Cost Effective High Performance Buildings for Reduced GHG Emissions in New and Existing Commercial Construction

Giuliano Todesco, CET
Jacques Whitford

ABSTRACT *Approximately 15 years have passed since the concept of integrated building design (IBD) or integrated design process (IDP) was conceived and articulated by individuals such as Dr. W. Braun from Gerlinger, Amory Lovins and William McDonough. Demonstration programs were developed in the late 1980s and 1990s such as the Energy Conscious Construction Program (~1987) from Northeast Utilities, PG&E ACT² (Advanced Customer Technology Test for Maximum Energy Savings), and Canada's C-2000 Advanced Commercial Construction Program to determine the energy and emissions reductions that could be achieved through application of IBD and IDP.*

The goal of the professionals involved in the early conceptualization of the integrated design philosophy was to determine how the design process could improve the performance of buildings beyond what was being achieved through simple introduction of energy efficiency measures.

The above programs did not fully recognize that the integrated design process did not require advanced technologies, or that IBD/IDP permitted the design of high performance construction at zero or minimal incremental costs due to downsizing of HVAC equipment and electrical components.

Still less intuitive is the fact that the incremental costs decrease as the improvement in performance increases. Ultra low energy designs such as Displacement Ventilation (DV) or Dedicated Outdoor Air System (DOAS) designs and hybrid ventilation designs have been shown to exhibit zero or lower first costs. Amory Lovins referred to this as "tunnelling through the cost barrier".

IBD/IDP has been amply demonstrated to be a win-win since this design approach delivers buildings with lower operating costs, increased occupant comfort at minimal or zero incremental costs, and yet after 15 years, high performance designs are still not standard design practice.

History of the Modern Day IBD/IDP

Some of the early practitioners of the modern day "renaissance of whole building designs" include Dr. W. Braun from Geillinger (Switzerland) who developed the high insulation multi-layer glazing systems (Visionwall Technology) as part of his concept of high performance buildings via extremely well insulated building envelopes

Another example is the headquarters of the NMB Bank in Amsterdam completed in 1987.[1] The head of the design team Dr. Tie Liebe had wanted, at the project onset, an "organic" building that integrated art, natural materials, sunlight, plants, energy conservation, low noise and water. The result was a building with overall energy intensity of 512 MJ/m².yr that, even for today standards, ranks among some of the best low energy designs.

In 1987 Northeast Utilities produced a guidebook to encourage energy efficient design [2] with the objective to prove that it is possible to:

"Build an energy efficient building without paying dearly for it in initial construction costs by placing energy efficiency on the agenda early in the design process".

Amory Lovins discussed the subject in the early 1990s and stated the need for designers to look at the building as a whole rather than the modern day practice of sequential design that came about with the introduction of air conditioning and ventilation systems. He repeatedly stated the need to design buildings "Right" by going back to basics and re-introduce the design process that had been used in the past.[3] [4] This past September [5] he stated that:

"A design approach that optimizes the whole building is not rocket science; it's just good Victorian engineering rediscovered"

In the mid 1990s ACT² from Pacific Gas and Electric (PG&E) and Canada's C-2000 Program were pursuing demonstration projects to develop high performance buildings that achieve the largest possible energy savings. The C-2000 programs objectives for example, were to promote the adoption of advanced technologies and management practices in commercial buildings to achieve a 50% energy savings over ASHRAE Standard 90.1.

In the late 1990s The Canadian Federal Government launched the Commercial Building Incentive Program (CBIP), and more recently, Canadian electric and gas utilities have initiated new construction programs that operate as companions to CBIP and leverage the success of the program. These programs have in common the stringent requirements for hourly modelling, the exploration of design alternatives via better collaboration and cooperation between architect and M&E designers.

Today, the proliferation of integrated designs and high performance construction is accelerating as evidenced by:

- The editor of the ASHRAE Journal, Fred Turner stated in the April 2005 editorial that: "Sustainable design is probably the biggest market opportunity in the mechanical industry and LEED is now used in 5% of new construction in the U.S. with more than 10,000 people having passed the LEED accredited professional exam".
- The drafting by ASHRAE/IESNA and AIA in 2003 for a proposal to develop the Next Generation Advanced Design Guidance and Criteria for Standard 90.1 with a 50% energy savings beyond 90.1-2001.
- The exponential growth in LEED certified and registered buildings between 2001 and 2005 as shown in the table below.

Growth in USGBC LEED Projects			
	2001	2005	Growth
Certified Projects	13	198	1,423%
Registered Projects	180	1867	937%

Despite the great strides and significant acceleration in popularity, integrated designs are not yet standard design practice. There are numerous barriers including the perception of higher initial construction cost, limited information that describes the degree of equipment downsizing, how cost trade-offs are achieved, and finally, lack of simple, well-written documentation on the concept of integrated design.

A Return to Design Basics

Climate was the major determinant of building design and form before the advent of mechanical HVAC equipment. Comfort was achieved through passive means and features built into the architectural design.[6]

Buildings were protected from the inclement weather or designed to take advantage of it through orientation and strategic placement of entrances and windows. In damp and windy locations such as England, for example, church entrances were usually from side porches facing south to protect from wind and rain, while cathedrals in France had the typical west facing entrance leading directly into the nave and aisles. [7]

Similarly, the use of natural lighting was planned into the building design. Architects resorted to a number of design features such as atriums, clerestories, and, more recently, the lightshelve, or simply narrow building designs to bring natural lighting into building interiors. The glazed clerestory, first used by the Romans circa 200 A.D., was a common design feature to introduce natural lighting to the interior of churches in Europe. Buildings were also designed with a narrow footprint to ensure that natural lighting reached everywhere inside the building. Figures 1 and 2 are examples of pre-20th Century construction designed to bring natural lighting into the building interiors. Figure 1 shows the atrium of the National Building Museum in Washington D.C. completed circa 1887. [8] This building was originally known as the Pension Building and was built to house 1,500 clerks responsible for distributing pension cheques to the Union veterans of the Civil War. The architect, Col. Montgomery C. Meigs, designed the building with a vision of:

"No dark corners and no ill-ventilated spaces"

The large interior atrium, known as the "Great Hall" provided natural lighting to the interior offices, while conventional windows on the building exterior provided natural lighting to the perimeter offices ensuring complete coverage of the entire space. The building also relied on the atrium to passively ventilate the offices. Fresh air entered the space beneath the window sills and flowed through the office space into the atrium and later exhausted through the roof.

Pre 20th Century industrial buildings were also designed to bring natural lighting into the building. Figure 2 shows the interior of the shop floor of the 19th Century British Greenhouse Manufacturer, Bolton & Paul Ltd.[9] As shown, the glass roof provides natural light to the entire shop floor as well as work areas on the second and third floors.

Designers also applied a miriad of techniques to keep buildings comfortable in the summer ranging from the very mundane such as finishing the building exterior in light colors to more sophisticated techniques to induce natural ventilation using thermal stacks such as the Natural History Museum in London, England (see Figure 3).[10] This building is an excellent example of 19th Century large scale ventilation system that is integral to the architectural design. Research work undertaken in 1998 revealed a sophisticated convective ventilation system that relied on fresh air inlets at ground level and six towers for exhausting the air.

In the original construction documents the towers were described as "Vent Towers" designed with a central boiler exhaust pipe with space surrounding the exhaust pipe used to exhaust air from the museum space.

The above three examples clearly demonstrate how buildings built before the 20th Century were designed with a whole building perspective that more seamlessly integrated architecture, function, comfort and efficiency.

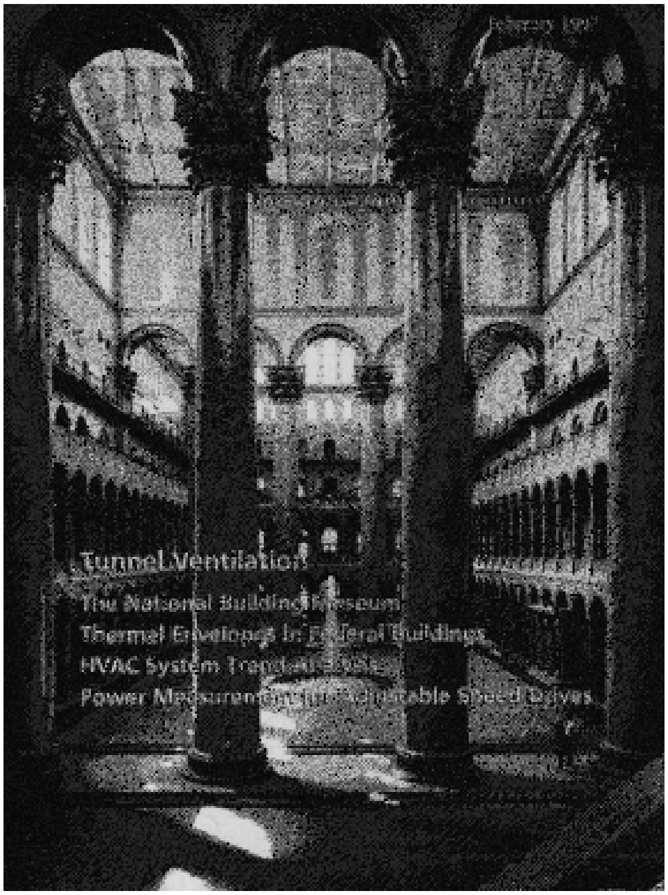


Figure 1: The National Building Museum in Washington D.C. was completed circa in 1887. Reprinted with permission from the ASHRAE Journal

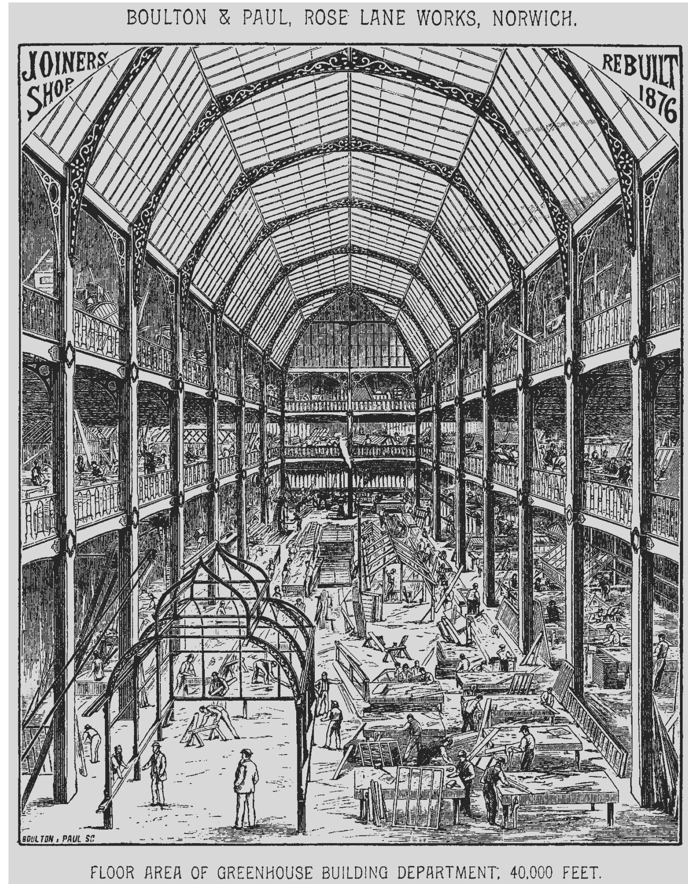


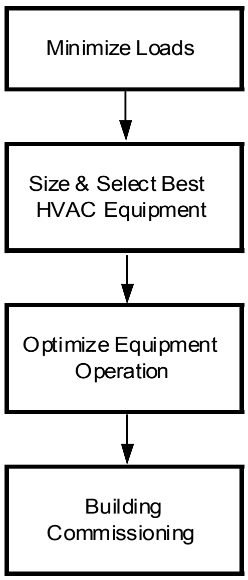
Figure 2: The manufacturing plant of the 19th Century British Greenhouse Manufacturer, Bolton & Paul Ltd. Reprinted with permission from Algrove Publishing Limited.

Figure 3: The Natural History Museum in London England completed in 1881 relied on six towers to passively ventilate the building. The four front towers are shown in this graphic. Reprinted with permission from the ASHRAE Journal.

Definition of IBD/IDP

Application of IBD/IDP is not complex and does not need sophisticated technologies. The process requires integration of the architectural design with the lighting and mechanical designs. The main goal is to optimize the design by minimizing loads and equipment size, as well as selecting the equipment with the highest available efficiency, and finally perform proper building commissioning to ensure that equipment operates as originally intended.[11] This approach is depicted in the flow chart shown below.

IBD / IDP Process



It can be inferred from the above approach that the focus of IBD/IDP is on quality designs rather than least cost designs. From an architectural perspective, the goal to minimize the loads requires a highly insulated envelope including high performance glazing systems. This applies to both heating and cooling dominated climates. Other architectural features that can provide further functionality and comfort such as increased use of natural lighting are equally important.

The HVAC and lighting designers have similar objectives to also minimize the size of the equipment through the use of good design principles avoiding excessive equipment oversizing and selection of most efficient components.

The option to consider quality and premium features in favour of a least cost design is possible due to two major benefits of integrated designs. Larger energy savings can be achieved from a whole building design compared to the savings that can be achieved from individual EEMs. The larger energy savings are achieved because the design optimization of one component induces energy savings in other components. An example would be an efficient lighting design that results in a very low internal heat gain which produces additional cooling, fan and pump energy savings.

The ability of integrated designs to incur only marginally higher incremental costs represents the second benefit. Properly applied IBD/IDP will result in smaller HVAC and electrical components, and lower first costs that can be used to offset the incremental cost of EE components.

While interaction between disciplines and a higher degree of communication is important, quality of the design, quality of the technologies and thorough documentation of the performance of components are the principles behind high performance integrated designs. The main focus of the increased cooperation and communication is related to better documentation and use of correct data assumptions by all the design disciplines. An example of this is the need by the architect to define and document the proper performance characteristics of the glazing system and provide this information to the mechanical designer to ensure that the HVAC equipment sizing is based on the real thermal performance of the glazing system as opposed to assumed values. It is typical for the window specifications to define the windows as having a low e-film, but seldom will the information include the emissivity value of the film and the overall window thermal performance. Similarly the mechanical designer needs to use actual LPD values based on the actual design and performance of the lighting system rather than typical LPD values customarily assumed.

In summary, load minimization through good architectural and lighting designs plus use of high performance equipment constitutes the essence of the integrated design process. These simple concepts that focus on the "How To" are significantly less convoluted than available documentation.

Energy Savings and Equipment Size Reduction

In the last 10 years, the new construction programs from gas and electric utilities designed to promote the IBD/IDP concept have amply demonstrated reductions in energy use of 25% to 50% relative to conventional design practices.[12,13]

Less documented is the magnitude of equipment size reduction that results from the minimization of loads, but can be significant as shown in Table 4. Energy savings relative to the total building energy use and reduction in equipment size are shown for four different levels of performance. The results are based on energy simulations of a hypothetical 18,600 m^2 (200,000 ft^2) large office in a heating dominated climate. The examples are based on progressively better performance levels starting with a moderate performance improvement, continuing to a displacement ventilation (DV) or Dedicated Outdoor Air Systems (DOAS) design that achieves a 70% reduction in the size of the air handling equipment due to the DV/ODAS system sized for fresh air only.

Table 4: Comparison of Energy Savings and Equipment Size Reduction					
	Improvement Level	**Energy Savings Relative to a Base Case**	**Equipment Size Reduction**		
			Heating Plant	**Cooling Plant**	**Air Handling Equipment**
Case 1	Small improvement in thermal performance, LPD 7.5 W/m², Boiler E_t 88%	27%	20%	25%	20%
Case 2	Better thermal performance including HIT windows, LPD 7.5 W/m², daylighting, Condensing boiler E_t 92%	35%	25%	30%	25%
Case 3	Case 2.+ better thermal performance	37%	27%	32%	40%
Case 4	Case 3 plus DOAS/DV + heat recovery	44%	34%	35%	70%

As shown, the calculated equipment size reduction is shown to be between 5% to 10% points lower than the energy savings. As an example, the 35% energy savings performance level shows a 25 to 30% equipment size reduction. Case 4 is an exception however where the air handling unit shows a reduction that is almost double the calculated energy savings. This is due to the DV/ODAS system which has an air flow of approximately 1.52 L/s.m² (0.3CFM/ft²) compared to the conventional air flow rates of 5.08 L/s.m² (1.0 CFM/ft²).

While Table 4 shows the reduction of the largest HVAC components, other components are also affected. Smaller HVAC and lighting loads also help reduce the size of pumps, the size of piping and, for heating dominated climates, the capacity of perimeter heating equipment. In addition, the smaller equipment also reduces the size of electrical components such as electrical panels, motor starters and transformers (see Table 5).

Table 5: Components that Can be Downsized	
Equipment and Component Affected	
Reduced Heating Load	-Smaller Boiler -Smaller Circulating Pump -Smaller Hot Water Piping -Smaller Perimeter Heating Equipment
Reduced Cooling Load	-Smaller A/C Equipment -Smaller Air Handling Equipment -Smaller Circulating Pump -Smaller Chilled Water Piping
Electrical Components	-Smaller Electrical Panels -Smaller Motor Starters -Smaller Transformers

Minimum or Zero Construction Costs Due to Cost Trade-Offs

The equipment size reduction already discussed helps to reduce the HVAC equipment first costs, which in turn can help offset some of the incremental costs of better components.

The cost savings from the smaller HVAC equipment can be significant as suggested by the small and zero incremental costs typically cited for IBD/IDP projects. There is however, little documentation and technical resources from actual projects that illustrate the incremental costs of the EE components, cost savings of the smaller HVAC equipment and the resulting net incremental costs.

Table 6 below presents a cost analysis of a hypothetical building based on average construction costs. [14] The cost savings from the equipment size reduction are based on the same energy simulation presented in the previous sections. Incremental costs can be cut by 50% for a moderate performance design improvement as shown in Case 1.[15] The premium of the EE components is estimated to be approximately $302,500, but thanks to savings of $150,500 from the smaller HVAC components results in a net overall construction cost increment of $152,000. As the level of performance increases, the incremental costs decrease such that the incremental cost of $1,732,500 shown for Case 4 is reduced by 82%, resulting in a net construction cost increment of $319,375. This illustrates the concept of “tunnelling through the cost barrier”, where the cost trade-offs have successfully offset most of the incremental costs of the highest cost option.

Application to Existing and New Construction

It is important to recognize that while to date, IBD/IDP has focused on new construction, the approach applies equally to existing buildings that are facing or undergoing a complete building renovation. As much as 50% of the existing commercial buildings in North America were built between 1960 and 1980. These buildings are currently facing the need to replace the building exterior including glazing systems plus a significant number of major HVAC components have reached the end of their expected lives, including chillers, boilers, and coils in air handling units. Further evidence of the need for replacement of HVAC components is the fact that at the end of 2004, there were still approximately 43% of large tonnage chillers in North America that still use chlorofluorocarbon (CFC) refrigerants.[16] These chillers serve an estimated 300 to 450 million m² of commercial space, which will have to be renovated. The opportunity also exists to replace the T12 fluorescent lighting systems in 70% of these buildings, replace the original boilers with condensing boilers and install modern DV/DOAS air handling systems.

Table 6: Comparison of Cost Savings Incremental Costs and Net Project Costs			
	Case 1 **27% Energy Savings**	**Case 2** **35% Energy Savings**	**Case 4** **44% Energy Savings**
Cost Savings from Smaller HVAC Equipment and Other Components			
Cooling plant	$42,500	$53,125	$53,125
Cooling tower	$14,000	$21,000	$21,000
Air handling equipment	$75,000	$75,000	$297,500
Heating plant	$15,000	$15,000	$21,000
Circulating pumps	$4,000	$6,000	$6,000
Perimeter heating equipment	--	$27,600	$38,500
Elimination of VAV boxes	--	--	$856,000
Other (elimination of drop ceiling)	--	--	$120,000
Total Cost Savings	**$150,500**	**$197,725**	**$1,413,125**
Incremental Costs from EE Components and Other			
Insulation	$45,000	$45,000	$45,000
High performance glazing	$175,000	$420,000	$525,000
Lighting system	$30,000	$60,000	$60,000
HE Chiller	$22,500	$22,500	$22,500
HE Boiler	$30,000	$120,000	$120,000
Radiant Cooling Panels	--	--	$960,000
Total Cost Increment	**$302,500**	**$667,500**	**$1,732,500**
Net Construction Cost Increment	**$152,000**	**$469,775**	**$319,375**

Conclusion

This paper has described some of the reasons why IBD/IDP are not yet standard design practice for new commercial construction. In addition, this paper has presented a simplified definition of IBD/IDP, and provided analytical information on the degree of equipment downsizing that is possible including the cost trade-offs that occur and how they impact the net incremental construction costs of high performance designs.

Construction of high performance designs using an integrated approach is not complex and does not require sophisticated technologies. It is a "back-to-basics" approach that focuses on quality designs and quality engineering.

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[15] Todesco, G. 2004. “ Integrated Designs..” op. cit supra.
[16] Todesco, G. 2005. “Chillers + Lighting + TES: Why CFC Chiller Replacement Can Be Energy-Savings Windfall” ASHRAE Journal. Atlanta, Georgia: ASHRAE. Vol. 47, No. 10, October, pp. 18-27.