Part I

Adapting to a New Reality—Strategies for Building Energy Design in a Changing Climate

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ABSTRACT

Building energy design is traditionally performed using retrogressive data sets (e.g., the past 30 years of weather data). The implied presumption has always been that this data will cycle back and forth around relatively static baseline averages. With increasing evidence that some level of climate change may be occurring, it is natural for building owners, developers, designers, and managers to question whether and to what extent these fundamental climate assumptions may be altered in future years. Depending on a building's locality, these could take the form of increasing or decreasing trends in seasonal average temperatures, daily maximum and minimum temperatures, relative humidity, barometric pressure, wind speed and direction, cloud cover, and total precipitation. These assumptions are crucial, because a typical building must remain habitable for 30-50 years (or longer) and provide its owner(s) with the maximum possible return on a sizeable capital investment.

This article will demonstrate how building owners and developers can employ intelligent strategies to maximize energy efficiency while concurrently meeting building energy requirements and retaining significant flexibility to cope with potential variations in local climate. Data from existing buildings that currently exhibit outstanding energy performance (e.g., net zero energy buildings, Leadership in Energy and Environmental Design [LEED®] Gold- and Platinum-certified buildings, buildings with ENERGY STAR® ratings above 90) will be utilized to identify energy efficiency and renewable energy production tech-

nologies that can further improve energy performance and reduce risk. This article will demonstrate that, by implementing these types of adaptive strategies, the building sector can more nimbly respond to potential climate variations.

INTRODUCTION

Building energy design is traditionally performed using retrogressive data sets (e.g., the past 30 years of weather data). The implied presumption has always been that this data will cycle back and forth around relatively static baseline averages. With increasing evidence that some level of climate change may be occurring, it is natural for building owners, developers, designers, and managers to question whether and to what extent these fundamental climate assumptions may be altered in future years. Depending on a building's locality, these could take the form of increasing or decreasing trends in seasonal average temperatures, daily maximum and minimum temperatures, relative humidity, barometric pressure, wind speed and direction, cloud cover, and total precipitation. These assumptions are crucial, because a typical building must remain habitable for 30-50 years (or longer) and provide its owner(s) with the maximum possible return on a sizeable capital investment.

This article will demonstrate how building owners and developers can employ intelligent strategies to maximize energy efficiency while concurrently meeting building energy requirements and retaining significant flexibility to cope with potential variations in local climate. An example might be deciding when to modularize equipment and systems (and to what extent). By maximizing flexibility, the risks associated with building capital investment and operating costs can be more effectively managed, even in cases where the building's use and configuration change over time. Data from existing buildings that currently exhibit outstanding energy performance (e.g., net zero energy buildings [NZEBs], Leadership in Energy and Environmental Design [LEED®] Gold- and Platinum-certified buildings, buildings with ENERGY STAR® ratings above 90) will be utilized to identify energy efficiency and renewable energy technologies that can further improve energy performance and reduce risk. The analysis will be conducted with the following four objectives:

(1) Evaluate the possible variations to climate design data, based on the available literature, and describe the uncertainties that accompany those projections.

(2) Assess the effects of the range of potentially variable design conditions on a variety of common building types and uses (e.g., offices, schools, multi-family residences) and determine whether these effects will significantly alter design assumptions and parameters.

(3) Analyze the benefits and costs of adaptive technologies and strategies that building owners and managers can utilize to address any negative impacts of climate change on building energy performance and capital investment risk.

(4) Describe five fundamental principles (FPs) and associated measures of effectiveness that can be used to guide building designers in making proactive, intelligent decisions throughout the design and construction process. (Two FPs are presented in this article, with three to follow in a subsequent article.)

It will be demonstrated that, by implementing these types of adaptive strategies, the building sector can begin to migrate from the traditional model of buildings as monolithic, largely inflexible systems to models which can more nimbly respond to potential climate variations.

BACKGROUND

It is not the purpose of this article to outline or summarize climate change projections, or to explain or debate the theory of climate change. Suffice it to say, the concept of climate change has caused a level of extraordinary concern among many major governmental and non-governmental entities, which prompts evaluations of the type contained herein. On December 15, 2009, administrator Lisa Jackson of the United States Environmental Protection Agency (EPA) issued an Endangerment and Cause or Contribute Finding for Greenhouse Gases under §202(a) of the Clean Air Act, stating that, "greenhouse gases (GHGs) in the atmosphere may reasonably be anticipated both to endanger public health and … public welfare … within the United States" and that "impacts in other world regions can in turn adversely affect the United States …"[1]. On January 29, 2010, President Barack Obama announced a mandatory goal of reducing Source 1 and 2 GHG emissions from federal government operations by 28% overall by the Year 2020 [2]. (Source 1 and 2 GHG emissions are those produced from the direct consumption of energy by federal buildings either generated on the site, Source 1, or purchased from off-site sources such as electric power plants, Source 2.) On July 20, 2010, President Obama proposed a reduction in Source 3 emissions of 13% [3]. (Source 3 emissions encompass other, more indirect sources such as those associated with transportation, commuting, and the manufacture of products purchased by the government, among others.)

In February 2010, the United States Securities and Exchange Commission (SEC) issued new guidelines that require public companies to disclose the possible effects of climate change impacts on their business operations. These new guidelines referenced the EPA's Endangerment Finding and reflected the growing interest from insurance companies in evaluating the risks associated with potential climate change impacts. This acknowledges that the growing trend toward regulating GHGs and climate change-related risks could result in significant impacts on business operations [4].

To date, there has been widespread recognition that buildings are a significant contributor to GHG emissions. It is often cited that approximately 40% of total energy and 72% of the electricity used in the U.S. is consumed by the buildings sector, producing 39% of the total carbon dioxide (CO_2) emissions (the most of any sector, exceeding transportation and industrial) [5]. Both the government and private sectors have set aggressive goals to reduce buildings sector fossil fuel usage and resultant GHG emissions. The American Institute of Architects (AIA) and World Business Council for Sustainable Development (WBCSD) have proposed voluntary goals of achieving a carbon-neutral buildings sector by the Year 2030. The Energy Independence and Security Act (EISA) of 2007 (Public Law 110-140) requires that certain new federal construction and major renovation projects reduce fossil fuel emissions by 100% by the year 2030. In addition, Executive Order 13514 requires that all new executive branch government buildings for which planning and design begins after the year 2020 be designed and constructed to achieve net zero energy status.

However, even if these efforts were completely successful, this only addresses a portion of total GHG emissions. Equally substantial emissions reductions from mobile sources, deforestation, methane from landfills, etc. would be required. Furthermore, most projections indicate that achieving the emissions reductions necessary to stabilize or reduce global temperatures from current levels will be extraordinarily challenging to achieve [6]. It thus behooves leaders and technical professionals working in the buildings sector to recognize that the design and operating conditions and assumptions for buildings in the 21st century could differ considerably from those experienced during the 20th century. This issue is beginning to be recognized, as discussed below.

PLANNING FOR THE EFFECTS OF POTENTIAL CLIMATE CHANGE ON BUILDINGS

This section briefly discusses the key findings of four studies that raised concerns regarding the possibility of climate change effects on buildings and building energy consumption.

Ontario Expert Panel Report

In its November 2009 climate change action plan, an expert panel convened by the Ontario Minister of the Environment issued a recommendation that the "Ministry of Energy and Infrastructure should … establish a minimum, climate-resilient, sustainable environmental standard for public buildings in Ontario, in order to proactively demonstrate climate-adaptive building design, materials, technology, and construction" [7]. Furthermore, the expert panel recommended that the Ministry of Municipal Affairs and Housing should:

(1) Work with other stakeholder organizations "to persuade Environment Canada (Canada's analog to the U.S. EPA) and Natural Resources Canada to update the climatic tables used in the building code to design structural and building envelope elements so that they reflect advances in climate change projections."

(2) "Identify opportunities within Ontario's existing building code to increase the resilience to climate change of structural and building envelope elements of new buildings and those undergoing renovation, including energy conservation provisions."

The expert panel's recommendations also addressed a straightforward and relatively low cost-per-unit-installed measure that could significantly reduce flooding risk—mandating installation of backflow prevention valves on residential sewer connections to forestall or minimize basement damage and resulting insurance claims. However, the report also emphasized that, for such a measure to be effective, in certain districts additional concurrent efforts to reduce reliance on combined sewer systems (i.e., installing new, separate storm drainage systems) would be prudent. In addition, while not stated in the expert panel's report, reduced basement flooding would in turn decrease the need for and use of sump pumps, and the energy consumed by those pumps. In areas where electric power utilities have failed due to the same storm event(s), that power would generally need to be supplied from internal-combustion engines, portable generators that emit additional GHGs (CO_2 and nitrous oxide [N_2O]) when operated.

CIER Report

In October 2007, the Center for Integrative Environmental Research (CIER) at the University of Maryland issued a report assessing impacts on the United States potentially resulting from climate change [8]. The CIER report echoed a theme presented in the introduction to this article, namely that building codes "typically reflect historical experiences," and that "with future climate conditions [potentially] quite different from the past, many of those codes and standards are becoming obsolete. Yet, because we continue to build on the basis of these standards, infrastructures [*sic*] that are expected to last many decades may be outdated, requiring retrofits and upgrades shortly after they have been built."

The CIER report also reemphasized an accompanying issue that cannot be overlooked by the buildings sector, namely that of insurance risk. According to the CIER report, from 1980 to 2005, federal insurance agencies paid out more than $76 billion in claims, and the overall risk exposure of the National Flood Insurance Program increased four-fold, from approximately $250 billion in 1980 to approximately $1 trillion in 2005. (Presumably due to its timing, most of the claims associated with Hurricane Katrina are not included in this total exposure estimate). Design and construction of buildings that, based on best possible projections and best available science, can withstand damage and substantially reduce insurance risk will be a high priority in the coming years. At the same time, these buildings cannot be overdesigned, over-resilient "fortresses," because their ability to interact with the external environment and adapt to potentially significant variations in daily and monthly climate conditions is also mandatory to minimize: (1) annual consumption and cost of energy, and (2) emissions of additional GHGs that may further impact the global climate.

Impacts of Climate Change on Indiana Report

A report was prepared for Senator Richard G. Lugar of Indiana describing potential impacts of climate change on the state of Indiana, including heating and cooling demand by buildings [9]. Purdue University's Department of Earth and Atmospheric Sciences faculty had already calculated the total meteorological heating and cooling demand for the United States, using the base 65°F method used by the National Oceanic and Atmospheric Administration (NOAA), and scaling for population density [10]. Specific projections for Indiana indicated that heating demand days are projected to decrease by up to 1,000 degree days (DDs), with the maximum decrease occurring in the northwest, central/north-central, and eastern portions of the state. Conversely, cooling energy demand is projected to increase by up to 700 DDs, on a relatively uniform basis across the state (a slightly higher increase in the southwest portion of the state, and a slightly lower increase in the northwest portion and the area bordering Michigan). The net effect is projected to be changes in annual DDs ranging from approximately -400 to -500 DDs in the northeastern part of the state to between -100 and -200 DDs in the extreme southwest corner (near the confluence of the Wabash and Ohio Rivers). Note that while, on a purely degree-day basis, net annual energy demand might appear to decrease, actual energy consumption depends on numerous key factors, including, to name a few: (1) land use and degree of urbanization; (2) types of buildings constructed; (3) occurrence or absence of extreme weather events, including heat waves or cold spells; (4) availability of, or distance to, utility connections; (5) relative prices of different energy sources; (6) tax incentives or penalties; (7) local utility rate bases; (8) ability to import energy to the area (e.g., natural gas pipelines serving the city gate); and/or (9) extent to which local buildings utilize on-site renewable energy sources, including solar, wind, and geothermal and/or cogeneration.

Battelle Paper, Building Energy Efficiency, and Climate Change

Several employees of Battelle's Pacific Northwest National Laboratory (PNNL) presented a paper at the 2005 Energy Program Evaluation Conference in New York City [11]. Their paper summarized research that had been performed to evaluate potential energy increases or savings that might result in the residential and commercial building sector, based on currently available and accepted climate change model predictions at that time. The research utilized a multi-step analysis approach, using (among other tools) the "top-down" Federal Energy Decision System (FEDS) model and the "bottom-up" Building Energy Analysis and Modeling System (BEAMS) model. The PNNL analysis estimated that, depending on the range of temperature change projections, the energy used for space heating/cooling, hot water heating, and lighting could change collectively by the following amounts:

- For commercial buildings only, total energy usage in United States in the year 2020 would increase by 0.75-.095 quads (quadrillion Btus) from the year 2005 baseline of 4.74 quads (16-20%). The analysis also projected that the demand for cooling and lighting energy alone (i.e., the energy almost completely supplied by electricity) would increase by 0.59-0.89 quads from the 2005 baseline (26-39%).

- For the commercial and residential sectors combined, total U.S. energy usage in 2020 would increase by 0.49-1.34 quads from the baseline of 14.6 quads (3-9%) . The analysis also projected that the demand for cooling and lighting energy alone would increase by 0.72-1.17 quads from the 2005 baseline (19-36%).

POTENTIAL CLIMATE CHANGE IMPACTS ON BUILDING ENERGY CONSUMPTION AND PEAK LOAD

To evaluate further the potential effects of climate change on building energy consumption and peak loads, the University of Southampton's CC WorldWeatherGen® model and the United States Department of Energy's (DOE's) EnergyPlus model were used to simulate energy performance for several types of "benchmark" buildings. The CC WorldWeatherGen® is a Microsoft Excel–based application that uses the Intergovernmental Panel on Climate Change (IPCC) Third Assessment

Report (TAR) summary data of the HadCM3 A2 experiment ensemble to transform existing EnergyPlus (.epw) files into climate-adjusted .epw files for future year scenarios [12]. The underlying weather file generation routines of the CC WorldWeatherGen® tool are based on the so-called "morphing" methodology for climate change transformation of weather data developed by Belcher, Hacker, and Powell [13]. In addition, the tool includes further calculation routines for generating simulation-ready .epw files. Thus, the compatibility of this software with the EnergyPlus software (discussed in the following paragraph), combined with its grounding in a recognized coupled general circulation climate model, was the rationale for its use on this project.

EnergyPlus is a DOE-developed whole building energy simulation (WBES) model that is similar to, but somewhat more sophisticated, than earlier WBES models such as Building Loads Analysis and System Thermodynamics (BLAST™) and DOE-2™ [14]. Based on the user's description of a building from the perspective of the building's physical make-up, associated mechanical systems, etc., EnergyPlus calculates the heating and cooling loads necessary to maintain thermal control set points; conditions throughout a secondary heating, ventilation, and air conditioning (HVAC) system and coil loads; and the energy consumption of primary plant equipment. It generates an integrated, simultaneous numerical solution of heat balance equations where the building response and the primary and secondary systems are tightly coupled, and iteration is performed when necessary. By default, EnergyPlus calculates the energy balances on an hourly basis throughout the simulation year.

Simulation Procedures

The CC WorldWeatherGen® file was utilized to produce transformed weather files for the years 2020, 2050, and 2080. Simulations were conducted for each of these years (and in the 2010 baseline year for comparison purposes) using the EnergyPlus software and six benchmark buildings provided in the public domain along with the software [15]:

- Primary School
- Secondary School
- Medium Office
- Large Office

- Midrise Apartment Building
- Large Hotel

More information regarding the benchmark buildings is provided in Table 1.

The conjoining of these two software packages allows for an almost innumerable set of analyses. Therefore, this research concentrated on evaluating a single hypothesis, namely, how change in North latitude could possibly affect future energy usage and peak load in the Midwestern United States and south-central Canada. A geographic "cross-section" connecting major Midwestern metropolitan areas (metro areas) was established, and simulations were performed using the transformed weather files for each metro area for the years 2010 (baseline), 2020, 2050, and 2080. The metro areas were, from south to north:

- New Orleans, Louisiana, USA
- Memphis, Tennessee, USA
- St. Louis, Missouri, USA
- Chicago, Illinois, USA
- Minneapolis and St. Paul, Minnesota, USA
- Winnipeg, Manitoba, Canada

Table 1. Summary of DOE EnergyPlus Benchmark Buildings*

Building Type	Square Footage	Brief Description
Primary School	73,959	Single-story primary school (25 zones); classrooms, gymnasium/multi-purpose room, cafeteria, and kitchen
Secondary School	210,887	Two-story secondary school (46 zones); classrooms, auditorium, gymnasium, cafeteria, and kitchen
Medium Office	53,628	Three-story, 15-zone office building
Large Office	498,588	Twelve (12)-story office building with basement
Midrise Apartment Building	33,742	Four-story apartment building; 31 apartments plus leasing office
Large Hotel	122,120	Six-story motel; 179 rooms and laundry facilities

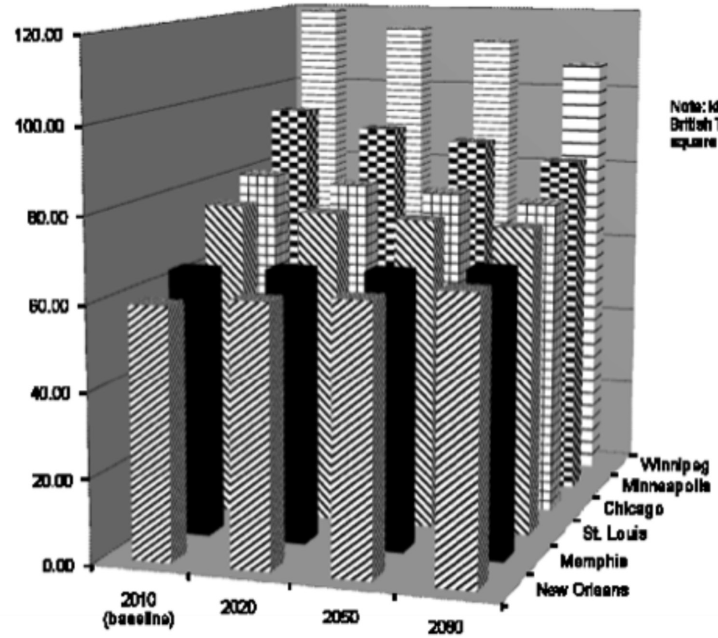
* Deru, M., B. Griffith, N. Long, K. Benne, K. Field, D. Studer, P. Torcellini, M. Halverson, D. Winiarski, B. Liu, and D. Crawley, 2009. *DOE Commercial Building Research Benchmarks for Commercial Buildings.* Office of Building Technologies. U.S. Department of Energy, Energy Efficiency and Renewable Energy. Washington, DC.

Design data parameters for summer and winter were provided in the transformed .epw files. EnergyPlus was configured to auto-size HVAC equipment and other key building systems based on projected, presumed climatic conditions from the CC WorldWeatherGen® output.

Simulation Results

The simulation results for annual energy consumption and peak load are contained in Appendix A. As illustrated in Figure 1, for the Benchmark Primary School, total annual energy consumption increases in the more southerly cities such as New Orleans and Memphis. As the North latitude becomes higher, total annual energy consumption begins to decrease, and the rate of decrease itself becomes greater with increasing North latitude. Using the assumptions in the CC WorldWeatherGen® model, annual total energy consumption for the Benchmark Primary School in 2080 is projected to decrease by approximately 11% in Minneapolis and Winnipeg, while in contrast it is projected to increase by approximately 12% for an identical school located in New Orleans.

This behavior of the total energy consumption parameter may be



Note: KBTU/SF = thousand British Thermal Units per square foot

Figure 1. Total Annual Energy Consumption—EnergyPlus Benchmark Primary School (kBtu/SF)

due to several factors, but it is clearly influenced significantly by the decrease in heating season energy consumption, as indicated in Table 2. For example, the changes in annual heating energy consumption of the Benchmark Primary School in 2050 for the six cities from New Orleans in the south to Winnipeg in the north are, respectively: -31.6%, -21.8%, -22.1%, -18.9%, -19.8%, and -12.6%. The Winnipeg Benchmark Primary School would experience less relative benefit (in terms of heating energy consumption reduction) than the New Orleans Benchmark Primary

Table 2. Contribution of Heating Energy Consumption to Changes in Total Energy Consumption, EnergyPlus Benchmark Primary School

Location	Year	Percent Change from Baseline		Heating Energy Consumption as a Percentage of Total (%)
		Total Energy Consumption (%)	Heating Energy Consumption (%)	
New Orleans, Louisiana	2010 (Baseline)	NA	NA	4.8
	2020	4.0	-13.6	4.0
	2050	6.7	-31.6	3.1
	2080	11.9	-49.1	2.2
Memphis, Tennessee	2010 (Baseline)	NA	NA	15.7
	2020	1.9	-9.7	13.9
	2050	3.0	-21.8	11.9
	2080	5.8	-37.7	9.2
St. Louis, Missouri	2010 (Baseline)	NA	NA	30.9
	2020	-1.1	-11.7	27.6
	2050	-1.9	-22.1	24.6
	2080	-2.8	-38.9	19.4
Chicago, Illinois	2010 (Baseline)	NA	NA	37.7
	2020	-2.0	-10.1	34.6
	2050	-3.5	-18.9	31.7
	2080	-5.6	-33.4	26.6
Minneapolis, Minnesota	2010 (Baseline)	NA	NA	47.2
	2020	-4.2	-11.2	43.8
	2050	-7.0	-19.8	40.8
	2080	-11.4	-34.0	35.2
Winnipeg, Manitoba	2010 (Baseline)	NA	NA	59.3
	2020	-3.6	-7.2	57.1
	2050	-6.1	-12.6	55.2
	2080	-10.9	-23.0	51.3

NA – not applicable

School. However, the relative effect of heating energy on total energy consumption is (also from south to north): 3.1%, 11.9%, 24.6%, 31.7%, 40.8%, and 55.2%. Therefore, even though the Winnipeg Benchmark Primary School's total annual energy consumption in 2050 is approximately 1.8 times greater than the New Orleans Benchmark Primary School (8,288 million British Thermal Units per year [MMBtu/yr] versus 4,678 MMBtu/yr), its total energy consumption decreases by 6.1%, compared with a 6.7% increase for the New Orleans School.

With these data, it is also possible to predict at approximately which North latitude the total annual energy consumption of the Benchmark Primary School transitions from an increasing trend to a decreasing trend. Figure 2 plots the average annual rate of change in total energy consumption for this building between 2010 and 2080, and contains a linear regression of this parameter to the distance north of New Orleans (i.e., increasing North latitude). The regression in this case is excellent, with a correlation (R2) of 97%. It also indicates that the crossover point, for this specific building and climate scenario, occurs at latitude 37 degrees North, 4 minutes, 59 seconds (the approximate latitude, for example, of Joplin, MO, or Paducah, KY). Note that each building and climate scenario would have a uniquely different crossover point and might not exhibit a similarly high degree of linear regression behavior. Additionally, in not all cases would the total annual energy consumption necessarily reverse behavior in this manner; in some instances, this parameter may remain relatively constant or even show increasing or decreasing behavior at all of the subject North latitudes.

Summer annual peak load exhibits an increasing trend for all of the six EnergyPlus Benchmark Buildings. (See Appendix A.) Figure 3 illustrates an example of this behavior, for the Benchmark Large Hotel. Depending on location, the projected summer peak kilowatt (kW) demand increases by:

(1) 2.9%-7.8% by 2020
(2) 6.1%-10.8% by 2050
(3) 18.1%-27.0% by 2080

As can be observed in Figure 3, the locations exhibiting the highest and lowest peak load change are not necessarily the same in each of these three future years. Increases in summer peak load forestall potentially significant consequences.

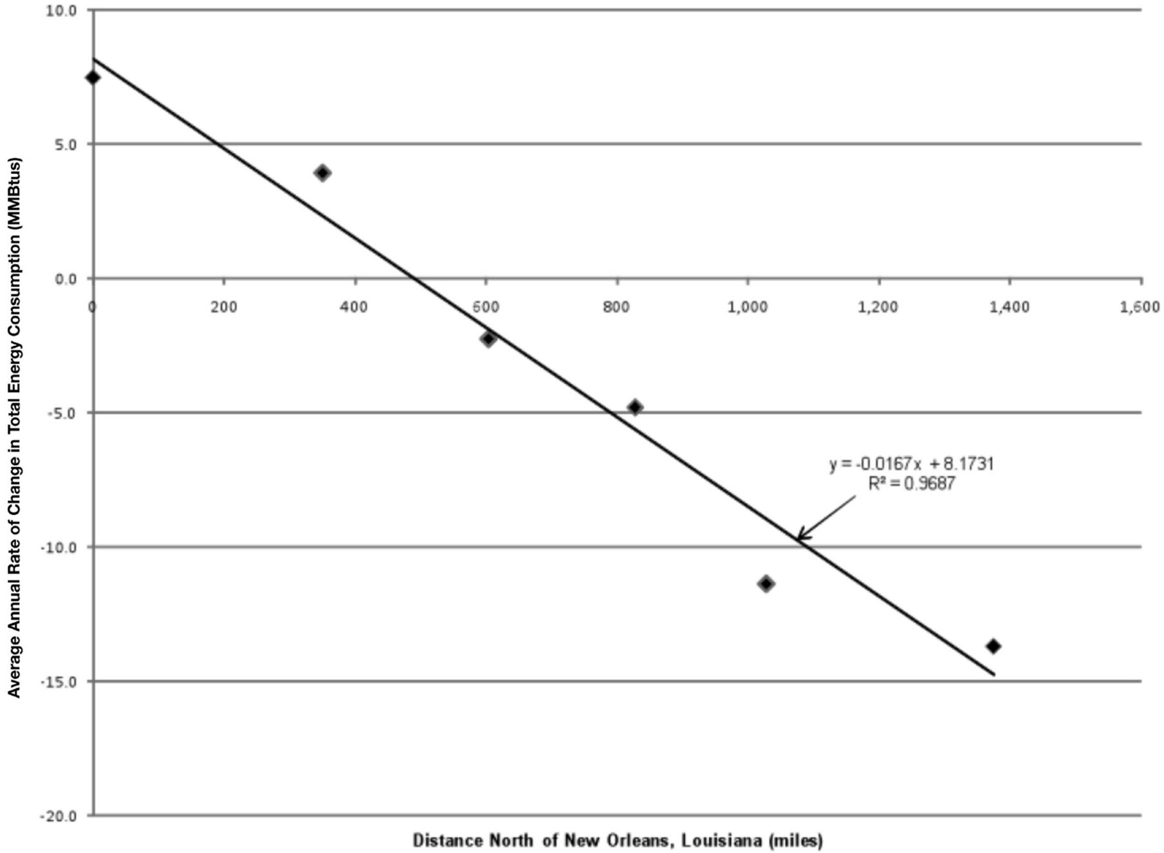


Figure 2. Crossover Point Where Annual Energy Consumption Begins to Decline with Increasing North Latitude—EnergyPlus Benchmark Primary School

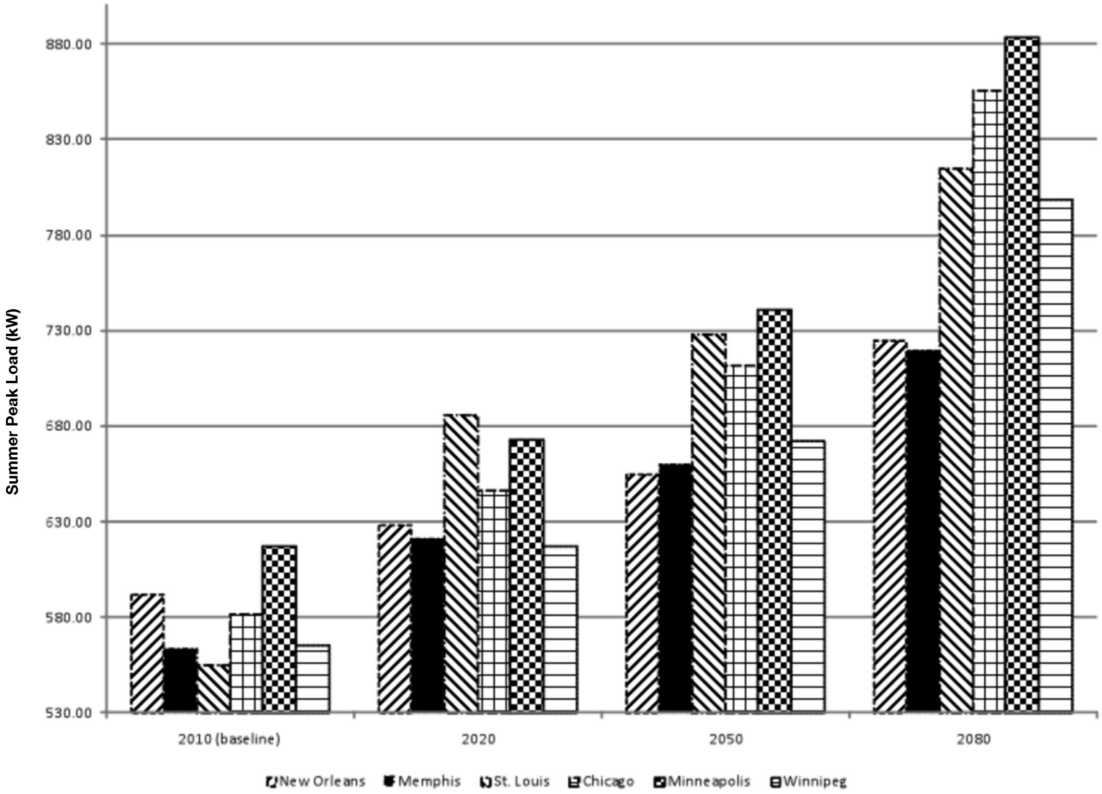


Figure 3. Summer Peak Load—EnergyPlus Benchmark Large Hotel (kW)

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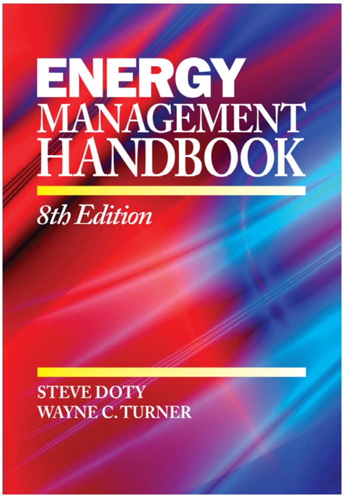

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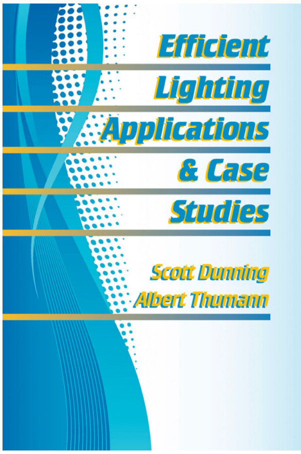

With the increased concern for facility energy conservation in recent years, much attention has been focused on lighting energy consumption and the methods for reducing it. Along with this concern for energy efficient lighting has come the realization that lighting has profound effects on worker productivity, as well as important aesthetic qualities. With this understanding in mind, this book presents an introduction to effective lighting design, and an examination of energy efficiency measures which can be implemented while simultaneously maintaining the required quality of illumination. Topics include lighting energy management, selection of lamps, task lighting, lighting design, lighting control, use of reflectors, ballast selection, natural daylighting, wireless lighting control, and case studies.

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They can be a parameter by which to evaluate future cooling load demands (since the vast majority of building air conditioning systems relies on electric-powered vapor compression cycles) and aid in representing the increased strain that could be imposed on the electric grid (in locations where additional generating capacity is not added or where inefficient distribution systems are not upgraded). They also strongly motivate intelligent design strategies, such as reducing lighting wattage, to aid in lowering overall building cooling demand.

Figures 4 and 5 provide bubble chart representations of the projected changes (based on the CC WorldWeatherGen® model transformed local climate data) in total annual energy consumption and cooling season peak load. The bubble charts allow these two key parameters to be viewed on the same set of axes. The “Y” coordinate of the bubble represents the energy consumption delta, while the size of the bubble (and the data value adjacent to the bubble) provides the relative scale of the peak load delta. These charts further depict the projected behavior of the two parameters under study, namely decreasing rates of change in total energy consumption with increasing North latitude, accompanied by increasing rates of change in summer peak load with increasing North latitude. Figure 4 compares the behavior of two building types, the Benchmark Primary School and the Benchmark High School. Likewise, Figure 5 illustrates for a single building type, the Benchmark Large Hotel, the projected values for the years 2050 and 2080. Naturally, numerous similar graphs could be generated, but they are not included here for brevity.

While the EnergyPlus Benchmark Buildings are useful to provide uniformity to an analysis of this type (and thus highlight the effects of potential climate changes in different regions more distinctly), it is important to state that this does not account for variations in local building codes and practices or architectural and engineering design variations (particularly in the building envelope). All other features being equal, it is highly unlikely that an identical midrise apartment building, for example, would be constructed in Memphis and in Minneapolis. These differences in design greatly compound the complexities of comparing and contrasting building behavior in different climates and would need to be factored into a much more complex modeling framework than that described herein. This was beyond the scope of the work conducted to prepare this article, but it is an important area for future study.

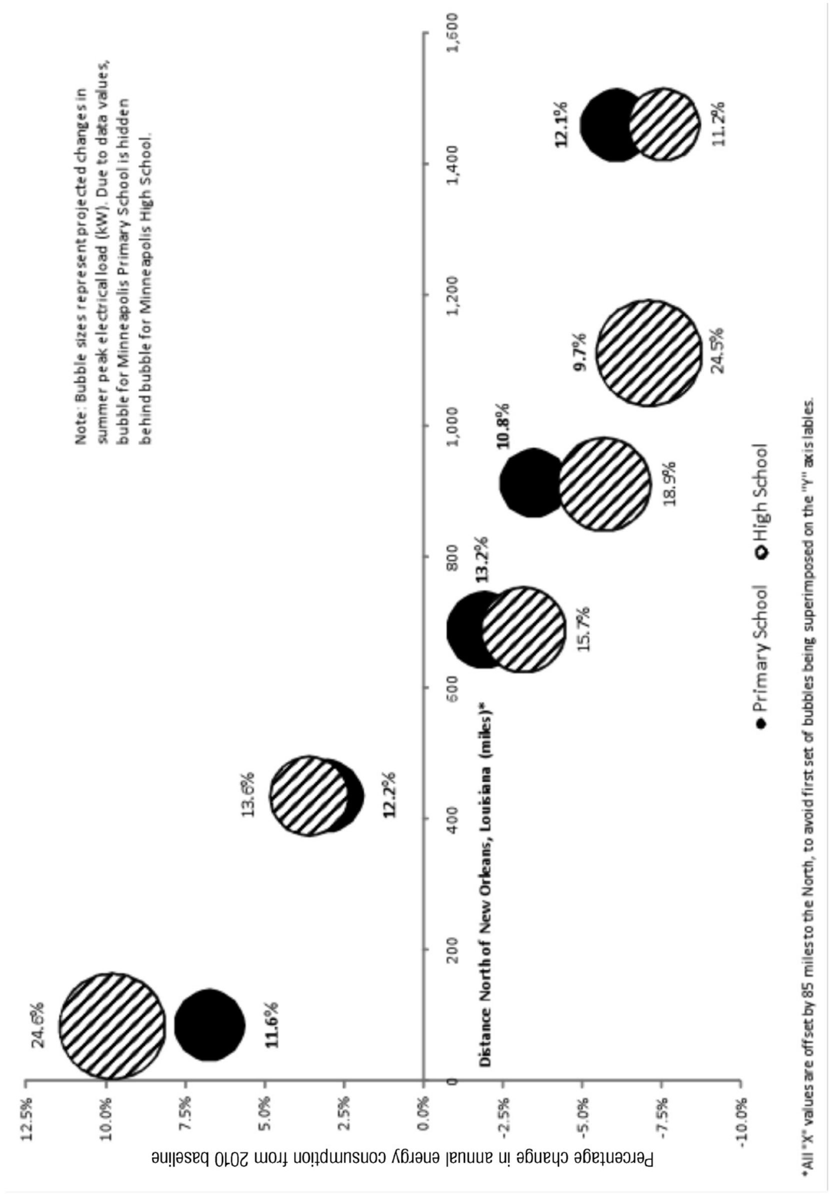

Figure 4. Projected Potential Changes in Annual Energy Consumption and Peak Load for the EnergyPlus Benchmark Primary School and High School (2050)

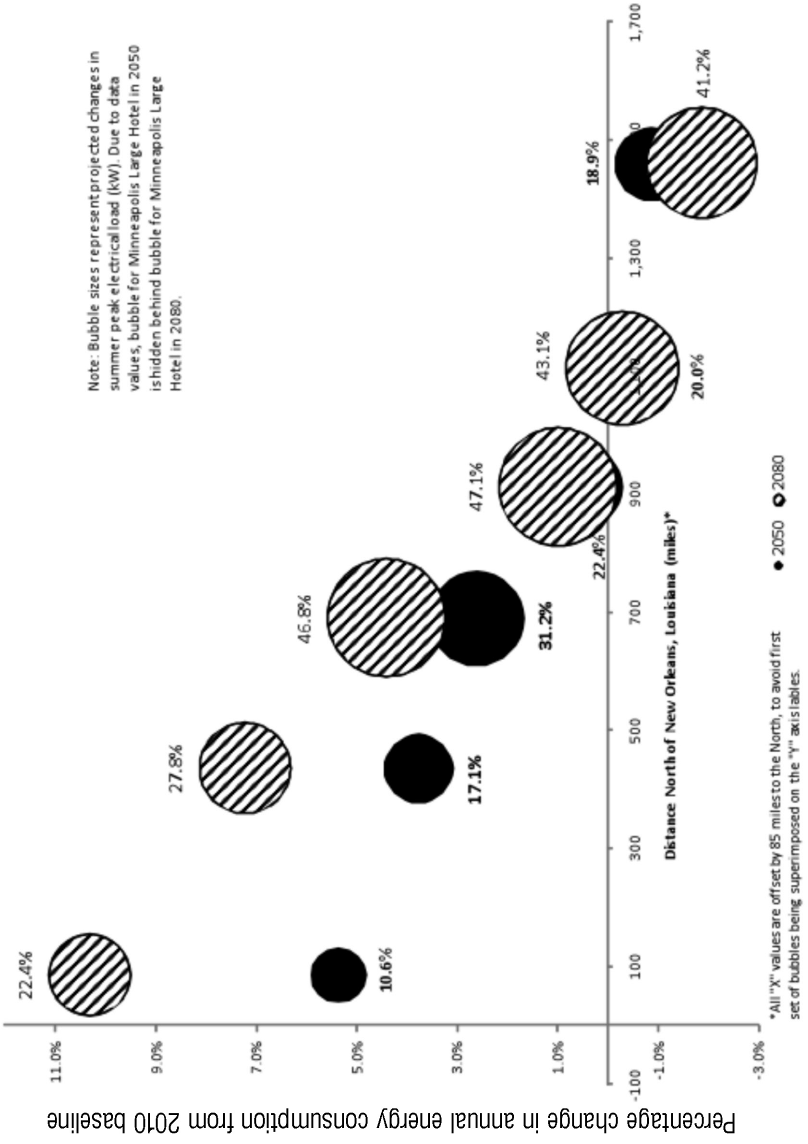

Figure 5. Projected Potential Changes in Annual Energy Consumption and Peak Load for the EnergyPlus Benchmark Large Hotel

It is also important to realize that reductions in peak load and overall energy consumption are themselves vital toward providing the flexibility and adaptability that will be discussed in greater detail below. Every Btu per hour of energy consumption or kW of electricity demand saved may provide a facility with additional potential for present or future expansion. Alternatively, if the facility developer, owner, or operator chooses not to expand, those benefits can be recouped in the form of lower energy costs and/or reduced carbon emissions.

FUNDAMENTAL PRINCIPLES TO ADDRESS THE THREAT OF POTENTIAL CLIMATE CHANGE IMPACTS

This article has demonstrated that climate change could affect building energy use and peak loads. These impacts could be positive or negative, depending on the facility's location, design, and other factors. Building owners and operators must be prepared to cope with these possible changes; in other words, climate change is one more factor that should be considered during the design process. The remainder of this article discusses examples of how these approaches are being implemented in real-world situations.

Most new buildings and some existing buildings already have or are planning significant projects or retrofits to address energy needs and maximize efficiency. Indeed, certain technologies such as daylighting, building automation systems (BAS), double- or triple-glazed windows, high reflectance ("cool") or green roofs, etc. are almost *de rigueur* elements of any new building construction. These technologies' function and performance are generally well known (with the exception of emerging technologies that have entered or are entering at pilot or full commercial scale). However, the combination of potential changes in energy demand and the uncertainty of projecting future climate conditions present a more radical set of challenges for building owners and operators.

Many green building projects have begun to recognize this necessity and are pursuing more innovative approaches to improve energy efficiency and on-site renewable energy production. Furthermore, as these data were examined, it was realized that they contain commonalities that can be expressed in a series of five fundamental principals (FP's), as indicated in Table 3. The following sections briefly describe some of these particular innovations that stretch above and beyond the

Table 3. Fundamental Principles for Adaptive Buildings

Fundamental Principle (FP) 1 – Treat the Building Envelope as a Dynamic Membrane Rather than a Static Barrier • FP 1.1 – Adaptive Architecture • FP 1.2 – Harmonization of Building Indoor and Outdoor Environments
FP 2 – Replace Construct-Operate Model with Continuous Construction Model
FP 3 – Leverage "Force Multipliers" • FP 3.1 – LEED®, ENERGY STAR®, and Other Green Rating Systems • FP 3.2 – Innovative Technologies and Strategies • FP 3.3 – Worker Productivity and Student Achievement • FP 3.4 – Project Location and Climate • FP 3.5 – Administrative Measures • FP 3.6 – Models Other than Whole Building Energy Simulation • FP 3.7 – "Free" or Low-cost Money • FP 3.8 – Submetering • FP 3.9 – Exponential Relationships
FP 4 – Build Down as Well as Up and Inward as Well as Outward
FP 5 – Create Systems that Augment Energy Savings through Occupant Behavior

application of merely installing and operating a system or technology on a site-by-site basis. The FPs will provide project planners and designers with straightforward, concise, and easily remembered axioms which will guide them as the project evolves from the charrette stage to conception and then to detailed design.

It also should be stressed that the purpose of this discussion is not to reiterate known information regarding established, widely used building energy efficiency measures that have been covered elsewhere in the literature. Rather, the purpose is to identify and briefly discuss particularly innovative technologies and methods (or particularly innovative applications of existing technologies and methods) that contribute to three central goals: reducing energy consumption, reducing peak load, and increasing adaptability to local climate fluctuations.

Numerous case histories are discussed to illustrate recent, real-world applications of these concepts. (See Appendix B for examples.) In many cases, due to limited data and information, the discussion is based on claims made by the project owner, sponsor, or other key stakeholders (e.g., the design architect or engineer). In general, due to limited time, it was not possible to obtain an objective confirmation of the building performance (e.g., interviews of occupants, public officials, etc.). In addition, while total facility energy performance data were available for nearly all case histories, disaggregation of this data to examine the contributions of individual measures or innovations discussed herein is an ongoing challenge that could require either additional years of operation or an increased body of literature.

FP1: Treat the Building Envelope as a Dynamic Membrane Rather than a Static Barrier

During the energy shortages of the 1970s, a significant shift in thinking regarding building envelope design occurred. It become much more common to develop designs which attempted to "seal off" the interior from weather occurring outside by reducing heat loss and gain through the building skin (and through infiltration by limiting cracks and establishing continuous air barriers). While energy consumption in these cases generally decreased, some positive aspects of the traditional design concepts were lost or severely limited. Buildings often became dry and "stuffy," prone to moisture imbalances and mold formation, and both less-healthful and less-tolerable for their occupants. This is the paradigm being referred to herein as the *static barrier* concept.

It has long been recognized that the building envelope is extremely important to achieve highly energy efficient buildings. Practices such as daylighting, double- and triple-glazed windows, and high R-value roof and wall insulation are almost de facto features of any new construction. The next evolution of technologies will be those that aim to make the envelope more adaptive to variable weather patterns.

The *dynamic membrane* is essentially an interface through which desirable aspects (e.g., the visible component of daylight) are admitted but undesirable ones (e.g., conductive and convective heat loss, precipitation/moisture intrusion) are blocked. However, this model is not as simplistic as it once may have been. At times, it may be beneficial to introduce, for example, infiltration air to a space to enhance natural ventilation and/or assist in maintaining desired temperatures and humidity levels (discussed in greater detail below). Similarly, in certain climates, limited solar heat gain through the north-facing wall(s) of a building may be permitted to reduce heating energy consumption during winter months.

Two emerging concepts—(1) adaptive architecture and (2) harmonization of the building interior and outdoor environments—aptly illustrate the types of processes designers can utilize to achieve improved energy performance notwithstanding climatic variations.

Adaptive Architecture

Within the last 10 to 15 years, a more inventive pattern of thought has emerged with respect to fundamental building envelope design, called by various names, including *adaptive architecture*, *smart facades*, or similar jargon. In essence, these are design approaches and systems that dynamically respond to changes in diurnal or climatic variations capable of influencing building energy performance and occupant comfort. These measures generally belong to one of several categories: (1) dynamic shading systems, (2) switchable glazings, and (3) double-skinned façades.

Dynamic Shading Systems

Dynamic shading systems are, as the name implies, mechanical shades, screens, or other permanent coverings that can be variably deployed to optimize wall or glazing performance. The major advancement from traditional shades or screens is that they are equipped with sensors (photocells, thermocouples) controlled by a centralized digital computer system, which combined form an automatic feedback control system (i.e., one that does not require constant operator intervention).

The most common type of dynamic shading systems used in buildings today are adjustable blinds, screens, or shades that are installed within windows or curtain walls containing double- or triple- window glazings. This design concept protects the shading from damage or tampering and makes it an integral element of the wall or window, thus increasing the energy and daylighting performance of that wall or window (and enabling the designer to better measure and monitor results). In addition, there are several projects (most in the design stage) that will use overhead shading panels (e.g., as part of a roof system) to admit daylight to a courtyard or atrium while limiting: (1) solar heat gain and direct glare from daylight; and (2) solar radiation heating.

An example of a currently installed dynamic shading system using movable window shades is found at the Pola Ginza Building in Tokyo, Japan. This is a 15-story office building which opened for business in October 2009. There are a total of 185 curved-profile, polycarbonate (acrylic) vertical shutters, each measuring approximately 1 meter (3.28 ft) wide at the widest point, by 3 m (9.84 ft) high. They are installed between the inner and outer glazings of a double-glazed façade and are automatically deployed by pivoting mechanisms (i.e., each shutter pivots around a vertical axis). The degree of opening/closing is determined by light sensors located within the occupied space. When the shading system is fully deployed, the total shaded area is approximately 10,000 ft^2 [16].

A project presently under design that will feature movable roof shading sections is the "City of Justice" Appeals Court and Superior Court Buildings in Madrid, Spain. On this project, automatically operated aluminum shading systems will be installed in two buildings:

(1) The Appeals Court Building will have a circular central atrium and eight peripheral atria. There will be a total of 257 hexagonal-shaped shading units covering approximately 20,000 ft^2 in total area.

(2) The Superior Court Building will have an atrium with a trapezoidal profile, and the shading system will consist of 115 parallelogram-shaped units covering 7,000 ft^2 in total area.

The primary function of the shading units will be to maximize admission of daylight to the core atria, while limiting solar radiation (glare, heat gain) to the surrounding office spaces. (The office areas will receive some diffuse and reflected daylight from the atria.) The instantaneous shading unit position will be digitally controlled, using a servomotor, and will be determined based on the Sun's tracking path for each applicable day. The benchmark tracking path data will be based on historical information for the site, but it will also be updated to reflect any changes once the building becomes operational. When not in use, the shades will retract into the structural profile of each atrium roof. For cloudy or overcast days, the degree of opening or closing of the shades will be controlled by photocell light meters [17, 18, 19].

Additional examples of dynamic shading systems are described in Table 4 (pages 40-41).

Switchable Glazing Systems

Switchable glazing systems allow the optical and/or thermal properties of the glazing system to be adjusted by an external source, such as an electric current. Two example technologies include *electrochromic glazings* and *adaptive fritting*. Electrochromic glazing systems contain low-voltage conducting materials that change in optical and thermal properties when an electric current is applied. This relationship between current and integral window properties means that the properties can be closely controlled in response to changing conditions (e.g., daylight angle, exterior temperature). In addition, they offer several advantages over other types of switchable glazings, including:

- Rapid response time between the control signal and desired alteration in properties
- Ability to modulate both visible light and infrared (heat) radiation
- Low voltage requirements (typically only 1 to 3 volts to activate)
- Wide spectrum of visible light transmittances (e.g., 5%-80 % of incident visible light)
- Relatively precise tuning ability, which aids in maximizing useful daylight transmission without excessive solar heat gain [20, 21]

Frit consists of a semi-opaque or translucent material (e.g., lead, ceramic) used to control or disperse incoming sunlight where dictated by project architectural requirements. Frit has been commonly used in building window systems for quite some time. The concept of adaptive fritting further advances this technique by making the frit segments mobile, e.g., as a set of spinning disks that, when put in motion, create pre-designed patterns of alternating translucent and transparent window sections. The spinning disks or other mechanisms can be controlled through electronic feedback control loops (e.g., using light or temperature sensors) to result in the desired daylight transmission patterns through the window glazing [22, 23].

Electrochromic technologies have been in research and development since the 1990s, while adaptive fritting systems are a relatively new concept (although, as mentioned previously, static fritted glass has been utilized in many buildings). Electrochromics have been relatively slow to emerge in building applications, although the technology has been commercialized and several product suppliers exist. At least two (Polytronix, Inc. of Richardson, Texas and Innovative Glass Corporation of Plainview, New York) reportedly have several field installations:

- Polytronix claims more than six installations in various U.S. states, with the largest two being the Brouse-McDowell Company in Akron, Ohio and Unical Aviation, Inc. in Irwindale, California (approximately 832 ft^2 and 896 ft^2 of “smart” glazing, respectively) [24].

Table 4. Examples of Dynamic Shading Systems

Facility (Location)	Facility Type	Shading Elements	Control Mechanism	Notes
Building Center Trust (London, United Kingdom)[1]	Exhibition hall	Horizontal, stacked shading panels that expand from a narrow, "Z"-shaped profile (closed position) to a group of three adjacent trapezoids when fully opened	Servo-motors	• Supports consist of "V"-shaped arms, which each rotate approximately 90 degrees when the panels are fully deployed • Shading panels are transparent, blue-tinted glass; supports are aircraft-grade aluminum
GSW Headquarters Building (Berlin, Germany)[2]	22-story office tower	Automatically-controlled, adjustable window blinds inside triple-glazed windows	Not specified	• The triple-glazed windows are located in the east façade of the building
Pola Building (Tokyo, Japan)[3]	15-story office tower	185 curved-profile vertical shutters, installed inside a double-glazed façade; each shutter is deployed by pivoting around its central vertical axis	Light sensors inside the occupied space determine optimal degree of opening or closing	• Each shutter measures approximately 1 m (3.28 ft) wide (at its widest point) by 3 m (9.84 ft) in height • Shutters are constructed from polycarbonate
Pearl River Tower (Guangzhou, China) (*under construction*)[4]	71-story office tower	Automatically-controlled, adjustable window blinds inside a double-glazed curtain wall	Not specified	• None
Aldar Central Market (Abu Dhabi, United Arab Emirates) (*in design*)[5]	Open marketplace	Movable shade roofs above three public squares, consisting of 72 panel segments	Servo-motors	• Total area covered by each segment will be approximately 3,000 ft^2 • Panels will be constructed from aluminum, steel, or wood and mounted within a lattice structure
City of Justice Appeals Court and Superior Court Buildings (Madrid, Spain) (*in design*)[6]	Court buildings	Automatically-operated, retractable shading units in roofs above central atria	Instantaneous Sun position and/or photocell light meters[7], digital controls, and servo-motors	• Total covered area will be approximately 27,000 ft^2; using a combination of hexagonal- and parallelogram-shaped panels • Historical benchmark solar path database will be updated continuously once the buildings become operational

Notes:

1. Source: Adaptive Buildings Initiative, LLC (ABI), a Joint Venture of Hoberman and Associates and Buro Happold, Adaptive Shading Esplanade, Building Centre Trust, London, UK, 2006 (www.adaptivebuildings.com/adaptive-shading-esplanade.html).
2. Source: E. Lee, S. Selkowitz, V. Bazjanac, V. Inkarojrit, and C. Kohler, High-Performance Commercial Building Façades, Building Technologies Program, Ernest Orlando Lawrence Berkeley National Laboratories, LNBL-50502, June 2002, p.101.
3. Source: ABI, Pola Ginza Building Façade, Nikken Sekkei + Yasuda Atelier, Tokyo, Japan, 2009 (www.adaptivebuildings.com/pola-ginza.html).
4. Source: K. Epstein, How Far Can You Go? Case Study: Pearl River Tower, Guangzhou, Peoples' Republic of China, High Performing Buildings, Winter 2008, pp. 22-29.
5. Source: ABI, Aldar Central Market, Grid Shading System, Abu Dhabi, UAE, Foster + Partners, date unknown, downloaded on January 31, 2010 (www.adaptivebuildings.com/aldar-central-market.html).
6. Sources:
    a. ABI, City of Justice (AP + TSJ), Linear Shading System, Madrid, Spain, Foster + Partners, date unknown, downloaded on December 28, 2009 (www.adaptive-buildings.com/city-of-justice.html).
    b. D. Cohn, Madrid's City of Justice Starts to Take Shape, Architectural Record, January 12, 2009.
    c. E-mail message from Z. Drozdowski of Hoberman and Associates to D. Briller of Booz Allen Hamilton, May 25, 2010.
7. Photocell light meters will be used to control the degree of opening of individual shading panels during overcast days.
8. UK=United Kingdom; UAE=United Arab Emirates

- Innovative Glass has installed 59 interior panels and nine exterior panels of Research Frontiers, Inc.'s SPD SmartGlass™ product at the Indiana University Health Information and Translational Sciences Building in Indianapolis, the largest integral panels being 9 ft high by 6 ft wide [25].

As architects and engineers continue to attempt to more finely modulate façade performance and make façade design an integrated part of building automated control systems, electrochromic glazings may be more frequently used. (As always, capital cost and payback will be key determinants.)

Double-skinned Façades

Double-skinned façades consist of two glazing systems with an air gap in between. There are several motivations for constructing these systems:

- The multiple layers of glazing reduce the level of total heat loss or gain, whichever is of most concern based on climate and season. The air gap provides an additional heat transfer barrier for buildings subject to extreme heat or cold climatic conditions.
- The air gap can be purged at night (either passively using the stack effect and/or mechanically using fans) to remove heat accumulated during the previous day from solar fenestration or to "pre-condition" the wall system for the following day. An example of pre-conditioning the façade would be to cool the air gap using mechanical ventilation during pre-occupancy hours (early morning) to help mitigate excessive warming of an east-facing wall system during the first few hours of daily operation.
- Manually and/or automatically operated windows can be installed within the exterior and interior skins to enable natural ventilation without safety concerns (e.g., in tall structures) and with a higher degree of control than with operable window systems in a single-skinned façade.
- If allowed under local and national fire codes, the air gap can provide an exit pathway for smoke in the event of a fire. By automatically sealing any windows within the interior skin, the smoke can be vented while limiting or eliminating occupant exposure to smoke during building evacuation.

Double-skinned façades generally use technologies that are already standard, such as high-performance curtain wall glazings, double- and tripled-glazed operable windows, electronic feedback control systems, and passive and active natural ventilation systems. The innovation, therefore, is provided by the design configuration of the double-skinned façade, and in how well it performs under the climate in question. (For example, a double-skinned façade in a tropical climate will likely use some of the same features as one in a northern, continental climate, but the design arrangements and component specifications—e.g., type and thickness of glazing—may be very different.)

One facility where a double-skinned façade has proved to be important for energy conservation and interior comfort conditions is the GSW Headquarters Building in Berlin, Germany. This building is a 22-story office tower with only an 11 m (33 ft)-wide floor plate; the building had to be oriented north-to-south due to site configuration and occupancy requirements (rather than the typically preferred east-to-west orientation, which minimizes solar heat gain along the east and west façades). The east façade was constructed as a single-skinned façade consisting of: (1) in some areas, triple-glazed windows (either automatically or manually operable) with adjustable blinds between the glazings; or (2) in other places, operable metal louvers. (Thus, both features can admit air for natural ventilation.) The west façade is the double-skinned façade and consists of (from outside to inside):

- A 10-mm (0.39 inch)-thick solid glazing (exterior skin).
- A 0.9 m (2.95 ft) interstitial space that contains vertical, perforated aluminum louvers whose position can be varied from completely open to completely closed. The louvers are automatically deployed to admit daylight but can be manually adjusted by occupants or maintenance staff.
- Double-glazed, automatically or manually operated windows (interior skin).

The west façade interstitial space is vertically vented to allow stack effect heat removal and air movement. During the cooling season, air is admitted through the above-mentioned openings, creating cross-ventilation through each floor, with the warmed air exhausted up through the west façade interstitial space. During the heating season, the west façade inner and outer skins are sealed, and the building interior is mechanically ventilated by a displacement ventilation system, with the exhaust air ducted back to the building's central heating plant. Radiant heating and cooling systems provide additional space temperature and humidity control during the heating and cooling seasons.

Double-skinned façades can also be an important technology for supplying safe natural ventilation to occupants in tall buildings. The Debis Headquarters Building in Berlin, Germany, a 21-story office tower, includes this type of system. The exterior skin consists of automatically controlled, pivoting, 12 mm (0.47 inch)-thick laminated glass louvers. The interior skin is a series of double-glazed, bottom-hung, electrically operable windows. Between the two wall systems is a 70 cm (2.8 inch) gap, with a steel walkway along each floor and glass panels that serve to prevent smoke migration in the event of a fire. During the summer cooling season, the exterior skin louvers are often opened, and individual users are able to concurrently activate nearby interior skin windows to receive natural ventilation. Moreover, at night, the louvers are automatically actuated to purge excess heat accumulated in the thermal mass of the structure during daytime hours [26].

For a long time, most double-skinned façades were located in European countries. One of the first large-scale installations in North America is located at the Richard J. Klarchek Information Commons Building on the Campus of Loyola University in Chicago, Illinois. The entire west wall of this four-story library and student center is a double-glazed wall façade, through which natural ventilation air at flow rates of up to 5 cubic feet per minute per square foot (cfm/ft^2) is introduced at ground level and conveyed to each floor. This system operates (in a design year) approximately 164 days out of the year, as follows:

- On approximately 52 days, natural ventilation is expected to be sufficient as the sole means of cooling.
- On approximately 62 days, natural ventilation is combined with radiant chilled ceilings.
- On the remaining 50 days where space cooling is required, a combination of natural ventilation, the radiant chilled ceilings, and a ducted underfloor air distribution (UFAD) system are utilized [27].

On the remaining 201 days of the typical (non-leap) year, the building is heated or cooled solely by mechanical HVAC systems, including the radiant ceilings and UFAD system mentioned previously.

One point to note is that this system takes advantage of a micro-climate that exists along the Lake Michigan shoreline in the Chicago area. Temperatures along the lakefront are often considerably lower (e.g., 10 to 15°F) than the inland temperatures on corresponding summer days, lake breezes are frequent, and during the spring and fall, cooling fog is not uncommon. It is questionable whether this approach would be as successful at a location, for example, at either of Chicago's airports or in the western suburbs.

Consideration of a moderating micro-climate such as the one described above can be an important factor in enhancing building adaptability. It should be included in the selection process for new sites, although naturally it is one of many factors. For example, Loyola University owned existing ground upon which to locate this facility; real estate (land) costs along the Chicago Lake Shore are substantially greater than what most projects can bear. One could also consider the Loyola project to embody the concept addressed in the following section, i.e., harmonizing the building interior with beneficial local climate conditions.

Harmonization of Building Interior and Outdoor Environments

As discussed above, the past design philosophy for buildings (especially commercial or institutional ones) centered on creating a sharp break between the indoor space conditions and the exterior climate. A newer model essentially reverses that position, i.e., advocating that where exterior conditions are pleasant, the building interior should be able to connect with those conditions. Whether consciously or not, occupants can then experience those conditions, at least partially, while indoors. Natural ventilation strategies and designs have long utilized this concept, and there are many effective examples. However, most of these installations were specifically designed to reduce (1) mechanical ventilation; and/or (2) space heating and cooling loads. The more recent design paradigm advances this concept to the next level by harmonizing or integrating the conditions on either side of the building envelope.

Case Histories

Two excellent case histories in North America illustrate this principle. Interestingly, they differ in North latitude by almost 20 degrees and as such have very different baseline climate characteristics.

Lavin-Bernick Student Center, Tulane University in New Orleans, Louisiana, USA. This facility replaced an earlier student center building irreparably damaged during Hurricane Katrina. The new facility is designed to, whenever possible, operate on 100% passive space conditioning (no HVAC other than supplemental ventilation) for approximately five months of the year. (Based on the local climate, this typically would encompass the fall, spring, and part of winter.) The contrast with the structure it replaced is notable, because that building was mechanically conditioned during all 12 months of the year. The new facility is designed to achieve this goal through several innovative measures as follows:

- ***Solar Vents***. Three "solar vents" located in the building clerestory, each measuring 60 ft horizontally and 16 ft vertically, promote stack effect cooling during the temperate seasons.

- ***Water-wall***. A large water-wall (i.e., a waterfall flowing over a vertical slab) provides both radiant and convection cooling to the open plan meeting and socialization area near the building center. Air that is cooled directly by the water-wall is further circulated to other areas of the building using oscillating pendulum fans and wave or "flap" fans. The chilled water circulated by the water-wall system is maintained at temperatures below the ambient dew point to avoid misting and condensation formation on building surfaces.

- ***Perimeter Rotary Fans***. Rotary fans promote air circulation in building perimeter areas that cannot be effectively cooled by the water-wall.

Additional energy conservation systems used in combination with the above devices include high-reflectance, low-emissivity window glazings and exterior trellis shading overhangs, both of which act to reduce solar heat gain. Some of the interior spaces also contain *micropore* ceilings, which capture or scatter a portion of the heat generated by interior sources (e.g., radiant heat from lighting fixtures, latent heat from occupants). The building designers estimated that these measures would result in a savings of approximately 30% in annual energy consumption of the building [28, 29, 30].

Manitoba Hydro Place in Winnipeg, Manitoba, Canada. One normally might not think of Winnipeg as a location where considerable communication between a building interior and the ambient would be feasible or advisable. This city experiences a continental climate with long, often bitterly cold winters and short, but sometimes intensely hot, summers. However, the Manitoba Hydro Place Building in downtown Winnipeg is constructed to take advantage of relatively high wintertime passive solar loads and prevailing southerly winds. Key design features include a "solar chimney," a southerly-facing double-skinned façade, and three south-facing "winter gardens." Louvers in the outer skin of the double-skinned façade are controlled to admit the minimum amount of air required for effective ventilation and space conditioning. During winter months, the cold air is warmed by passive solar heating, first within the interstitial space of the double-skinned façade and then inside the winter gardens, which are structures with predominantly glass surfaces and interior space largely devoted to vegetation. The winter gardens also each contain a water feature—280 tensioned Mylar® ribbons that act as individual waterfalls. As the incoming dry airflow rises through the winter gardens, it is humidified by these water features.

Next, the air is conveyed through fan coil units, with hot water coils partially supplied from ground source heat pumps (GSHPs), to bring the air up to the appropriate temperature and then to the building's HVAC system, consisting of a combination of UFAD and alcohol fluid-radiant ceilings. (Radiant heating and cooling will be discussed in Part II of this article in another edition of SPEE.) Exhaust air from the building's occupied spaces is vented into the solar chimney, which, because of the cold exterior temperatures in winter, is forced downward (in essence, a "reversed" stack effect). From there, the warmed air is conveyed through heat exchangers for heat recovery and, lastly, used to provide warm air ventilation to the belowground parking structure.

Thus, to recapitulate, energy savings are generally attained during the heating season from the following design features:

- Passive solar heating, received through the south façade glazing and the ceilings and walls of the winter gardens
- Optimization of ventilation rates and reduction of fan energy, by leveraging stack effects inside the solar chimney
- Radiant heated ceilings, further reducing fan energy compared with conventional forced air systems
- Heat exchanger recovery from exhaust air
- Conveyance of remaining warmed exhaust air to the underground parking areas (saving ventilation and heating)

The HVAC system described above also reduces energy consumption during the cooling season. Automatically controlled shades within the double-skinned façade modulate passive solar heat gain. Chilled water flowing down the water features dehumidifies incoming air to reduce chiller loads, and the radiant ceilings and GSHPs remove heat from (instead of supplying heat to) the occupied spaces. In addition, the solar chimney exhibits the classic stack effect, thus enhancing natural ventilation and cool air conveyance through the building [31]. (The stack effect also operates during nighttime hours; a heated sand mass, 17 tons in 632 pipes, aids in preventing cool air infiltration into the solar chimney that would potentially suppress air buoyancy from the stack effect.)

As of April 2010, Manitoba Hydro Place was operating at approximately 66% below Natural Resources Canada's Model National Energy Code for Buildings (MNECB), with an average energy consumption of 88.4 kilowatt-hours per square meter (kWh/m2) (28.0 thousand Btus per square foot [kBtu/ft^2]) [32].

FP2: Replace Construct-Operate Model with Continuous Construction Model

Since the inception of the building industry, the general model followed has been one of design, construct, and operate. While this model may have been adequate (even optimal) in the past, the threat of potentially rapid, unpredictable, and significant climate change demands a more flexible and forward-looking paradigm, which one can call *continuous construction.* The use of this term is not intended to conjure up (for building operators) nightmarish visions of constant noise from construction equipment and vehicle traffic, construction personnel working inside the building at all hours, partitions and sealed off areas hindering normal commerce, or thousands of dollars spent on frequent construction oversight. Rather, the intent is to convey the message that the building must be a dynamic system and that its configuration, utilities, envelope, and other key elements will most likely require modifications, even significant upgrades, to allow the building to remain occupied and comfortable, retain tenants, and control operation and maintenance (O&M) costs.

To an extent, the initial processes mirror those found in today's design-contract-build or design-build construction projects; however, there are some key differences. The primary variation is that a group of designers should be charged with, to the best degree possible, selecting and preparing preliminary plans for significant future upgrades. Some of these upgrades may never come to fruition, while others could be vital to keeping the building habitable in future years. While this will entail some additional costs, preparing these preliminary plans or designs (i.e., a "library" of possible design upgrades) will aid the building developer in:

(1) Forecasting future costs and contingencies
(2) Conceptualizing mitigation plans for possible risk factors
(3) Deferring future effort and cost, if quick adjustments to the building configuration are found to be essential during construction or future operation

It is not necessary or even conceivable that all or a majority of the projects conceived for the "upgrades library" would be eventually implemented. Furthermore, new ideas and subsequent projects could (and almost certainly would) be introduced, evaluated, and potentially implemented throughout the operating life of the facility. In the continuous construction paradigm, it is imperative that building developers assign an individual (or preferably a committee of persons or organizations) to evaluate on a continuous basis those factors that could promote the appropriateness of one or more upgrade projects for each of the buildings they develop or operate. These factors include, among others: (1) mission or purpose; (2) operational changes; (3) local climate changes; (4) availability and prices of different energy suppliers; and (5) introduction and commercialization of new technologies.

The process would essentially consist of five major steps:

- Identification of a need(s)
- A feasibility analysis (technical and cost) of potential alternatives
- Design of the selected upgrade alternative (if proven feasible and effective in the prior step)
- Construction of the upgrade
- An "exit strategy" (i.e., a procedure for, at any point during the process, abandoning the upgrade project, if circumstances dictate, with the least cost possible)

The following sub-sections describe several of the technologies, existing projects, and other items (e.g., financial analysis) that could be employed as part of a continuous construction model.

Modular HVAC Equipment and Systems

Modular HVAC equipment and systems are almost certain to serve a vital role if truly adaptable and flexible buildings are to be achieved. While this option has long been available to building designers, the potential for significant climate change has begun to increase the magnitude, extent, and frequency with which these systems are being installed. To some extent, the way forward has been demonstrated by buildings with specialized uses, whose owners have long grappled with the requirement to provide acceptable space conditioning at reasonable energy costs.

An example of this type of building is the Jewish Reconstructionist Congregation in Evanston, Illinois. Because of its varying occupancies based on day, time, and date (weekly worship services, holiday worship services, social events, and programs), the building has numerous and significant daily, weekly, and seasonal variations in heating and cooling load. (The continental climate of the Chicago area also contributes to wide swings in heating and cooling demand.) Therefore, the designers of this facility selected and specified a large number of modular chillers (seven units, rated at 15 tons of refrigeration [tons R] each). In addition, these chillers have significantly higher turn-down ratios (TDRs) (14:1 and 14.3) and integrated part load values (IPLVs), compared with more typical values of 4:1 TDR and 3.05 IPLV. In part because of this flexible, modular design, the facility has been able to achieve an energy consumption rate approximately 57% below its calculated American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) 90.1-2004 baseline [33].

A scenario that will likely be observed much more frequently is the incremental installation of modular units, which allows near-term conditioning needs to be fulfilled while remaining flexible with respect to future conditions. Operating more closely to design capacity is generally more energy efficient (as described in the previous paragraph), and building developers are naturally reluctant to sink capital investments into HVAC equipment that may ultimately may be unnecessary (and, if unnecessary, carry serious potential disadvantages, including space wastage, inability to fully depreciate the investment, and/or a soft secondary market if it must be sold at salvage). The more conservative, but often more astute, decision may be to pilot test system(s) and/or incrementally increase capacity (e.g., by adding units) where project requirements allow.

The modular GSHP systems at the Plano Elementary School in Bowling Green, Kentucky exemplify how incremental purchases of modular, small- to moderate-sized, packaged, multi-stage HVAC systems can contribute long-term cost savings and allay risks. The school is reportedly able to use modular GSHPs and desiccant energy recovery as the sole means of space conditioning, notwithstanding its location in a relatively warm and humid climate. Typical units that serve classroom areas (two classrooms and the corridor area in-between) are rated at 4 tons R. Larger GSHP units are used for common and specialized use areas and have a dual-compressor system that enables two stages of operation. For example, two 15 tons R-rated GSHPs condition the gymnasium, and the heat recovered from the gymnasium GSHP system is utilized to produce 110°F domestic hot water.

While modularization adds operational flexibility across the space, as well as redundancy, standardization, and reduction in infrastructure (e.g., chilled water piping), what is of most interest about this case study is the pilot testing procedure and the results it produced. The pilot test GSHP for the classroom areas consisted of a 3.5 tons R-rated GSHP with three stages of operation (1.5, 2, and 3 tons R). During the initial year of operation, the pilot test unit produced energy efficiency ratios (EERs) of 18 under Stage 1 and 11 under Stage 2. Furthermore, the pilot GSHP unit was able to effectively meet space conditioning parameters 87% of the time, thus demonstrating that Stage 1 operation (i.e., operation on a single compressor) was possible the vast majority of the time, which could generate substantial energy efficiency benefits over the building's operating life [34].

Computerized control systems are essential to balancing and optimizing operation of HVAC equipment, and these are compatible with modular equipment/systems. The 5 Houston Center Building in Houston, Texas, a 27-story office building, is a typical example. The building operates three chillers, one rated at 300 tons R and two rated at 800 tons R. The building automation system (BAS) uses preprogrammed algorithms to optimize the combination of chillers to meet the building's cooling demand. During low cooling load seasons (generally December and January in Houston), operation of the 300 ton R "pony" chiller alone is often sufficient to meet the total building cooling load. The BAS uses chilled water supply temperature as the principal feedback parameter to determine how many of the three chillers must be online at a given time [35].

Modular and Prefabricated Buildings or Building Components

Modular and prefabricated buildings have long been and continue to be used in a wide variety of applications such as warehouses, solid waste and recycling facilities, light manufacturing, and any type of structure intended only for temporary occupation. The technology of prefabricated building systems has advanced greatly; no longer are these buildings necessarily simply metal siding mounted on steel members. Rather, some have the architecture and systems to closely resemble permanent buildings and deliver many of the other benefits (e.g., energy efficiency, including renewable energy features; daylighting; use of environmentally preferable materials of construction; etc.).

Prefabricated buildings are not generally used for the types of major building projects discussed in this article. However, it is conceivable that their use will continue to expand because of the following advantages they offer:

- Relatively less work to assemble and break down
- Universality of replacement components (provided the same suppliers are used)
- Most or all materials and components are recycled and reused (at least until worn out or no longer functional)
- Modularity, and thus the ability to tailor structures to applications while minimizing energy, materials, water, and other inputs

Several suppliers have perceived the need for such structures; two examples are:

- A company known as Project FROG of San Francisco, California constructs prefabricated, modular buildings using 1,200 ft^2 modules nominally designed to meet LEED® Silver Certification. According to the company's web site, it has constructed projects ranging from 3,500 ft^2 to 14,000 ft^2 (mostly in the educational sector). One 3,500 ft^2 prefabricated educational facility (located at Watkinson School, Hartford, Connecticut) reportedly achieved energy consumption levels approximately 60% below that of neighboring schools [36, 37].
- American Modular Systems (AMS) has recently introduced a "Gen7 Indoor Learning Environment" modular education building. These prefabricated structures reportedly are designed to meet California Title 24 energy efficiency requirements and include lighting systems with "integrated daylight harvesting

features"—an example being ENERGY STAR®-rated tubular skylights with adjustable light dampers [38].

In summary, prefabricated structures may find a niche in smaller or moderate-sized facilities that require additional flexibility for a number of reasons, possibly including the need to maximize energy efficiency and to have greater responsiveness to climate variation. One must also remember that prefabricated buildings still require permanent infrastructure such as foundations, utility connections, drainage features, security systems, etc. These factors can affect available choices of prefabricated structures for a given building site or project.

Financial Evaluations

This new paradigm of uncertainty and risk-based decision-making may compel use of more sophisticated financial tools as well. To date, simple payback, net present value (NPV) on discounted future cash flow, and/or internal rate of return (IRR) on discounted future cash flow over the entire expected project lifetime have been sufficient for most purposes. However, these techniques do not allow investors to weigh options and respond accordingly to new and changing information, such as climate fluctuations. A system has been proposed, based on financial techniques already in use, to enhance typical discounted cash flow analysis to evaluate the following scenarios:

- The option of waiting to invest [which] recognizes the decision-makers' opportunity to: (1) postpone or delay acceptance of a project for one or more time periods; (2) accelerate or slow down the process of implementing a project in response to new information; and/or (3) discontinue a project temporarily in response to changes in the economic landscape or general market conditions.
- The option to terminate or abandon a project before the end of its planned lifespan. This option allows the project owner to minimize or avoid monetary losses.
- The option to change scale (expand or contract), i.e., to develop follow-on projects, expand in new or existing plants, reconfigure plans, etc. that would not be possible "without the ongoing existence of the project that is being evaluated" [39]. ("Without the ongoing existence of the project that is being evaluated" means

that this technique applies only to upgrades/downgrades or other modifications, i.e., the cash flow analyses associated with stand-alone projects are not considered an "option" and thus do not benefit from this type of evaluation.)

Naguib's article [39] discusses these techniques in considerable detail, including use of the Black-Scholes Model to evaluate the "call" values associated with different options. The article also presents an example showing how options cost/value analysis can convert a project with a negative NPV to one with a positive NPV (using conventional discounted cash flow analysis) when the Black-Scholes call value is considered. (The example illustrates how a hypothetical facility, instead of immediately installing a replacement for two-chillers in a plant, could install one chiller, "test drive" the chiller for one year, and then install the second chiller plus three additional chillers inside the plant, assuming favorable results from the first test year).

J.M. Waller Associates does not specifically endorse the Black-Scholes model or any other specific models and emphasizes to our clients that cash flow models must meet project- and organization-specific criteria and may (and often do) vary from project to project. At present, federal agencies are limited by regulations as to the types of financial evaluations they may conduct for life cycle analyses [40]. In addition, given the current economic outlook, there is trepidation among many organizations to use models that attempt to quantify or describe potentially risky investments. Furthermore, in 2010 Congress enacted the Dodd-Frank Wall Street Reform and Consumer Protection Act (Public Law 111-203), which could have broad impact on investment decision-making of the type discussed herein.

NOTE: Part II of this article (in a future edition of *SPEE*) will discuss the remaining three FPs and provide some additional observations regarding the role of carbon footprint quantification and capital cost in building energy planning and design.

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Appendix A

Table A-1. Results of Climate Change and Whole Building Energy Simulation Modeling for the EnergyPlus Benchmark Primary School and Benchmark High School

Location (North Latitude)	Year	Benchmark Primary School			Benchmark High School		
		Total Annual Energy Consumption (mmBTU)	Total Annual Energy Consumption (kBTU/GSF)	Annual Peak Electrical Load (kW)	Total Annual Energy Consumption (mmBTU)	Total Annual Energy Consumption (kBTU/GSF)	Annual Peak Electrical Load (kW)
New Orleans, Louisiana (30 deg N, 0 min, 0 sec)	2010 (Baseline)	4,384	59.27	311.1	13,009	61.69	1,153
	2020	4,558	61.63	335.2	13,697	64.95	1,340
	2050	4,678	63.25	347.1	14,276	67.69	1,436
	2080	4.906	66.34	367.5	15,395	73.00	1,580
Memphis, Tennessee (35 deg N, 4 min, 12 sec)	2010 (Baseline)	4,712	63.71	329.0	14,285	67.74	1,226
	2020	4,803	64.94	350.9	14,576	69.12	1,307
	2050	4,854	65.64	369.0	14,791	70.13	1,392
	2080	4.987	67.43	399.8	15,279	72.45	1,630
	2010 (Baseline)	5,609	75.84	343.7	17,426	82.63	1,235

St. Louis, Missouri (38 deg N, 45 min, 0 sec)	2020	5,548	75.02	362.6	17,115	81.16	1,312
	2050	5,500	74.37	389.2	16,872	80.00	1,429
	2080	5,450	73.69	436.5	16,644	78.93	1,582
Chicago, Illinois (41 deg N, 58 min, 48 sec)	2010 (Baseline)	5,974	80.77	328.6	19,546	92.69	1,242
	2020	5,854	79.15	342.4	18,937	89.80	1,340
	2050	5,764	77.94	364.2	18,426	87.38	1,478
	2080	5,637	76.21	400.3	17,570	83.32	1,686
Minneapolis, Minnesota (44 deg N, 52 min, 48 sec)	2010 (Baseline)	6,998	94.62	321.2	23,110	109.58	1,076
	2020	6,707	90.68	330.6	22,107	104.83	1,212
	2050	6,510	88.02	352.5	21,459	101.75	1,340
	2080	6,201	83.84	382.2	20,135	95.48	1,550
Winnipeg, Manitoba (49 deg N, 54 min, 0 sec)	2010 (Baseline)	8,825	119.3	296.2	30,549	144.86	1,012
	2020	8,507	115.0	314.1	29,212	138.52	1,109
	2050	8,288	112.1	331.9	28,226	133.84	1,126
	2080	7,866	106.4	367.7	26,300	124.71	1,355

Table A-2. Results of Climate Change and Whole Building Energy Simulation Modeling for the EnergyPlus Benchmark Medium Office and Benchmark Large Office

Location (North Latitude)	Year	Benchmark Medium Office			Benchmark Large Office		
		Total Annual Energy Consumption (mmBTU)	Total Annual Energy Consumption (kBTU/GSF)	Annual Peak Electrical Load (kW)	Total Annual Energy Consumption (mmBTU)	Total Annual Energy Consumption (kBTU/GSF)	Annual Peak Electrical Load (kW)
New Orleans, Louisiana (30 deg N, 0 min, 0 sec)	2010 (Baseline)	2,227	41.53	208.2	20,191	40.50	1,686
	2020	2,305	42.97	223.2	20,865	41.85	1,766
	2050	2,367	44.14	232.4	21,452	43.03	1,822
	2080	2,476	46.17	246.8	22,452	45.03	1,918
Memphis, Tennessee (35 deg N, 4 min, 12 sec)	2010 (Baseline)	2,303	42.95	208.1	19,799	39.71	1,710
	2020	2,360	44.00	225.8	20,270	40.65	1,795
	2050	2,407	44.89	234.3	20,709	41.54	1,844
	2080	2,504	46.69	241.0	21,461	43.04	1,907
St. Louis, Missouri (38 deg N, 45 min,	2010 (Baseline)	2,469	46.05	226.1	20,333	40.78	1,867
	2020	2,472	46.10	247.5	20,586	41.29	1,926

	2080	2,551	47.57	280.7	21,257	42.63	1,899
Chicago, Illinois (41 deg N, 58 min, 48 sec)	2010 (Baseline)	2,650	49.42	188.0	21,683	43.49	1,628
	2020	2,624	48.93	200.5	21,728	43.58	1,727
	2050	2,625	48.95	212.8	21,860	43.84	1,810
	2080	2,641	49.24	238.3	22,147	44.42	1,941
Minneapolis, Minnesota (44 deg N, 52 min, 48 sec)	2010 (Baseline)	2,887	53.83	191.6	23,086	46.30	1,657
	2020	2,831	52.79	206.1	22,922	45.97	1,743
	2050	2,807	52.35	237.1	22,928	45.99	1,829
	2080	2,770	51.66	259.2	22,882	45.89	1,975
Winnipeg, Manitoba (49 deg N, 54 min, 0 sec)	2010 (Baseline)	3,431	63.97	180.1	26,911	53.98	1,609
	2020	3,348	62.43	191.3	26,620	53.39	1,689
	2050	3,298	61.50	220.3	26,508	53.17	1,773
	2080	3,199	59.65	252.7	26,008	52.16	1,911

Table A-3. Results of Climate Change and Whole Building Energy Simulation Modeling for the EnergyPlus Benchmark Midrise Apartment Building and Benchmark Large Hotel

Location (North Latitude)	Year	Benchmark Midrise Apartment Building			Benchmark Large Hotel		
		Total Annual Energy Consumption (mmBTU)	Total Annual Energy Consumption (kBTU/GSF)	Annual Peak Electrical Load (kW)	Total Annual Energy Consumption (mmBTU)	Total Annual Energy Consumption (kBTU/GSF)	Annual Peak Electrical Load (kW)
New Orleans, Louisiana (30 deg N, 0 min, 0 sec)	2010 (Baseline)	1,545	45.80	77.29	17,676	144.8	592.1
	2020	1,617	47.94	84.05	18,241	149.4	628.5
	2050	1,677	49.70	87.82	18,623	152.5	654.7
	2080	1,779	52.72	94.35	19,499	159.7	724.8
Memphis, Tennessee (35 deg N, 4 min, 12 sec)	2010 (Baseline)	1,540	45.64	79.53	17,433	142.8	563.1
	2020	1,587	47.02	86.80	17,758	145.4	621.2
	2050	1,630	48.30	91.43	18,088	148.1	659.6
	2080	1,710	50.67	100.6	18,692	153.1	719.7
St. Louis, Missouri (38 deg N, 45 min, 0 sec)	2010 (Baseline)	1,618	47.95	76.99	17,610	144.2	554.9
	2020	1,630	48.31	82.68	17,904	146.6	685.7
	2050	1,647	48.81	88.27	18,068	148.0	727.7

	2080	1,686	49.97	96.48	18,387	150.6	814.6
Chicago, Illinois (41 deg N, 58 min, 48 sec)	2010 (Baseline)	1,702	50.44	76.93	18,139	148.5	581.5
	2020	1,685	49.95	84.13	18,181	148.9	646.3
	2050	1,683	49.88	90.92	18,230	149.3	711.9
	2080	1,678	49.73	104.6	18,317	150.0	855.7
Minneapolis, Minnesota (44 deg N, 52 min, 48 sec)	2010 (Baseline)	1,831	54.26	80.22	18,911	154.9	617.4
	2020	1,793	53.13	87.68	18,864	154.5	672.9
	2050	1,784	52.88	95.61	18,886	154.7	741.0
	2080	1,758	52.09	110.9	18,853	154.4	883.4
Winnipeg, Manitoba (49 deg N, 54 min, 0 sec)	2010 (Baseline)	2,192	64.96	75.07	20,544	168.2	565.5
	2020	2,126	63.01	81.44	20,459	167.5	616.9
	2050	2,095	62.10	87.69	20,365	166.8	672.5
	2080	2,023	59.96	99.98	20,161	165.1	798.6

Appendix B

Examples of Case Histories Used in Part I of this Article

Facility	Location	Square Footage	Primary Facility Use(s)	Sustainability Ratings or Scores			Capital Cost per Square Foot
				LEED®	ENERGY STAR®	Other	
Richard J. Klarchek Information Commons Building, Loyola University	Chicago, Illinois	70,500	Student/faculty digital library	Silver(a)	85.6(b)	NA	$397.16
Lavin-Bernick Student Center, Tulane University	New Orleans, Louisiana	148,000	University center	NA	Not specified	NA	$192.05
Manitoba Hydro Place	Winnipeg, Manitoba, Canada	698,000	Commercial office	NA	NA	NA	$398.28
Jewish Reconstructionist Congregation	Evanston, Illinois	31,600	Religious institution	Platinum (NC)	Not specified	NA	$231.01
Plano Elementary School	Bowling Green, Kentucky	81,147	Elementary school	NA	99	NA	$140.49
5 Houston Center Building	Houston, Texas	580,875	Office	NA	86	NA	Not specified

Notes:

(a) LEED® rating system was not specified, believed to be New Construction due to recent completion date.

(b) Maximum ENERGY STAR® score is 100 points.

NC – New Construction; NA – not applicable