The New Subtropical Cities

Wind speeds in East Coast Cities from Virginia to Long Island may see a doubling of wind speeds in the next century, higher temperature variations, humidity levels and flooding potential. The potential for structure damage in these cities exists because most existing buildings were designed for lower wind loads, and minimum required building design loads are not based on predicted increases in wind speeds.

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CLIMATE CHANGE 101

Climate Change 2007: The Physical Science Basis (Meehl 2007, p.768) is a report developed by the Intergovernmental Panel on Climate Change Working Group I that analyses indicators of climate change. The report summary, based on multiple models, states that typhoons and hurricanes will become more intense with higher peak wind speeds and heavier precipitation. Further, the report predicts cyclone patterns will move farther from the equator making cities as far north as 40 degrees latitude subject to hurricane force winds in excess of 150mph.

Global Greenhouse Gas (GHG) emissions have seen an increase of 70% between 1970 and 2004. With current climate change mitigation policies and sustainable development policies, the GHG levels are expected to increase anywhere from 9,7% to 36.7 & between 200 and 2030. This may well be the largest contributor to the rising average global temperatures. The report indicates that "The warming trend over the last 50 years... is nearly twice that for the last 100 years." Although the warming is less than 1^{o}C, it is significant from the perspective that paleoclimatic research indicates the temperatures now are higher than at any time in the last 1300 years.

THE NEW SUBTROPICAL CITIES

The definition of what makes a City subtropical is vague and varied from source to source. Generally described as the area between the tropical and temperate zones, the subtropics tend to fall between latitudes from the tropic lines (23o26'22") to about 35^{o} from the equator. Subtropical climates can be divided into humid-subtropical and arid-subtropical zones. Humid-subtropical zones have relatively high temperatures and a fairly even distribution of precipitation throughout the year. Based on the Koppen Climatic Groups (Peel 2007), Cfa: Mild with no dry season, a humid subtropical zone has an average temperature above 10ºC (50^{o}F) for eight months of the year, and precipitation throughout the year. Changes in climatic conditions are pushing the humid-subtropical zone on the Eastern coast of the United States further north. The annual mean daily temperature as shown in Figure 1(b) was created using data from 1961 to 1990. If consideration is given to the fact that the 2012 was the hottest year on record, the U.S. locations seeing subtropical conditions has probably extended further north. Figure 1 (c) shows the tropical and subtropical extents predicted for the Eastern United States in 2099 (Kottek 2006). What this map indicates is that the entire Northeast corridor as far north as Portland, Maine will become subtropical during the lifetime of most buildings being built today.

CURRENT BUILDING CODES

Most municipalities have building codes that refer to State codes which in turn refer to the International Building Code (IBC). The IBC refers to various sources such as The American Society of Civil Engineers (ASCE) and the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). All codes are the minimum standards allowed for design. And yet, most professionals use the minimum design standard to reduce the cost of a design. LEED motivates designers to think beyond minimum standards by offering certification for buildings that exceed positively beyond the norm environmentally. But there is no motivation for an architect or engineer or developer to design structurally for loads above the minimum.

STRUCTURAL IMPLICATIONS OF CLIMATE CHANGE

The ASCE Minimum Design Loads for Buildings and Other Structures is the guide for design loads in structural design. Maps for 3-sec wind gust speeds are used in the calculation of wind loads on buildings. The values in this map are based on historical data, not current or predicted future data. The map values, as all data provided by the ASCE, are the minimum allowed. However, economic motives force engineers to design as efficiently as possible; using minimum wind speed values in order to obtain lower loads and consequently use less material. This means that many buildings designed today are designed based on historic climatic conditions when in reality, buildings should be designed using the worst case scenario of historic and predicted climatic conditions.

Buildings in DC constructed prior to the 2010 change in wind speeds on the ASCE 7 wind maps could be designed to a minimum 90mph 3-sec gust wind speed. One hundred years from now, those buildings may be subjected to double that speed. A doubling of wind speed results in roughly four times the wind pressure on a building surface because velocity pressure at height z = qz = 0.00256(Kz)(V)2(I) where V = the wind speed velocity.

The impact of 4 times the wind load on a moment frame would mean four times the additional shear, moment and axial loads caused by wind on every beam and column in the frame. In a braced frame, the accumulated axial loads due to the wind loads are also quadrupled when wind speeds are doubled. While this may sound significant, the actual impact varies from case to case because wind loads are much smaller than gravity loads. The taller the building, the larger the impact double wind speeds will have on additional loads. Yet, even in a 100′ building, the impact of wind loads can mean a change in the design size of wind-resisting components. If a column line has a tributary width of 60′ for lateral loads, a moment frame analysis for three bays @ 30′ would yield the results shown in Figure 2.

(a)

Koppen Climatic Map (Peel 2007) showing tropical and subtropical zones

(b)

Annual Mean Daily Average Temperature (NCDC 2011) using data from 1961 - 1990.

(c)

End of century predicted tropical and subtropical zones (Kottek 2006)

1

Figure 1: Comparison of (a) current tropical and subtropical extent to (b) Annual Mean Daily Temperature to (c) Predicted 2099 tropical and subtropical extents

EXTERIOR COLUMNS														
60.00 tributary width (ft) - **90** mph windspeed								60.00 tributary width (ft) - **180** mph windspeed						
p(psf)	P(k)	Total P (k)	Col V (k)	Col M (k-f)	Beam V (k)	col Paxial (k)	LEVEL	p(psf)	P(k)	Total P (k)	Col V (k)	Col M (k-f)	Beam V (k)	col Paxial (k)
14.55	6.55	6.55	1.09	8.19	0.55	0.55	R	57.66	25.95	25.95	4.33	32.44	2.16	2.16
13.90	12.51	19.06	3.18	23.83	2.13	2.68	5	55.05	49.55	75.50	12.58	94.37	8.45	10.62
13.10	11.79	30.85	5.14	38.56	4.16	6.84	4	51.85	46.67	122.16	20.36	152.70	16.47	27.09
12.23	11.01	41.86	6.98	52.32	6.06	12.90	3	48.37	43.53	165.69	27.62	207.12	23.99	51.08
11.21	10.09	51.95	8.66	64.93	7.82	20.72	2	44.30	39.87	205.56	34.26	256.95	30.94	82.01
9.76	11.71	63.66	10.61	132.62	13.17	33.89	1	38.50	46.20	251.76	41.96	524.51	52.10	134.11

INTERIOR COLUMNS														
60.00 tributary width (ft) - **90** mph windspeed								60.00 tributary width (ft) - **180** mph windspeed						
p(psf)	P(k)	Total P (k)	Col V (k)	Col M (k-f)	Beam V (k)	col Paxial (k)	LEVEL	p(psf)	P(k)	Total P (k)	Col V (k)	Col M (k-f)	Beam V (k)	col Paxial (k)
14.55	6.55	6.55	2.18	16.38	0.00	0.00	R	57.66	25.95	25.95	8.65	64.88	0.00	0.00
13.90	12.51	19.06	6.35	47.65	0.00	0.00	5	55.05	49.55	75.50	25.17	188.74	0.00	0.00
13.10	11.79	30.85	10.28	77.13	0.00	0.00	4	51.85	46.67	122.16	40.72	305.40	0.00	0.00
12.23	11.01	41.86	13.95	104.64	0.00	0.00	3	48.37	43.53	165.69	55.23	414.23	0.00	0.00
11.21	10.09	51.95	17.32	129.87	0.00	0.00	2	44.30	39.87	205.56	68.52	513.91	0.00	0.00
9.76	11.71	63.66	21.22	265.24	0.00	0.00	1	38.50	46.20	251.76	83.92	1049.01	0.00	0.00

2

Figure 2: Moment frame exterior and interior column comparisons for 90 mph wind speeds and 180 mph wind speed given a 60' tributary width.

Assuming a factored load of 0.2ksf per level and column lines @ 20'o.c., Changing the design wind speed from 90 mph to 180 mph would change exterior columns from a W14X90 to a W14X211 and interior columns from a W14X176 to a W14X283. This may sound like a large increase, but with only 2 out of 7 column lines resisting lateral loads, the increase in column steel is 32%. If all column lines resist lateral loads, the additional moment and axial loads on the columns is reduced significantly as shown in Figure 3. The result changes exterior columns from a W14X82 to a W14X109 and interior columns from a W14X132 to a W14X193. However, because all columns resist lateral loads, the overall amount of column steel is greater and the increase in column steel due to a doubling of wind loads is 41%.

In 2010, ASCE published a new set of wind maps in the Minimum Design Loads for Buildings and Other Structures. Increased wind speeds create structural design issues on two levels. First, there is the consideration for new design. While all designers like to think that their creations will be standing a century from now, the fact is that many structures designed in the past century have been demolished either because of poor design or antiquated technology or because developers can make a better profit by building a taller building on the site. The client must decide if the building should be designed for higher wind loads at a higher initial cost, or designed for current wind loads and either retrofitted as wind speeds increase or chance structural failure. Second is the consideration for existing buildings. Retrofitting is sustainably preferable to demolition in most cases because there the embodied energy in buildings is so high. But, structural retrofitting may be difficult. Most commercial buildings are beam and column types, designed in either concrete or structural steel. Structural Steel is easier to retrofit as members can be built up unless the steel is encased in concrete for fire protection.

Since the gravity loads will not change, retrofitting can focus on components that transfer lateral loads to the ground. One strategy would be to create additional column lines to resist lateral loads by adding diagonal bracing or shear walls to

EXTERIOR COLUMNS												
20.00	tributary width (ft) - **90** mph windspeed						20.00	tributary width (ft) - **180** mph windspeed				
p(psf)	P(k)	Col V (k)	Col M (k-f)	Beam V (k)	col Paxial (k)	LEVEL	p(psf)	P(k)	Col V (k)	Col M (k-f)	Beam V (k)	col Paxial (k)
14.55	2.18	0.36	2.73	0.18	0.18	R	57.66	8.65	1.44	10.81	0.72	0.72
13.90	4.17	1.06	7.94	0.71	0.89	5	55.05	16.52	4.19	31.46	2.82	3.54
13.10	3.93	1.71	12.85	1.39	2.28	4	51.85	15.56	6.79	50.90	5.49	9.03
12.23	3.67	2.33	17.44	2.02	4.30	3	48.37	14.51	9.21	69.04	8.00	17.02
11.21	3.36	2.89	21.64	2.61	6.90	2	44.30	13.29	11.42	85.65	10.31	27.34
9.76	3.90	3.54	44.21	4.39	11.29	1	38.50	15.40	13.99	174.83	17.37	44.70

INTERIOR COLUMNS												
20.00	tributary width (ft) - **90** mph windspeed						20.00	tributary width (ft) - **180** mph windspeed				
p(psf)	P(k)	Col V (k)	Col M (k-f)	Beam V (k)	col Paxial (k)	LEVEL	p(psf)	P(k)	Col V (k)	Col M (k-f)	Beam V (k)	col Paxial (k)
14.55	2.18	0.73	5.46	0.00	0.00	R	57.66	8.65	2.88	21.62	0.00	0.00
13.90	4.17	2.12	15.88	0.00	0.00	5	55.05	16.52	8.39	62.91	0.00	0.00
13.10	3.93	3.43	25.71	0.00	0.00	4	51.85	15.56	13.57	101.80	0.00	0.00
12.23	3.67	4.65	34.88	0.00	0.00	3	48.37	14.51	18.41	138.08	0.00	0.00
11.21	3.36	5.77	43.29	0.00	0.00	2	44.30	13.29	22.84	171.30	0.00	0.00
9.76	3.90	7.07	88.41	0.00	0.00	1	38.50	15.40	27.97	349.67	0.00	0.00

3

column lines not currently resisting lateral loads. But this is not usually a practical solution not only because either the bracing or shear walls might interfere with program or circulation, but because all columns would have to be beefed up despite the addition of additional lines of resistance. Further, pinned connections in the column lines not currently resisting lateral loads would need to be changed to fixed connections to resist moment. The easier solution would be to wrap the existing columns in steel plate on all four sides, increasing the area and the section modulus. In the example above a 5/8" plate wrapping a W14X90 would have an area of 63.69in2, ry = 5.27in. and a section modulus, Sx to 306.65in3 making the retrofitted column adequate to resist 180 mph winds.

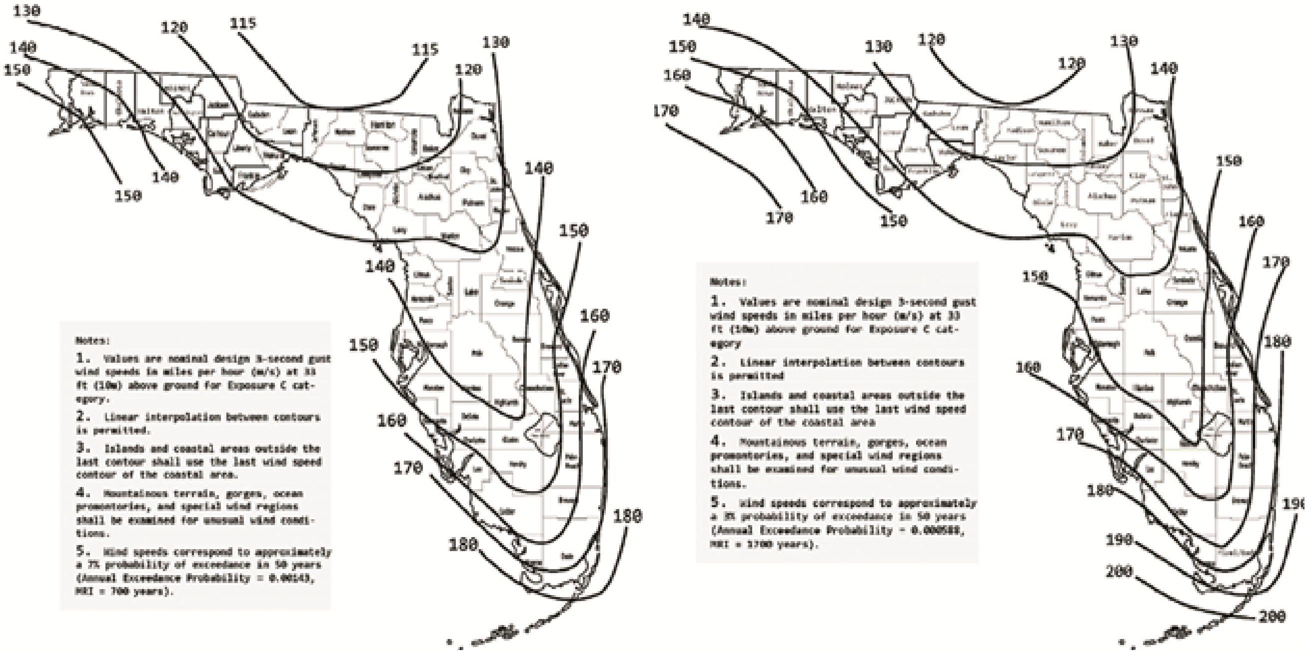
In 1992, Hurricane Andrew made landfall in Dade County on the east coast of Florida. With category 5 winds along the shore and category 4 winds inland, the widespread destruction of housing in Dade County prompted a revision of building codes to require tie-downs and other measures for lateral force and uplift resistance.

From August through September, 2004, three Hurricanes damaged or destroyed homes throughout the Florida peninsula. In 2008, the State of Florida enacted the Florida Building Code, replacing 470 local codes. Prior to 2010, the 2004 and 2008 Florida Building Code used design wind speed stricter than the ASCE Minimum Design Standards for Buildings and Other Structures. used by the International Building Code. The base inland speed was raised from 90mph to 115mph, and coastal speeds increased as well. The ASCE and Florida Building Codes now correspond and are based on a 15% probability of occurrence. The highest wind speed listed is 200 mph which will probably remain adequate in light of the fact that hurricanes are predicted to move farther away from the equator. It should be noted, however that the increase in wind speeds from the 2005 to the 2010 editions of the the ASCE Minimum Design Standards for Buildings and Other Structures wind maps are typically 30 – 40 mph higher in Florida, but only 10-30 mph higher along coastal mid-Atlantic and New England states. If hurricanes are predicted to move away from the equator, logic would dictate northern values should increase as much if not more than Florida values.

Superstorm Sandy wreaked havoc on the New Jersey shoreline and Long Island in October 2012. With wind speeds in the Category I range combined with a strong storm surge, damage from flooding outweighed damage due to

Figure 3: Moment frame exterior and interior column comparisons for 90 mph wind speeds and 180 mph wind speed given a 20' tributary width.

4



lateral forces. But the storm made designers and lawmakers aware that the combination of storm surge force and wind forces should be considered in the design of coastal structures. The State of New Jersey follows building codes based on the 2009 IBC while New York City follows the 2008 City of New York Building Code, which is based on the 2003 IBC. The State of New Jersey is currently debating what changes should be made to building codes to avoid future catastrophes of this nature.

Changes can and should be made to building codes before disaster strikes. The additional cost of materials to ensure structural adequacy during a high wind event is far less than the cost of replacement if the building fails. The problems currently facing New Jersey and New York with regard to code changes is not related to higher wind speed, but to storm surge flooding. The FEMA 2000 guideline for coastal retrofitting suggests that the force of a breaking wave on a building is . (Caraballo 2006). Using an average value of 2.5 for the dynamic pressure coefficient, CW, and ρ g = 62.4pcf = density of water: F = 0.32bh2 where h = height of surge in feet and b = length of wall. Superstorm Sandy had a maximum storm surge of 4.5m (14.63'). A storm surge height of 14.63ft entered into the equation above yields a lateral force of 68.49k per foot of wall length. This is a significantly higher value than lateral forces due to winds. Discussion is ongoing in New Jersey and New York to require homes to be raised 8' above sea level. The problem with this solution is that, as seen in Superstorm Sandy, the surge can be higher than 8ft. This means that flooding will still occur, and great care must be taken not to create a soft story condition when raising the structure. Raising structures creates non-structural problems as well. For example, there is the problem of accessibility: an ADA ramp would require over 120' meaning it would need to wrap back and forth in front of the home or wrap around it.

Figure 4: 2010 Florida Building Code Wind Speed Design Maps for Risk Category 1 (left) and ASCE Risk Category III (right).

THERMAL COMFORT

The vernacular in any given area is a reflection of the building strategies best suited to the climate and the available materials. As a result of global climate change, many areas are already faced with a building stock that does not adequately provide comfort for inhabitants. Many residential buildings throughout the Northeast Corridor were designed in the eighteenth and nineteenth century to protect against cold winters. Small, segregated rooms, low ceilings and a desire for southern exposure defined the northern home. Climatic conditions have changed for this region as has the standard of thermal comfort. ASHRAE 55 defines thermal comfort as that condition in which 80% of the occupants are thermally comfortable. Central air-conditioning, once a luxury to most homeowners has become an industry standard. As a result, occupants perceive a tighter range of temperature as a comfort zone. The air-conditioning dilemma extends to all climatic zones, but is of particular interest in zones that were once temperate but are now or will soon be subtropical.

Homes designed for subtropical climates utilize strategies to deal with the combination of heat and humidity. For example, wrap-around porches provide shaded exterior space which when combined with cupolas or high windows provide natural convection by virtue of a heat stack effect. Dense materials with a high thermal mass do not work well in hot humid areas. In a thermal mass, heat is slowly absorbed during the day and then radiated once the air cools. Because humid air retains heat, evenings are not significantly cooler than daylight hours. A thermal mass radiates heat toward the cooler side, which in a hot humid environment would be the inside. Materials above grade should be light, reflective and thermally non-conductive. Below grade, the earth is a wonderful thermal mass, unless in areas with high levels of radon gas.

Placement of a vapor barrier depends on the thermal gradient through the envelope section. When climatic conditions create extremes in temperature, the thermal gradient reverses direction as shown in Figure 5. Northern homes are typically built with a vapor barrier on the inside or warm side of the insulation. Southern homes should place the vapor barrier on the outside, also the warm side, of the insulation. There is now debate in cities such as Washington, DC about placement of vapor barriers on both sides of the insulation to deal with extremes in temperature.

Temperature extremes affect more than vapor barrier placement. As every good designer knows, mechanical systems should be the last resort to obtaining thermal comfort and IAQ. Following Norbert Lechner's (Lechner 2008) three-tier approach to design, orientation and shading can play key roles in effective heat-avoidance strategies as are reducing the surface-to-volume ratio and utilizing earth mass where possible.

DESIGN THINKING

0The challenge for designers in the new subtropical cities is to change their design thinking. And the demand by clients for justification of every design aspect helps designers to change their thinking. It is easy to employ subtropical strategies out of context, but not so easy when set amidst a vernacular that was designed for a cooler climate. Many cities create historic districts to save the vernacular rather than allowing the vernacular to naturally evolve. Even outside of historic districts, the urban landscape of northern cities is littered with brick-faced row-houses with east-west exposure and dark roofs.

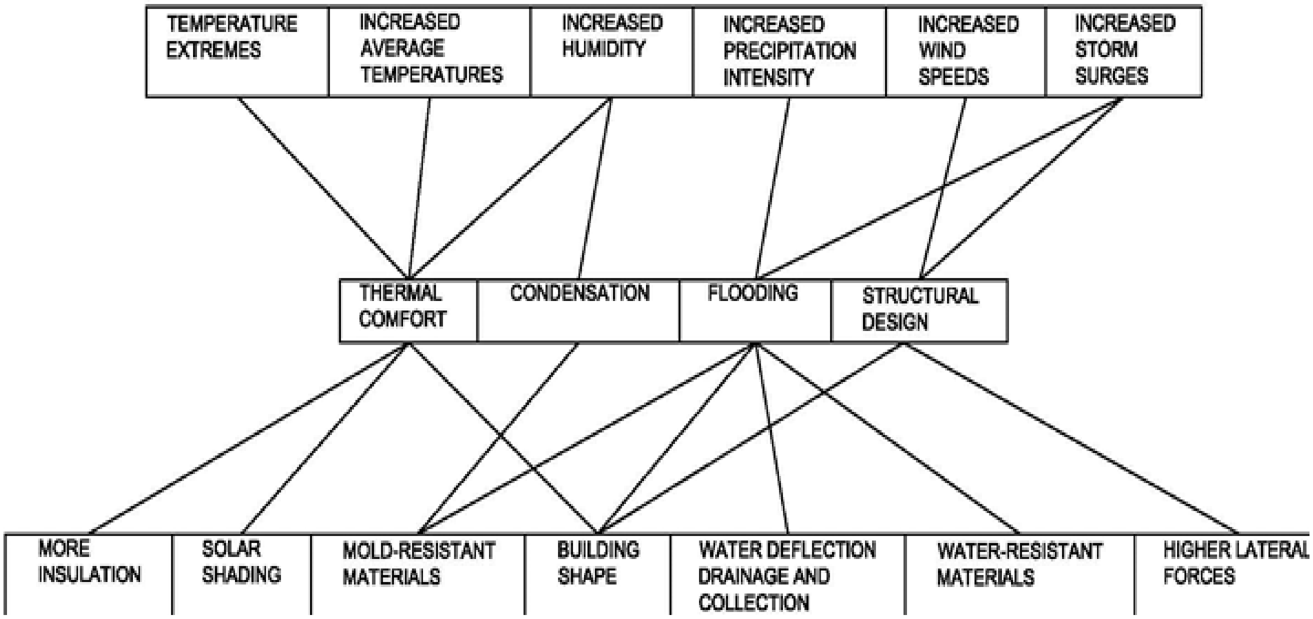


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Figure 5: Correlation between climate change, effects and adaptation strategies

Many designers look to southern cities for inspiration, but often without success. Coastal cities are cooled by the diurnal winds on and off the shore. Yet many cities have allowed dense, high-rise development along the waterfront, inhibiting the cooling effect of the diurnal winds. Others have suburban sprawl littered with paved streets and driveways and dark shingled roofs. The challenge is to find what works and understand why it works.

Expected changes affect specific aspects of design which in turn direct the designer to strategies for adaptation.

For example, higher temperatures justify the use of more expensive glazing with higher R values. Many vendors offer a translucent highly insulated material such as Lumira Aerogel. NASA is currently working on a transparent solid version of Aerogel that could produce a clear single pane glazing with R-20 insulation values. The availability of such a material at a reasonable cost could justify the retrofit of virtually every existing building. Even before this glazing becomes available, triple glazed, gas-filled glazing offers fenestration options with an R-8 insulation value.

Glazing retrofits have already proven a viable strategy for adaptation. The renovations to the Empire State Building in New York rebuilt the glazing in 6514 windows with SeriousGlass Windows to increase from R-2 to an average of R-6.5. At a cost of four million dollars, and an anticipated energy savings cost of $410,000 annually, this is roughly a ten-year payback (Campbell, 2009). The retrofit overall saw a decrease in energy use of 38%.

TEACHING NEW DESIGNERS TO DESIGN FOR THE FUTURE

Climate Change 2007: Mitigation of Climate Change is a report developed by the Intergovernmental Panel on Climate Change Working Group III that analyses how much time until major impacts of climate change are felt and what measures can be taken to avoid climate change. Political denial of climate change, apathy and greed, have slowed efforts toward mitigation. If climate change is a certainty, it is the responsibility of educators to prepare students for this change.

In the architecture school, preparation for change includes stressing passive strategies and requiring all design work to meet progressively stringent sustainable benchmarks throughout the curriculum. Teaching students to design for the worst case scenario of present and predicated future conditions, and not minimum building code standards should be a given. Teaching students to think creatively in order to find viable solutions to new problems of limited resources and extreme environmental conditions, while adapting to constantly changing technologies and socio-economic trends, should be an obligation. We can no longer afford to allow our students to mindlessly design glass boxes. The conceptual, contextual and spatial strategies of design must holistically develop a sustainable solution for the intended user.

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