Relationships Between Variables and Energy Consumption in Different Building Types

Ju Chan Kim[1], Jonathan Salter[2], Ronald Kellett[2] and Cynthia Girling[2]

[1]University of British Columbia
Vancouver, Canada
juchankim.kor@gmail.com

[2]University of British Columbia
Vancouver, Canada
{jsalter, rkellett,
cgirling}@sala.ubc.ca

ABSTRACT

Cities and municipalities have set energy and greenhouse gas (GHG) emissions reduction targets in attempts to manage energy consumption and mitigate climate change. Numerous variables, that vary significantly across climates and design options impact energy consumption in the building sector. It is important to understand the relationships between these variables to reduce energy consumption and GHG emissions. This paper describes ongoing research showing the potential of a parametric simulation approach with regression analysis to investigate and compare relationships among building design variables and energy consumption by building type in the Vancouver region of British Columbia, Canada.

Author Keywords

Energy simulation; parametric simulation; regression analysis

ACM Classification Keywords

I.6. SIMULATION AND MODELING; G.3 Correlation and regression analysis

1 INTRODUCTION

Energy and climate change have been significantly elevated among important global urban planning issues. Many municipalities have set energy and greenhouse gas (GHG) emission targets in attempts to manage energy consumption and mitigate climate change [8]. In parallel, municipalities seek capacity to simulate energy and emissions at urban scales, in combination with measures of land use, transportation and quality of life.

Buildings contribute up to 30% of global GHG emissions and consume approximately 40% of global energy [8]. In 2009, the energy consumed in residential buildings was 17% of total energy used nationwide and released 15% of total GHG emissions in Canada [6].

The United Nations Environment Programme (UNEP) acknowledges the potential of the building sector to reduce GHG emissions to achieve the emissions reduction targets of municipalities and recommends the building sector should be prioritized as a key to reaching emission targets successfully [8]. Because buildings have a long lifespan, operating energy exceeds embodied energy in most cases [1]. Most countries have developed or adopted policies and standards to regulate and encourage reduction in operating energy in the building sector.

Numerous variables, that vary significantly across climates and design options, impact energy consumption in the building sector. Analyzing these variables can help policy makers effectively address energy and emissions reductions and help users make beneficial decisions. Studies have been conducted in different parts of the world looking into these variables [3, 7]. For example, in Canada, only 1% of total energy was used for space cooling and 63% of energy was used for space heating in the residential sector in 2009 [6]. Unfortunately, these studies show limitations in generalizability. They investigated variables in a local context, making results difficult to generalize because of variances in building type, climate, location, etc., which create a unique environment for each case and its use of energy. This paper proposes a method to evaluate variables and predict consequences reflecting local contexts more efficiently by conducting parametric simulations and regression analysis [2].

This paper is a preliminary part of a project investigating effective strategies to reach energy and emissions targets in different types of urban form. Identifying key variables in the built environment for different building types and climate conditions will provide important guidance towards establishing those strategies. We conducted parametric simulations using EnergyPlus and regression analysis to investigate the impacts of different variables on building energy consumption and relationships between and among those variables. Results from the later phase of the project will aid industry professionals and governments to make informed planning and design decisions.

2 METHODOLOGY

Parametric energy simulations were conducted by using EnergyPlus and jEplus. The reference building models (Section 2.2) were simulated parametrically by changing input variables (Section 2.1) in fixed increments while the remaining variables were held constant. To be more time efficient, regression analysis was implemented after the

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simulations to predict the results that are not simulated. Phases in the research included the following steps: determining the input variables; setting the reference building models; running the energy simulations; collecting the simulation results; and running the regression analyses.

2.1 Determine Variables

The US Department of Energy (DOE) has categorized the input variables of building energy models by program, form, fabric, and equipment (Table 1) [5]. The variables investigated in this research are: U-value of exterior wall, roof and windows; infiltration rate; lighting; and equipment efficiency (Table 2).

Program	Form	Fabric	Equipment
Location	Number of floors	**Exterior walls**	**Lighting**
Total floor area	Aspect ratio	**Roof**	HVAC system types
Plug and process loads	Window fraction	Floors	Water heating equipment
Ventilation requirements	Window locations	**Windows**	Refrigeration
Occupancy	Shading	Interior partitions	**Component efficiency**
Space environmental conditions	Floor height	Internal mass	Control settings
Service hot water demand	Orientation	**Infiltration**	
Operating schedules			

Table 1. Building energy model input categories

This paper focuses on fabric and equipment variables which could be regulated and controlled by codes and standards. Other variables will be studied in the later stage of the research.

The ranges and distributions for each input variable are summarized in Table 2. These ranges were determined by observing typical buildings built prior to the 1970s when there were no energy efficiency requirements and new construction with strict energy efficiency requirements - the Passive house standard.

Exterior wall

The reference models assigned insulation materials as "Material:NoMass" in EnergyPlus. Therefore, thermal resistance values of insulation were changed instead of changing the thickness in order to have equivalent results of changing U-values.

Roof / attic floor

Thermal resistance values of insulation in roofs were controlled for high-rise apartment, strip mall and primary school types. Thermal resistance values of attic floors were controlled for single-family detached house and multi-family low-rise apartment types.

Window

To overcome the limitations in controlling the U-value of windows in EnergyPlus, "WindowMaterial: SimpleGlazingSystem" was used. Solar Heat Gain Coefficient (SHGC) and visible transmittance (VT) values were fixed to 0.426 and 0.308 respectively – the default of the ASHRAE 90.1 reference model - when controlling the U-values.

Infiltration rate

The "AirChanges/Hour" method was used for "Design Flow Rate Calculation Method" to control the infiltration rate of zones for reference models in EnergyPlus.

	Variables	**High-rise apartment**	**Single-family detached house**	**Multi-family low-rise apartment**	**Strip mall**	**Primary school**
		Input values				
Exterior wall	Thermal resistance of insulation [m2K/W]	[0.6:0.5:6.1] *	[0.1:0.5:6.1]	[0.1:0.5:6.1]	[0.6:0.5:6.1]	[0.6:0.5:6.1]
Roof / attic floor	Thermal resistance of insulation [m2K/W]	[0.6:0.5:6.1]	[0.1:0.5:6.1]	[0.1:0.5:6.1]	[0.6:0.5:6.1]	[0.6:0.5:6.1]
Window	U-value [W/m2K]	[0.8:0.5:5.8]				
	Solar Heat Gain Coefficient (SHGC)	[0.01:0.1:0.99]				
Infiltration rate	ACH rate for zones [ACH]	[0.1:0.5:4.6]	[0.1:0.25:2.35]	[0.1:0.5:4.6]	[0.1:0.5:4.6]	[0.2:1.0:9.2]
Lighting	Lighting power density (LPD) [W/m2]	[1.0:2.0:13.0]				
Equipment efficiency	Boiler efficiency [%]	[50.0:10.0:90.0]				
	Gas heater efficiency [%]					

* [A:B:C] indicates the range of input value is from A to C with increments of B

Table 2. The summary of range of input values modelled

2.2 Reference Building Models

The Pacific Northwest National Laboratory (PNNL) developed prototype building models that comply with ASHRAE Standard 90.1 baselines and the International Energy Conservation Code (IECC) [9]. These models are representative of 80% of buildings constructed in the U.S. which represent 65% of the total building energy consumption. Five of those building types (high-rise apartment, single-family detached house, multi-family low-rise apartment, strip mall and primary school) were used as reference building models in this study (Table 2), more building types will be considered in the future.

2.3 Run energy simulations

EnergyPlus and jEplus [10] were used for this study because a later stage of the research uses the Urban Modelling Interface (UMI) which utilizes EnergyPlus. jEplus automates parametric simulations by batch simulating the EnergyPlus Input Data Files (IDF).

2.4 Assumptions and Limitations

The reference prototype building models do not contain models for the Vancouver (British Columbia, Canada) region, therefore, the Seattle (Washington, U.S.) models with Vancouver weather data were used for the simulations. Effects of thermal mass are not accounted for because we used “Material:NoMass” for envelope constructions and “WindowMaterial:SimpleGlazingSystem” for windows. Calculated U-values may differ from those in compliance with the local energy efficiency codes because the recommended R-values of inside/outside air film varies and simulation tools treat them differently. This paper assumes the reference building models represent the buildings in Vancouver. The method does not currently account for complex interactions between input variables. This will be addressed in future iterations.

3 SIMULATION RESULTS

349 simulations were carried out for this research, and regression analyses were conducted to predict the results of every input values.

3.1 Regression Analysis

The annual end uses of electricity and natural gas were used as the dependent variables and the input variables (Section 2.1) as independent variables for the regression analysis. Figure 1 shows a summary of the relationship between variables and the annual energy end use, as well as their regression equations. Only selected cases of the total end uses are presented for illustrative purposes. All R^2 values exceeded 0.94 meaning the selected regression equations fit the data well. The wall and roof U-values correlate with the end use energy by a linear relationship except for the primary school model. All other variables correlate by a quadratic relationship.

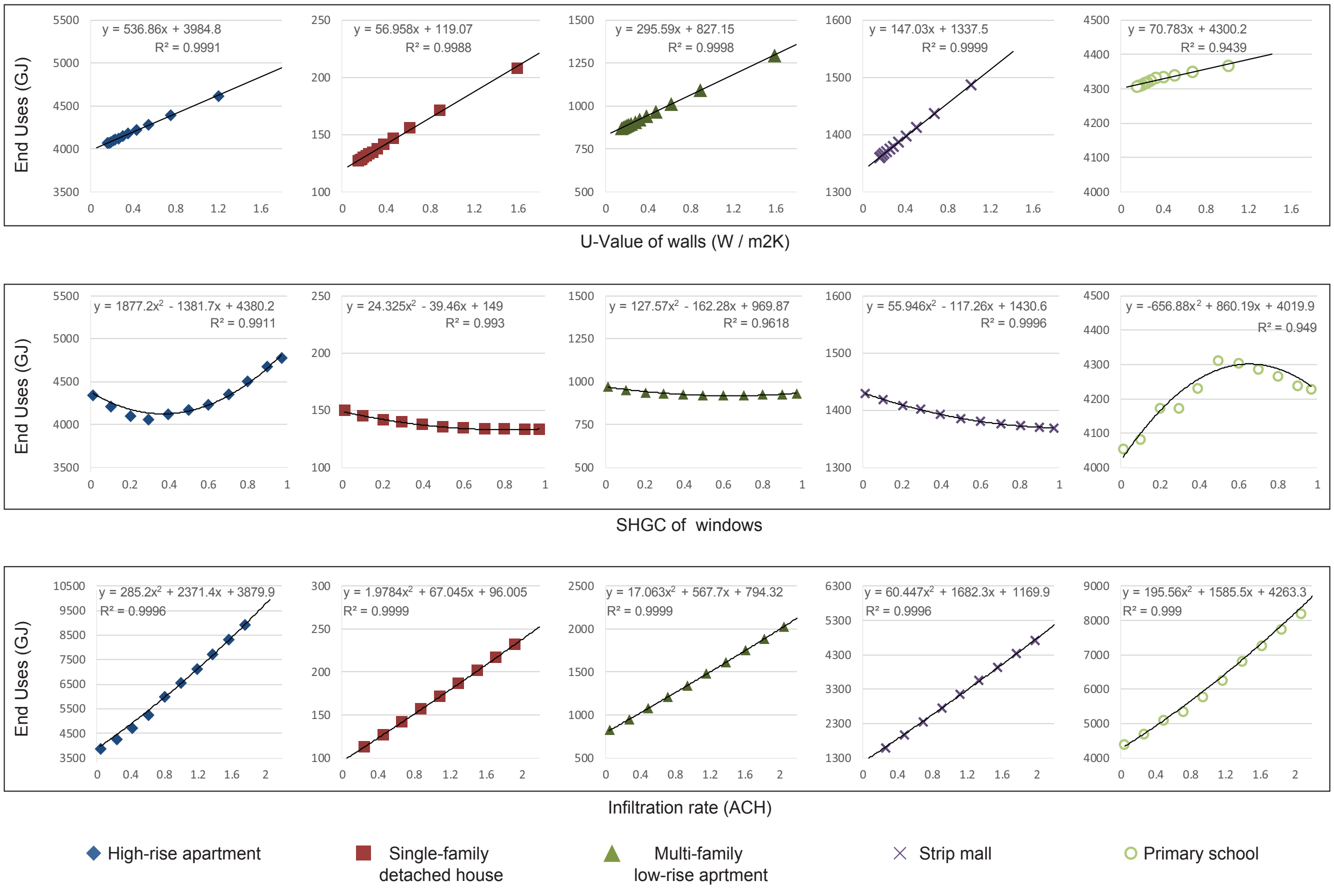

Figure 1. Selected summary of regression analysis

4 CONCLUSION AND FUTURE RESEARCH

The results of this study show that, in residential building types, U-values of exterior wall, roof and windows had significant impact on energy consumption, while in strip mall and primary school types they had less. The SHGC value of windows had a non-linear relationship with the end use energy in all buildings suggesting the importance of windows with the appropriate SHGC for different building types. Among the variables tested, infiltration rate had the highest impact on the end use energy for all building types, particularly for large building types (high-rise apartment, primary school, and strip mall) (Figure 2). This demonstrates significant potential savings on energy and emissions from large buildings if effective policy and practices could be developed to address infiltration in the existing building stock. Preliminary results from a study conducted in the Prince George region of British Columbia suggest that this is more pronounced in less temperate climates common across Canada.

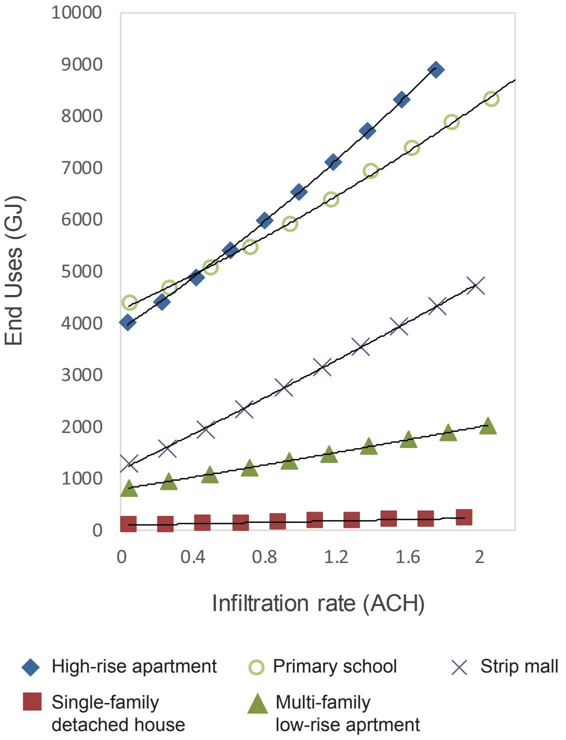

Figure 2. Relationship of infiltration rate and end uses

Current National Energy Code of Canada for Buildings (NECB) or ASHRAE 90.1 standard do not specify the requirements by different building types by climate zones. An accurate understanding of the variables that are most important to different building types could help us adjust regulations and building codes by building type to better realize large energy and emissions savings.

This study shows the potential of a parametric simulation approach with regression analysis to investigate and compare relationships among building design variables and energy consumption. In future work, more building types in other locations across British Columbia will be simulated to make the data representative of different local contexts and a diverse building stock. The end goal of this research is to aid development of effective strategies to reach energy and emissions targets in different types of urban forms and in different climate conditions.

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