Achieving Super Efficient Construction Through An Integrated Design Approach (IDA)

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Abstract

Climate Change concerns and certain ongoing utility Demand Side Management (DSM) Programs are influencing, and to some extent, revolutionizing building design methods. While historically North American low energy prices have limited the public demand for energy-efficient buildings, there is now a tendency toward measuring building performance in terms of both \$/m² (\$/ft²) and kg eCO_2/m² (lb eCO_2/ft²) emitted into the atmosphere. The drive towards efficiency and preservation of the environment continues to foster research activities to explore the limits of energy efficiency which embrace a “back-to-basics” design philosophy. This research was started in the 1980's by designers, utilities and government agencies to demonstrate the concept of whole building design to minimize building energy use and capital costs.

This paper discusses the concept of whole building design and provides a step-by-step approach. The objective is minimization of loads, optimized selection of mechanical equipment addressing both proper sizing and equipment efficiency, commissioning and operation. The approach hinges on the integration of the architectural and mechanical designs early in the design process.

The intrinsic synergies between energy end-uses that are present when integrating the design of all end-uses is also discussed. This is illustrated by showing that opportunities to downsize air handling equipment and chillers can be derived from energy efficient lighting designs. The discussion of such opportunities includes the offsetting effects on incremental design and equipment costs that result with equipment downsizing. The ability to achieve superior efficiency with only marginal cost increases is one of the most appealing features of IDA.

The effect on energy use and reduction on equipment size is quantified through hourly simulations using DOE 2.1E. The simulation outputs are based on two hypothetical high rise office building built in San Francisco and Ottawa.

Background

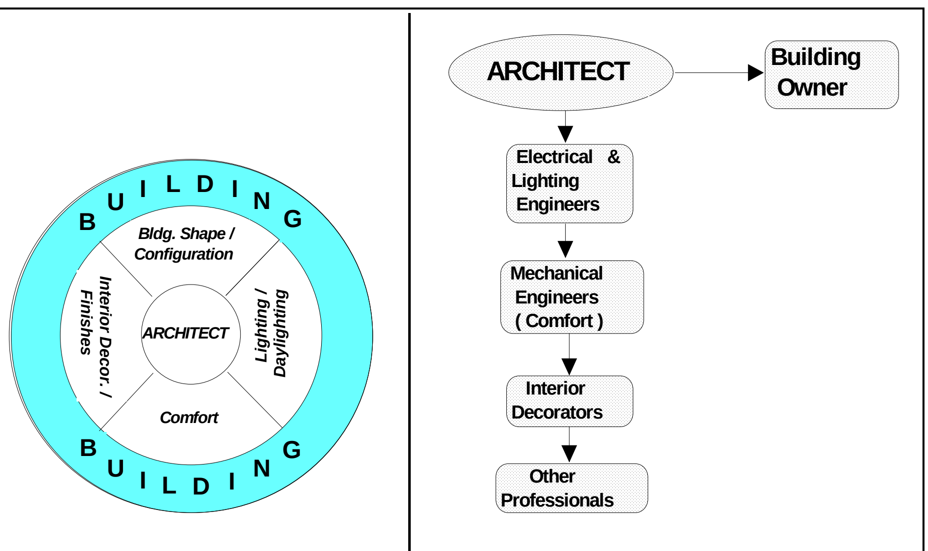
As a way of explaining the concept of whole building or integrated design, consider the efforts or design methods generally employed to produce an energy efficient design.

For the most part, such efforts tend to be “technology oriented” with no attempt to include the design process as a legitimate energy efficiency measure. The technology oriented philosophy narrows the focus with little consideration given to integration of all design aspects.
Designers normally look at each energy efficiency measure in isolation. The cost effectiveness or financial viability (i.e., payback period) of each technology is usually evaluated in isolation without consideration of the interactive effects that the technology might have on other end-uses or equipment. This automatically

preselects the technologies that are known to be cost effective. Thus a designer might suggest to a client measures such as T8 lighting systems, a facility management systems (FMS), use of VFD's for fans and pumps and a higher efficiency chiller. Other technologies such as high performance glazing or a condensing boiler would not be considered due to the perceived high premium and long payback period.

On the other hand a whole building design attempts to include the effects that a technology has on other end-uses. For example, high performance glazing such as "super double" windows with U values of 1.42 W/m².°C (0.25 Btu/hr.ft².°F) would enable reduced boiler size, pipe size, hot water flow and pump size. The reduction in HVAC equipment size would help offset some of the incremental cost of the technology and improve its financial performance. In general, all technologies and measures exhibit such interrelationships to other end-uses and technologies.

To take into account such interactions requires a higher level of effort, and performance not of only iterative calculations of the required HVAC equipment, but also increased cooperation between all design disciplines including the architect, mechanical and electrical designers, lighting designers, equipment suppliers and cost estimators.



Past Integration of all Disciplines

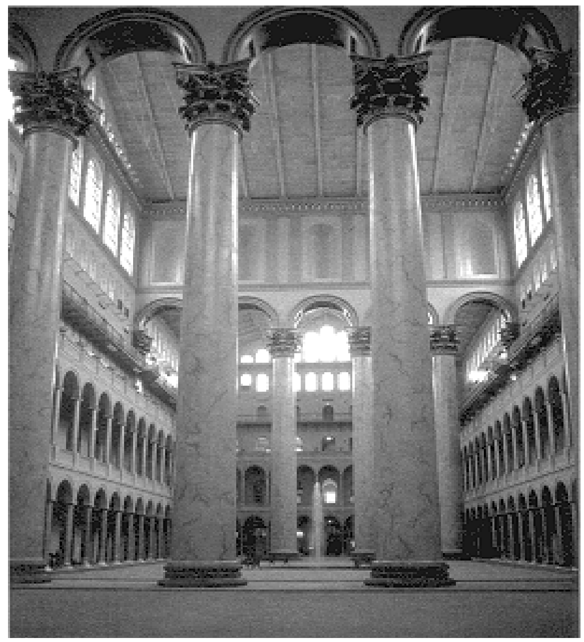
Present Day Sequential Design Process

A high cooperative effort among all disciplines however is usually not realized. Present day hierarchical interaction between professionals involved in a typical new construction project is linear as depicted in Figure 1. The architect typically acts as the overall project manager whose design imposes constraints on all other disciplines. Such sequential design works against potential cooperation, since the architectural design is essentially frozen by the time it is passed on to the mechanical consultant who has to "fit" his equipment.[i]

In the past however, the design process was based on team work and integration of the architectural and mechanical designs. The Natural History Museum in London, England and the National Building Museum (Figure 2) in Washington D.C. are excellent examples of 19th Century designs that emphasized integration of passive architectural techniques and mechanical systems to achieve low energy buildings.[ii iii] These examples are compelling evidence of what is possible and suggest that a "back to basics" approach is needed that applies the design principles used in the past coupled with design integration and optimization.

Part 1 Integrated Design Approach

- **IDA Process** (Integration & Optimization)



The concept of IDA does not require sophisticated methods or techniques. The main objectives are to emphasize integration of all disciplines and perform a high level of iterative optimization. The emphasis is placed on minimizing the loads through passive and active means plus meeting the remaining loads with the best technologies and design practices. This is shown conceptually in figure 3. The steps that are followed from architectural optimization to building commissioning are shown sequentially in Figure 4. Each design element is briefly described below.

Building Form (minimize surface/floor ratio): The building form with the smallest surface to floor area ratio is a cube. As a result, large footprint low rise buildings will exhibit higher heating energy use per unit floor area compared to a more compact cube shape.

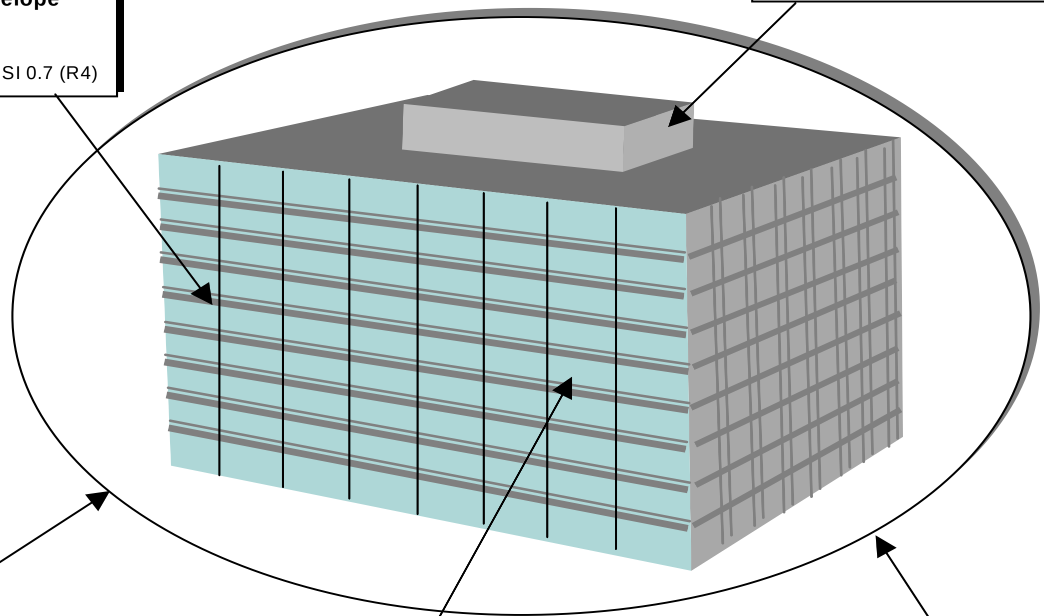
Building Site (orientation): Whenever possible buildings should be oriented with the long axis running in an east to west direction to minimize exposure to these orientations.

Building Envelope (optimum thermal characteristics): Use insulation levels as high as possible for walls and roofs as well as high performance glazing. High performance windows displaying whole unit thermal performance levels of RSI 0.70 (R4) are available. Windows are the weakest envelope component from a thermal standpoint and as a result it is important to select the best available window technology. Although high performance glazing displays very high incremental costs, the cost can be offset through substantial downsizing of the heating plant and perimeter radiation systems. In some instances, total elimination of the perimeter radiation system is possible, even in northern climates.[iv] Glazing selection and

Anatomy of a Super Efficient Building

HVAC Equipment
> reduced air flows due to smaller internal loads
> reduced friction losses from LFV/HCV coils (2" wg.)
>high efficiency AHU fans (backward curved centrifugals)
> high efficiency cooling plant (0.5 kW/Ton
>high efficiency condenser fans (axial fans)
>high efficiency heating plant (condensing boiler)

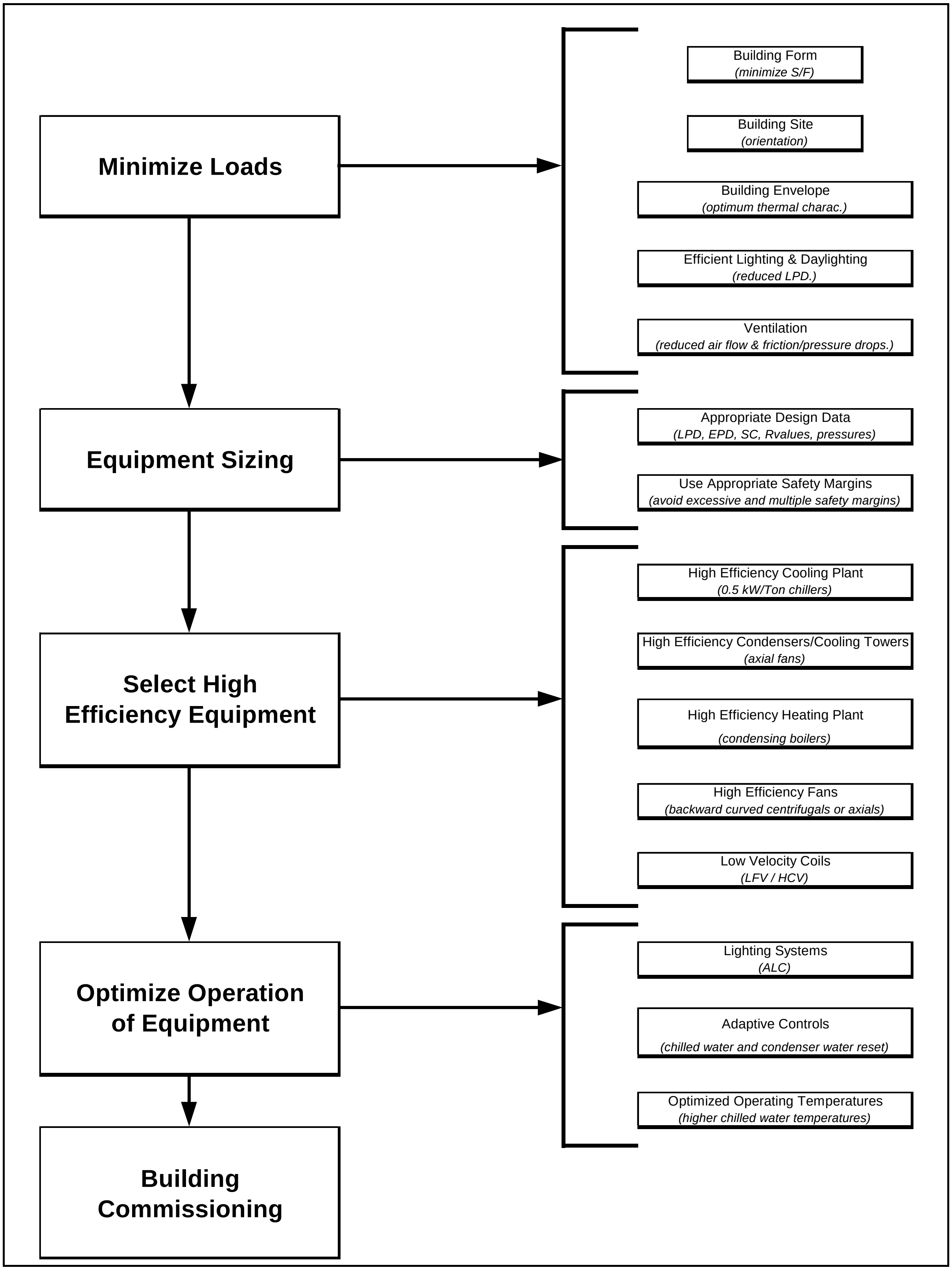
Building Design & Envelope
> minimize surface area
> orientation
> high performance glazing RSI 0.7 (R4)



Design
> appropriate design data
> appropriate safety margins

Lighting
> low ambient light levels (30 fc)
> perimter daylighting
> overall LPD of 0.7 W/ft²

Optimize Operation
> adaptive controls
> equipment runtime


Minimize Loads
Building Form
(minimize S/F)
Building Site
(orientation)
Building Envelope
(optimum thermal charac.)
Efficient Lighting & Daylighting
(reduced LPD.)
Ventilation
(reduced air flow & friction/pressure drops.)
Equipment Sizing
Appropriate Design Data
(LPD, EPD, SC, Rvalues, pressures)
Use Appropriate Safety Margins
(avoid excessive and multiple safety margins)
Select High Efficiency Equipment
High Efficiency Cooling Plant
(0.5 kW/Ton chillers)
High Efficiency Condensers/Cooling Towers
(axial fans)
High Efficiency Heating Plant
(condensing boilers)
High Efficiency Fans
(backward curved centrifugals or axials)
Low Velocity Coils
(LFV / HCV)
Optimize Operation of Equipment
Lighting Systems
(ALC)
Adaptive Controls
(chilled water and condenser water reset)
Optimized Operating Temperatures
(higher chilled water temperatures)
Building Commissioning

location should also consider maximization of daylighting and minimization of solar heat gain. Glazing tints should be selected to match the geographic location. As an example, reflective glazing with low shading coefficients should be avoided in northern climates.

Efficient Lighting & Daylighting (reduced LPD): Indoor lighting should emphasize quality, good design and integration of natural and artificial light sources. Proper application and integration of these elements will create lighting designs with very low lighting power densities (LPD). Low ambient light levels of 300 Lux (30 fc) should be specified, supplemented with user controlled task lighting. These light levels are more appropriate for office environments with high computer use.[v] Use of available daylighting for the building perimeter should also be part of the overall design by considering luminaire layout, lighting circuit layout and lighting control strategy.[vi] Architectural features such as lightshelves or interior design techniques such as a sloped ceiling should also be included as part of the design strategy. These features not only help to inject/re-direct natural light further into the building interior, but also improve the overall lighting quality by minimizing glare.

A low ambient light level design with active perimeter lighting control can produce LPD's in the range of 5.5 to 8 W/m² (0.5 to 0.75 W/ft²). It must also be noted that an efficient lighting design induces additional energy savings in cooling and fan energy. The reduced connected load and internal heat gain will achieve cooling energy savings equal to the lighting electricity savings divided by the cooling plant COP. Buildings with VAV systems will experience additional fan energy savings from the reduced internal heat gain.

Table 1
Cooling Load Comparison Between Current Practice and Optimum Design

Load	**Current Practice**		**Optimum Design**	
Lights	16.1 W/m²	1.50 W/ft²	12.9 W/m²	1.20 W/ft²
Plug Loads	16.1 W/m²	1.50 W/ft²	8.6 W/m²	0.80 W/ft²
People	9.0 W/m²	0.84 W/ft²	5.1 W/m²	0.47 W/ft²
Fresh Air	18.3 W/m²	1.70 W/ft²	18.3 W/m²	1.70 W/ft²
Sol. & T.	20.0 W/m²	1.86 W/ft²	20.0 W/m²	1.86 W/ft²
Total	79.5 W/m²	7.40 W/ft²	64.9 W/m²	6.03 W/ft²
20% Safety	95.5 W/m²	8.88 W/ft²	77.9 W/m²	7.24 W/ft²
Density		396 ft²/Ton		485 ft²/Ton
	· Lights are based on T-8 lighting designed to 4.5 m²/luminaire (48 ft²/luminaire). Lighting catalogues suggest 1.2 W/ft², but designer carries the value shown · People load is determined as follows: (400 Btu/person) (1 person/140 ft²) (1W/3.413 Btu) · Fresh air was determine assuming 20 CFM/person, occupant density of 140 ft²/person and an enthalpy difference between outside air and room air of 10.8 Btu/lbm. · Solar heat gain plus transmission load was assumed to represent 25% of the total load.		· Lights are based on T-8 lighting designed to 4.5 m²/luminaire (48 ft²/luminaire). A value of 1.2 W/ft² suggested in the Lighting Catalogue is carried. · A value of 0.8 W/ft² is used for plug loads based on end-use metered data. .· People load is determined as follows: (400 Btu/person) (1 person/250 ft²) (1W/3.413 Btu)The value of 250 ft²/person is based on end-use surveys of actual occupant densities.	

Ventilation (reduced air flow & pressure drops): The minimization of loads through an improved thermal envelope and reduced lighting loads will help reduce the total air flow required to meet the peak cooling load at design conditions. Designers should take into account this synergistic effect to achieve fan energy savings as well as equipment costs savings. Further savings in fan energy can be achieved by minimizing the ventilation system friction losses with low pressure components such as low face velocity coils (see Low Velocity Coils below).

Appropriate Design Inputs & Safety Margins (LPD, EPD, SC, Rvalues, pressures): Heating and cooling plants need to be sized as close as possible to the actual loads avoiding excessive equipment oversizing. Large oversizing causes equipment to operate at low part loads and poor seasonal efficiencies. Appropriate input data that reflect the design intent or measures to be specified should be used to size heating and cooling plants. As an example, a value of 12.9 W/m² (1.2 W/ft²) should be used for the LPD if the general lighting in an office is expected to be based on T-8 lighting designed on an 6' x 8' grid pattern displaying a density of 4.5 m²/luminaire (48 ft²/luminaire). It is however very common for designers to carry what they might consider “more appropriate” values. A designer might carry an LPD value of 1.5 W/ft² or higher for the purposes of calculating the cooling plant size. Plug loads are another load that is often overestimated.

Table 1 illustrates the system wide impact of using overstated values on the overall cooling load. The example assumes a new office where T-8 lighting is specified at 4.5 m²/luminaire (48 ft²/luminaire). In the typical design practice, LPD and EPD values of 16.1 W/m² (1.5 W/ft²) are carried. As shown, the load based on typical design values is 79.5 W/m² (7.4 W/ft²) or 475 ft²/Ton. A 20% safety margin increases this total to 95.5 W/m² (8.9 W/ft²) or 396 ft²/Ton. In reality, the cooling plant has a 47% (95.5/64.9) safety margin due to the multiple margins carried for lighting, plug loads and internal loads from people. In comparison the load under good practice is 19% lower.

High Efficiency HVAC Equipment: Select the HVAC equipment with the highest available efficiency to meet the heating, cooling and ventilation loads. It is important to note that although the high efficiency equipment will display an incremental cost over standard efficiency, the cost increment is offset by a reduction in equipment size. As shown in Table 2, a 400 Ton high efficiency chiller with a performance of 0.5 kW/Ton and a cost of $350/Ton selected for a 18,600 m² (200,000 ft²) building might cost $10,000 less than a 500 Ton 0.6 kW/Ton unit. This would be possible due to a reduction in the cooling load resulting from high efficiency lighting and a better thermal envelope. The best HVAC equipment would consist of:

Table 2
Comparison of Chiller Cost for a 200,000 ft² Building

	Base Case	Efficient Building
Cooling Density	400 ft²/Ton	500 ft²/Ton
Chiller Size	500 Tons	400 Tons
Cost/Ton	$300/Ton	$350/Ton
Total Cost	$150,000	$140,000

· High efficiency centrifugal chillers with performance levels of 0.48 kW/Ton;

· Cooling towers equipped with axial fans that exhibit fan loads of 0.05 kW/ton compared to 0.1 kW/ton for towers with centrifugal fans;

· Condensing boilers capable of operating at a seasonal efficiency of 90% available in large capacities over 290 kW (1,000,000Btu);

· Backward curved centrifugal fans with mechanical efficiencies of 80% compared to traditionally specified forward curved centrifugal fans with mechanical efficiencies of 60%.

· Low Face Velocity/High Coolant Velocity (LFV/HCV) coils as an alternative to traditional high face velocity coils.

Optimized Operation of Equipment: It is important to ensure that adaptive/optimum control strategies are specified for the equipment operation. Specifically, equipment should only operate at design conditions as dictated by weather. Thus chilled water temperatures of 7 °C (45 °F) should only be provided at design summer conditions. Adaptive control strategies that provide condenser and chilled water reset can be used to optimize the operation of chiller plants. Similar adaptive controls can be used to optimize the hot water reset schedule and establish the highest water temperature required to satisfy the heating load at design conditions. Finally, equipment should also have strict operating schedules to ensure that it only operates when needed.

Building Commissioning: Building Commissioning should be built into the overall design by including a “Building Commissioning Agent” that is responsible to undertake a thorough “Shake-Down” of the HVAC and electrical systems.

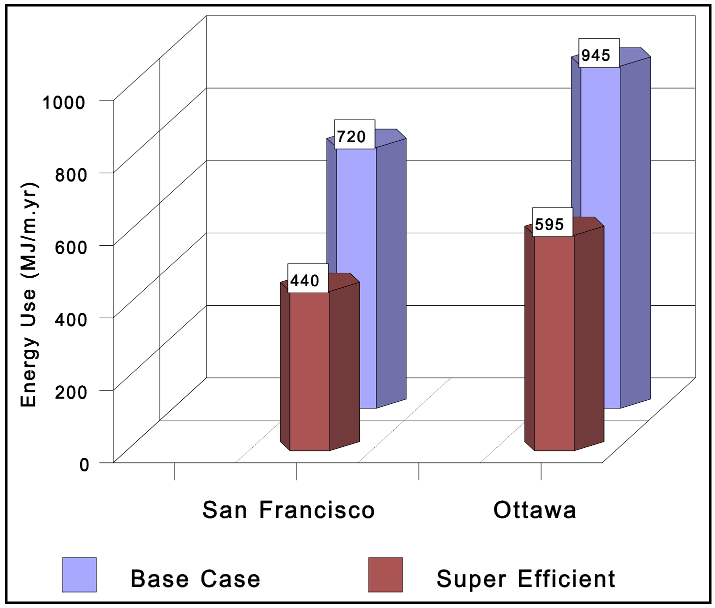
- **Synergies** (Offsetting Incremental Costs & Compounding Energy Savings)

Two interesting phenomena occur when applying a whole building design process. The first is that the minimization of heating and cooling loads also minimizes the size of HVAC equipment. Therefore, although premium equipment and components (higher levels of insulation, high performance windows and premium dimming ballasts) are required to minimize the loads, the smaller HVAC equipment displays lower equipment costs. These cost savings help offset some of the incremental costs of the premium equipment and higher performance components.[vii] The overall result is often a very small increment in total construction costs. [viii][ix]

The reduction in equipment applies to a large number of HVAC and electrical components including:

· reduced boiler size due to better thermal envelope;
· reduced hot water piping size and pump due to better thermal envelope
· reduced chiller size due to a better thermal envelope and reduced internal heat gains from lights;
· reduced condenser/cooling tower size from smaller chiller;
· reduced size of air handling equipment from reduced internal heat gains and required air flows;
· reduced costs of MCC’s from smaller HVAC equipment due to smaller disconnects, smaller cabling;
· reduced cost of lighting panels due to lower LPD values;
· reduced cost of transformers due to reduced electrical loads;

The second phenomena is a cascading or compounding effect of the energy savings, where the energy savings of one end-use induces additional energy savings from other end-uses. The most obvious example is the use of efficient lighting. The direct energy savings are the electrical energy savings from a lower LPD. Additional savings in cooling and fan energy are achieved from the lower internal heat gains. Some studies have shown that 65% of the energy savings typically realized are direct savings while the remaining 35% are induced savings.



- **Quantifying the Effects of IDA** (Energy Analysis of a Hypothetical New Commercial Building)

The following hypothetical low rise office building quantifies the effect of applying a whole building design approach. The building is a 4 storey large footprint office building with a floor area of approximately 9,300 m² (100,000 ft²) typical of buildings in a high technology office park. The simulations were done for Ontario (Silicon Valley North) and San Francisco's Silicon Valley. In each location a basecase and a super efficient design were modelled .

Both basecase buildings were configured to current designs practices. In San Francisco the building conforms to California Title 24 while the Ottawa office is assumed to meet Canada's Model National Energy Code for Buildings (MNECB). The super efficient design incorporates all the design components and energy efficiency measures described.

The simulations were performed using VisualDOE running the DOE 2.1E engine. Figure 5 shows a comparison of the whole building energy use index. (EUI). Energy savings of 39 and 38% were achieved for San Francisco and Ottawa respectively. Savings were achieved in all end-uses. Reduction in equipment capacities was also achieved for all HVAC equipment including the hesting and cooling plant and air handling units.

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