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Challenging Conventional Wisdom in the Age of Computing

Khaled A. Mansy[1]

[1] Oklahoma State University, Stillwater (USA)

Abstract

This paper examines what might be referred to as the "Designer's Conventional Wisdom". In both practice and academia, some designers still follow what they consider to be well-established design recommendations to make buildings more energy efficient by responding to site-specific sun angles and climate. Among the early schematic design recommendations are some that address building massing and orientation. In terms of building massing, it is advised to design rectangular buildings that spread from east to west; the longer the building is the more energy efficient it is. In terms of orientation, it is advised to orient the building to north and south rather than to east and west. In order to protect windows from the sun, overhangs should be used to protect south-facing glass, while vertical fins should be used for glass facing east and west. Nowadays, with the availability of powerful design-assisting tools, such as energy modeling computer programs, it is imperative that we examine the validity and/or accuracy of such conventional wisdom. This paper takes office buildings in the US as a case study in examining the aforementioned design recommendations grandfathered into design until our current time. The paper will examine the sensitivity of performance to such recommendations at different climatic zones within the United States.

Keywords: *Energy performance, energy efficiency, energy simulation, eQuest, orientation, xternal shading devices, evidence-based design, design-assisting tools*

1. The Problem

During the early stages of design, architects rely on their basic design knowledge to find simple answers to design problems. When it comes to considering building performance during the early schematic design stages, a certain set of generic design recommendations is often used (refer to the list below). Such recommendations belong to an inherited body of knowledge that was passed on from generation to generation and from master to apprentice. They gained the trust of today's architects because of the long time they have been in use. This is what might be referred to as the "Designer's Conventional Wisdom". In academia, in most cases, the same inherited knowledge is currently being passed on from design faculty to students. Examples of such performance-related design recommendations are:

1. West is the worst orientation. Use smaller windows on west compared to east (Autodesk, 2018).
2. Orient rectangular buildings to north and south, not to east and west (Mazria, 1979).
3. The longer the building (east to west) is, the more energy efficient it is.

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4. Differently oriented walls need different kinds of shading devices. Use external shading devices to shade windows. On the south side, use overhangs. On east and west, use vertical fins (Olgyay and Olgyay, 1957) and (Grondzik and Kwok, 2014).
5. For better performance, apply as many energy-saving measures as possible.

A real concern regarding the use of this Designer's Conventional Wisdom is the fact that it is still being passed on to architecture students unquestioned as inherited without being verified using readily-available advanced design-assisting tools. This paper aims to examine the validity and accuracy of such widely-used initial design recommendations taking advantage of government-validated energy simulation computer programs.

2. Methodology

The paper employs energy simulation of a simple office space to test the "performance sensitivity" to each single design recommendation under question. An energy model is built for a single perimeter thermal zone that represents a typical office space. Hourly simulation, using eQuest 3.64, is run for the model when facing eight different orientations (North, NE, East, SE, South, SW, West, and NW) once with no protection of windows, then with twelve design variations of external shading devices (Figure 1). For each simulation, performance sensitivity (to the two aforementioned design variables, i. e., orientation and external shading) is documented in terms of its Energy Use Index (EUI) in KBtu/sf.yr. The tabulated results (EUI values) are then used to assess the validity and accuracy of each of the design recommendations under question.

In each climate zone, besides the baseline for comparison (no external shading), the twelve tested design variations of external shading devices are (1) overhangs with protection factors of 0.20, 0.35, 0.50, and 1.00, (2) vertical fins with protection factor of 0.20, 0.35, 0.50, and 1.00, and (3) egg-crate with protection factors of 0.20, 0.35, 0.50, and 1.00 (Figure 1).

3. Energy Simulation

Energy performance of an office space, that is 15-ft (4.5 M) deep middle bay on a middle floor, is tested in three different climate zones. From the eight climate zones established by the International Code Council (ICC) (Figure 2), the energy model is tested in three representative cities that represent the warmest, the coldest, and a middle point in bewteen within the continental United States. Miami, Florida, represents hot climate, Los Angeles, California, represents temperate climate, and Fairbanks, Alaska, represents cold climate. Future research may cover all eight climate zones. Refer to Table 1 for locations and climatic data of the eight cities representing climate zones within the USA.

The energy model is customized per climate zone according to the "Building Envelope Requirements" in Chapter 4 (CE) of the International Energy Conservation Code (IECC 2015). Refer to Table 2 for the IECC climate-specific building envelope requirements for commercial buildings. In each of the three tested climate zones, the exterior wall of the model is linked to a construction type of the maximum allowed U-factor in such climate zone. In terms of fenestration requirements, glass ratio is 40% of the gross above-grade wall area; assuming daylight responsive control. The window is linked to a glass type of the performance properties required by code for 0.2 Protection Factor (PF), while facing SEW (South, East, West). Although the code allows higher Solar Heat Gain Coefficient (SHGC) under greater PF and when facing north, in order to maintain consistency of the results by testing one variable at a time, only one SHGC value is used in each climate zone, regardless of the PF and orientation. Glass Visible Transmittance (VT) is kept to the code minimum at 1.1 x SHGC. All other input data into the energy model represent a typical office space in compliance with applicable codes (IECC), ASHRAE standards, and common practice. Occupancy is 200 SF/Person, heat gain from occupants is 250 Btuh sensible + 105 Btuh latent heat per person, required fresh air is 5.0 CFM/Person + 0.06 CFM/SF (ANSI/ASHRAE Standard 62.1-2016), illumination level is 25 fc, thermostat temperature is 72 ºF (22.2 ºC) in the summer and 70 ºF (21.1 ºC) in the winter, light load is 0.98 W/SF (IECC, 2015), equipment load is 1.3 W/SF, working hours are 9:00 am – 5:00 pm (Standard Time), equipment maintain thermostat temperature 8:00 am – 6:00 pm, mechanical equipment is an air-to-air heat pump with an economizer, and no heat recovery. Simulation is run for twelve months with US typical holidays using TMY3 weather files.

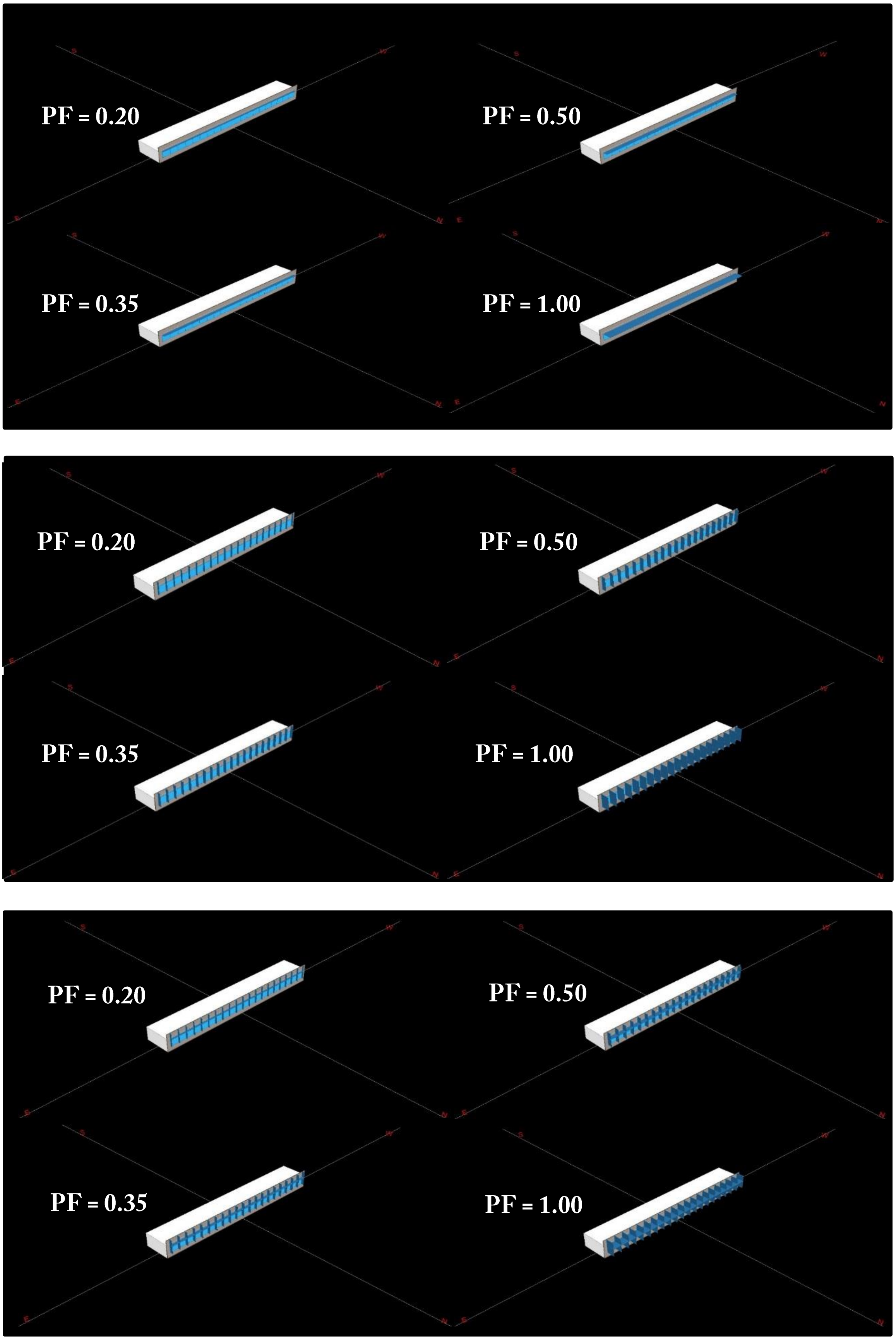

Fig 1: The twelve tested design variations of external shading devices. Three groups of (1) overhangs, (2) vertical fins, and (3) egg-crate

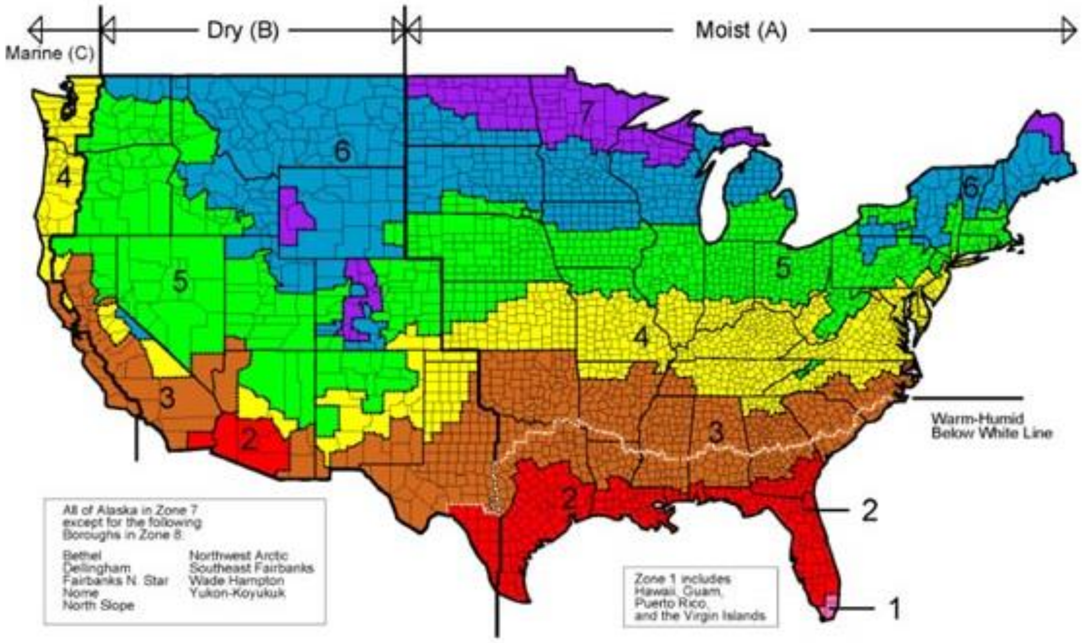

Fig 2: Climate zones, according to International Energy Conservation Code 2015

Table 1: Location and climatic data of the eight reference cities of climate zones within the USA

	Climate Zone	City	State	Latitude (degrees)	Longitude (degrees)	Elevation (ft)	Time Zone (hr)	HDD65	CDD50
1A	Hot, Humid	Miami	Florida	25.80	80.30	12	-5	200	9,474
2B	Hot, Dry	Phoenix	Arizona	33.43	112.02	1,110	-7	1,350	8,425
3B	Warm, Dry	Los Angeles	California	33.93	118.38	100	-8	1,458	4,777
4B	Mild, Dry	Albuquerque	New Mexico	35.05	106.62	5,326	-7	4,425	3,908
5B	Cold, Dry	Denver	Colorado	39.77	104.87	5,286	-7	6,020	2,732
6B	Cold, Dry	Helena	Montana	46.60	112.00	3,893	-7	8,031	1,922
7	Very Cold	Duluth	Minnesota	46.83	92.18	1,428	-6	9,818	1,536
8	Extremely Cold	Fairbanks	Alaska	64.82	147.87	436	-9	13,940	1,010

Table 2: Building envelope requirements per climate zone (commercial buildings)

	Climate Zone	City	State	Ext. Wall U-Factor (max)	Glass U-Factor (max)	Glass SHGC (max)			Glass VT (min)		
						PF<0.2	0.2<PF<0.5	0.5<PF	PF<0.2	0.2<PF<0.5	0.5<PF
1A	Hot, Humid	Miami	Florida	0.077	0.500	0.250	0.300	0.400	0.275	0.330	0.440
2B	Hot, Dry	Phoenix	Arizona	0.077	0.500	0.250	0.300	0.400	0.275	0.330	0.440
3B	Warm, Dry	Los Angeles	California	0.064	0.460	0.250	0.300	0.400	0.275	0.330	0.440
4B	Mild, Dry	Albuquerque	New Mexico	0.064	0.380	0.400	0.480	0.640	0.440	0.528	0.704
5B	Cold, Dry	Denver	Colorado	0.064	0.380	0.400	0.480	0.640	0.440	0.528	0.704
6B	Cold, Dry	Helena	Montana	0.064	0.360	0.400	0.480	0.640	0.440	0.528	0.704
7	Very Cold	Duluth	Minnesota	0.064	0.290	0.450	NR	NR	0.495	NR	NR
8	Extremely Cold	Fairbanks	Alaska	0.045	0.290	NR	NR	NR	NR	NR	NR

4. Performance Results

After performing energy simulation, all needed performance data are generated and tabulated in terms of the Energy Use Index (EUI). The performance of the case study office space is documented in Appendices 1, 2, and 3, which show the performance of the baseline (no protection) and the twelve variations of external shading. With the help of this dataset, it is possible to look carefully into the performance sensitivity to both of the orientation and the design of external shading devices in the three selected climate zones.

4.1. Performance in Hot Climate

In Miami, Florida, the sun is high in the sky almost all year long. Climate is hot with mild winters. Performance is dominated by the high need for cooling, with almost no need for heating, especially during working hours. In reference to simulation results for Miami (Appendix 1), the following conclusions can be drawn:

- Worst orientation is SW at EUI of 35.87 KBtu/sf.yr for windows without external shading (Table 3). SW remains to be the worst orientation even with external shading devices. However, SW is not significantly higher than SE and South. A deep overhang or egg-crate diminishes the effect of orientation on performance since EUI becomes almost flat regardless of orientation.
- Rectangular buildings facing north and south are more efficient than buildings facing east and west (Table 4). However, it is worth mentioning that the E&W orientation is only 5.8% higher than N&S without shading devices and can be up to 8.1% in case of deep vertical fins (PF = 0.5).
- Facing all orientations, overhangs are more effective than vertical fins; with potential energy savings of 16.85% in case of very deep overhangs (PF = 1.0). The only exception is with very deep vertical fins facing north and northeast.

Table 3: EUI of the perimrter office space in KBtu/sf.yr and relative to the index (north-facing)

Miami, FL

	South	SW	West	NW	North	NE	East	SE	South
Baseline (no protection)	35.60	35.87	34.33	32.20	30.00	32.60	35.07	35.60	35.60
Relative to index	1.187	1.196	1.144	1.073	1.000	1.087	1.169	1.187	1.187
% Higher than index	18.67%	19.56%	14.44%	7.33%	0.00%	8.67%	16.89%	18.67%	18.67%
		highest			index				

Los Angeles, CA

	South	SW	West	NW	North	NE	East	SE	South
Baseline (no protection)	28.27	28.20	27.20	24.53	22.27	24.44	26.60	27.73	28.27
Relative to index	1.269	1.266	1.222	1.102	1.000	1.098	1.195	1.246	1.269
% Higher than index	26.95%	26.65%	22.16%	10.18%	0.00%	9.76%	19.46%	24.55%	26.95%
	highest				index				

Fairbanks, AK

	South	SW	West	NW	North	NE	East	SE	South
Baseline (no protection)	34.67	35.93	36.60	36.20	36.20	38.13	37.80	35.80	34.67
Relative to index	0.958	0.993	1.011	1.000	1.000	1.053	1.044	0.989	0.958
% Higher than index	-4.24%	-0.74%	1.10%	0.00%	0.00%	5.34%	4.42%	-1.10%	-4.24%
					index	highest			

Table 4: Combined EUI of two perimeter spaces facing two opposite orientations (north & sout, and east & west) in KBtu/sf.yr and relative to the index (index is north-facing with no protection)

	Miami, FL				Los Angeles, CA				Fairbanks, AK			
	N&S	E&W	E&W/N&S		N&S	E&W	E&W/N&S		N&S	E&W	E&W/N&S	
No Protection	32.80	34.70	105.8%		25.27	26.90	106.5%		35.43	37.20	105.0%	
Overhang, PF = 0.20	31.83	33.30	104.6%		24.47	25.87	105.7%		34.90	36.63	105.0%	
Overhang, PF = 0.35	31.20	32.43	104.0%		24.03	25.23	105.0%		34.53	36.30	105.1%	
Overhang, PF = 0.50	30.63	31.63	103.3%		23.57	24.60	104.4%		34.23	36.00	105.2%	
Overhang, PF = 1.00	29.30	30.10	102.7%		22.77	23.17	101.8%		33.83	35.27	104.2%	
Vertical Fins, PF = 0.20	32.37	34.70	107.2%		24.53	26.10	106.4%		35.07	37.03	105.6%	
Vertical Fins, PF = 0.35	31.77	34.27	107.9%		24.07	25.67	106.6%		34.77	36.87	106.0%	
Vertical Fins, PF = 0.50	31.43	33.97	**108.1%**	**Max.**	23.87	25.43	106.6%		34.73	36.87	**106.1%**	**Max.**
Vertical Fins, PF = 1.00	30.37	32.50	107.0%		23.07	24.77	**107.4%**	**Max.**	34.67	36.60	105.6%	
Eggcrate, PF = 0.20	31.53	33.47	106.1%		23.93	25.20	105.3%		34.63	36.57	105.6%	
Eggcrate, PF = 0.35	30.60	32.23	105.3%		23.23	24.33	104.7%		34.33	36.30	105.7%	
Eggcrate, PF = 0.50	29.87	31.23	104.6%		22.73	23.63	104.0%		34.13	36.03	105.6%	
Eggcrate, PF = 1.00	28.87	29.47	102.1%		22.00	22.47	102.1%		34.40	35.73	103.9%	

4.2. Performance in Temperate Climate

In Los Angeles, California, the sun is still relatively high in the sky. Climate is relatively temperate due to proximity to the Pacific Ocean. However, building performance is dominated by cooling with the need of some heating in the winter. In reference to simulation results for Los Angeles (Appendix 2), the following conclusions can be drawn:

- The worst orientation is south at EUI of 28.27 KBtu/sf.yr for windows without external shading (Table 3). South remains to be the worst orientation only in case of not-so-deep overhangs, otherwise SW is the worst for all other variations of external shading.
- Rectangular buildings facing north and south are more efficient than buildings facing east and west (Table 4). However, it is worth mentioning that the E&W orientation is only 6.5% higher than N&S without shading devices and can be up to 7.4% in case of deep vertical fins (PF = 1.0).
- Facing all orientations, overhangs are more effective than vertical fins; with potential energy savings of 16.27% in case of very deep overhangs (PF = 1.0). The only exception is when the building is facing North, NE, and NW where vertical fins become more effective than overhangs.

4.3. Performance in Cold Climate

In Fairbanks, Alaska, the sun is low in the sky almost all year long. The climate is extremely cold and building performance is dominated by heating with much less need for cooling. In reference to simulation results for Fairbanks (Appendix 3), the following conclusions can be drawn:

- The worst orientation is NE at EUI of 38.13 KBtu/sf.yr for windows without external shading (Table 3). NE remains to be the worst orientation except in case of deep fins and egg-crates.
- Rectangular buildings facing north and south are more efficient than buildings facing east and west (Table 4). However, it is worth mentioning that the E&W orientation is only 5.0% higher than N&S without shading devices and can be up to 6.1% in case of deep vertical fins (PF = 0.5).
- Facing all orientations, overhangs are more effective than vertical fins; with potential energy savings of up to 7.69% in case of very deep overhangs (PF = 1.0). The only exception is when the building is facing North, NE, and NW where vertical fins become more effective than overhangs.

5. Conclusions

With the help of the calculated EUI values (Apendices 1, 2, and 3), it was possible to examine the performance sensitivity to both orientation and design variations of external shading and draw climate-specific conclusions, as listed in the following:

1. In terms of worst orientation: In climates dominated by cooling, the worst orientation is the south or SW. In climates dominated by heating, NE is the worst orientation. Here, it is worth mentioning that this result contradicts previous research results in which SE was found to be the worst orientation in climates dominated by cooling (Mansy et al., 1999). Cooling load of a space facing SE may be higher than when facing all other orientations only when the HVAC system is set to respond to the occupied thermostat temperature starting the same time when employees first enter the space (no pre-cooling). In such case, the HVAC system must respond to very high cooling load in the early morning due to sudden change in occupancy coupled with extracting stored heat in space.

2. Assuming no external shading devices, rectangular buildings facing north and south outperform buildings facing east and west in all climates, including climates dominated by heating. However, compared to buildings facing N&S, buildings facing E&W only consume an additional 5.0% to 6.5% in annual energy consumption, which is not as significant as designers may initially assume.

3. Here, it is worth mentioning that when rectangular buildings do not have windows on the short sides, the length of the building has no effect on building performance. In such case, the EUI of the building remains equal to the average EUI of the two opposite sides of the rectangle, regardless of how long the building is. A possible exception would be when the HVAC system is capable of transferring heat between thermal zones facing the two opposite directions (such as closed-loop heat pump systems).

4. The interesting observation is that overhangs outperform vertical fins in all three climate zones when facing all orientations, except the north. EUI values obtained from the simulation clearly show that: (1) overhangs are significantly more effective than vertical fins in hot climates, (2) overhangs are slightly more effective than vertical fins in temperate climates, and (3) both overhangs and vertical fins are somehow effective in cold climate, in which overhangs still outperform vertical fins.

5. Tabulated EUI values clearly make the case for the fact that implementing multiple energy saving measures (to the same building) does not mathematically add up, which is often an interesting subject of discussion with design students. For example, when an overhang results in 2.00% energy saving and a vertical fin saves 1.78%, the egg-crate integrating both together does not save 3.78%, it actually saves 2.67%. Shading the same area of the glass twice does not yield energy savings twice. The same principle is ture in case of applying multiple measures that simultaneously affect the same load component, i.e., solar load component, transmitted load component, internal heat gain component, and outside air load component.

It should be noted that designers should be cautious if they refer to the EUI values generated in this paper. These EUI values apply to a perimeter thermal zone on which enevlope load has the greatest influence. EUI of a complete building that includes a mix of perimeter and internal thermal zones is typically lower. Another precausion is due to using the same HVAC system, an air-to-air heat pump, in all three climates. Air-to-air heat pumps lose efficiency when heating in a very cold climate like Fairbanks, Alaska. Therfore, lower EUI values may be achieved in cold climate when using gas-fired heating equipment.

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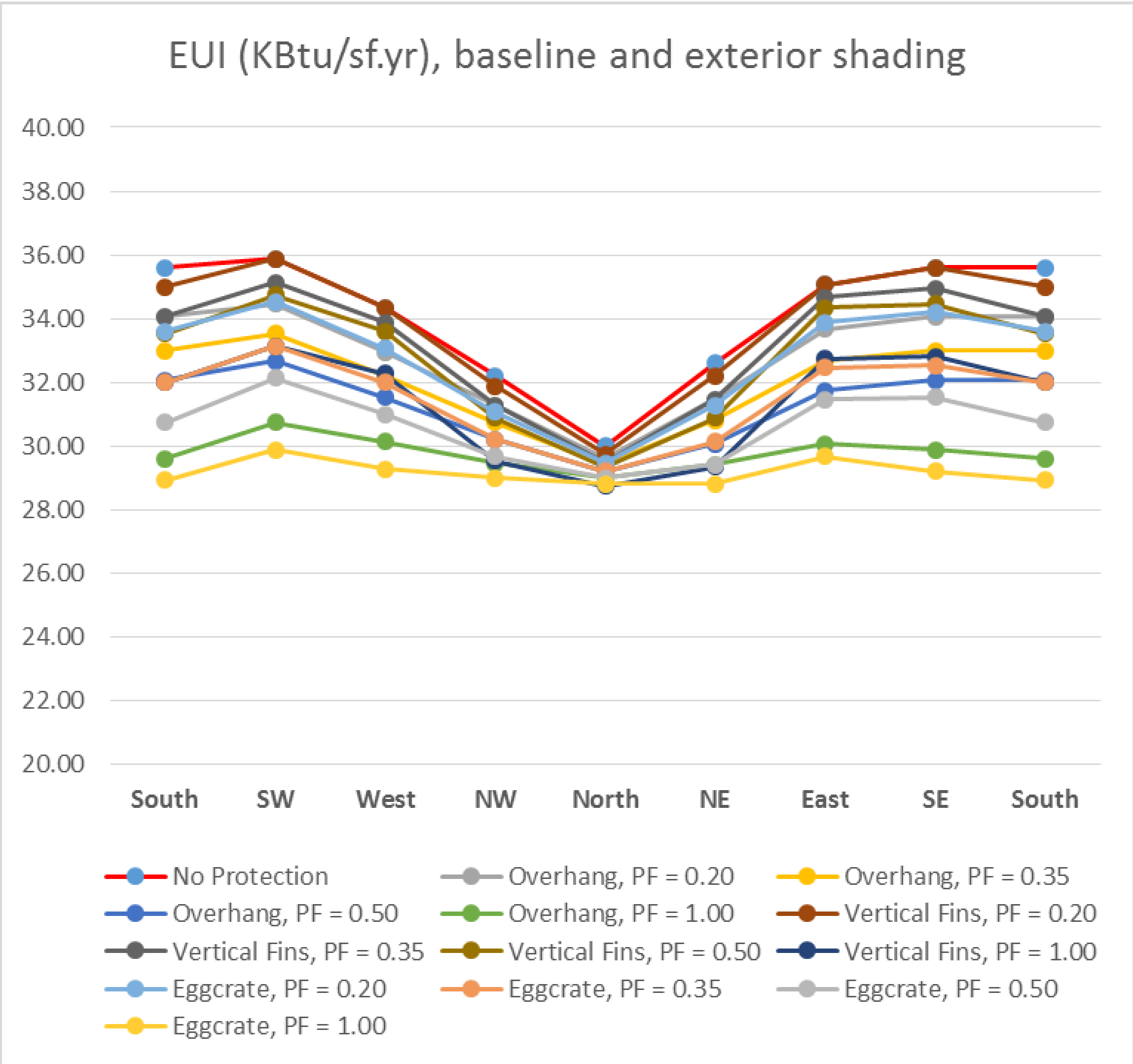
Appendix 1: Dataset for Miami, Florida

Energy simulation results in EUI (KBtu/sf.yr) of the baseline model (no protection) and 12 design variations of external shading devices in Miami, Florida (Climate Zone # 1).

Miami, FL	EUI Per Orientation in KBtu/sf.yr								
	South	SW	West	NW	North	NE	East	SE	South
No Protection	35.60	35.87	34.33	32.20	30.00	32.60	35.07	35.60	35.60
Overhang, PF = 0.20	34.07	34.47	32.93	31.27	29.60	31.47	33.67	34.07	34.07
Overhang, PF = 0.35	33.00	33.53	32.20	30.73	29.40	30.80	32.67	33.00	33.00
Overhang, PF = 0.50	32.07	32.67	31.53	30.20	29.20	30.07	31.73	32.07	32.07
Overhang, PF = 1.00	29.60	30.73	30.13	29.47	29.00	29.40	30.07	29.87	29.60
Vertical Fins, PF = 0.20	35.00	35.87	34.33	31.87	29.73	32.20	35.07	35.60	35.00
Vertical Fins, PF = 0.35	34.07	35.13	33.87	31.27	29.47	31.47	34.67	34.93	34.07
Vertical Fins, PF = 0.50	33.53	34.73	33.60	30.87	29.33	30.87	34.33	34.47	33.53
Vertical Fins, PF = 1.00	32.00	33.13	32.27	29.53	28.73	29.33	32.73	32.80	32.00
Eggcrate, PF = 0.20	33.60	34.53	33.07	31.07	29.47	31.27	33.87	34.20	33.60
Eggcrate, PF = 0.35	32.00	33.13	32.00	30.20	29.20	30.13	32.47	32.53	32.00
Eggcrate, PF = 0.50	30.73	32.13	31.00	29.67	29.00	29.40	31.47	31.53	30.73
Eggcrate, PF = 1.00	28.93	29.87	29.27	29.00	28.80	28.80	29.67	29.20	28.93

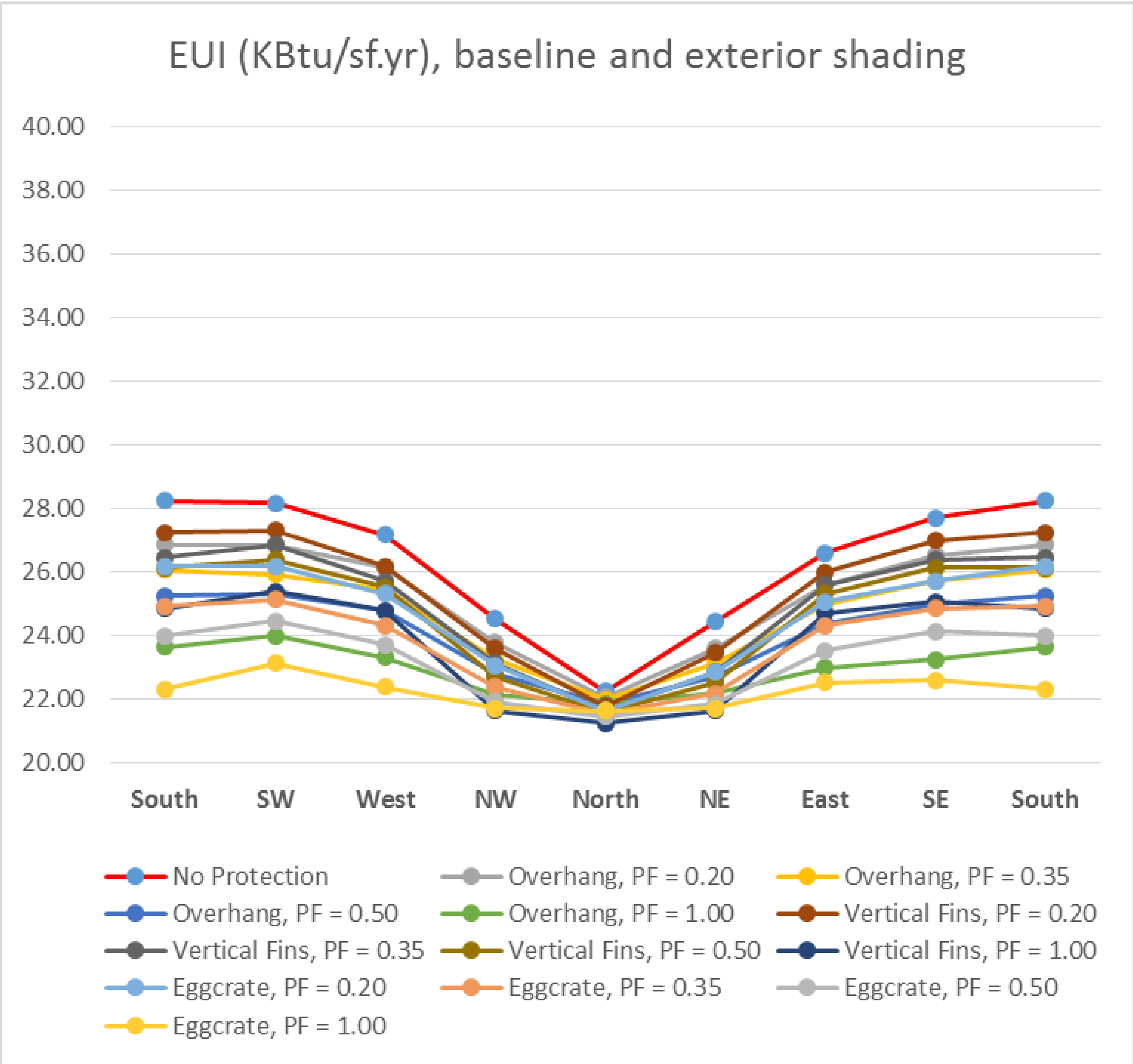


Appendix 2: Dataset for Los Angeles, California

Energy simulation results in EUI (KBtu/sf.yr) of the baseline model (no protection) and 12 design variations of external shading devices in Los Angeles, California (Climate Zone # 3).

Los Angeles, CA EUI Per Orientation in KBtu/sf.yr

	South	SW	West	NW	North	NE	East	SE	South
No Protection	28.27	28.20	27.20	24.53	22.27	24.44	26.60	27.73	28.27
Overhang, PF = 0.20	26.87	26.87	26.13	23.80	22.07	23.60	25.60	26.53	26.87
Overhang, PF = 0.35	26.07	25.93	25.47	23.27	22.00	23.13	25.00	25.73	26.07
Overhang, PF = 0.50	25.27	25.33	24.80	22.80	21.87	22.73	24.40	25.00	25.27
Overhang, PF = 1.00	23.67	24.00	23.33	22.13	21.87	22.20	23.00	23.27	23.67
Vertical Fins, PF = 0.20	27.27	27.33	26.20	23.60	21.80	23.47	26.00	27.00	27.27
Vertical Fins, PF = 0.35	26.47	26.87	25.73	23.13	21.67	22.87	25.60	26.40	26.47
Vertical Fins, PF = 0.50	26.13	26.40	25.53	22.73	21.60	22.53	25.33	26.13	26.13
Vertical Fins, PF = 1.00	24.87	25.40	24.80	21.67	21.27	21.67	24.73	25.07	24.87
Eggcrate, PF = 0.20	26.20	26.20	25.33	23.07	21.67	22.87	25.07	25.73	26.20
Eggcrate, PF = 0.35	24.93	25.13	24.33	22.40	21.53	22.20	24.33	24.87	24.93
Eggcrate, PF = 0.50	24.00	24.47	23.73	21.93	21.47	21.87	23.53	24.13	24.00
Eggcrate, PF = 1.00	22.33	23.13	22.40	21.73	21.67	21.73	22.53	22.60	22.33



Appendix 3: Dataset for Fairbanks, Alaska

Energy simulation results in EUI (KBtu/sf.yr) of the baseline model (no protection) and 12 design variations of external shading devices in Fairbanks, Alaska (Climate Zone # 8).

Fairbanks, AK	EUI Per Orientation in KBtu/sf.yr								
	South	SW	West	NW	North	NE	East	SE	South
No Protection	34.67	35.93	36.60	36.20	36.20	38.13	37.80	35.80	34.67
Overhang, PF = 0.20	33.80	35.20	36.27	35.93	36.00	37.60	37.00	34.87	33.80
Overhang, PF = 0.35	33.13	34.73	36.00	35.80	35.93	37.33	36.60	34.27	33.13
Overhang, PF = 0.50	32.67	34.27	35.80	35.60	35.80	37.07	36.20	33.73	32.67
Overhang, PF = 1.00	32.00	33.33	35.27	35.33	35.67	36.33	35.27	32.60	32.00
Vertical Fins, PF = 0.20	34.27	35.80	36.53	35.87	35.87	37.53	37.53	35.87	34.27
Vertical Fins, PF = 0.35	33.87	35.87	36.47	35.60	35.67	37.33	37.27	35.13	33.87
Vertical Fins, PF = 0.50	33.87	35.93	36.40	35.53	35.60	36.93	37.33	35.13	33.87
Vertical Fins, PF = 1.00	33.87	36.00	36.20	35.40	35.47	36.13	37.00	35.07	33.87
Eggcrate, PF = 0.20	33.53	35.20	36.20	35.67	35.73	37.20	36.93	34.53	33.53
Eggcrate, PF = 0.35	33.00	34.80	36.00	35.53	35.67	37.00	36.60	34.07	33.00
Eggcrate, PF = 0.50	32.80	34.87	35.80	35.40	35.47	36.47	36.27	33.73	32.80
Eggcrate, PF = 1.00	33.13	34.53	35.47	35.60	35.67	35.80	36.00	33.60	33.13