 62°F; Cooling setpoint 76°F (equivalent mixed air temperature)
Ceiling HVAC	Supply air temperature 55°F; Cooling set point 72°F

Table 19. HVAC Options Energy Use Summary:

Case	Electrical End-Use (kWh)							Gas End-Use (Therm)		
	Light	Equip	Heat	Cool	Pump	Fans	**Total**	Heat	DHW	**Total**
Floor HVAC	296,967	339,542	2,824	223,206	2,598	126,059	991,196	6,677	1,136	7,813
Ceiling HVAC	296,967	339,524	3,766	270,697	3,074	110,730	1,024,776	8,831	1,136	9,967

Table 20. HVAC Options Energy Cost Summary:

Case	Electric ($)	Gas ($)	Total ($)	Savings ($)
Basecase	122,877	2,844	125,721	-
CeilingAir	122,968	3,628	126,596	-875

Further parametric analyses revealed that the energy predictions are significantly impacted by the assumptions for equivalent mixed air temperature in a floor-based system. The tables below illustrate this.

Table 21. Floor HVAC Analysis

CoolSet75	Cooling setpoint 76°F (equivalent mixed air temperature)
CoolSet76	Cooling setpoint 76°F (equivalent mixed air temperature) This was the basecase assumption
CoolSet78	Cooling setpoint 78°F (equivalent mixed air temperature)

Table 22. Floor HVAC Analysis - Energy Use Summary:

Case	Electrical End-Use (kWh)							Gas End-Use (Therm)		
	Light	Equip	Heat	Cool	Pump	Fans	**Total**	Heat	DHW	**Total**
CoolSet75	296,967	339,542	2,874	229,965	2,632	141,886	1,013,866	6,793	1,136	7,929
CoolSet76	296,967	339,542	2,824	223,206	2,598	126,059	991,196	6,677	1,136	7,813
CoolSet78	296,967	339,524	2,733	212,269	2,541	102,843	956,895	6,463	1,136	7,599

Table 23. Floor HVAC Analysis - Energy Cost Summary:

Case	Electric ($)	Gas ($)	Total ($)	Savings ($)
CoolSet75	125,730	2,886	128,616	-
CoolSet76	122,877	2,844	125,721	2895
CoolSet78	117,151	2,766	119,917	8699

4.0 Concluding Remarks

Based on the results displayed in section 3, the following observations may be made:

- The enclosure alternatives studied do not significantly affect energy use in this building, largely because *a)* this is a core-dominated building, and *b)* more advanced options such as dynamic external and internal shading devices, operable windows, etc. were not considered.
- Lighting is a major part of the total energy use in the building and reduction of lighting loads through the use of split task ambient lighting significantly reduces power use as well as cooling loads.
- Since this is a core dominated building, daylight-based dimming does not have as significant an impact on energy as it would in a perimeter-dominated building.

- Equipment loads are a significant part of the total energy use, and efforts to reduce it will yield savings in both cooling and power costs.
- Compared to ceiling-based HVAC systems, floor-based systems have the potential to reduce cooling loads in the space, since only the lower occupied zone in the space needs to be conditioned to comfort levels. However, these reduced cooling loads are partly offset by increased fan energy, since the floor-based system requires a higher supply air temperature, which in turn requires higher air volumes. Simulations on the Tech Office Building showed that the net savings from a floor-based system are significantly impacted by the equivalent mixed air temperature (used as a cooling set point) in the space, which is determined by the floor-ceiling temperature gradient.

Finally, it should be noted that the parametric alternatives studied have many performance implications in addition to energy use. A discussion of these is beyond the scope of this technical report. Suffice it to note that overall evaluation of the design alternatives must take into account multiple performance measures, including those related to life-cycle cost, occupant comfort, and environmental impact.

5.0 References

Winkelmann, F. (1998): "How to Get a Better Underground Surface Heat Transfer Calculation in DOE-2.1E", Building Energy Simulation User News, Vol 19, No.1, Spring 1998, Lawrence Berkeley Laboratories, Berkeley, CA.