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#### Investigating different modeling techniques for quantifying heat transfer through building envelopes

Sodiq Akande

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# Investigating different Modeling techniques for quantifying Heat Transfer through Building Envelopes Author: Sodiq Akande Committee Members: Dr. Mohammad Moin Uddin, Dr. Keith Johnson & Thomas Horan, P.E. Department of Engineering Technology, College of Business and Technology



#### DEPARTMENT of

**ENGINEERING TECHNOLOGY** 

College of Business & Technology

EAST TENNESSEE STATE UNIVERSITY

# ABSTRACT

There is an interest concerning the energy performance of buildings in the United States. Buildings, whether residential, commercial or institutional, generally underperform in terms of energy efficiency when compared to buildings that are constructed following sustainably and energy efficiency standards. A substantial percentage of energy loss in these buildings is associated with the thermal efficiency of its envelope (exterior walls, windows roof, floors and doors). The objective of this study will evaluate the results of three energy modeling techniques developed to investigate the energy transfer through the envelope of existing campus buildings. The techniques employed are solving the heat transfer calculations using spreadsheets, using a stand-alone modeling software (OpenStudio) and using an integrated building energy modeling software (eQuest) employed in AutoDesk® Revit. The first technique is the application of a mathematical methodology employing heat transfer algorithms entered into the spreadsheet's cells to estimate the heat transfer through the building envelope. The OpenStudio technique involves a 3D representation of the building which implores a front-end software (SketchUP) to sketch out the building geometry. The building operational and thermal features was assigned to the building geometry in the OpenStudio interface. The engine runs an energy simulation of the building and provides detailed information on the building energy performance. The last technique uses AutoDesk® Revit software to create the building geometry and also perform building energy analysis. The process is somewhat similar to the OpenStudio technique; the main difference is the level of detail and limitation provided by both energy modeling engine (eQuest vs EnergyPlus). It is hypothesized that by the end of this study, the best technique for investigating the building envelope for this study is expected to be the Spreadsheet technique because of it's usage simplicity and the fact that, the scope of the project at hand requires less input parameters to generate the required output.

Keywords: Energy modeling, Building envelope, R- value, Building Energy simulation, Heat transfer.

# INTRODUCTION

**Energy modeling is the use of software to predict the energy** usage of a building. Energy modeling permits design decisions, material choices, equipment selections and retrofits to be effectively made to reduce energy consumption and demand while there is still time to affect the design. Energy model began in **1925 using the Response Factor Methods (RFM) to calculate the** heat flow of a model. Technological advancements in computer hardware and software, has led to the development of numerous modeling methods. It is important to know the right technique needed to determine the most efficient output for a project, so that the time spent performing the calculation balances the possible improvements in efficiency.

### **Energy Modeling Techniques**

- . Engineering calculation methodologies using calculators, spreadsheets (Excels)
- Simulation engines using computer software's such as Open-Studio (EnergyPlus), Revit (eQuest).

This study focus on using three energy modeling techniques to quantify the energy transfer through building envelope (Wall, Windows, Roof) of a campus building (Wilson Wallis Hall).

different methods

### **ELEMENTS OF A BUILDING ENVELOPE**

- (LAS, 2017)

		,			V	Vinter								
Interior Temp		70,00	70.00	70,00	70.00	70.00	70,00	70,00	70.00	70.00	70,00	70,00	70.00	70.00
Hours of Occ	8760.00	0.00	0.00	0.00	0.00	0.00	0,00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Range		-10.000	-5.000	0.000	5.000	10.000	15.000	20.000	25.000	30.000	35.000	40.000	45.000	50.000
Range		-5.001	-0.001	4.999	9.999	14.999	19.999	24.999	29,999	34.999	39,999	44.999	49.999	54.999
Ext Temp		-7.50	-2.50	2.50	7.50	12.50	17.50	22.50	27.50	32.50	37.50	42.50	47.50	52.50
Change in Tem	np	77.50	72.50	67.50	62.50	57.50	52.50	47.50	42.50	37.50	32.50	27.50	22.50	17.50
						Summe	er							
Interior Ter	np		75.00	75.00	75.0	0 75	.00	75.00	75.00	75.00	75	.00	75.00	75.00
Hours of Oc	ci 8	3760	0.00	0.00	0.0	0 0	.00	0.00	0.00	0.00	0	.00	0.00	0.00
Range			0.001	5.001	10.00	1 15.0	001	20.001	25.001	30.001	35.0	001	40.001	45.001
Range			5.000	10.000	15.00	0 20.0	000	25.000	30.000	35.000	40.0	000	45.000	50.000
Ext Temp			2.50	7.50	12.5	0 17	.50	22.50	27.50	32.50	37	.50	42.50	47.50
Change in T	emp		72.50	67.50	62.5	0 57	.50	52.50	47.50	42.50	37	.50	32.50	27.50
1				_		_	-				-		-	

Wall (Components)	R-
4 in Brick	
Air Gap	
8 in Block	
Total R-value	
Total U-Value(Watt/SqmK)	
	-

### Building dimensions were used to compute the surface area of the building envelope elements.



induction through the glazing spacer bars

r leakage around opening lights & frame

induction through the window frame

## **STUDY OBJECTIVES**

. Evaluate heat transfer through building envelope using three

. Establish the most effective method to quantify the heat transfer through building envelope for similar future projects.

#### Wall

About **35%** of heat loss in a building escapes through the walls and through the gaps (Greenage, 2014)

**Fenestration (Doors and Windows)** 

An average home loses up to **30%** of its heating and cooling energy through air leakage around windows and doors

Roof

**25%** of heat is loss through the roof (Greenage, 2014)

# **METHODOLOGIES**

• Spreadsheet Method of quantifying Heat Transfer

 Annual weather dataset of the building geographical site(TMY3) downloaded from United State Department of Energy (USDOE) datasets to estimate the exterior temperature.

• Average hourly dry bulb temperature was sorted into 5bins . "COUNT IF" function in Excel used to tally the total hours (23

bins) that ADB temperature fell in each 5° bins.

. Interior temperature was established to be 70F during the winter (blue) and 75F during the summer.

. Thermal Resistivity value (R-value) of each building envelope materials were acquired from the design values table of the **ASHRAE Fundamentals handbook** 

. Coefficient of Heat transfer (U-value) for the building envelope was computed by using the equation U=1/R

-value(SqmK/\	Natt)	Window		Roof(Com	ponents)	R-value(Sqmk	(/Watt)	
0.130256		Window Type	DblLoEClr	Roof Merr	ibrane 4	<mark>0.059375</mark>		
0.15		Total U-value(Watt/SqmK)	1.785	Roof Insulation		4.295918367		
0.169066				Lightweig	ht Concrete	0.191698113		
0.449322				Total R- va	lue	4.546991481		
2.225575423				Total U-va	lue(Watt/SqmK)	0.219925637		

ea (sqft)					
21.16					
17.01					
9					
9.17					
orth	South	East	West		
102.06	338.56	526.9	451.02		
170.1		374.22	340.2		
18		272.16			
290.16	338.56	1173.28	791.22	2593.22	
1949.496	2076.12	2519.436	2519.436		
2111.954	2249.13	2729.389	2729.389		
1063.188		1079.004	1079.004		
5124.638	4325.25	6327.829	6327.829	22105.55	
25189.80332					

# **METHODOLOGIES (CONTD)**

### . The OpenStudio (EnergyPlus) method of quantifying heat transfer through building envelope

### **SketchUP Interface**

- . SketchUP tools was used for drawing building model
- . "Select Attribute "tool was used to assign space attributes
- . Window to Wall Ratio was used for window fenestration





- Weather data file of the building location was imported to properly estimate the exterior temperature
- . Building materials were downloaded from OpenStudio
- **Building Component Library (BCL) to make construction set** Elements of building envelope (wall, Window, Roofs) were designed according to the physical and thermal properties of
- the building
- . Run simulation

File	Preferences Components & Measures Help							
	Site Weather File & Design Days Life Cycle Costs	Utility	r Bills					
	Weather File Change Weather File							
II	Name: Bristol Tri City Airport							
画	Latitude: 36.47							
	Longitude: -82.4							
	Elevation: 457							
(1)	Time Zone: -5							
-	Download weather lifes at www.energyplus.gov							
6								
	Maagura Taga (Optional)							
	reasure rags (optional).							
	ASHRAE Climate Zone 4A		¢					
-	CEC Climate Zone 4		\$					
~	Design Days Import From DDY							
16	Design Days				_			
52				184	<i></i>			
5	Date Temperature Humidity Pre-	essure Vind ipitation	Solar	Custom	]			
~	Design Day Name	All						
0				Day Of	Month			
				Apply to	Selected			
	Bristol Tri City Airport Ann Clg ,4% Condns DB=>MWB			21				
	Bristol Tri City Airport Ann Clg .4% Condns DP=>MDB		5	21				
	Bristol Tri City Airport Ann Clg .4% Condns Enth=>MDE			21				
	Bristol Tri City Airport Ann Clg ,4% Condns WB=>MDB			21				

Image Showing the weather data file and climate zone

East Tennessee State University, Johnson City, TN, USA.

Wilson Wallis Hall, ETSU (*Render by Surface Type*)

Wilson Wallis Hall, ETSU (*Render by Boundary Condition*)

#### **OpenStudio Interface**



### **METHODOLOGIES (CONTD)**

Ext wai	Thesis Exterior Wall
Interior Ceiling	Measure Tags (Optional):
Interior Door	
	Intended Surface Type: Standards Construction Type:
	Exterior Wall Mass Fenestration Type: Fenestration Assembly Context:
Interior Partition	<b>*</b>
Interior Window	Fenestration Number of Panes: Fenestration Frame Type:
Roof	Fenestration Divider Type: Fenestration Tint:
Thesis Floor	Fenestration Gas Fill: Fenestration Low Emissivity Coatin
Thesis GLass Door EXT	Laver:
Thesis Interior Wall	Outside
Thesis Exterior Wall	Brick - Fired Clay - 4 in BCL 110 lb/ft3
Drag From Library	F04 Wall air space resistance 1
	Concrete Block - 8 in 105 lb/ ft3 - Solid

Sample Wall Construction in OpenStudio Interface

### **Quantifying Heat Tranfer through building envelope using** Autodesk Revit Computer program.

- . Standalone energy modeling technique
- Building model was drawn using the Revit Architectural tools
- . The "edit type" tool was used to associate thermal **&physical properties to the building element**
- . "Space type and zone" tool was used to assign spaces and thermal zone respectively
- Weather data file of the building location was imported to properly estimate the exterior temperature
- . Energy model was created



### **3D Model of Wilson Wallis hall in Autodesk Revit**

pe Properties							
Family: System Family: Basic Wall							
Type: Thesis Wall							
Type Parameters							
Parameter	Value						
Construction	1						
Structure	Edit						
Wrapping at Inserts	Do not wrap						
Wrapping at Ends	None						
Width	1' 0 13/128"						
Function	Exterior						
Graphics							
Coarse Scale Fill Pattern							
Coarse Scale Fill Color	Black						
Materials and Finishes							
Structural Material	Brick, Common						
Analytical Properties							
Heat Transfer Coefficient (U)	2.2339 W/(m <sup>2</sup> ·K)						
Thermal Resistance (R)	0.4476 (m²·K)/W						
Thermal mass	21.5013 BTU/°F						
Absorptance	0.700000						
Roughness	3						
Identity Data							
Tuno Imago							
<< Preview	ОК						

Modification of Physical and Thermal properties of a wall in Revit



## OUTPUTS

### **Microsoft Excel Spreadsheet computation result**

	Wall	Window	Roof	Change in Temp (DegF	Hours of Occurrence	Q(Wall)	Q(Window)	Q(roof)
J-Value (Btu /HSQF/°F)	0.392209	0.314567	0.038757	77.5005	0	0	0	0
Area(sf)	16069	2581	25190	72.5005	0	0	0	0
				67.5005	7	2977907.523	383624.4374	461300.65
				62.5005	21	8271970.244	1065624.069	1281391.454
Heat transfer can be calculat	ed using the equ	uation. (Q) = UA	Α ΔT Η	57.5005	66	23917827.75	3081178.022	3705054.438
				52.5005	164	54264207.49	6990504.542	8405940.745
0 - Vast transfor				47.5005	260	77835497.6	10027040.38	12057313.85
Q - rical transier				42.5005	271	72588781.68	9351140.126	11244557.43
A= Heat transfer area				37.5005	535	126443648.1	16288911.92	19587088.11
4T-T			32.5005	625	128019532.5	16491922.85	19831204.66	
	e(12-11)			27.5005	588	101911711	13128622.2	15786903.45
U= Heat Transfer coefficien	t			22.5005	610	86502404.79	11143541.6	13399884.06
II-II				17.5005	764	84265536.97	10855380.48	13053376.13
— H= Hour of Occurrence				17.5005	848	93530334.23	12048903.99	14488564.08
				12.5005	982	77365092.54	9966441.155	11984444.51
				7.5005	1157	54692748.84	7045710.735	8472325.078
				2.5005	693	10921097.15	1406893.84	1691761.472
				2.4995	578	9105151.086	1172957.332	1410457.538
				7.4995	475	22450814.22	2892192.222	3477802.824
				12.4995	112	8823011.406	1136611.114	1366751.944
				17.4995	5	551444.5153	71039.0065	85422.97278
				22.4995	0	0	0	0
				27.4995	0	0	0	0
					Heat Transfer	1044438720	134548240	161791545.4
					Total Heat Transfer (BTU)	1340778505		

#### **OpenStudio simulation result**

Annual Building Sensible Heat Gain Components



	HVAC Zone Eq & Other Sensible Air Heating [GJ]	HVAC Zone Eq & Other Sensible Air Cooling [GJ]	HVAC Terminal Unit Sensible Air Heating [GJ]	HVAC Terminal Unit Sensible Air Cooling [GJ]	HVAC Input Heated Surface Heating [GJ]	HVAC Input Cooled Surface Cooling [GJ]	People Sensible Heat Addition [GJ]	Lights Sensible Heat Addition [GJ]	Equipment Sensible Heat Addition [GJ]	Window Heat Addition [GJ]	Interzone Air Transfer Heat Addition [GJ]	Infiltration Heat Addition [GJ]	Opaque Surface Conduction and Other Heat Addition [GJ]	Equipment Sensible Heat Removal [GJ]	Window Heat Removal [GJ]	Interzone Air Transfer Heat Removal [GJ]	Infiltration Heat Removal [GJ]	Opaque Surface Conduction and Other Heat Removal [GJ]
THERMAL ZONE 1	15.425	-3.344	0.000	0.000	0.000	0.000	11.138	50.116	17.173	1.192	0.000	0.005	0.000	0.000	- <mark>2.2</mark> 13	0.000	-51.127	-38.365
THERMAL ZONE 2	1.155	-1.813	0.000	0.000	0.000	0.000	<u>39.62</u> 7	172.934	<u>59.892</u>	13.312	0.000	0.000	0.000	0.000	-6.882	0.000	-138.501	-139.724
THERMAL ZONE 3	111.606	-0.094	0.000	0.000	<mark>0.000</mark>	0.000	36.026	159.058	55.638	21.280	0.000	0.007	0.005	0.000	-9.472	0.000	-315.774	- <mark>58.276</mark>
Total Facility	128.186	-5.251	0.000	0.000	0.000	0.000	86.791	382.108	132.704	35.784	0.000	0.012	0.005	0.000	-18.567	0.000	-505.403	-236.365

	Window Heat Addition [GJ]	Opaque Surface Conduction and Other Heat Removal [GJ]	Window Heat Removal [GJ]	Opaque Surface Conduction and Other Heat Addition [GJ]
THERMAL ZONE				
1	1.192	-38.365	-2.213	0
THERMAL ZONE				
2	13.312	-139.724	-6.898	0
THERMAL ZONE				
3	21.28	-58.276	-9.578	0
Total Facility	35.784	-236.365	-18.69	0
1 GJ = 94	7817 Btu; 1 Btu = 1.0	DE-6 GJ		
eat Transfer(BTU)	33916683.53	-224030765.2	-17714699.73	0
tal Heat Loss (BTU)	241745464.9			

#### Autodesk Revit simulation result

AUTODESK° GREEN BUILDING STUDIO My Profile My Account My Projects Dashboards My Project

ly Projects >	Thesis Revit 3					
Run List	Run Charts	Project Defaults	Project Details	Project Members	Utility Information	Weather Station

A	Actions -															
											Total Annual Cost <sup>1</sup>			Total Annual Energy <sup>1</sup>		
	Name	Date	User Name	Floor Area (ft²)	En	ergy Use Intensi (kBtu/ft²/year) (	ty Electric	: Cost /kWh)	Fuel Cost (/Therm)	Electric	Fuel	Energy	Electric (kWh)	Fuel (Therm)	Carbon Emissions (tons)	
Project Default Utility Rates														Weathe		
	Project Default Utility Rates							\$0.10	\$0.87			-				
_	Base Run	2/0/2010 11:50 414	ala dava 001	47.042		200	0	50.40	60.07	637.663	634 663	652.224	260.247	20.467		
	Alternate Run(s) of Thesis Revit 3	3/8/2018 11:59 AM	oladayo001	17,943		209	.9	\$0.10	\$0.87	\$27,002	\$24,002	\$52,324	269,347	28,407		
	Thesis Revit 3 ASHRAE 90 1-2010	3/8/2018 12:00 PM	oladavo001	17 943		131	2	\$0.10	\$0.87	\$22 074	\$14 044	\$36 117	214 933	16 210		
-	WWP Northern Walls 05% Window	5101201012.00111	chaddy oco i	11,040	101.2		.2		00.07	922,014	014,044	000,111	214,000	10,210		
	Shades - North_No change Window Glass Types - North_No change	hades - North_No change Window Glass /pes - North_No change		17,943	221.6		.6	\$0.10	\$0.87	\$29,957	\$25,821	\$55,778	291,697	29,804		
	WWR - Northern Walls_95% Window Shades - North_No change Window Glass Types - North_Sgl Clr	3/8/2018 12:00 PM	oladayo001	17,943	245.1		.1	\$0.10	\$0.87	\$33,031	\$28,586	\$61,617	321,625	32,996	-	
	WWR - Northern Walls_95% Window Shades - North_No change Window Glass Types - North_Dbl Clr	3/8/2018 12:00 PM	oladayo001	17,943		224.8		\$0.10	\$0.87		\$26,184	\$56,596	296,124	30,224		
	WWR - Northern Walls_95% Window Shades - North_No change Window Glass Types - North_Dbl LoE	s 3/8/2018 12:00 PM oladayo001 17,94		17,943	215.7		.7	\$0.10	10 \$0.87		\$25,123	\$54,335	284,446	28,998		
	WWR - Northern Walls_95% Window Shades - North_No change Window Glass Types - North_Trp LoE	rrn Walls_95% Window n_No change Window Glass Trp LoE 3/8/2018 12:00 PM oladayo001 17,943			208.0 \$0.10		\$0.10	\$0.87	\$27,972	\$24,284	\$52,256	272,364	28,030			
	WWR - Northern Walls 95% Window															
w	R - Eastern Walls 30% V 3/8/201	8 12:00 oladayo00	17,943	208.7	\$0.10	\$0.87	\$27,635	\$24,492			5	\$52,127		269,0	85 28,271	
w	R - Eastern Walls_30% V 3/8/201	8 12:00 oladayo00	17,943	210.1	\$0.10	\$0.87	\$27,764	\$24,676			Ş	\$52,439		270,3	36 28,482	
/w	R - Eastern Walls_30% V 3/8/201	8 12:00 oladayo00	17,943	212.5	\$0.10	\$0.87	\$28,030	\$24,966			Ş	\$52,997		272,9	33 28,818	
w	R - Eastern Walls 30% V 3/8/201	8 12:00 oladayo00	17,943	210.4	\$0.10	\$0.87	\$27,805	\$24,708			5	\$52,512		270,7	38 28,520	
/WR - Eastern Walls 30% V 3/8/2018 12		8 12:00 oladayo00	17,943	209.4	\$0.10 \$0.87 \$27		\$27,723	\$24,579		\$52,302			269,945		45 28,371	
w	R - Eastern Walls 30% V 3/8/201	8 12:00 oladavo00	0 17.943 2		\$0.10	\$0.87	\$27.616	\$24,542			\$	\$52,158		268.9	00 28.328	
/WR - Eastern Walls 0% W 3/8/2018 12:00		8 12:00 oladayo00	17 9/12	210	\$0.10 \$0.87 \$		\$27,629	\$24,690		\$52,200		\$52 219	269,000		28 28 499	
	1 Lastern Wans_0/0 - W - 5/6/201	0 12.00 Oldday000	17,040	210	φ0.10	90.07	<i>421,023</i>	<i>92</i> <del>7</del> ,050				02,020		50 20/ 0	5/	
	$1 \frac{1}{2} \frac{1}{2} \frac{1}{1} $								Tatal	-			17104	00,004,2	07	
		1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	1 - 34	12.14	10331	ム / プサ D	DI UIT		Total	energy	Transt	er (BIU	1/191	8229212.	07	

 $1 \text{ kWh} = 3412.14163312794 \text{ BTU}_{\text{IT}}$ 

**HYPOTESIZED CONCLUSION** 

It is hypothesized that the most efficient method for this study according to the scope of the study is the spreadsheet computation technique because

- requires less input parameter
- . does not require complex formula
- . requires less computation and generates faster and accurate outputs
- . supportes dynamic updating of input parameters without delaying output.