A PARAMETRIC SIMULATION STUDY ON KINETIC ENVELOPES

Julian (Jialiang) Wang, Ph.D.
School of Architecture, Tsinghua University, China
State Key Laboratory of Subtropical Building Science,
South China University of Technology, China
Lawrence Berkeley National Laboratory, Berkeley, CA
Julianwang@lbl.gov

Liliana O. Beltrán, Ph.D., LEED AP.
Department of Architecture, Texas A&M University,
College Station, TX
lbeltran@arch.tamu.edu

Jooghoon Kim
Department of Architecture, Texas A&M University
College Station, TX
jonghoon7kim@gmail.com

ABSTRACT

This simulation study reveals the nature of kinetic envelopes in terms of heating and cooling loads, and compares kinetic models and other three referenced models. This research first selected the small office prototype model created by Pacific Northwest National Laboratory in accordance with the design and construction requirements of 90.1-2010. Second, we used *jEPlus* and *Energyplus* to conduct parametric simulation for the small office prototype model for the selected representative cities related to the different climatic zones in the U.S. Third, we compared the heating and cooling loads. The results showed: 1) Compared to other three referenced models, kinetic technologies significantly reduced heating and cooling loads and peak demands of buildings in the representative climates. 2) Kinetic windows played a more significant role of saving energy than the other elements in the four climates, and the savings were around two times as large as the savings of the highly-insulated glazing.

Key words: building envelopes; building energy; parametric simulation; kinetic properties

1. INTRODUCTION

As interest increases in the area of net zero energy buildings, some studies are focusing on variable envelope components which may greatly impact on indoor environmental performance and building energy usage. These kinetic components are phase-change materials, thermochromatic glazing, automated shadings, and etc. In order to evaluate the potential energy savings of kinetic building envelopes, it is important to conduct a comparative simulation study.

This study utilized a small office prototype model developed by the Pacific Northwest National Laboratory (PNNL). The energy performance was simulated by using *EnergyPlus* v8.0 (released in Apr. 2013). The selected four cities (see Figure 1 and Table 1) represented a range of climates: Houston, TX (Climatic zone number 2A), San Francisco, CA (Climatic zone number 3C), Baltimore, MD (Climatic zone number 4B), and Chicago, IL (Climatic zone number 5A). The purpose of using four climatic conditions was to explore energy saving potentials of kinetic envelopes for different climatic zones relative to other three referenced models.

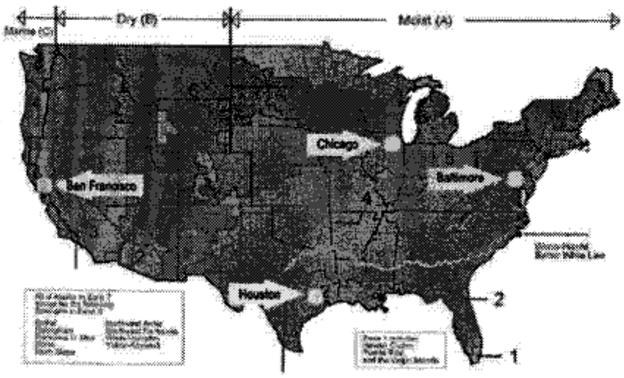

Fig. 1: US climatic zones and their characteristics (ASHRAE, 2011)

TABLE 1: THE SELECTED CITIES AND CLIMATIC ZONES

A: Moist	**B: Dry**	**C: Marine**
2A: Houston	4B: Baltimore	3C: San Francisco
5A: Chicago		

This study compared these hypothetical future features to three models: 1) **Baseline Models** with minimally code compliant -- ASHRAE Standard 90.1-2010 (ANSI/ASHRAE/IES, 2010); 2) **Advanced Models** that used the recommendations in Advanced Energy Design Guides (AEDG) developed by ASHRAE and Technical Support Document (TSD) created by PNNL with 50% energy saving goals compared to ASHRAE Standard 90.1-2004 and 30% energy saving relative to ASHREA Standard 90.1-2010; and 3) **Ultra Models** that might be the next generation of energy-efficient technologies with "ultra" insulation but "static" properties rather than dynamic features. Ultra models' envelope properties comply with or slightly better than the Passive House Guidelines developed by International Passive House Association (iPHA). Some of the dynamic features of Kinetic Models and some highly insulated materials of Ultra Models are still in the hypothetical stage, but they represent technologies that can be realistically developed in a real world in the next decade.

2. MODELING AND SIMULATION PROCESS

2.1 Building Shape and Basic Information of Prototype

This one-floor prototypical small office building (see Figure 2) was developed by DOE. The building model was a rectangular form (90.8 ft. ╳ 60.5 ft. ╳ 10 ft.) with an attic roof. The windows were evenly distributed over the four façades of the model. Table 2 presents more information of the models.

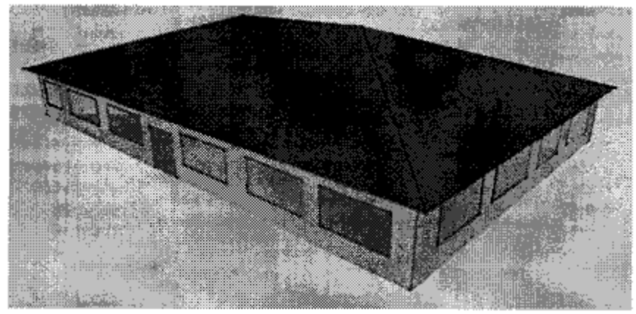

Fig. 2: The prototypical office model based on DOE models (Thorton et al., 2011)

TABLE 2: THE BASIC GEOMETRIC INFORMATION OF THE PROTOTYPICAL MODELS

Total Floor Area (sq. ft.)	5500 (90.8 ft. x 60.5ft)
Aspect Ratio	1.5
Number of Floors	1
Window Fraction (Window-to-Wall Ratio)	24.4% for South and 19.8% for the other three orientations (Window Dimensions: 9.0 ft. x 5.0 ft. punch windows for all façades)
Azimuth	non-directional
Floor to floor height (feet)	10
Floor to ceiling height (feet)	10
Glazing sill height (feet)	3 (top of the window is 8 ft. high with 5 ft. high glass)

2.2 Simulation Methods

The goal of this simulation study was not only to evaluate the whole energy uses, but also to analyze the effects for envelope assemblies, which included the relationships of walls vs. roofs vs. windows, and opaque vs. fenestration. Therefore, at least 60 *EnergyPlus* simulations required for these three reference models of the four climates, which was very time-consuming. Therefore, the reference models developed by PNNL were used as the template IDF input, and then utilized *jEPlus* to run a batch of jobs. As illustrated in Figure 3, a complete *jEPlus* simulation involved multiple steps. The first step was to select the IDF file and the climate data for that IDF file. The second step was to set up parameters related to values of walls' insulation, roofs' insulation, windows' U-factor, SHGC, and text strings for the input of weather files. The third step was to manage parameter trees and input their alternative values that could be inserted in to the IDF file. The last step was to identify the results information what was useful for the next analysis. Thus, by using *jEPlus*, we could compile a single output table containing the useful information from the batch. End-use (heating, cooling, fans, and interior lighting), peak cooling loads, and peak heating loads were selected for the further comparison with kinetic building envelopes.

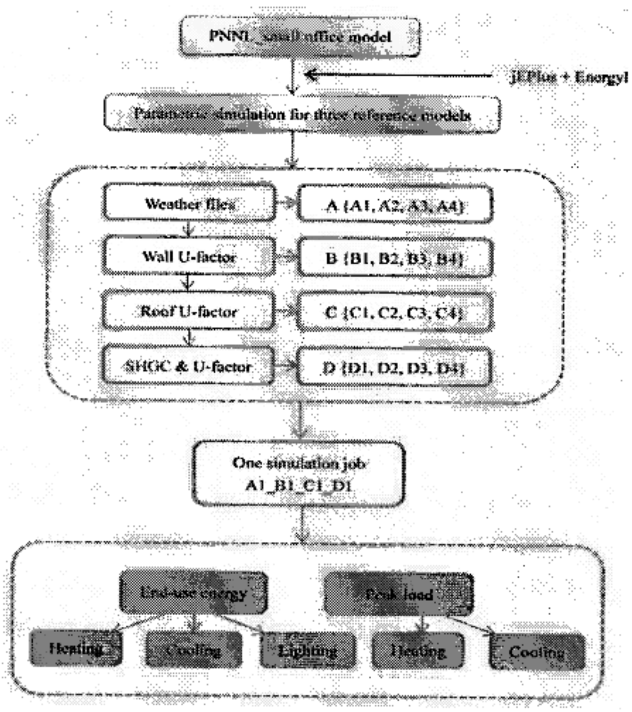

Fig: 3: Parametric simulation of using *jEPlus* and *EnergyPlus* for reference models

2.3 Kinetic Models and Simulation Methods

Kinetic building envelopes had different properties responding to the other stimuli, e.g., outside temperature, indoor temperature, air-conditioning status, etc. These variables were considered as independent variables. With regard to dependent variables, there were four variables in the Kinetic Models: U-factors of opaque components (walls and roofs), U-factors of windows, and SHGC of windows.

We utilized the Energy Management System (EMS) approach of *EnergyPlus* in modeling and simulation for kinetic envelopes. EMS is an advanced application for users who need to write *EnergyPlus* Runtime Language (Erl) for the high-level and supervisory control to override selected aspects of *EnergyPlus* modeling. Therefore, we achieved variable insulation of opaque assemblies and dynamic windows and glazing. The variable insulation of opaque assemblies referred to that the high U-factor 0.089 Btu/h•ft²•°F (0.507 W/m²•K) was used in walls and roofs when the outside temperature was within the comfort zone, and the low U-factor 0.016 Btu/h•ft²•°F (0.091 W/m²•K) was used when the outside temperature was too high or too low. In addition, dynamic windows and glazing meant that the windows had two seasonally-changeable parameters: U-factors and SHGC. The U-factors were changed from 0.1Btu/h•ft²•°F (0.57W/m²•K) to 0.81Btu/h•ft²•°F (4.6W/m²•K), and the values of SHGC ranged from 0.10 to 0.35..

3. RESULTS

Kinetic envelope properties offered significant savings on the annual heating and cooling loads in the four climates, which were 47.2% for the cooling-dominated climate in Houston, 47.9% for mixed-climate in San Francisco, 47.7% and 42.6% for the heating-dominated climate in Baltimore and Chicago respectively in relation to the baseline energy usages, as seen in Figure 4. Even compared to the highly-insulated envelopes, the dynamic features produced relatively large savings, which was about 14.8~20.6% difference between Kinetic Models and Ultra Models for the four cities. Also, the kinetic envelopes dramatically reduced the peak heating loads and the peak cooling loads in the four climates. As seen in Figure 5, compared to the other models, the kinetic envelopes in Kinetic Models reduced the peak cooling loads around 50.4% (Houston) ~79.7% (San Francisco) relative to Baseline Models. The savings percentages of the peak heating loads relative to Baseline Models ranged from 15.3% (Houston) to 83.9% (Baltimore).

TABLE 3: THE SUMMARY OF THE ENVELOPE PROPERTIES OF THE FOUR TYPES OF BUILDING MODELS

Climate Zone		Wall			Roof			Fenestration			
		Assembly U-factor		Equivalent R-value	Assembly U-factor		Equivalent R-value	Assembly U-factor		Assembly SHGC	VT
—		Btu/h • ft² • ° F	W/m² • K	h • ft² • ° F/Btu	Btu/h • ft² • ° F	W/m² • K	h • ft² • ° F/Btu	Btu/h • ft² • ° F	W/m² • K	—	—
Baseline Models											
Houston, TX	2A	0.09	0.51	R-13	0.03	0.16	R-38	0.81	4.60	0.29	0.13
San Francisco, CA	3C	0.09	0.51	R-13	0.03	0.16	R-38	0.50	2.85	0.29	0.20
Baltimore, MD	4B	0.09	0.51	R-13	0.03	0.16	R-38	0.47	2.65	0.43	0.31
Chicago, IL	5A	0.06	0.36	R-13 + R-3.8 c.i.	0.03	0.16	R-38	0.47	2.65	0.43	0.31
Advanced Models											
Houston, TX	2A	0.07	0.42	R-13.0 + R-3.8 c.i.	0.03	0.14	R-38	0.45	2.56	0.25	0.25
San Francisco, CA	3C	0.07	0.42	R-13.0 + R-3.8 c.i.	0.03	0.14	R-38	0.41	2.33	0.25	0.25
Baltimore, MD	4B	0.07	0.37	R-13.0 + R-7.5 c.i.	0.02	0.11	R-49	0.38	2.16	0.26	0.25
Chicago, IL	5A	0.05	0.26	R-13.0 + R-10.0 c.i.	0.02	0.11	R-49	0.35	1.99	0.26	0.25
Ultra Models											
Houston, TX	2A	0.02	0.09	R-75	0.02	0.09	R-75	0.10	0.57	0.10	0.25
San Francisco, CA	3C	0.02	0.09	R-75	0.02	0.09	R-75	0.10	0.57	0.10	0.25
Baltimore, MD	4B	0.01	0.07	R-90	0.01	0.07	R-90	0.10	0.57	0.10	0.25
Chicago, IL	5A	0.01	0.07	R-90	0.01	0.07	R-90	0.10	0.57	0.35	0.25
Kinetic Models											
Houston, TX	2A	0.01~0.09	0.07~0.5	R-13~R-90	0.01~0.09	0.07~0.5	R-13~R-90	0.10~0.81	0.57~4.60	0.10~0.35	0.25
San Francisco, CA	3C	0.01~0.09	0.07~0.5	R-13~R-90	0.01~0.09	0.07~0.5	R-13~R-90	0.10~0.81	0.57~4.60	0.10~0.35	0.25
Baltimore, MD	4B	0.01~0.09	0.07~0.5	R-13~R-90	0.01~0.09	0.07~0.5	R-13~R-90	0.10~0.81	0.57~4.60	0.10~0.35	0.25
Chicago, IL	5A	0.01~0.09	0.07~0.5	R-13~R-90	0.01~0.09	0.07~0.5	R-13~R-90	0.10~0.81	0.57~4.60	0.10~0.35	0.25

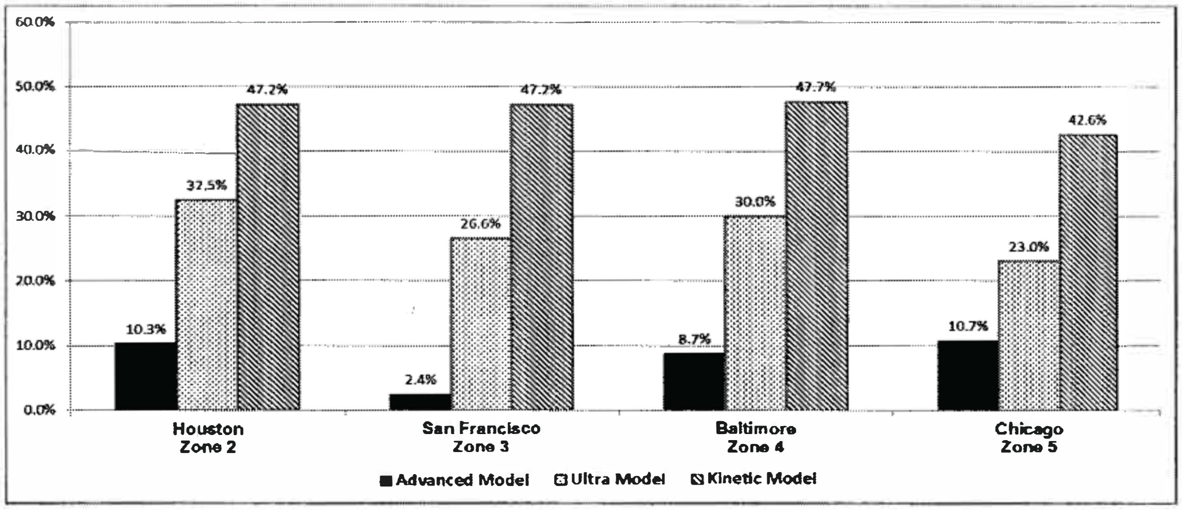

Fig: 4: Savings percentages of the annual heating and cooling loads on a basis of Baseline Models

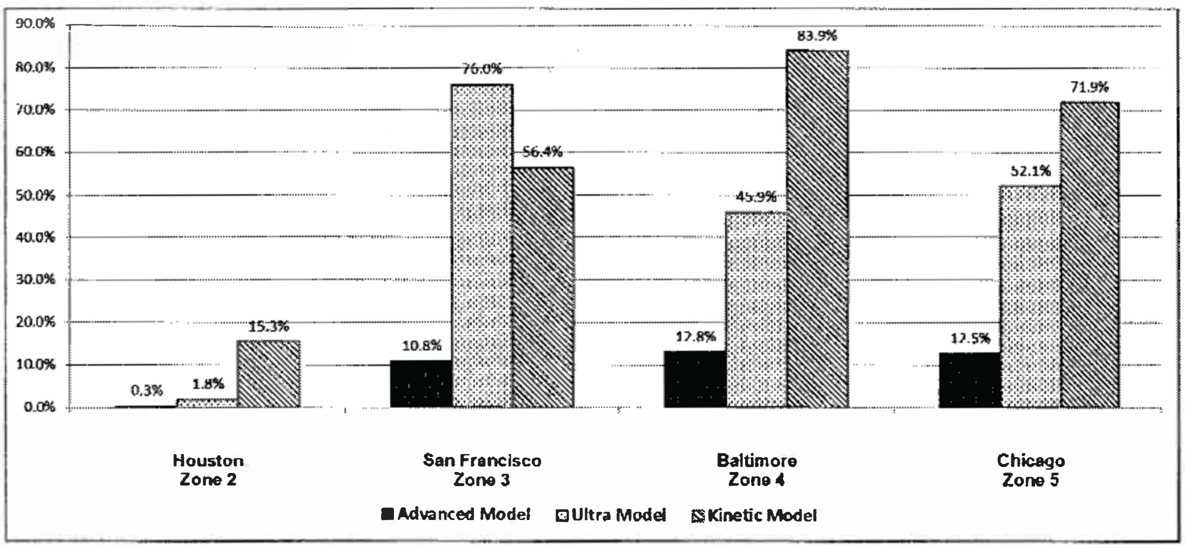

Fig. 5: Savings percentages of peak heating loads on a basis of Baseline Models

4. ACKNOWLEDGMENTS

Partial funding for this research was provided by the State Key Laboratory of Subtropical Building Science Open-End Fund (No. 2013KA01) and the Young Scientist Fund of National Natural Science Foundation of China (No. 51208275).

5. REFERENCES

(1) ANSI/ASHRAE/IES. (2010). *ANSI/ASHRAE/IESNA 90.1-2010, Energy standard for buildings except low-rise residential buildings*. Atlanta, GA: ASHRAE Press

(2) ASHRAE. (2011). *Advanced energy design guide for small to medium office buildings.* Atlanta, GA: ASHRAE Press

(3) Thorton, B.A., Rosenberg, M.I., Richman, E.E., Wang, W., Xie, Y., Zhang J., Cho, H., Mendon, V.V., Athalye, R.A., Liu, B. (2011). *Achieving the 30% goal: Energy and cost savings analysis of ASHRAE standard 90.1-2010.* Richland, WA: PNNL Press