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Investigating different modeling techniques for quantifying heat transfer through building envelopes

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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 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 OpenStudio (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).

STUDY OBJECTIVES

- Evaluate heat transfer through building envelope using three different methods
- Establish the most effective method to quantify the heat transfer through building envelope for similar future projects.

ELEMENTS OF A BUILDING ENVELOPE

Wall

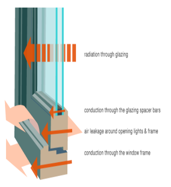
- About 35% of heat loss in a building escapes through the walls and through the gaps (Greenage, 2014)

Fenestration (Doors and Windows)

- An average home loses up to 30% of its heating and cooling energy through air leakage around windows and doors (LAS, 2017)

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.

		Winter												
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 Temp		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

		Summer									
Interior Temp		75.00	75.00	75.00	75.00	75.00	75.00	75.00	75.00	75.00	75.00
Hours of Occ	8760	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Range		0.001	5.001	10.001	15.001	20.001	25.001	30.001	35.001	40.001	45.001
Range		5.000	10.000	15.000	20.000	25.000	30.000	35.000	40.000	45.000	50.000
Ext Temp		2.50	7.50	12.50	17.50	22.50	27.50	32.50	37.50	42.50	47.50
Change in Temp		72.50	67.50	62.50	57.50	52.50	47.50	42.50	37.50	32.50	27.50

- 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 $U = 1/R$

Wall (Components)	R-value(SqmK/Watt)	Window		Roof(Components)	R-value(SqmK/Watt)
4 in Brick	0.130256	Window Type	DblLoEClr	Roof Membrane 4	0.059375
Air Gap	0.15	Total U-value(Watt/SqmK)	1.785	Roof Insulation	4.295918367
8 in Block	0.169066			Lightweight Concrete	0.191698113
Total R-value	0.449322			Total R- value	4.546991481
Total U-Value(Watt/SqmK)	2.225575423			Total U-value(Watt/SqmK)	0.219925637

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

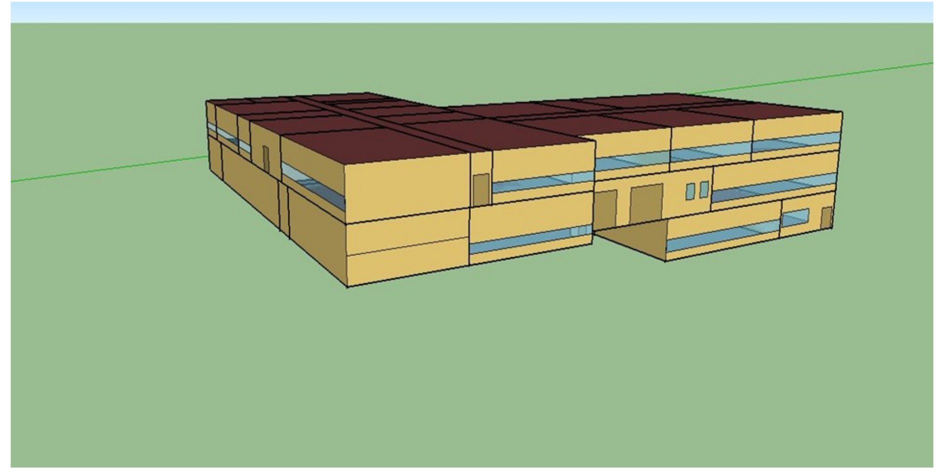
Window Type	Area (sqft)				
81	21.16				
82	17.01				
83	9				
84	9.17				
	North	South	East	West	
Window (Area)					
Second Floor	102.06	338.56	526.9	451.02	
First Floor	170.1		374.22	340.2	
Basement	18		272.16		
Total	290.16	338.56	1173.28	791.22	2593.22
Wall (Area)					
Second floor	1949.496	2076.12	2519.436	2519.436	
First Floor	2111.954	2249.13	2729.389	2729.389	
Basement	1063.188		1079.004	1079.004	
	5124.638	4325.25	6327.829	6327.829	22105.55
Roof (Total Area)					
	25189.80332				

METHODOLOGIES (CONTD)

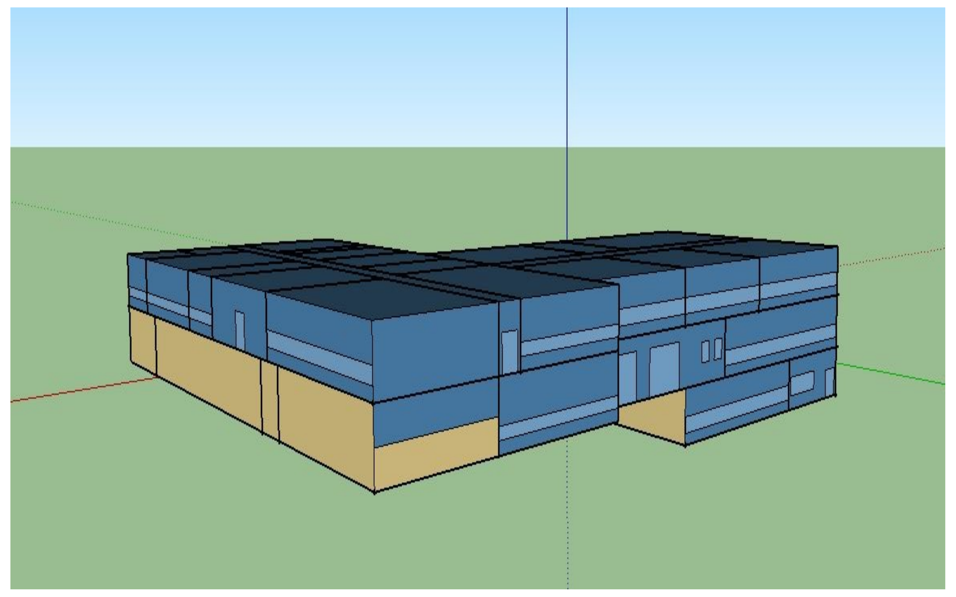
- The OpenStudio (EnergyPlus) method of quantifying heat transfer through building envelope

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



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



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

OpenStudio Interface

- 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

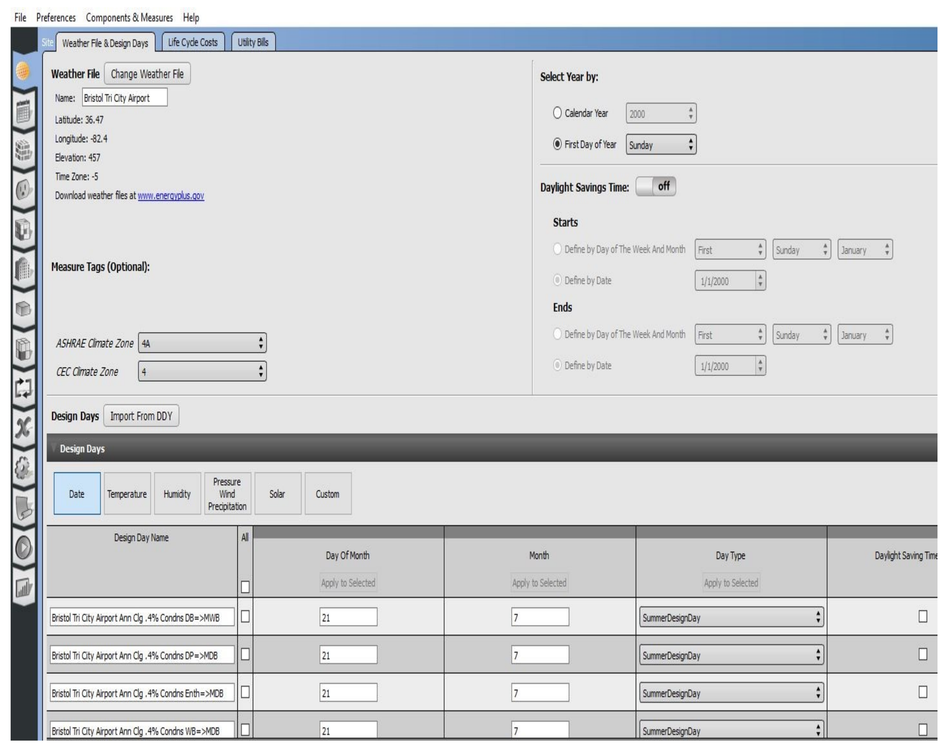
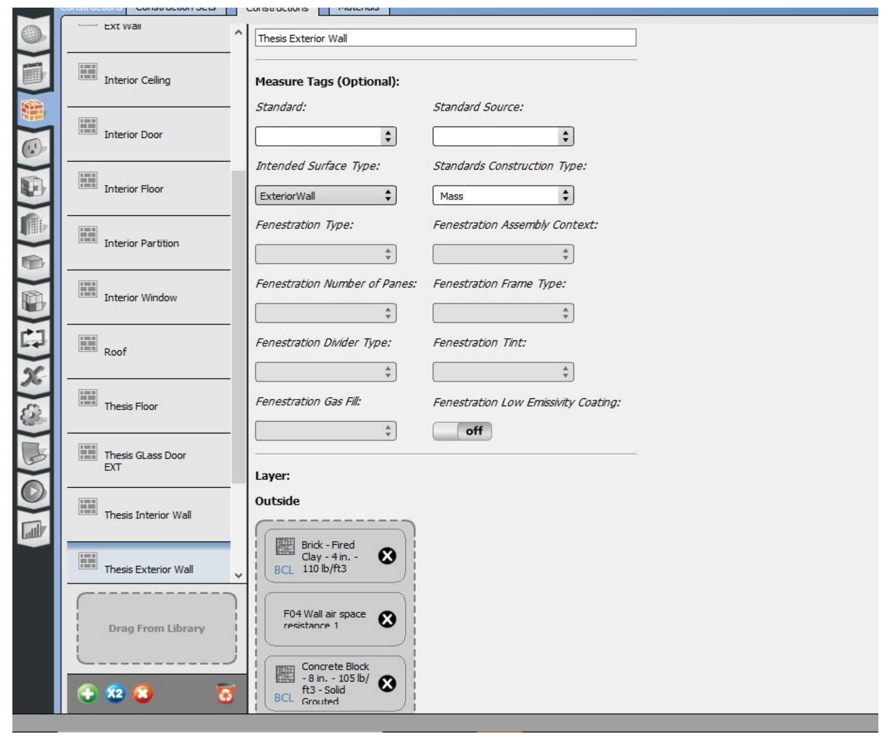


Image Showing the weather data file and climate zone

METHODOLOGIES (CONTD)

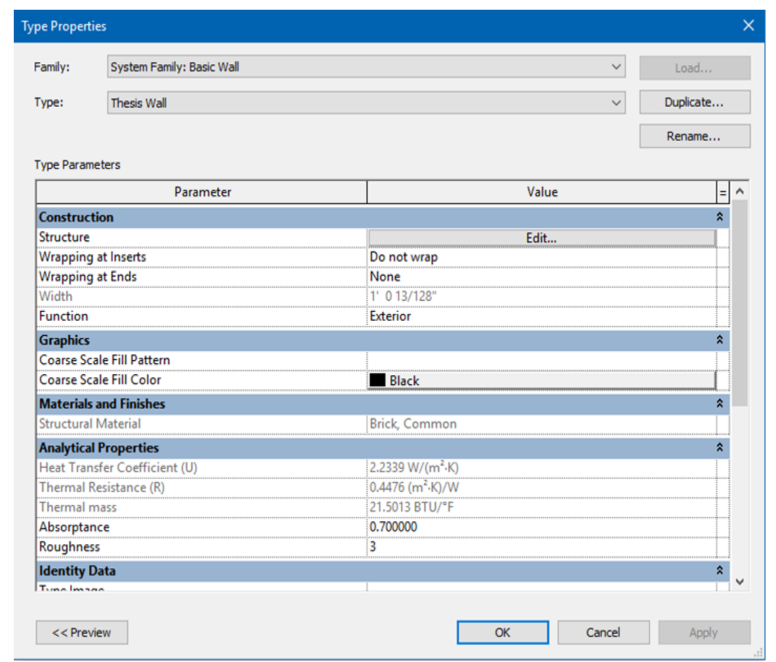


Sample Wall Construction in OpenStudio Interface

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

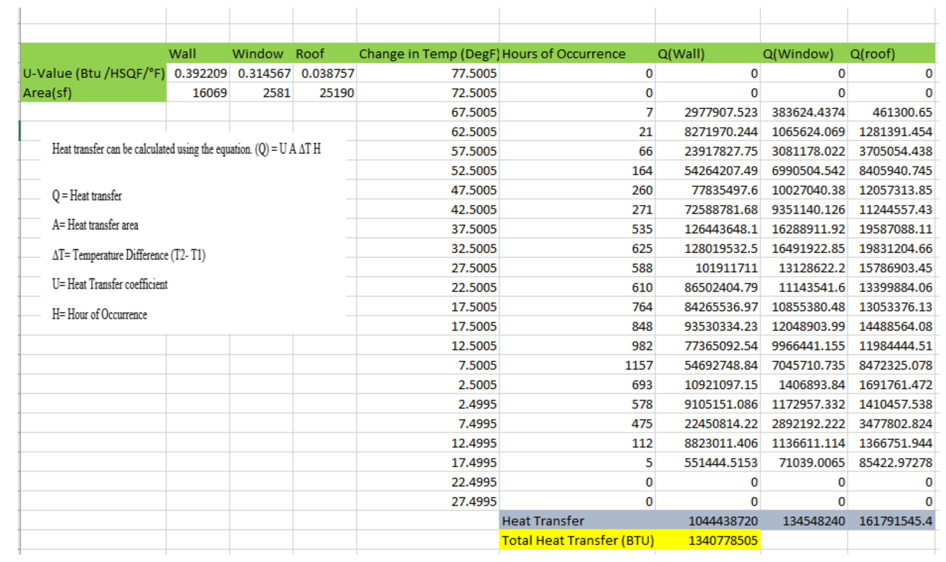
3D Model of Wilson Wallis hall in Autodesk Revit



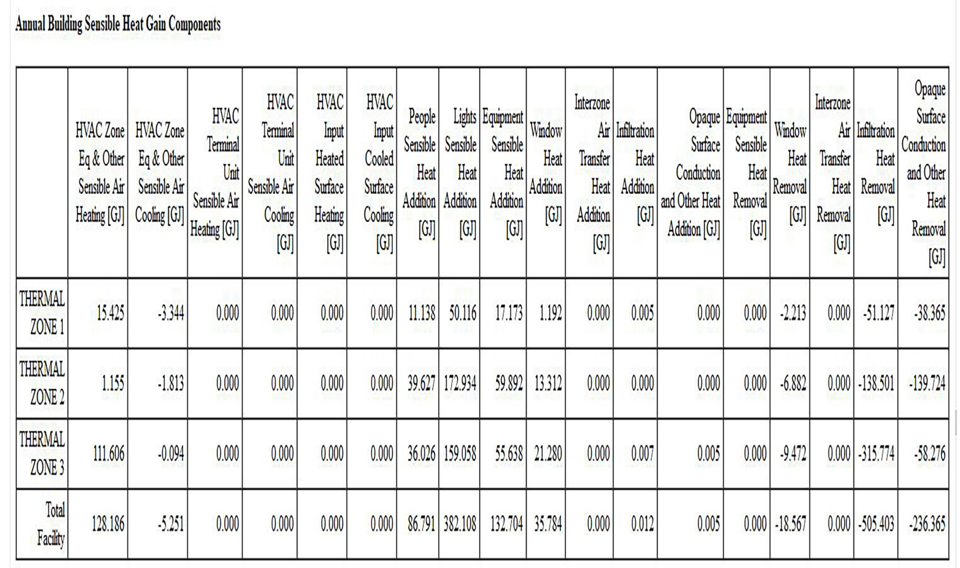
Modification of Physical and Thermal properties of a wall in Revit

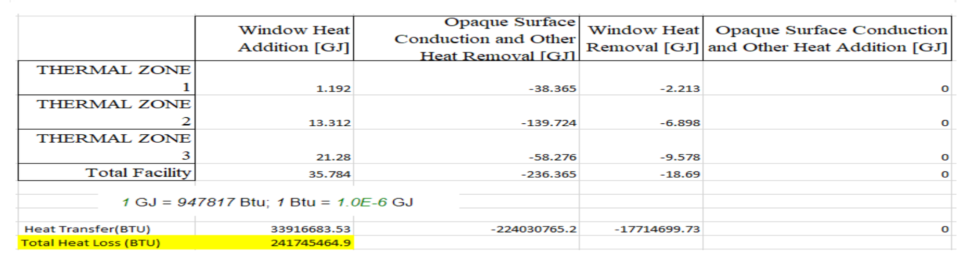
OUTPUTS

Microsoft Excel Spreadsheet computation result

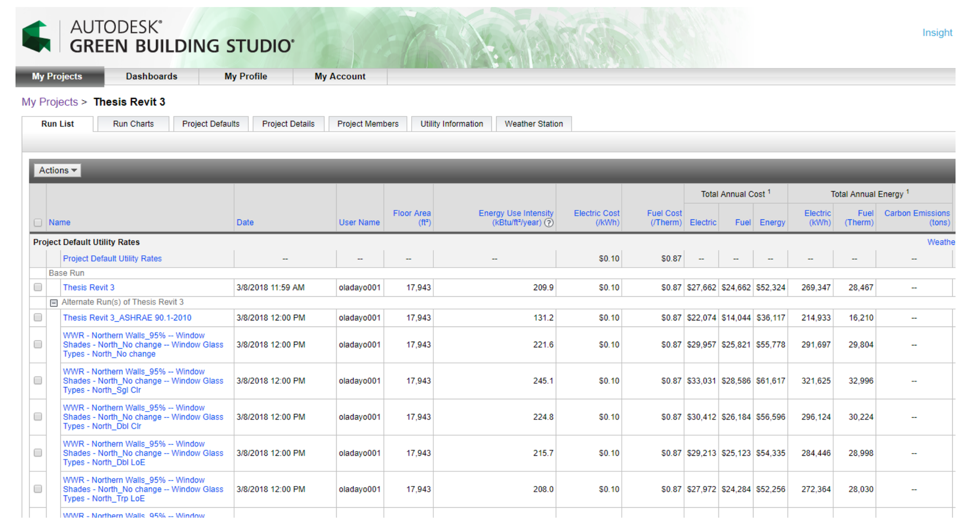


OpenStudio simulation result





Autodesk Revit simulation result



WWR - Eastern Walls_30% -- V	3/8/2018 12:00	oladayo00	17,943	208.7	$0.10	$0.87	$27,635	$24,492	$52,127	269,085	28,271
WWR - Eastern Walls_30% -- V	3/8/2018 12:00	oladayo00	17,943	210.1	$0.10	$0.87	$27,764	$24,676	$52,439	270,336	28,482
WWR - Eastern Walls_30% -- V	3/8/2018 12:00	oladayo00	17,943	212.5	$0.10	$0.87	$28,030	$24,966	$52,997	272,933	28,818
WWR - Eastern Walls_30% -- V	3/8/2018 12:00	oladayo00	17,943	210.4	$0.10	$0.87	$27,805	$24,708	$52,512	270,738	28,520
WWR - Eastern Walls_30% -- V	3/8/2018 12:00	oladayo00	17,943	209.4	$0.10	$0.87	$27,723	$24,579	$52,302	269,945	28,371
WWR - Eastern Walls_30% -- V	3/8/2018 12:00	oladayo00	17,943	209	$0.10	$0.87	$27,616	$24,542	$52,158	268,900	28,328
WWR - Eastern Walls_0% -- W	3/8/2018 12:00	oladayo00	17,943	210	$0.10	$0.87	$27,629	$24,690	$52,319	269,028	28,499
										50,384,254	
									Total Energy Transfer (BTU)	171918229212.07	

$1\ kWh = 3412.14163312794\ BTU_{IT}$

HYPOTESIZED CONCLUSION

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

- 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.