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Looking Across the Water

Climate-adaptive buildings in the United States & Europe

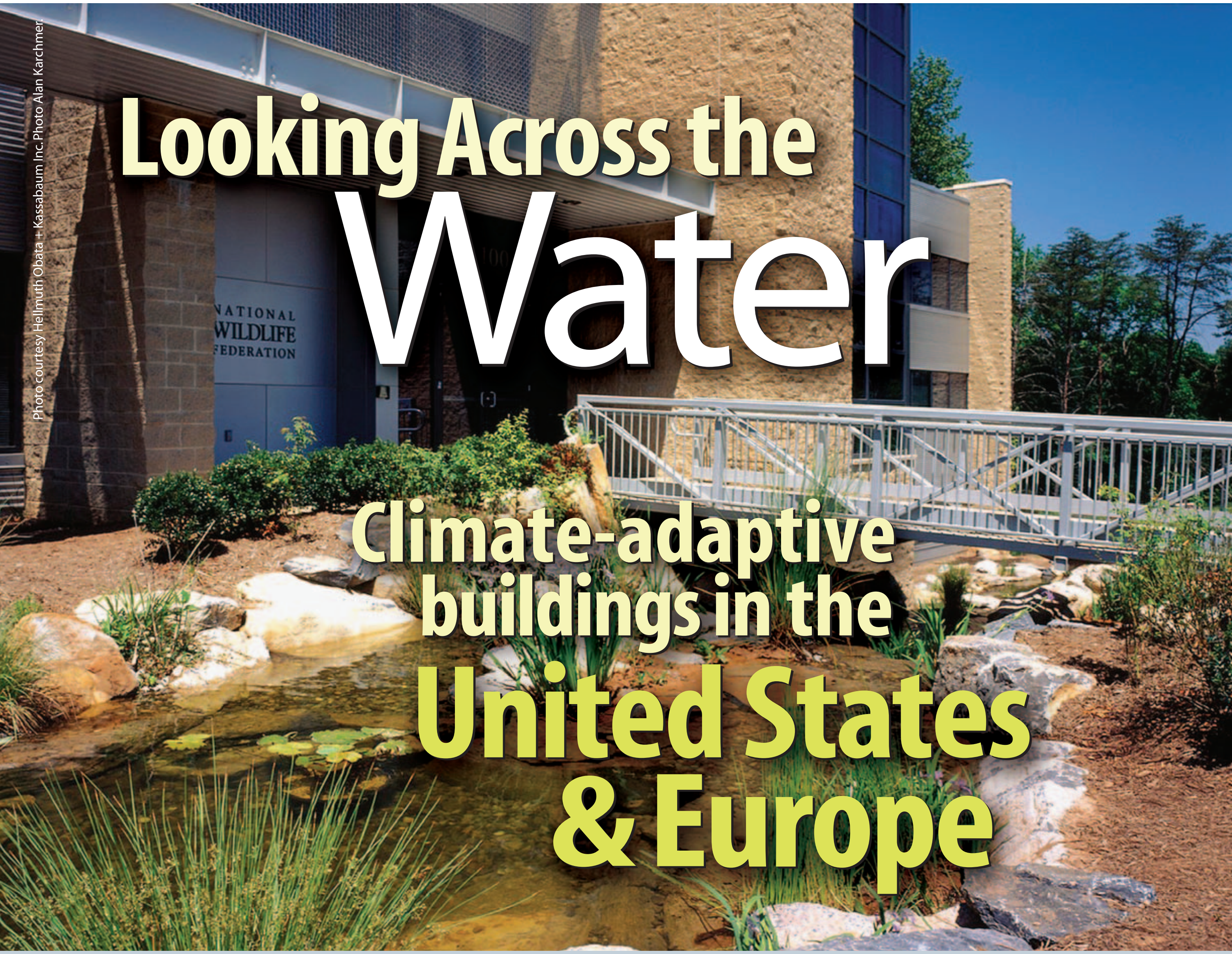

Photo courtesy Hellmuth Obata + Kassabaum Inc. Photo Alan Karchmer

The National Wildlife Federation (NWF) headquarters in Reston, Virginia, is a good example of a building properly climatically adapted to the Washington, D.C. area. The design has appropriate building envelope configuration and glazing—not an overabundance of glass.

by Daniel H. Nall, FAIA, PE, LEED AP

Indigenous architecture has taken spectacularly diverse forms throughout the world, as it has been adapted to locally available materials and optimized for regional climates. Over the millennia, cultures have tailored various architectural stratagems for minimizing the cost of providing shelter.

However, with globalization, modern architecture has lost much of its local specificity, with construction techniques and materials standardized internationally. While climate remains a variable that should generate diverse forms (especially since energy efficiency and comfort are primary design considerations), there seems to be an expectation of uniformity in appearance across the planet.

Buildings in diverse climates are expected to have a similar look, should they be classed as 'climate adaptive,' or in the current parlance, 'sustainable.' Nowhere is this uniformity more acute than in the comparison of green buildings designed for the two most industrialized areas of the world—Northern Europe and North America. The expectation seems to be climate-adaptive buildings optimized for energy efficiency should be similar in these two regions, if not identical.

This article will ask and attempt to answer (in a preliminary fashion) two questions underlying this expectation.[1]

1. Are these two climates similar from the standpoint of parameters important to both human comfort and energy efficiency?
2. Is European-style green design equally as effective in North America?

Architectural implications

European sustainable architecture seems to have struck a chord with many critics—the prototype of the narrow cross section, all glass facade, and use of operable windows for cooling has been accepted as the 'correct' climatically adapted style for the industrialized world. Given the climatic differences between Northern Europe and North America, this may be erroneous.

The low humidity levels prevalent throughout Northern Europe enable most buildings to be conditioned without dehumidification, often relying completely on outside air ventilation for comfort maintenance. Admittedly, the elevated air temperatures can result in discomfort, but operable windows are still a staple of European green design. On the other hand, larger office buildings in the United States rarely use operable windows, and cooling systems are a real estate necessity.

The amount of glass used in Europe seems to be related to the scarcity of sunlight during the winter months—simply transplanting the same ratio onto American soil could be excessive for sunnier locations (as explained below). From an energy standpoint, the glass in the facade should be limited to the amount necessary to provide daylighting to the workstations immediately adjacent to the window wall.

Additional window area (designed to push daylighting deep into the floor plate or to provide daylighting on dark, overcast winter days) may result in overheating, or additional energy use for air-conditioned cooling. While there is an assumption increased glass area means improved daylighting (and, in turn, additional energy efficiency benefits), this is contingent on the installation of automatic daylight responsive lighting controls. Unfortunately, such systems are rarely used in the United States. (Expensive initial costs and unproven technologies are oft-cited reasons.)

In Europe, any overheating through the all-glass facades may be vented simply by opening the windows. The very high air exchange rates can shed high rates of solar heat gain with an acceptable rise over the outside ambient temperature. However, the United States' higher humidity levels mandate refrigeration-based cooling. On this side of the Atlantic, the removal of solar heat gain during the summer requires not only forced air ventilation, but also refrigeration. In other words, the energy penalties of summer heat gain are considerably higher than with a natural-ventilation based cooling system. Therefore, buildings climate-adapted to North American locations should have less glass and more solar controls than their European counterparts.

Setting the climate comparison tables

Dry-bulb temperature, insolation (sunlight exposure), and moisture ratio are the most important climate variables for human comfort and building energy efficiency. The impression Northern European and North American climates are similar seems to derive mostly from experience of dry-bulb temperatures and, more specifically, winter temperatures.

Table 1 compares weather data for seven U.S. cities (all commercial and real estate centers) and four European cities, both commercial centers and sites for commonly discussed green buildings. The first discrepancies apparent are the latitudes—the European cities are generally about 10 degrees higher than their American counterparts. This is felt through lower sun angles throughout the year, decreased solar intensity, and greater total insolation over the significantly longer summer days.

Northern Europe and the northeastern United States are very similar in terms of heating design temperatures and degree days (DDs)—the measure in a specific location of the accumulated differential from a base temperature. More southerly locations, such as Washington, D.C., and Atlanta, Georgia, have comparable design heating temperatures to the European cities (even though their lower DD totals illustrate the decreased persistence of cold weather), while California has very mild winters compared to both East Coast and European cities.

Northern European cities have significantly different summers from their North American counterparts. For the latter, cooling design dry-bulb temperatures are consistently about 5 C to 9 C (9 F to 16 F) higher, and cooling degree days at base 10 C (50 F) are approximately double. Even the relatively benign climate of Long Beach, California, has more than twice as many cooling degree days as Paris, France.

The temperatures for January are comparable between the regions, with Chicago, Illinois, being more extreme than Europe, and Atlanta less extreme. However, the greatest difference is felt in the summer months, with the U.S. cities averaging between 6 C to 8 C (11 F to 14 F) higher than the European ones. The European average summer highs and lows are more comparable to San Francisco, California, than to New York City or the nation's capital. Ultimately, the average daily low temperature along the East Coast is too high to provide overnight cooling of thermal mass, while cities in California can make use of this measure. To achieve a useful

Table 1 **Climate Conditions in European and North American Cities**

City	Latitude	Heating dry-bulb	Heating degree day (DD) base 18.4 C (65 F)	Cooling dry-bulb	Cooling DD base 10 C (50 F)
New York City, New York	40.8	–8 C	2641	31.5 C (88.7 F)	1970
Chicago, Illinois	41.8	–15	3380	31.5 C (88.7 F)	1806
Washington, D.C.	38.9	–6.5	2253	33.6 C (92.5 F)	2466
Atlanta, Georgia	33.7	–4.9	1662	32.6 C (90.7 F)	2799
San Francisco, California	37.6	2.7	1676	25.6 C (78.1 F)	1602
Long Beach, California	33.8	5.0	794	30.9 C (87.6 F)	2934
Davis, California	38.7	–1.0	1527	36.2 C (97.2 F)	2486
London, England	51.5	–4.0	2786	25.7 C (78.3 F)	1052
Paris, France	49.0	–5.0	2803	27.7 C (81.9 F)	1228
Berlin, Germany	52.5	–11.7	3517	27.8 C (82.0 F)	1001
Amsterdam, Netherlands	52.3	–8.3	3162	25.0 C (77.0 F)	899

Table data courtesy the American Society of Heating, Refrigerating, and Air-conditioning Engineers' (ASHRAE's) *Handbook of Fundamentals 2001*

amount of storage, the building thermal mass must be cooled to a maximum of 18 C (64.4 F), and such cooling would require at least a temperature difference of 3 C to 4 C (5 F to 7 F).

The average daily low temperatures are also important because they are related to dew point (DP) temperatures, which are usually set at dawn with the daily low dry-bulb temperature. Often, night sky radiation loss from the ground depresses dry-bulb temperatures below the ambient DP, resulting in condensation on these surfaces (*i.e.* dew). The ambient air humidity's significant recharging usually requires either heavy rainfall or large, adjacent bodies of warm water—without these, the ambient humidity ratio set by the morning low dry-bulb temperature results in a relatively flat DP temperature profile throughout the day.

The greatest discrepancy between the cities on the two continents is in the area of humidity, as shown in Table 2. Coincident dew point temperatures at design conditions are approximately 5 C to 7 C (9 F to 13 F) higher for North American locations. Even an inland city such as Chicago suffers from an elevated DP temperature at cooling design conditions. The most telling statistic is the average number of hours per year the dew point temperature exceeds 18 C (64 F). This temperature is important because the absolute humidity level during the overheated period is the primary limitation of natural ventilation's efficacy for comfort maintenance.

When the humidity level is too high, comfort cannot be maintained, regardless of the air change rate. Since there is no means of passive dehumidification, active conditioning must be applied to the space for maintaining comfort. Once this need becomes pervasive, the form of the optimal energy-efficient architectural solution changes radically.

The simulation study

To determine appropriate climate-adaptive green design for North America, simulations were performed using eQUEST (QUick Energy Simulation Tool) v.3.37, with weather data for New York City.[2]

Building A

The simulation's 'base case' for a typical U.S. office building is 15 stories tall with a floor plate of 1998 m^2 (21,506 sf). Its dimensions are approximately 55 x 37 m (179 x 120 ft), with a total floor area of 29,970 m^2 (322,594 sf), and about 335 m^2 (3606 sf) consumed by core functions, such as elevator shafts, fire stairs, electrical, and mechanical equipment rooms. The building's floor-to-floor height is 3.96 m (13 ft), with a ceiling height of 2.75 m (9 ft).

The building uses insulated clear glass with thermally broken aluminum frames, approximately 2.4 m (7.9 ft) in height, effectively floor to ceiling. Ambient lighting power density is 10.8 W per 1 m^2 (10.76 sf), and 3.2 W per 1 m^2 for task lighting. Office equipment density is 21.5 W per 1 m^2, and occupant density is approximately one person per 18.6 m^2 (200 sf). (Occupancy schedule is a standard five-day, 10-hour week with systems operation extending one hour before/after the occupied period.)

The base case building employs an HVAC system comprising a variable air volume with a series of flow fan-powered terminals on the perimeter, using variable speed drives for the fans, and no economizer. The cooling sources are two water-cooled chillers/cooling towers with variable flow primary/secondary pumping schemes, while the heating source is a gas-fired boiler with variable pumping. The utility rate schedules are a generic demand consumption electric rate with a $16/kW demand charge and a $0.06/kWh energy charge, while gas is billed at $0.90 per 1 Btu (1055 J).

Building B

The second case in the simulation is the optimized U.S. building, which has the same floor plate, systems,

Table 2 **Summer Humidity Conditions in European and North American Cities**

City	Cooling dry-bulb	Cooling dew point (DP)	Cooling DD base 10 C (50 F)	Hours above 18 C (64.4 F) DP
New York	31.5 C (88.7 F)	19.1 C (66.4 F)	1970	821
Chicago	31.5 C (88.7 F)	19.0 C (66.2 F)	1806	688
Washington, D.C.	33.6 C (92.5 F)	20.5 C (68.9 F)	2466	922
Atlanta	32.6 C (90.7 F)	19.8 C (67.7 F)	2799	850
San Francisco	25.6 C (78.1 F)	10.5 C (50.9 F)	1602	0
Long Beach	30.9 C (87.6 F)	13.1 C (55.6 F)	2934	291
Davis	36.0 C (96.8 F)	12.2 C (53.9 F)	2486	10
London	25.7 C (78.3 F)	13.1 C (55.6 F)	1052	0
Paris	27.7 C (81.2 F)	16.0 C (60.8 F)	1228	9
Berlin	27.8 C (82.0 F)	12.4 C (54.3 F)	1001	22
Amsterdam	25.0 C (77.0 F)	14.4 C (57.9 F)	899	0

Table data courtesy ASHRAE 90.1-2001, *Energy Standard for Buildings Except Low-Rise Residential Buildings.*

Table 3 **Simulation Results: New York City, New York**

Building	Case	Total energy (per 0.09 m^2 [1 sf])	Electricity demand	Gas cost	Electric cost	Total energy cost
Building A	U.S. base case	45.2 kBtu	1608 kW	$21,852	$473,514	$495,366
Building B	U.S. optimized	39.0 kBtu	1393 kW	$16,358	$414,036	$430,394
Building C	Climate-adaptive European without daylighting controls	46.1 kBtu	1658 kW	$26,744	$471,667	$498,411
Building D	Climate-adaptive European with daylighting controls	42.9 kBtu	1502 kW	$29,368	$419,438	$448,806
Building E	Climate-adaptive U.S. optimized	38.4 kBtu	1350 kW	$22,202	$387,173	$409,375

and occupancy as above, but with window substitutions. The window height is reduced to 1.4 m (4.6 ft) and the glass type is changed to a low-E triple glazing using a plastic film insert and a very high performance thermally broken frame, representing the highest performance lighting system in the North American marketplace. Daylight responsive lighting controls with continuous dimming and shut-off are added for the ambient lighting.

Buildings C and D

The third and fourth cases are the climate-adaptive European buildings. They have a different floor plate, shaped like an ‘E’ (with prongs pointed north) to increase the office area adjacent to the window wall, and to decrease interior zones. The prongs are approximately 15 m (49.2 ft), and the base of the E has a similar dimension. The core elements are moved to the southwest and southeast corners to provide perimeter access for incorporating an airside economizer into the air-conditioning system, while glass is the same as Building A. Two structures were simulated—one without daylight responsive controls for the ambient lighting, and one with such controls.

Building E

The fifth case is the climate-adaptive U.S. building that marries the floor plate and systems of the European case with the envelope of the optimized U.S. building, incorporating economizer and daylighting controls. Additionally, the glass is inset about 0.3 m (1 ft) from the spandrel above.

Analysis of results

The simulation results of the five cases are presented in Table 3. It is important to note the single largest energy cost avoidance measure is the installation of daylighting controls. (Improvement of the building envelope is second, but still important.) The additional window wall area afforded by the climate-adapted floor plate improves daylighting, but increases solar heat gain and heat loss. Overall, the energy cost reduction from the European non-daylighting case to the optimized, climate-adaptive U.S. case is about 18 percent, without changes in mechanical systems, lighting, or equipment power density.

When simulations were performed for these same building types in London, England, the annual energy cost was somewhat reduced, but the relationships among the alternatives changed only slightly. The simulation assumes a closed building, without natural ventilation, but with an airside economizer for some of the cases. The energy rates used for the simulations were identical to New York City—almost certainly an error—but the identical rates provided a better comparison of building performance. One should note fuel use for heating is slightly elevated, and greatly increased for the higher glass alternatives. Additionally, the energy-cost penalty for larger glass amounts is reduced compared with the New York simulations.

Conclusions

The simulation studies demonstrate Northern European climate-adaptive prototypes are not optimal for North American climates. In short, many green buildings on U.S. soil simply have too much glass. It is important to note the study only looked at energy cost/consumption, and did not address the comfort issues also affected by the amount of glass and its orientation. Overglazing can lead to glare, local overheating, and cold downdrafts off windows.

From an energy cost standpoint, the study draws the following conclusions:

- Daylight responsive lighting controls result in significant energy cost savings, even when ambient lighting power densities are as low as 10.8 W per 1 m^2 (10.76 sf).
- Whether dealing with floor-to-ceiling window walls or strip glazing with a 0.75-m (2.5-ft) sill height, reducing glass results in significant heating/cooling savings, and only minimal reduction in daylighting.
- When combined with daylight responsive lighting controls, a complex floor plate that enhances perimeter zone length leads to energy savings.
- The use of high performance glazings/frames can minimize any additional heating/cooling brought about by an enhanced perimeter area.
- Prevailing humidity levels in the eastern United States preclude natural ventilation as the sole solution for comfort cooling. This has yielded a very different climate-adaptive architecture aimed at limiting solar heat gain, rather than accommodating it.
- The energy efficiency advantages of European-style buildings in European climates are achievable only with maximized use of natural ventilation.

The lesson for both designers and specifiers is climate-adaptive architecture is achieved by working within the local climate and understanding the nuances of its extreme and average conditions. Climate adaptation cannot simply be imported through imitation of attractive images from other, perhaps climatically diverse, locations.

Notes

[1] This article is based upon the author's white paper submitted at GreenBuild 2003, entitled, "Climate Adaptive Buildings... The United States and Europe."

[2] For more information on the eQUEST program, visit the Department of Energy's (DoE's) Web site at doe2.com/equest/index.html.

Additional Information

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08500–Windows
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16570–Dimming Control

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B2020–Exterior Standard Windows
B2020–Glazed Curtain Wall
D3060–HVAC Instrumentation and Controls
D5020–Interior Lighting

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Abstract

Green buildings throughout the industrialized world are expected to have a uniform look, regardless if they are located in London, England or Los Angeles, California. The understanding amongst many design professionals seems to be climate-adaptive buildings optimized for energy efficiency should be similar in both North America and Northern Europe. However, these two regions vary climatically. How should European-style architecture be adapted for buildings on U.S. soil?