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Analysis of passive louver shading systems and impact on interior environment

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ANALYSIS OF PASSIVE LOUVER SHADING TECHNOLOGY AND IMPACT ON INTERIOR ENVIRONMENT

by

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A THESIS

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MISSOURI UNIVERSITY OF SCIENCE AND TECHNOLOGY

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2012

Approved by

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Dr. William Eric Showalter

ABSTRACT

An installed passive louver shading systems can affect the heating, cooling, and lighting loads of any building, by altering the amount of solar energy, in the form of light and heat, from entering. The benefits of a louver system are derived from the application of solar geometry incident on the site and the climate within the area. By optimizing a passive louver system's design parameters, a building can reduce the total annual energy consumption due to artificial heating, cooling loads and artificial lighting.

This research has implemented simulation modeling software, Energy Plus, to predict the effect of passive louver shades across a standard year on a home within the Midwest part of the country. This energy model of the building has been validated against actual experimental data, over the course of six months. This research has optimized a passive louver shading array, unique to this latitude, by generating converging simulations to track energy demands of the heating and cooling systems of the home. The optimized array characteristics are derived from the minimization of the overall energy performance of these systems.

The simulations of each of the combinations of variable configurations were compiled to outline the energy reduction due to a set louvers installed on a residence. The louver configuration that performed that best was a depth of 6 inches, a height of 8 inches, an offset of 0 inches, and a width of 4 inches. This louver configuration reduced the energy consumption of the model house 17% compared to the same house model without a louver array. All of the simulation outputs were compiled to create the Louver Configuration Input Program, to allow a user to input continuous values within the range of variable and be output an estimate of energy loading.

ACKNOWLEDGEMENTS

This thesis is the culmination of many hours from a great group of people, and their support has been invaluable during the entire creation, design, and development of this work.

For my advisor, Dr. Stuart Baur, I realize I am not the easiest graduate student to work with, but you have given me a great opportunity to showcase my ability. Thank you for allowing me to be part of your team. To my advisory committee, Dr. Jonathon Kimball and Dr. William Showalter, thank you for all your support. Your experience in these areas has been the deciding factor for much of the work done here. I hope this work is something you can be proud of.

To the Office of Sustainable Energy & Environmental Engagement, you gave me the opportunity to continue my graduate education at Missouri S&T and I am deeply grateful for that. The work I am able to do through the office takes passion, creativity, and hard work, but I would not want it any other way. Also, thank you for the use of the 2009 Missouri S&T Solar House.

Finally, to my questioning, but ever-supportive family, “The idea that education is a life-long experience, does not mean I can stay in grad school forever.” You have been a great guide and sounding board, even when you may not understand what I’m talking about, and for that I appreciate every one that has helped me to achieve this goal.

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NOMENCLATURE

d	Depth- The distance between the tip of the triangular louver and the point of the louver nearest the structure (in).
h	Height- The distance between the lower louver and the next subsequent louver in an array (in).
o	Offset- The distance between the back of the louver and the structural wall (in).
w	Width- The distance between the top and bottom of a louver (in).
δ	Solar Declination Angle- The angle between the equator of the planet and the equator of the celestial sphere (deg).
n	Day of the year- The numerical date of the year.
hs	Solar Hour Angle- The angle of sun in the sky compared to the zero point of solar noon. Sign convention is before solar noon is negative (deg).
Solar time	Solar Time- The time of day in 24 hour format (hour).
θ	Solar Altitude Angle- The position of the sun in the sky relative to the viewer latitude, day of the year, and time of day (deg)

1. INTRODUCTION

1.1 THESIS OVERVIEW

This thesis has outlines the use of passive solar shading techniques in practice today to determine the use and applicability of such systems in the Midwest region of the United States. This research examines a location in Rolla, Missouri (Figures 1.1, and 1.2), a region representing the Midwest climate prone to large fluctuations of temperature between the seasons and high daily changes in temperature, according to the National Oceanic and Atmospheric Association (NOAA).

Figure 1.1. Rolla, Missouri in Reference to the United States

This research was completed to better understand the relationship between solar gain and its application in residential buildings, as well as the inherent benefits and issues with using natural energy sources, by way of passive energy strategies

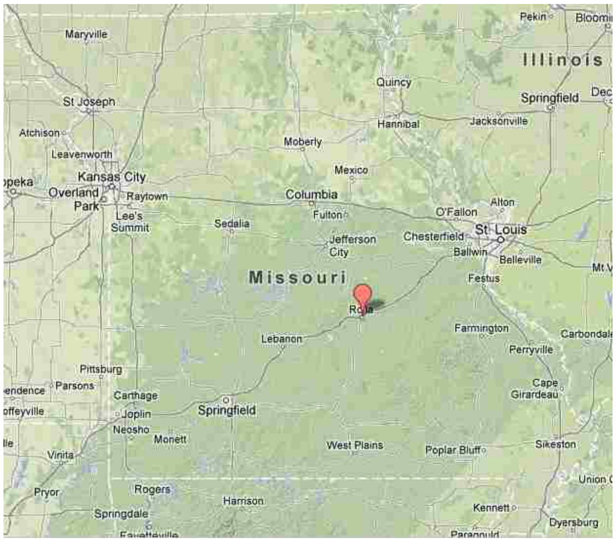


Figure 1.2. Rolla, Missouri in Reference to the State of Missouri

The optimization of these passive strategies is unique within the Midwest due to the effect to the interior climate on all the four seasons. According to the National Climatic Data Center (NCDC) at NOAA (2012), Rolla, Missouri, as a representative Midwest, can range in exterior temperature throughout the year from an average annual high of 75.3° F in the summer season to an average low of 33.4° F within the winter season, across the thirty years of collected data for the site, with an annual average of 55.1degrees F, as seen in Table 1.1.

Table 1.1. NOAA NCDC Weather and Climatic

STATION	DATE	Annual Average (°F)	Autumn Average (°F)	Spring Average (°F)	Summer Average (°F)	Winter Average (°F)
GHCND: USW00013997	1981-2010	55.1	56.5	54.8	75.3	33.4

This climatic data, accessed from the Climatic Data Online (CDO) database of all of the NCDC and NOAA (2012) weather stations, was taken for the Vichy National Airport, in Vichy Missouri. This station was chosen to highlight the weather data within the region, rather than the station in Rolla, due to its longer availability of historical weather data. This study provides a model that illustrates the benefits of passive cooling through passive louvered shading devices during the summer seasons, and also demonstrates the issues associated with louvered shading, rejecting beneficial solar gain within the winter seasons. The thesis has examined horizontal passive louvers, and their effectiveness as a sun shading device, and has optimized, the louver and array characteristics to minimize mechanical energy demands for heating and cooling systems.

1.1.1. Passive Louver Shade. Passive louver shading systems are defined as a series of fixed, horizontal or vertical extensions of a building's façade, used to reflect direct insolation away from a building's interior. A louver shading system affects many of the interior environmental systems of a building, as well as the aesthetic of a building's façade. The most commonly affected systems within a building's envelope are the building's heating, cooling, and lighting systems. A louver array, or a patterned series of louvers, can be built into a structure's façade, acting on the main purpose to reduce solar energy entering the space. In many cases, louvers are placed in front of fenestration or glazed surfaces to maximize the amount of energy rejected from a building.

A louver array is most commonly placed on the exterior of fenestration surface because these surfaces allow the greatest percentage of energy to pass into and out of a building. In some cases, louvers are made to span full lengths of buildings, covering both fenestration and façade, as was the case chosen for this research. (Figure 1.3).

This technique is generally performed to integrate the passive solar louver installation into the façade aesthetics.

Figure 1.3. A View of the 2009 Solar House and Its Full Façade Louver Array

The goal for an optimized louver array is to passively reflect the sun's energy away from the building during the summer months, thus reducing the demand on the cooling system, while permitting direct solar gain to be unimpeded during the winter months thus, reducing the demand on the heating system. From a systems' energy perspective, the best case scenario would be to shade all the fenestration of the building during the cooling months. This would in direct effect remove all solar gain from the interior of the building. During the heating months, revealing all the fenestration, to provide the greatest benefit to the interior conditioning of the home from direct solar gain. This option for most fixed louver cases is unreasonable, due to the fact that the scale at which most of the systems are implemented is too large to economically validate the installation and removal of an entire façade biannually for each season. Other attempts have been made to automate or control a louver array, to produce this seasonally optimized effect, but this concept is considered a dynamic louver array, and is outside the scope of this research.

The option that most louver designers use, in lieu of full scale façade renovation, is the geometric optimization of their arrays, according to the Nysan Solar Control Company's article on louver and sun shading devices (Nysan, 2012). Louver array optimization is derived from the understanding of the energy demand with and without the louver array. By understanding the seasonal energy requirement of each of the conditioning systems, both heating and cooling, the array can be optimized to minimize the cooling load, while maintaining or negligibly increasing the heating load. The decrease in cooling load is proportional to the amount of solar heat gains that are rejected from the building envelope, either through the fenestrations surfaces or the façade. This decrease is a direct effect of the louver array ability to reject energy from the house. This work has attempted to quantify the amount of energy rejected from the representative Missouri home, by the comparison of the home with and without an optimized array. The heating load is a direct effect of the solar gains incident on the home. The goal of an optimized array is to find the balance point between mitigating summer heat gains, and allowing winter heat gains into the building envelope. The array geometry design is crucial to the discovery of this balance point. The optimization of this array is dependent on the geometric shape of the louver and the array, and the solar gains incident on the site, based on the location and latitude of the building.

The geometry of the louver and the array is significant to the effectiveness of the system and its ability to shade during the cooling months, April - September, and allow energy to pass during the heating months, October - March. The key aspects of louver geometry are the depth and width of the louver. For these variables, the louver can be considered within a 2 dimensional plane. The depth of the louver is the distance between the louver's back and the tip. The depth is representative of critical to the amount of shade a single louver can provide. As the louver top and bottom are at the same angle with the vertical, the profile of a louver can be considered as a triangle. The section view of any louver displays the width and depth of an individual louver. Figure 1.4 displays the section or profile of a louver, and highlights the 2-D elements of the louver, its depth and width. These characteristics can be shown on a single louver and are the building blocks of the louver array. The depth and width are the variables that define how energy is reflected away from a single louver.

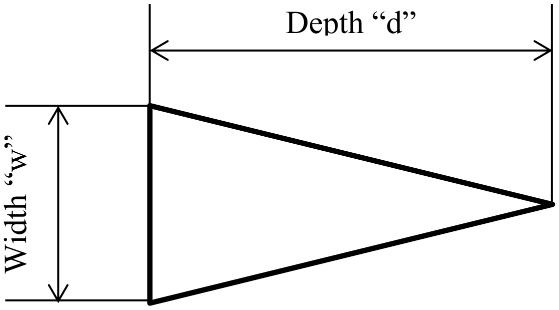


Figure 1.4. The Section View of a Louver displaying Depth and Width

The width is the distance between the outermost edges of louver, nearest to the building. The width of the louver is set by the manufacturer for ease of manufacture or aesthetic.

The two other important factors of the louver shading system are the parameters surrounding its array design. The two factors of array design include the height and the offset. To illustrate the height and offset, at least two louvers in the array must be designed, as seen in Figure 1.5. The height of the array is the distance between the tips of the individual louvers. This height characteristic sets the amount of shading possible for each season and also the number of possible louvers can be included within the array. Much like the depth of an individual louver, this design criterion is closely tied to the seasonal solar angles as well as the latitude of the building, and is further explained in the Solar Geometry section.

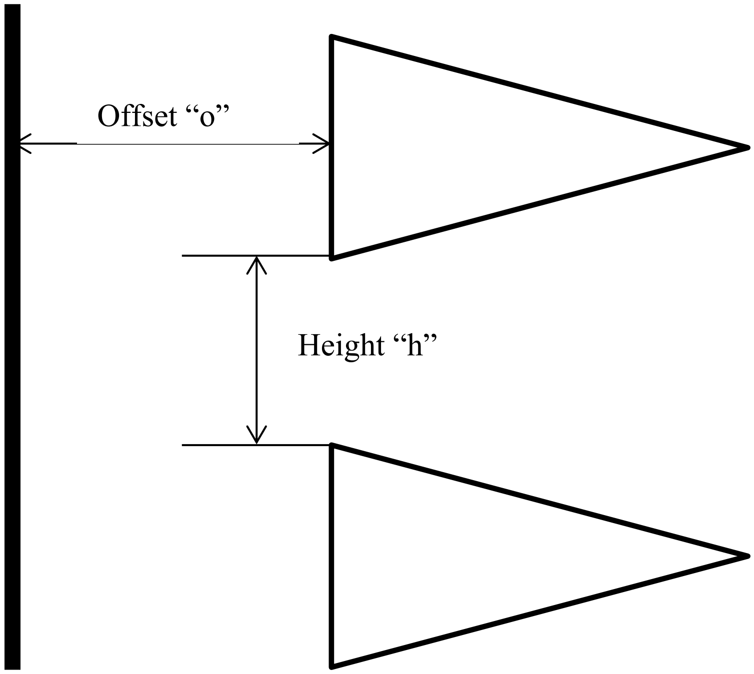


Figure 1.5. The Section View of the Louver Displaying the Height and Offset

The array offset is the distance between the building and the louver array. The effect of the offset is most noticeably recognized within the heating months, October through March. The offset facilitates a greater amount of solar energy to enter the interior space as compared to an array without an offset. The offset also facilitates an ease of installation, making the distances between louvers a uniform connection point along the length of the array. The length of the array is one of the factors that will not be considered within this work. Although the length is an important portion of the array design, this research has maintained an array length equivalent to the experimental building. The length of the array is the physical distance of a louver from one end to the other. Figure 1.6 showcases the length of a louver in comparison to the louver sectional characteristics like the depth and width. As an apparent factor in the design of the length, the effect of the incident solar energy is predominantly dependent on the solar geometry of the site.

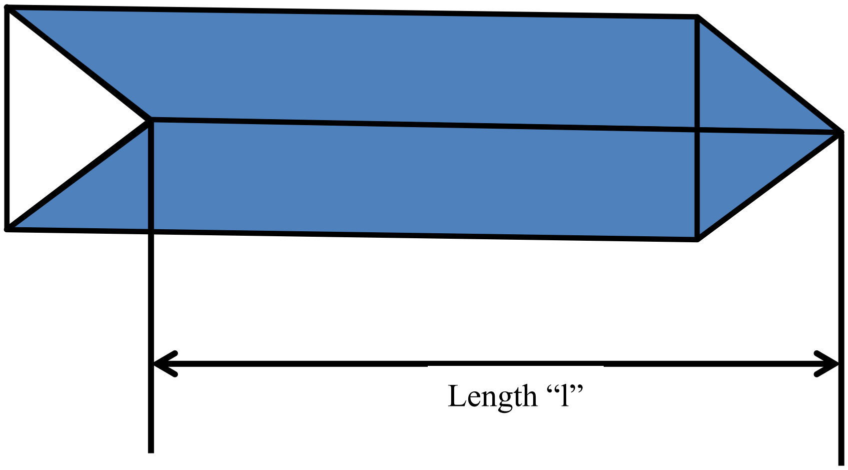


Figure 1.6. Length of Louver Array- Front View

A building's heating and cooling load is defined by a building's passive and active systems and the built environment. Each of these systems is present within the building to control some natural environmental effect. The environmental factors that these systems attempt to mitigate include the exterior temperature, humidity, wind effect and solar gains that surround the building. As a building system, the installed louver array will reject excess solar gain during the summer months and the building's mechanical systems will condition the interior environment and insulate the space. The mechanical systems are generally considered to be a static factor of the system once the construction and implementation have been completed, whereas, the environmental factors of the system are constantly changing according to daily and seasonal trends. Lechner (1991) describes the environmental factors have the ability to change constantly throughout the year, but they change according to a set pattern derived from the Earth's heating and cooling cycles, the seasons, and the celestial mechanics of the solar system, as they apply to the Earth's solar gains.

The environmental factors that were examined within this research all correspond to the effects associated with temperature, namely seasonal changes in temperature, incident solar energy on the site, and accessible solar energy to be used within the building as light or heat. Temperature changes due to season can be considered to be reasonably predictable according to the weather history of the site, which is available through the NCDC and NOAA (2012). Foregoing any climate change developments, the temperature of an area can be estimated from historical data and seasonal trends. Although for the Midwest region, the change from winter to summer temperature can range from 62 degrees F, based on the composite thirty year weather history provided by NOAA (2012), the seasonal temperatures remain consistent for the past 30 years.

Direct and indirect solar gains on a site are dependent on the revolutionary cycles of the Earth, as well as, its orbit around the sun, and the site's weather conditions at any given time of day. Specifically these factors are brought about within the change of season, change in day to evening, and the cloud cover. These factors are crucial to the development of passive strategies and are linked to the solar geometry of a site. The geometry of the site is one of the key parameters for the optimization of a passive louver shading system, and is the basis for the relationship between the site, the building, and the incident solar gains. Solar Geometry is a broad term for the direction and angles of the sun’s direct beam insolation with the Earth, in this case, the building and louver array. By understanding the level of solar gains that a building can expect, the building’s mechanical systems can be sized accordingly to utilize the passive strategies, either in regard to the heating and cooling of the building, or at least during the day, the lighting of the space.

The factors that reduce or block the amount of solar energy incident on the site are outside the scope of this work, but are another factor in the amount of incident solar energy available for use. These factors include natural factors, manmade factors, and reflection. A good example of both a natural and manmade factor is cloud cover. Whether the cloud cover is natural, or manmade, in the case of smog, cloud cover will reduce the energy incident on the site. Reflection is also a factor that has not been considered within this level of research. Figure 1.7 Kambezidis (2012) on Solar Resources highlights the losses due to reflections from natural sources.

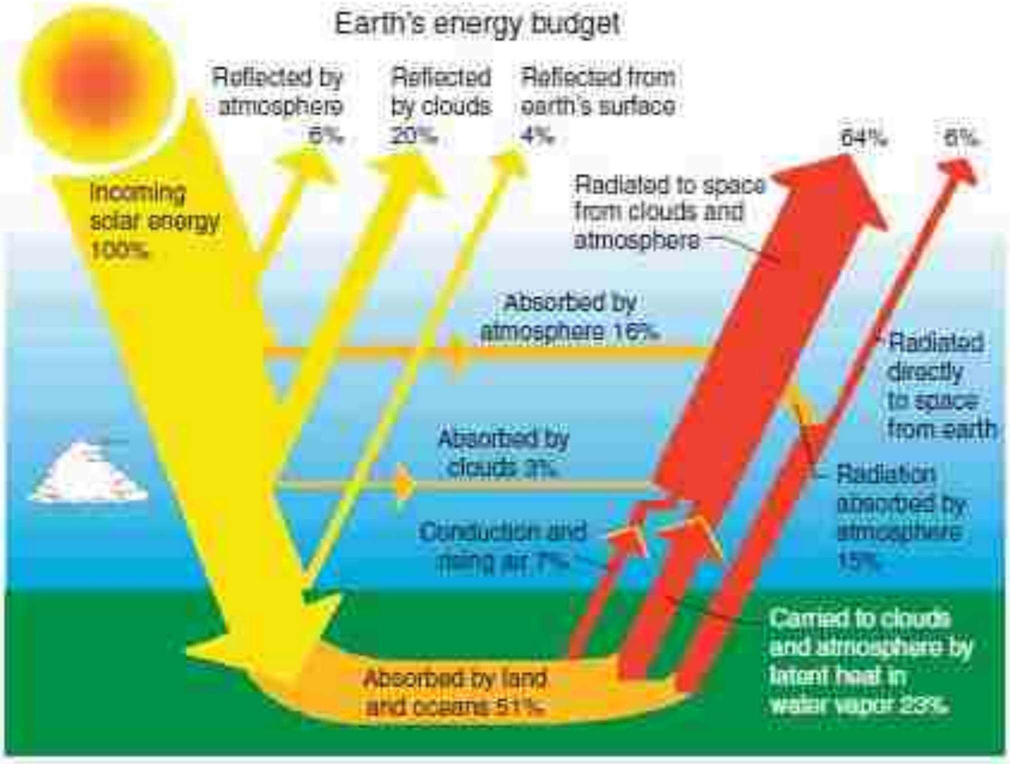


Figure 1.7. The Natural Reflection of Solar Resources

Reflection off the ground, as well as, nearby objects could have a beneficial effect to the louvers, but its indirect nature is only relevant to specific locations and thus has been neglected from this work. The restriction of these auxiliary factors has greatly simplified the solar geometry calculations for the calculations of solar gains.

The position of the sun can be derived from two equations, the solar altitude and the solar azimuth (Figure 1.8). The solar altitude is the angle between the horizontal at certain latitude and a line to the center of the sun. The solar altitude can be described as the “height” of the sun in the sky. The solar altitude is a straightforward calculation relying primarily on the latitude of the location, the time of day, and the day of the year.

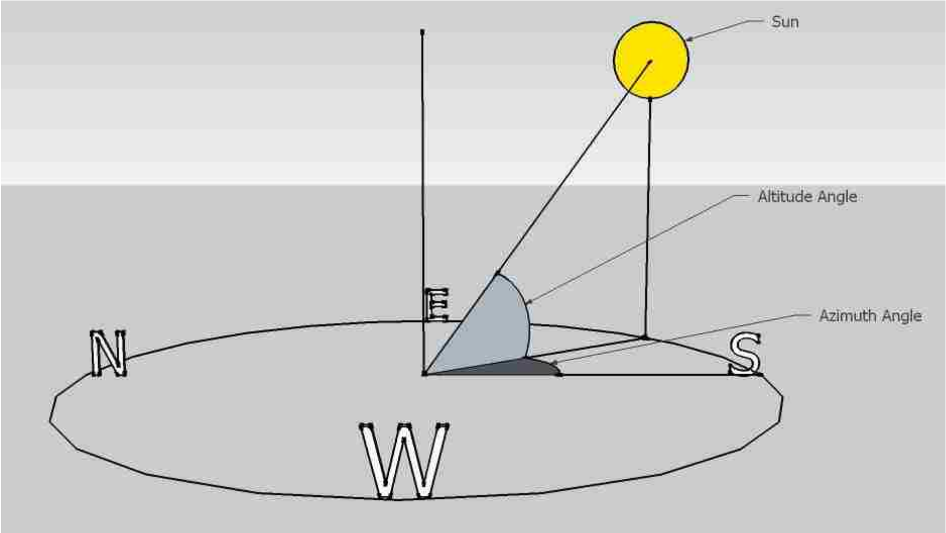


Figure 1.8. Solar Altitude and Solar Azimuth

As referenced by Lechner (1991) and Kambezidis (2012), the calculations for the position of the sun are set for the latitude, day of the year and time of day, the amount of solar insolation, or the solar radiation incident on an area per a finite amount of time, can be calculated for the site. The amount of insolation incident on the latitude is directly proportional to the generation of heat according to the heat absorption coefficients of the incident material. A material that is able to absorb the energy will tend to increase its internal temperature, and will radiate heat to the area around it. In this case, the solar energy incident on the site at the building’s latitude will enter the building through the fenestration areas first, followed by the facade areas, and strike a surface material. The solar energy will be absorbed by the material and raise its internal temperature. The material will then begin to radiate that heat into the building space, raising the air temperature through radiation. By controlling the amount of solar energy that enters a building, a louver array can passively affect the heat and cooling cycles of a building, on a daily, monthly, or seasonal calendar. This information taken from the early calculations can give a passive louver system designer the opportunity to access the effective dimensions to either reject or accept the solar light and heat, to fit the designed space. By optimizing the louver dimensions, in terms of depth and width, and the array dimensions in terms of height and offset, in conjunction with the solar geometry throughout the year, this research has generated a systematic approach to the minimization of the necessary artificial cooling load on a building by rejecting the heat introduced by solar energy during the cooling months, while reducing the loss of beneficial solar heat gain during the heating months. Although this research has been generated for a Midwest climate, the principles and elements work in most warm, solar heat driven climates. The benefits to cooler climates are less apparent due to a necessity for increased heating loads rather than decreased cooling loads.

By determining the optimal array geometry for the fixed louver system, a building can reject unwanted summer heat, accept necessary winter heat, and reduce direct glare from daylighting applications. This concept has been further illustrated in an example of optimized geometry, as depicted in Figure 1.9. These passive strategies of passive heating, cooling, and daylighting without glare, reduce a significant portion of the energy demand in a building. The reduction in energy demand across the year is the premise and metric by which the optimization has been accomplished.

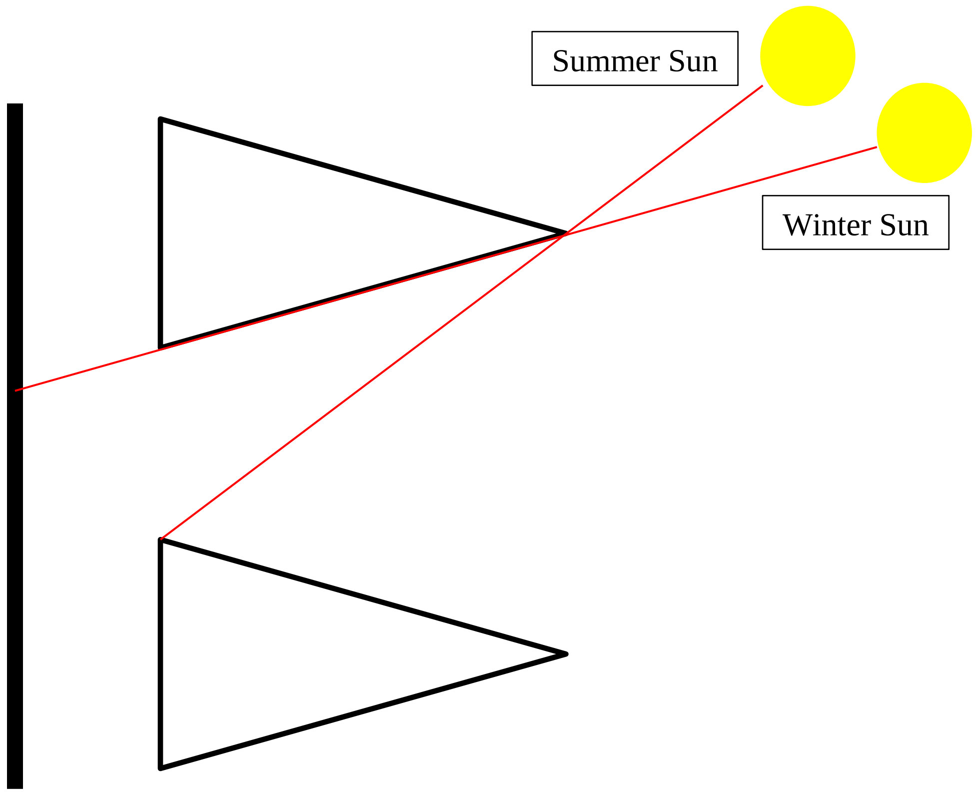


Figure 1.9. An Optimized Louver Array

This research suggests that an optimized louver array is the combination of louver geometry and array geometry that, when introduced into a building system, will create the most dramatic decrease in energy load for the heating and cooling systems across the year. As the most prominent and largest energy loads within a building tend to be the heating and cooling loads, it is the hypothesis of this research, that an optimized solar shading application has the potential to reduce the amount of energy used for cooling, while minimally affecting the heating demand.

1.1.2. United States Energy Statistics. According to the United States Building Energy Data Book (2012) issued by the Department of Energy, the United States accounted for 19% of the world's energy consumption in 2010. Figure 1.10 from the

Building Energy Data Book distributes the world's energy consumption, and the sectors of that have consumed this energy.

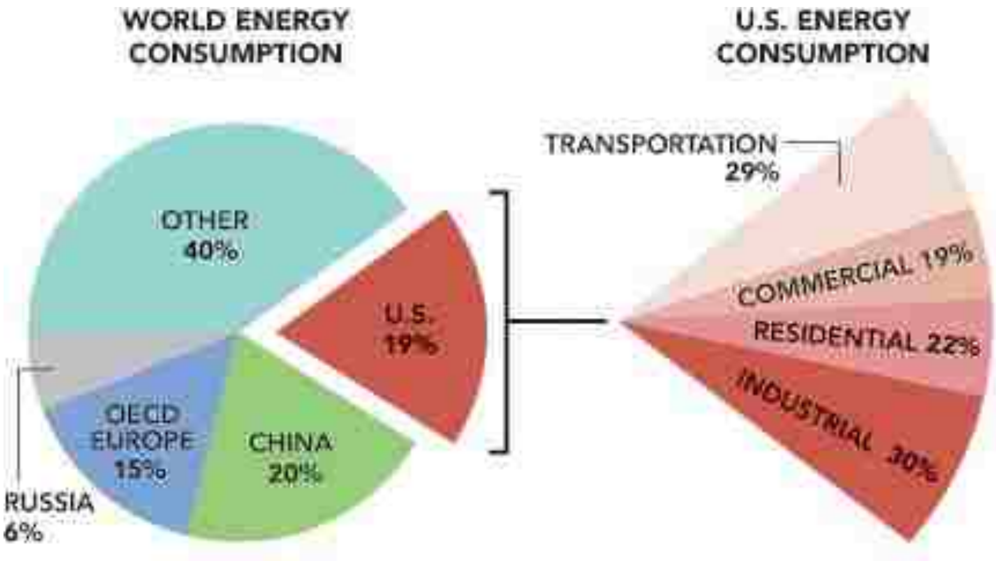


Figure 1.10. The Graph of World and US Energy Consumption

The residential sector accounted for 22% of the country's energy demand in 2010. Of that total amount of energy, Figure 1.11 broke that 22% into its respective consumption end consumers. (Building Energy Data Book, 2012)

Of the 22% used for residential energy, 45% for the energy was consumed for heating and 9% for the energy cooling of the house. Also, the commercial sector accounted for 22% of the country's energy demand in 2006 as seen in Figure 1.10, with 27% consumed for heating and 10% consumed for cooling of the commercial sector as seen in Figure 1.12. (Building Energy Data Book, 2012)

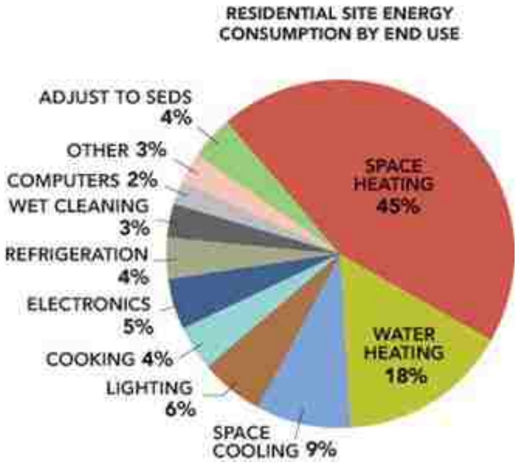


Figure 1.11. Residential Energy End Use

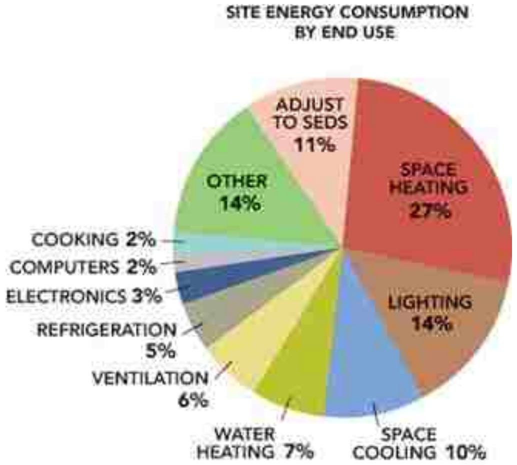


Figure 1.12. Commercial Energy End Use

With this energy consumption information in hand, it might have seemed to have been more beneficial to focus on reducing the heating load rather than minimizing the cooling loads, but the energy consumption, is not specifically representative of the expenditures for that energy. Tables 1.2 and 1.3 highlight the same material from the Building Energy Data Book of the Department of Energy, but consider the price of the energy instead of the quantity in comparing the average fuel source of the energy. (Building Energy Data Book, 2012)

Table 1.2. Residential Expenditures for Energy by Fuel Source

2010 Commercial Energy End-Use Expenditure Splits, by Fuel Type ($2010 Billion)										
	Natural	Petroleum								
	Gas	Distil.	Resid.	LPG	Other	Total	Coal	Electricity	Total	Percent
Lighting								35.4	35.4	19.7%
Space Heating	15.0	2.9	0.9		0.1	3.9	0.1	8.5	27.5	15.3%
Space Cooling	0.4							25.0	25.3	14.1%
Ventilation								15.9	15.9	8.9%
Refrigeration								11.6	11.6	6.5%
Water Heating	4.0	0.6				0.6		2.7	7.3	4.1%
Electronics								7.8	7.8	4.3%
Computers								6.3	6.3	3.5%
Cooking	1.6							0.7	2.3	1.3%
Other	2.7	0.3		3.3	1.2	4.8		20.4	28.0	15.6%
Adjust to SEDS	6.2	5.2				5.2		0.6	12.0	6.7%
Total	29.9	9	0.9	3.3	1.3	14.5	0.1	134.8	179.4	100%

The reason this research focus on minimizing cooling costs was because cooling for both residential and commercial applications is performed almost exclusively with electricity, while the space heating has a multitude of options for fuel sources.

The amount of energy being used to heat and cool buildings, either residential or commercial, is dependent on a large number of variables, which can be broken into two groups: functional usage, and energy usage. Functional usage in a building corresponds to what the building is used for, and what systems maintain the quality of service within. This is a very easy qualification for a residence, mostly broken down into size of the building, but the actions within the residence are limited to what can be done within a home. On the other hand, a commercial building can have a highly varied work quality, and in some cases can be independent of size. In other words, an office building and a warehouse may be the same size, but have incredibly different needs in terms of heating and cooling.

Table 1.3. Residential Expenditures for Energy by Fuel Source

2010 Residential Energy End-Use Expenditure Splits, by Fuel Type ($2010 Billion)									
	Natural	Petroleum							
	Gas	Distil.	LPG	Kerosene	Total	Coal	Electricity	Total	Percent
Space Heating	38.7	11.2	8.0	0.5	19.8	0.0	14.3	72.9	28.9%
Space Cooling	0.0						35.4	35.4	14.0%
Water Heating	14.3	2.1	2.0		4.0		14.2	32.6	12.9%
Lighting							22.6	22.6	9.0%
Refrigeration							14.9	14.9	5.9%
Electronics							17.8	17.8	7.1%
Cooking	2.4		0.8		0.8		6.0	9.2	3.7%
Wet Cleaning	0.6						10.7	11.3	4.5%
Computers							5.6	5.6	2.2%
Other	0.0		4.4		4.4		6.7	11.1	4.4%
Adjust to SEDS							13.6	13.6	5.4%
Total	56.1	13.3	15.2	0.5	29.0	0.0	166.8	251.8	100.0%

Qualifying the needs of the functional usage is critical into determining the benefit of energy savings. The other variable group that can define a buildings energy profile is the energy usage group. This group of variables corresponds to the way that energy is handled within the space. The way that energy is brought into the space, maintained with the space and rejected from the space, are all key variables to the energy usage classification. In a building, energy can be brought into the space through a few methods, either through delivered energy; solar energy incident on the building, or fuel energy consumed within the space, or through electricity brought to the site. Energy is maintained is a building through its ability to restrict energy from escaping the envelope.

The easiest way to understand this concept is through the example of insulation. Insulation maintains a barrier between the exterior energy trying to get in and the interior energy trying to get out. The insulation restricts or slows the flow of energy from the high level to the low level. Energy rejection explains the route of energy out of the building, generally through an action. Simple air conditioning pulls energy, in the form of heat, from the air inside the building and deposits it on the outside of the envelope, rejecting the energy from the space.

For almost all the buildings built to today standards, the control and manipulation of each of these systems are commonplace, but it is just getting to the point where control for solar heat gain, as an architectural feature, is becoming prominent within the building design process. According to *External window shading treatment effects on internal environmental temperature of buildings,* (Offiong, 2004) solar heat gain and the effects of shading devices on solar heat gain are two critical design criteria necessary within the building design. The increase in energy costs in the last decade has pushed the development and in many cases rediscovery of these passive techniques to control light and heat ability to enter a building envelope. The invention and rediscovery of many of these techniques can be traced back to the earliest days of architecture, but had been lost to the advent of custom buildings and cheap energy of the late 20th century.

Passive solar shading techniques are not a new concept, and in many ways are reemerging across many architecture styles. Passive architecture and the concept of solar shading have been in existence since the earliest days of recorded architecture. Elements of passive architecture and light and heat control techniques can be seen in most historical designs (Lechner, 1991), throughout many regions of the world including:

Ancient Greece, utilizing shading colonnades, Asian, employing large overhangs to shade and cool, as well as indigenous American like seen in Figure 1.13, mainly of the Southwest region, as well as similar techniques used in India. Many of these societies used that built with passive architecture did so to remedy the extensive heat load of the building, before any kind of cooling systems had been developed. These cultures derived many of these techniques from the natural environment they lived in, and these techniques that, today, have been scientifically proven have all been formed from an early understanding of a buildings interaction with its environment, both climate and solar gain potential.

Figure 1.13. American Indian Homes Employing Shading and Insulation Techniques

Across the United States, the ways that homes are heated and cooled varies significantly on the type of systems implemented. This variability of these systems is dependent upon the location and the apparent climate of the residence. In essence the systems designed to heat, cool, and light a building are in many ways dependent on regional architecture and design. This analysis of a passive louver shading system in the

Midwest has highlighted the most prominent benefits to a passive louver shade, in terms of summer heat rejection and winter heat gain, for this climate and location of solar gain potential.

1.1.3. Simulation Modeling. The variability and time sensitivity of collecting climatic and seasonally based data, like heating and cooling loads of homes, employs a unique challenge to research that does not have years to collect data or a multitude of homes to conduct experiments upon. This challenge has been remedied within this work by the introduction of an energy simulation model. This model has the ability to create a digital representation of a building, including the prominent characteristics of the home, such as size, shape, insulation, etc. and subject that home to the climate, weather and solar patterns incident on the site. In a similar study, (M. David et al., 2011), research conducted on a simulated home used a multitude of different louver array designs and several years of weather conditions, to understand the effect of the solar gains on the mechanical systems of the home and the effect of the louver array on the energy demand. Similarly, the development of an optimized geometric passive louver array for the Midwest climate will introduce a passive technique for building energy efficiency and development of non-energy dense HVAC systems. An energy simulation is a computer model of a building, with representative materials, building geometry, mechanical systems, environmental loading, and scheduled use. This model can simulate the actions and response of the building prior to it being constructed, to validate theories in construction techniques, heating and cooling demand, and other building response effects. The benefits to generating a simulated model is the chance to examine how a building will respond to its environment and how it the needs of the building can be met.

Simulation modeling also reduces the need to build and examine situations in the real world that can be easily altered in the digital space. There is no replacement for experimental and empirical data, but simulation modeling generates the closest account to what would actually happen in the real world. This research has taken a building within the Midwest, specifically within the city of Rolla, Missouri, and modeled this existing building including its in-situ louver array. While the geometry of the building and the geometry of the louver array are paramount to considering the effect of the louver array on the heating and cooling loads of the house, the house's mechanical systems are of lesser concern and were modeled within the work to represent ideal loads. This was done to facilitate the speed of the simulation modeling, as well as, to ensure a simple understanding of the energy entering and leaving the building. Simulation modeling can predict the factors incident on a building prior to the construction, allowing designers or engineers to plan for beneficial natural effects to heating and cooling, thus reduce the size of the necessary mechanical loading. Minimizing the mechanical heating and cooling system prior to the construction of a building reduces the cost of the unit's up front cost and the operating cost of the systems over its lifetime. To compare the effects on the heating and cooling systems, the building was modeled using identical models of the house without a louver array as the baseline compared with a series of models to optimize the louver system characteristics.

This research has explored the installed louver array at the Missouri University of Science and Technology (Missouri S&T) entry into the US Department of Energy (USDOE) Solar Decathlon 2009. This residence as seen in Figure 1.14 competed in the USDOE Solar Decathlon employing a number of passive strategies, one of which was a passive louver system on the south façade. This building has been modeled to simulate its' passive energy profile using the energy modeling software system, Energy Plus.

Figure 1.14. Missouri S&T 2009 Solar House.

This house was used the example within the Midwestern climate and was used as the test case residence to optimize the array geometry of the existing system, based on parameters such as: site latitude, louver geometry, time of day, and time of year.

1.1.4. Energy Plus. Energy Plus is an energy analysis and thermal load simulation program . The goal of these simulations is to model the effects in a virtual space to understand the restrictions and benefits inherent in a project. This research used a simulation model of the 2009 Solar House at the Missouri University of Science and Technology or Missouri S&T to model the effects changing the geometry of a louver array. Without manipulating a physical array within the real world, the model is able to determine the changes in the energy delivered into the space, while all other factors remain the same. The energy allowed or rejected into the space is directly affected by the level of shading the louver array produced of the façade and fenestration surfaces of the home. By systematically varying the design characteristics of the louver and array, the energy demand of the systems within the house can be analyzed by maintaining all other variable constant within the model. To ensure the model accurately represented the real world version of the 2009 Solar House, this model was validated against the experimental data collected from a past project. This data included the internal and external temperature of the space. By validating the model, the research was able to compare the physical data against the effects of the louvers and their array geometry.

1.1.5. Passive Louver Array Optimization. With this simulated residence, validated against an existing home, in a Midwest region of the United States, the array was geometrically optimized to prioritize the energy demands of the home, in regard to the solar gain profile of the house. This solar gain profile represents the effective heat generation capabilities of the building with respect to the season and climate. This research has varied the design characteristics of the each individual louver, in terms of depth and width, and the geometry of the louver array, in terms of height and offset, to converge upon a systemic design according to minimizing the energy requirements of the building. The simulation model has varied the combined design characteristics of the system to minimize the necessary annual energy demand of building’s heating and cooling systems. The system components that were varied to attain minimizing convergence of the buildings energy demand included: depth, height, offset, and width.

The process of the research, the results of those simulations, and the conclusions drawn from that body of work have been compiled within this thesis. The methodology, experimental procedure, and convergent results of the research are also included within this body of work.

1.2 LITERATURE REVIEW

In a previous research study of a model to evaluate solar heat gain through an equation to develop an interior absorption coefficient dependent upon the three factors apparent with incident solar energy (Oliveti, Arcuri, Bruno, and De Simone, 2010). The energy transmitted through the glazed surface, the absorbed gains directly from direct beam solar energy, and the energy absorbed through the reflected and diffuse solar gains within the space were examined. This paper view renders the incident energy as an internal heat gain. The understanding of the research aids in the determination of the solar heat gains as source of energy in the building. This research also demonstrates the need for passive shading devices in order to manipulate the amount of energy transmitted to the glazed surface and eventually absorbed.

In a similar study, researchers examined effective absorption coefficient of a sunspace adjoining an interior space (Oliveti, De Somine, and Ruffolo, 2008). The research viewed simple geometries, compared various orientations, and fenestration percentages. It also accounted for the latitude, volume of the investigated space, type of glass, and exposure of the fenestration surfaces. This work evaluated the ability to showcase the solar gain potential through an absorption coefficient using simplified models. This paper simulated their model across an average year of weather data according to the location and latitude of the model. With this information in hand, the concept that window placement and fenestration type are once again validated against the amount of solar gain. The latitude and incident weather of the location again also play an important role in the generation of solar gains to the building. In many ways, this work supported the effect of louvers as a sunshade device dependent on latitude, building geometry, and orientation, even though shading is not a topic breached within this research.

In a previous study, researchers examined the implementation of a fixed shading device during the summer months of the year within a tropical climate (Offiong,2004). The work looks at multiple different applications of fixed exterior shading devices, including simple overhangs, reveals, and side fins. Although these shading technologies are not fixed louvers, the shading devices represented follow many similar design characteristics, in terms of solar geometry and the devices ability to block incident gains into the building. In many ways, this research is similar to this thesis in regard to the fact that it focuses on one unique climate. This work differed from the thesis in terms of the concept that a horizontal louver array was not considered for a shading device, and there was no attempt at full system modeling of the building with the shading devices.

In 2011, researchers used multiple configurations of differing solar shading applications were applied to a simple rectangular geometry (M. David, 2011). These differing systems included a Simple overhang, an overhang of infinite width, a simple overhang with rectangular side fins, and a simple overhang with triangular side fins. Although none of these are a louver array, the method of conducting the test and the simulation within the simulation engine, Energy Plus, was similar to this research. The research did examine a tilted louver array on the West side, but their research focused primarily on the tilt angle and not of the critical dimensions of a horizontal flat louver.

In a different study, researchers examined two configurations of louver shading systems, including tilted horizontal, and tilted vertical installations (Palmero - Marrero, and Olivera, 2010). In their work, they use a differing naming convention then this research has found in other articles involving louvers. The research defined a horizontal louver as a louver that is perpendicular to the wall placed above the fenestration surface, much like a classic overhang split into parts. They define a vertical louver array much like this work has described a horizontal array, as a series of horizontal louvers in plane parallel to the face of a fenestration surface. This work also examined the angle of tilt rather than the flat critical dimensions. This research study used a different simulation engine, TRNSYS, for their simulation calculations. This work also examined key latitudes and cities across the globe.

Another previous research study examined a similar horizontal louver array configuration to the examples within this research (Janak, 2003). This work focused on an office complex within simple rectangular geometry with a South façade of full windows. The researcher is quoted as saying that “Solar radiation is one of the most significant energy fluxes contributing to the thermal zone energy balance.” This work used the energy modeling program ESP-r as its main simulation engine and the Radiance energy program to calculate their energy demand and louver shading characteristics. Depth of the louver was the only dynamic system characteristic within this work. The main focus was the research of this situation between the two energy modeling programs ESP-r and Radiance.

Researchers in the past have examined another shading technique using an energy modeling approach (Dubois, 2000). This study employed external overhangs within this research to attain the shading goals for the office building that was the focus of the work. The research examined a shading coefficient of the windows, as a factor of the internal heat gain, rather than using ideal conditions for mechanical systems, as was attempted within this research. The work also reported the difficulty of maintaining a shaded face during the times of the year when it was necessary, summer cooling months, while discouraging the loss of winter solar heat gain.

In a previous study highlighting an area with an immense cooling load, researchers have considered the application of side fins and upper overhangs to a simple building model in Energy Plus to lower the effective cooling load by reducing transmitted solar energy (Abdulsalam, 2011). Using Energy Plus, this research has model a simple office building and has placed a series of overhangs or fins on each window facing out to the cardinal directions of North, West, East, and South. They have also compared the effect of a window above the Iranian building codes to minimize losses from the fenestration surfaces. The work created outputs and suggestions for each cardinal façade face and what to do to minimize the cooling loads and losses.

2. METHODOLOGY

2.1 SITE DEPENDENT CHARACTERISTICS

2.1.1. Latitude. The simulation parameter derived from the latitude is necessary to determining the incident solar of the site. The latitude is also a variable vital to the understanding of the weather of the area, in regard to the type of micro climate the site is placed, such as tropical, temperate, or otherwise. These simple weather types and solar potential can be derived almost directly from latitude, as seen in Figure 2.1 (Kambezidis, 2012).

The latitude is the measurement that runs east and west, above over below the equator, which defines the North to South location on the face of the Earth. Solar geometry is similar, independent of weather, around the entire planet. In other words, the potential solar gains on one side of the planet are the same as the other side of the planet, along the same latitude lines, foregoing any weather effects.

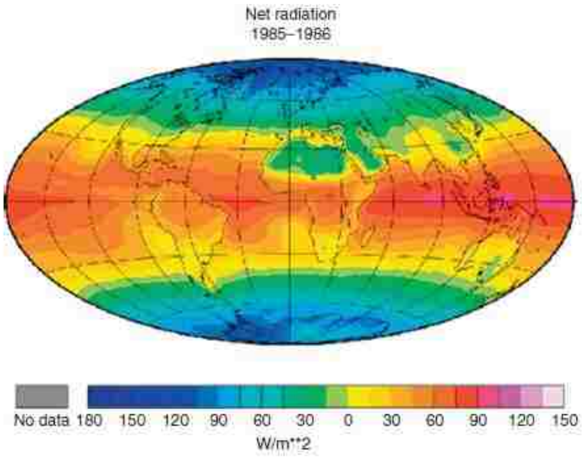


Figure 2.1. Solar Radiation Potential of Earth

In this research, the latitude was determined by the physical location of the house that was used to validate the model. The experimental data recovered from the house's data collection system was directly connected to the latitude, through the microclimate the house was in. It would be possible to change the latitude of the simulated model, but that approach is outside the focus of this research and would be unable to validate the finding against known experimental data from the physical house.

This model used a latitude central to Rolla, Missouri of 37.9 degrees. This corresponds to the climate and solar potential available to Rolla, Missouri, the location of the modeled building, as well as, the NOAA NCDC data that was collected for the weather analysis (NCDC, 2012). The latitude of the research will also be a critical factor in determining the components of the solar potential, including the solar altitude and the solar hour angles of the site.

2.1.2. Solar Declination Angle. The solar declination angle is the angle between the direct beam solar energy and the equator. During the Earth's revolution around the sun, the orbital tilt of the planet stays consistent. This orbital tilt creates disparity between the seasonal declination angles, as seen in Figure 2.2 (Kambezidis, 2012). During the summer cooling months, the declination angle is positive, meaning the angle between the Earth's equator and the direct beam is positive.

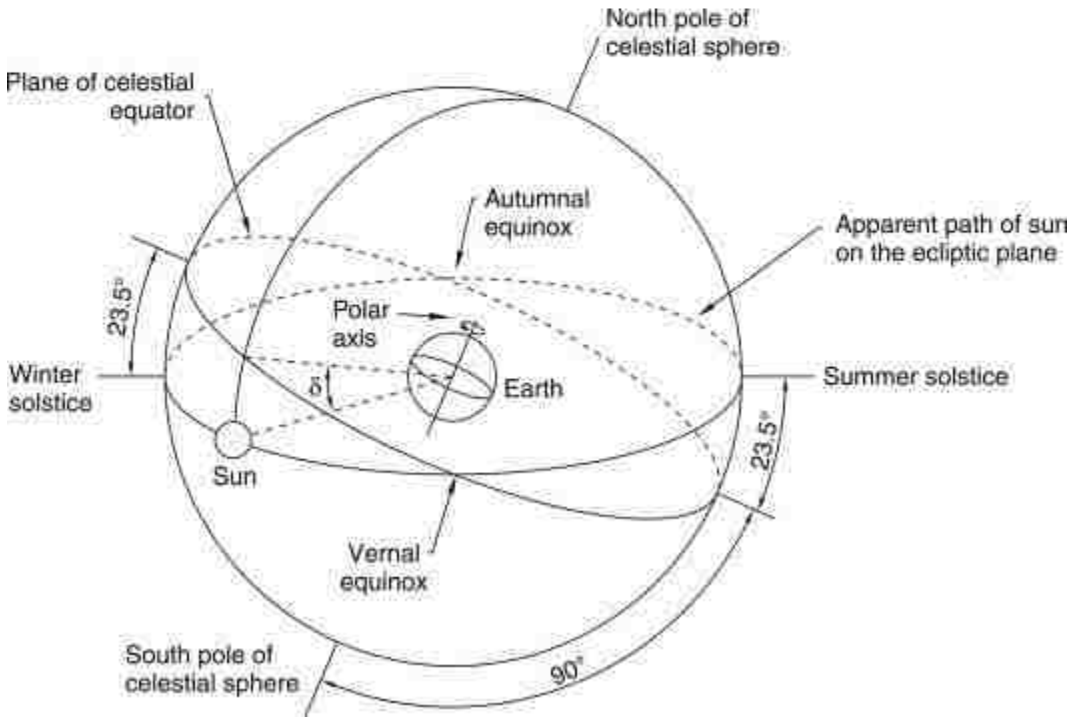


Figure 2.2. Diagram of the Planetary Sphere and Celestial Sphere

This celestial event occurs during the aphelion portion of the Earth's revolution around the sun, or the point within the sun is the furthest from the sun. During the winter heating months, the declination is negative, and occurs during the perihelion; or time when the Earth is closest to the sun. The declination gradually changes throughout the year. The extremes of the declination are found during the equinoxes of the season. The most negative declination angle occurs during the winter solstice, yearly occurring on or around December 22. The equation for the solar declination angle, in Equation 1, utilized the day of the year as the only reference to the declination. In regard to louver geometry, this extreme corresponds to the time of the year when the greatest amount of solar energy will be allowed to pass through louver array and the least amount of the façade or fenestration surfaces will be blocked or shaded. Table 2.1 highlights the declination angle of the incident solar energy against the equinoxes and solstices.

$$\boldsymbol{\delta = 23.45 \times \sin\left(\frac{360^\circ \times (284\, day + n\, day)}{365\, day}\right)} \qquad (1)$$

$$\boldsymbol{n = day\ of\ the\ year}$$

The design of the louvers takes this winter angle characteristic into the design to minimize the rejection of beneficial solar gains. The other extreme of the declination angle occurs during the summer solstices, on or around June 21.

Table 2.1. List of Declination Angles against Celestial Dates

	Winter Solstice	Vernal Equinox	Summer Solstice	Autumnal Equinox
Date	December 22-23	March 22-23	June 21-22	September 22-23
Declination Angle (deg)	-23.45	0	23.45	0

This altitude angle corresponds to the highest solar altitude angle, or the greatest angle between the latitude's tangential horizontal and the direct beam solar energy. This high angle is the design characteristic for the summer cooling months and when the least amount of solar energy should be allowed into the building. This is the design input that emphasizes the rejection of heat and energy from being allowed to pass into a building. The balance of these two characteristics in the design of a passive louver array system is vital to designing an array that is able to perform well during both the winter and summer months. Figure 9 illustrates the application of a louver assembly with the extreme declination angles at the winter and summer solstices.

2.1.3. Solar Hour Angle. The solar hour angle is the angle that corresponds to the hour of the day. This variable is used in many solar geometry calculations to describe the sun's movement across the sky during a day. The illustration in Figure 2.3 highlights this affect from 6:00 AM until 2:00 PM, with the corresponding angle. The sign convention used within this work is that the solar hour angle is decreasing negative degrees from sunrise to noon, 0 degrees at noon, and increasing positive degrees from noon to sunset. Solar hour angles range from -180 degrees to 180 degrees, but for most solar geometry calculations only the angles from sunrise to sunset are considered. The equation for the solar hour angle can be viewed in Equation 2.

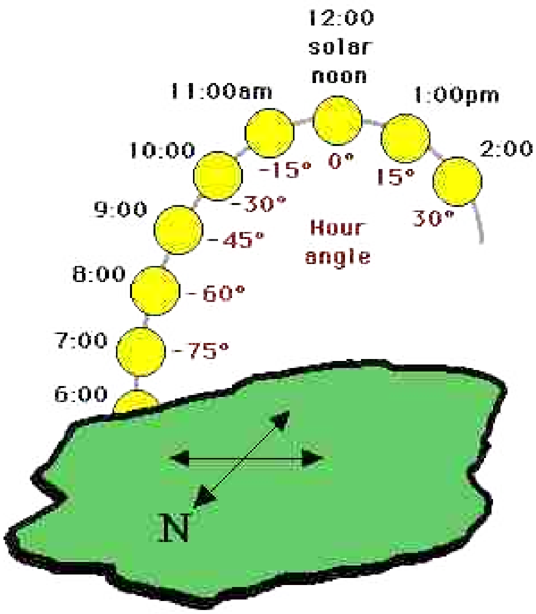


Figure 2.3. Solar Hour Angle over the Course of a Single Day

$$hs = (\,Solar\ Time - 12hour) \times 15 \frac{\circ}{hour} \tag{2}$$

$Solar\ Time\ in\ 24\ format$

2.1.4. Solar Altitude Angle. The solar altitude is the angle between the direct beam of solar energy and the tangential horizontal at certain latitudes. It can be described as the relative elevation of the sun in the sky, with respect to the viewer. The altitude angle is derived from the latitude, declination, and solar hour angle. Using these site dependent characteristics, the location of the sun's center, or direct beam origin, can be determined for any day of the year. The sun path in Figure 2.4 is a graphic representation of the location of the sun across the day. The location of the sun within the sun path graphic is representative of the coordinates defined by the altitude and the hour angle.

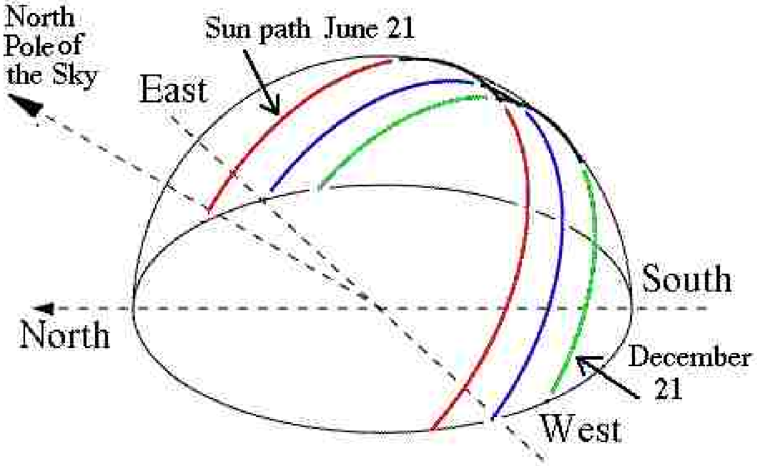


Figure 2.4. Sun Path

The multiple lines are representative of the differing paths through the sky the sun takes due to the declination. The solar geometry and sun path are crucial to the external environment of the simulation model. The equation of the solar altitude angle, in Equation 3, accounts for the Latitude derived from the site, the declination described above, and the solar hour angle. Using these simple calculations to verify the simulation model characteristics is another way the model can be validated against physical experimentation and real world development.

$$\theta = \sin^{-1}(\sin(L) \times \sin(\delta) + \cos(L) \times \cos(\delta) \times \cos(hs) \qquad (3)$$

L= Latitude

δ= Declination

hs= Solar Hour Angle

2.2 MODEL INPUT CHARACTERISTICS

2.2.1. Materials. All of the prominent building materials used during the actually construction of the house were researched and entered into the model. The physical characteristics for each material were included within the model to allow the simulation computation to create the most accurate digital representation of the building, as possible. The façade materials were divided into two categories: the surface materials and the fenestration materials. The surface materials were broken into three specific materials types, including the floor types, roof type, and wall type.

2.2.2. Floor Material and Construction. The floor was subdivided into two zones, to correspond to the two types of flooring within the house, either wood flooring or tile flooring. The Zone 1 floor material was modeled after a composite wood floor of three layers. The layers, in order from outermost to inner most layers, were insulation, subfloor, and wood flooring. The Bathroom floor material was modeled after a tile floor in three layers. The layers, in order from outermost to innermost layers, were insulation, subfloor, and tile flooring. The physical details of each of the materials are highlighted within the Table 2.2 for each material, including relevant characteristics like roughness, thickness, conductivity, density, and specific heat for the main floor of the building. The material characteristics for the Bathroom floor zone are within Table 2.3.

Table 2.2. Zone 1 Floor Material Characteristics

Name	Units	I06 244 mm Batt Insulation	1" Plywood	Wood Flooring
Roughness		Very Rough	Medium Smooth	Smooth
Thickness	m	0.24	0.03	0.02
Conductivity	W/m-K	0.05	0.02	0.11
Density	kg/m^3	19.00	112.13	96.11
Specific Heat	J/kg-K	960.00	25104.00	1210.00
Thermal Absorptance			0.90	0.90
Solar Absorptance			0.78	0.78
Visible Absorptance			0.78	0.78

2.2.3. Roof Material and Construction. The roof material was modeled as a single unit across the entire building. The roof was modeled to represent a Structurally Insulated Panel (SIP), covered on the exterior by a weatherproof membrane and metal roofing, and covered on the interior with a gypsum drywall.

Table 2.3. Bathroom Zone Floor Material Characteristics

Name	Units	I06 244 mm Batt Insulation	1" Plywood	Ceramic Tile
Roughness		Very Rough	Medium Smooth	Very Smooth
Thickness	m	0.24	0.03	0.01
Conductivity	W/m-K	0.05	0.02	1.01
Density	kg/m^3	19.00	112.13	160.18
Specific Heat	J/kg-K	960.00	25104.00	836.80
Thermal Absorptance			0.90	0.90
Solar Absorptance			0.78	0.70
Visible Absorptance			0.78	0.70

The layers, in order from outermost to inner most layers, were metal roofing, roofing membrane, plywood, expanded polystyrene, plywood, and gypsum drywall board. These materials also included the roughness, thickness, conductivity, density, and specific heat into the model to accurately describe the insulation ability of the roof and are included in Table 2.4.

2.2.4. Wall Material and Construction. The wall materials for the exterior walls are the same for all four sides of the façade. The only deviation from the wall construction is the placement of the fenestration surfaces. The walls were simulated using a SIP wall similar to that of the roof material. The wall materials include, from outermost to innermost, the wood siding, weather proofing material, plywood, expanded polystyrene, plywood, and gypsum. The insulation value of the wall composition was computed using the characteristics like the roughness, thickness, conductivity, density, and specific heat. Table 2.5 shows these values.

Table 2.4. Roof Material Characteristics

Name	Units	Metal Roofing	Roof Membrane	1/2" Plywood
Roughness		Medium Smooth	Very Rough	Medium Smooth
Thickness	m	0.00	0.01	0.01
Conductivity	W/m-K	45.01	0.16	0.12
Density	kg/m^3	7680.00	1121.29	545.00
Specific Heat	J/kg-K	418.40	1460.00	1213.00
Thermal Absorptance		0.90	0.90	0.90
Solar Absorptance		0.70	0.70	0.78
Visible Absorptance		0.30	0.70	0.78
Name	Units	Insulation: Expanded polystyrene - extruded (smooth skin surface) (HCFC-142b exp.)	1/2" Plywood	G01 16 mm Gypsum Board
Roughness		Medium Smooth	Medium Smooth	Medium Smooth
Thickness	m	0.14	0.01	0.02
Conductivity	W/m-K	0.03	0.12	0.16
Density	kg/m^3	29.00	545.00	800.00
Specific Heat	J/kg-K	1210.00	1213.00	1090.00
Thermal Absorptance			0.90	
Solar Absorptance			0.78	
Visible Absorptance			0.78	

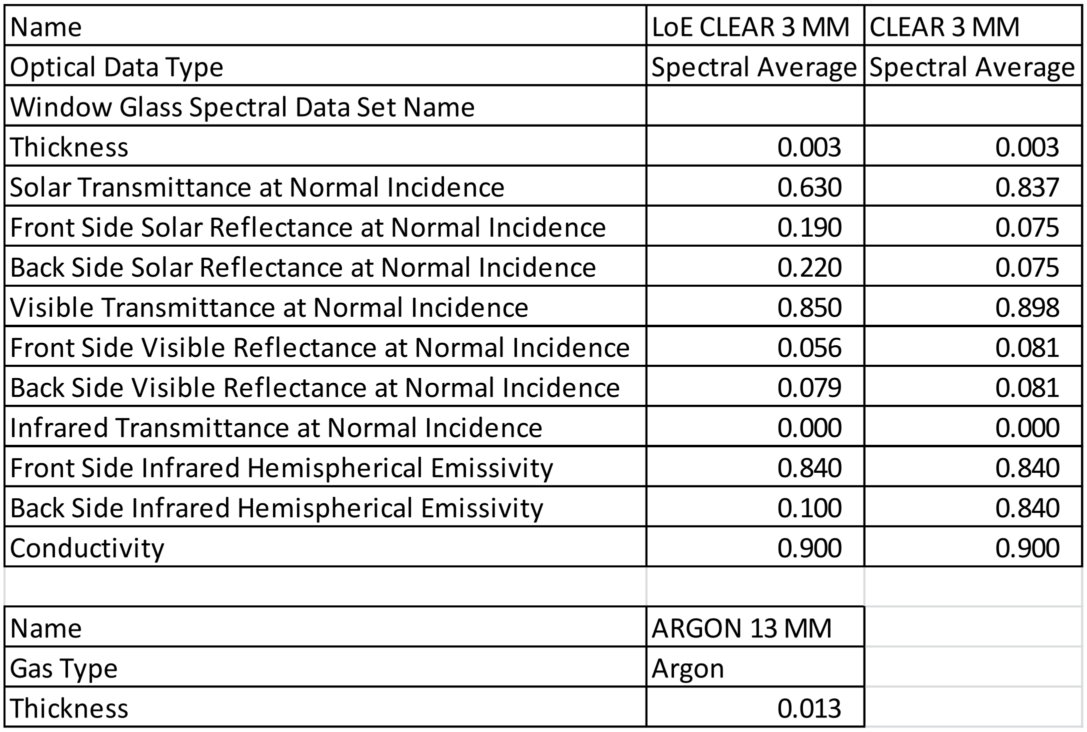
2.2.5. Fenestration Material and Construction. The fenestration surfaces, or any exterior glazing or window, throughout the façade was created using the same fenestration type within the energy model. As all of the windows in the real building share the same characteristics, the models also used the same characteristics for each of the fenestration surfaces within the model. These surfaces are a 3 mm low E clear glass, 13 mm of argon vapor, and another 3 mm of clear glass. These materials and vapor employed the thickness and solar transmittance as the vital characteristics within the model, as seen in Table 2.6.

Table 2.5. Wall Material Characteristics

Name	Units	F11 Wood Siding	1/2" Plywood	Insulation: Expanded polystyrene - extruded (smooth skin surface) (HCFC-142b exp.)
Roughness		Medium Smooth	Medium Smooth	Medium Smooth
Thickness	m	0.01	0.01	0.14
Conductivity	W/m-K	0.09	0.12	0.03
Density	kg/m^3	592.00	545.00	29.00
Specific Heat	J/kg-K	1170.00	1213.00	1210.00
Thermal Absorptance			0.90	
Solar Absorptance			0.78	
Visible Absorptance			0.78	
Name	Units	1/2" Plywood	G01 16 mm Gypsum Board	
Roughness		Medium Smooth	Medium Smooth	
Thickness	m	0.01	0.02	
Conductivity	W/m-K	0.12	0.16	
Density	kg/m^3	545.00	800.00	
Specific Heat	J/kg-K	1213.00	1090.00	
Thermal Absorptance		0.90		
Solar Absorptance		0.78		
Visible Absorptance		0.78		

2.2.6. Energy Plus. Energy Plus acts as a simulation translator and engine for many modules created throughout the development of the software. The modules specific to this research that are being used within the simulation engine and were the precursor to the software Energy Plus, are the software; DOE-2 and its generations. DOE-2 is a building energy analysis tool created by a team at Lawrence Berkeley National Lab and the Department of Energy. Building Loads Analysis and System Thermodynamics (BLAST) is another software utilized for the building loads and thermodynamics of the Energy Plus simulation. Figure 2.5 is a simple illustration explaining the order of operations for the Energy Plus simulation.

Table 2.6. Window Material Characteristics- Glass and Gas Membrane



Name	LoE CLEAR 3 MM	CLEAR 3 MM
Optical Data Type	Spectral Average	Spectral Average
Window Glass Spectral Data Set Name		
Thickness	0.003	0.003
Solar Transmittance at Normal Incidence	0.630	0.837
Front Side Solar Reflectance at Normal Incidence	0.190	0.075
Back Side Solar Reflectance at Normal Incidence	0.220	0.075
Visible Transmittance at Normal Incidence	0.850	0.898
Front Side Visible Reflectance at Normal Incidence	0.056	0.081
Back Side Visible Reflectance at Normal Incidence	0.079	0.081
Infrared Transmittance at Normal Incidence	0.000	0.000
Front Side Infrared Hemispherical Emissivity	0.840	0.840
Back Side Infrared Hemispherical Emissivity	0.100	0.840
Conductivity	0.900	0.900
Name	ARGON 13 MM	
Gas Type	Argon	
Thickness	0.013	

Beginning with the description of the building by the user, the data is then accessed by a group of simulation modules, all computing interdependent calculations, drawing results to the heat and mass balance of the simulated building, as well as simulating the building as a whole in a virtual space. Once the computations are collected and ordered from each of the modules, the calculations results are output in text based, or Comma Separated Values (CSV) formats for greater evaluation by the user. Energy Plus has been described as a simulation engine and not as a user interface by many of the works describing the software. For this reason, many third party Energy Plus interfaces have been developed in conjunction with the Energy Plus developments.

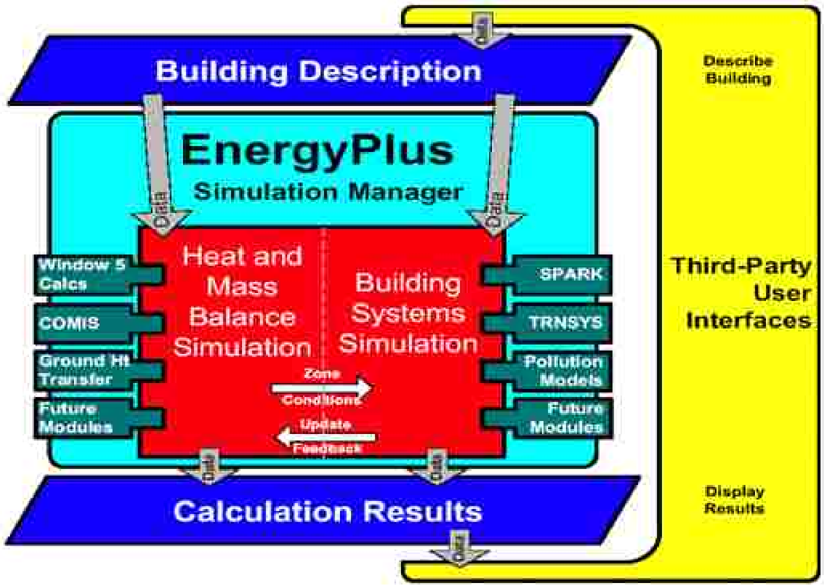


Figure 2.5. Illustration Describing the Operations within Energy Plus

This research did not use any of these third party interfaces for input characteristic development. This work did however use Sketch Up’s open source plug in for Energy Plus, Open Studio, to validate the building geometry after input into Energy Plus directly.

2.2.7. Equations. Energy Plus utilizes a series of thermal and load calculation modules to access the cumulative effect of multiple factors on a single building. Most of the thermal and environmental equations Energy Plus has used to compute within this research have been focused on thermal mass transfer through materials and solar gain calculations, including incident solar on the site and transmitted energy into the building. Figure 2.6 from the Department of Energy (DOE), Energy Efficiency and Renewable Energy (EERE) University Course curriculum exemplifies the multiple factors that Energy Plus considers through the simulation modules.

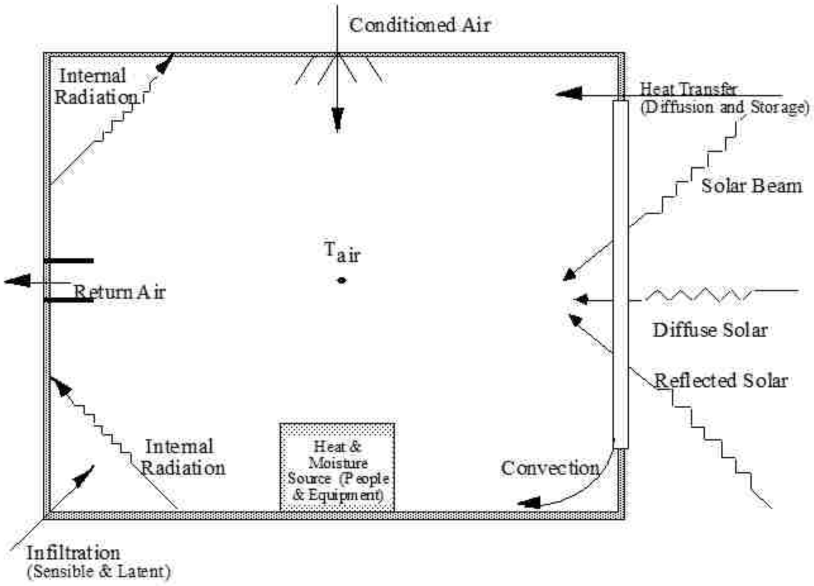


Figure 2.6. Factors Involved in Analyzing Interior Temperature and Energy

2.2.8. Building Geometry. Building Geometry is the relationship of how the structure is built and the orientation of the building on the site. Within Energy Plus, building geometry corresponds to the size, shape, scale, and orientation of the building and includes the models characteristics, including the building materials and weather considerations. The process of the construction of the building within a virtual space is vital to the development of the energy model, in regards to the generation of an accurate solar gain profile from the orientation and shape of the building, as well as, the building load analysis derived and computed from the exterior environmental factor analysis. The combination of the previous factors into an active energy model, set on a specific site, under specific weather conditions, allow for understanding of the building loads necessary for the site and the building. By comparing these simulated load estimates against actual experimental data retrieved from the actual house's monitoring systems, the accuracy and validity of the model can be accessed. This research compared the model against multiple test cases of the home to access the validity of the model.

2.3 SIMULATED MODEL VALIDATION

2.3.1. Test Cases. The validation tests are the four cases involved within the research, used to validate the simulation. Of the four tests, each features a differing response to the amount of energy entering the building. The four test include the baseline test, with no response to the energy incident upon the building, the mechanical systems test, employing mechanical control of the temperature of the building, the louver test, featuring no mechanical systems, but employing a louver array modeled after the experimental building, and finally, the systems case, utilizing both a louver array and the mechanical systems. The systems test has been compared against the experiment to assure the validity of the simulation. The experimental data collected was collected for periods within the fall and winter season, and a short period in the spring. There was no data collected during the summer. The collected data can be viewed in Figure 2.7, as the comparison between the exterior and interior temperatures.

The other tests have been used to understand the role that each individual technology played in the amount of energy allowed into the space, and also the comparison against the a building retaining no technology, to understand the capabilities of a louver array individually. The test cases are explained in detail below.

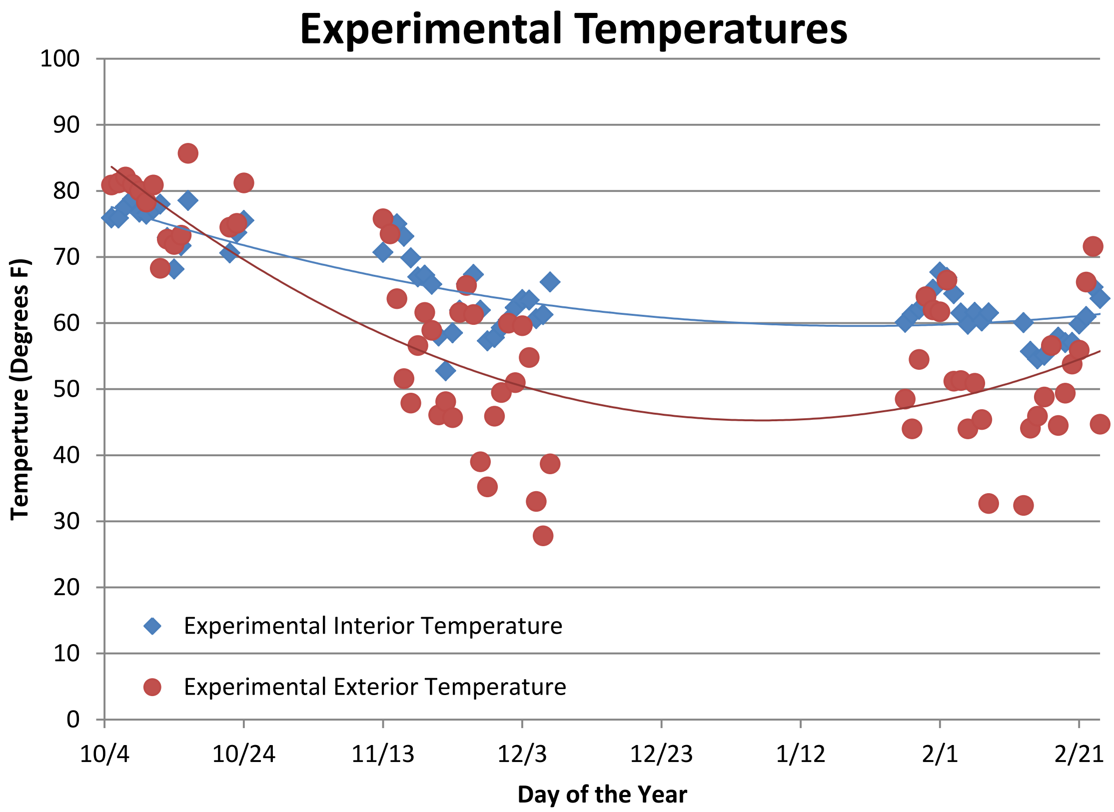


Figure 2.7. Interior and Exterior Experimental Temperatures within the House

2.3.1.1 Test case 1: simple box case- no mechanical systems, no louver array. The box case is the baseline test case. The simulated results that are found within this test correspond to how the building would respond to the environment situation without any interference of conditioning systems or passive louver techniques. The box case has high temperature swings throughout the year, but attains a lagging temperature profile within the house compared to the environmental surrounds. The box case's temperature profile is dependent entirely on the external temperature and the solar gain. The box case has no artificial energy use and is considered uninhabitable. This case is identified by the highest interior temperature ranges during the summer months, due to the high external heat and solar gains, and low internal temperature during the winter months, due to the external temperature, but addition of the solar heat gains. The simulated results of the Box Case are compared with the Mechanical Case to compare the baseline case to the energy necessary to fully heat and cool the space to American Society of Heating Refrigeration, and Air-Conditioning Engineers (ASHRAE) Standards, to understand the amount of energy necessary to maintain the comfort level. The Box Case is also compared against the Louver Box case to understand the amount of energy removed from the system by solely the louver array.

2.3.1.2 Test case 2: mechanical case- mechanical systems attaining ASHRAE 55 comfort standards, no louver array. The mechanical case is the highest artificial energy consumer. The mechanical case used ideal air conditioning and heating systems to condition the building to ASHRAE 55 Standards 19.6 degrees C at the lowest, and 25.1 degrees C at the highest across the year, without any benefit of the solar gain shading of a louver array. The mechanical case is identified by the full temperature regulation throughout the year, while also maintaining the largest artificial energy consumption. The mechanical case is an example of how most construction has been complete to date, assuming little interest in the passive solar strategies. The Mechanical Case is directly compared against the Systems Case to showcase the differential between the implementation of louver arrays.

2.3.1.3 Test case 3: louver case- no mechanical systems, louver array.
The louver case, like the box case also uses no artificial energy. The simulated results that are found within this test correspond to how the building would respond to the environment situation without any interference of conditioning systems. The box case has high temperature swings throughout the year, but resists the box case’s temperature

profile within the house, and lags the box case due to the influence of the louver array. The louver case is another uninhabitable building and used just to reinforce the proof of concept for the louver array. The Louver Case is directly compared against the Systems Case to showcase the differential between the mechanical systems alone conditioning a space and the introduction of the louver array.

2.3.1.4 Test case 4: systems case- mechanical systems attaining ASHRAE 55 comfort standards, louver array. The Systems Case is the culmination of the all the systems introduced within the research. The systems case includes an ideal air conditioning and heating systems to condition the building to ASHRAE 55 Standards, 19.6 degrees C at the lowest temperature, and 25.1 degrees C at the highest temperature across the year, in addition to all the benefits of the louver array. The reduction in artificial cooling energy is due to the removal of a portion of the solar heat gains in the cooling months, as well as, the minimization of the increase of necessary artificial heating in the heating months.

2.3.1.5 Test case results. The test cases compare different data to understand similar concepts of the research. The interior air temperature is simulated within each test case, but the test cases without mechanical systems offer the most useful results, due to the fact that the interior air temperature is able to vary influenced only by the exterior temperature and the amount of solar heat gain. The test cases with mechanical systems only show the non-influenced temperature swings within the ASHRAE 55 range of 19.1 degrees C to 25.6 degrees C. Figure 2.8 shows the interior temperatures of the model and the experimental house side by side. The mechanical test cases show the amount of energy that is necessary to attain ASHRAE 55 comfort levels through standard heating and cooling practices, both with and without a louver array. By comparing the mechanical test cases, the research was able to understand the connection between the artificial energy use to condition the space in both louvered and un-louvered conditions. The non-mechanical cases aid in the understanding of how the systems tend to interact with the natural surrounds, including the exterior environmental temperature and the solar heat gain potential.

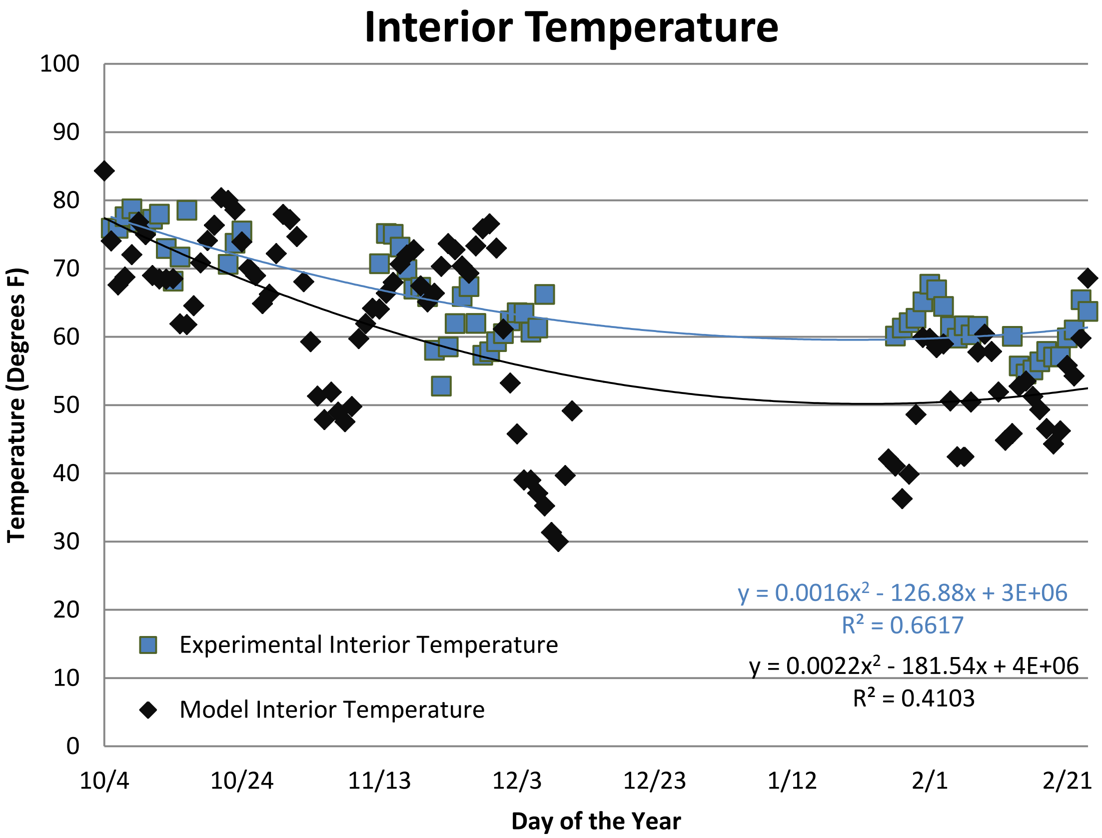


Figure 2.8. Graph of Interior Temperature Comparing Model Temperature and Experimental Temperature

2.3.2. Dynamic Model Characteristics. Every simulated model within this research includes the same building, materials, and weather data, goal of this work is to discover the optimized louver and optimized louver array geometry for this building and building like it. This is achieved through dynamically altering the variable of the louver array to include every variable possible within a set range. This variable range is unique to each louver variable and is explained further within the experimental design section. By systematically altering the each variable and executing an Energy Plus simulation, this work was able to create a series of data points to categorize the effects of changing the individual variable and the interdependent effects the variable had on one another. These simulated output results were compiled to showcase the effects of the variables and to determine the array and louver configuration with the least annual energy consumption within the house. Figure 2.9 illustrates all of the dynamic variables considered within this work, and the interaction between each of the variables.

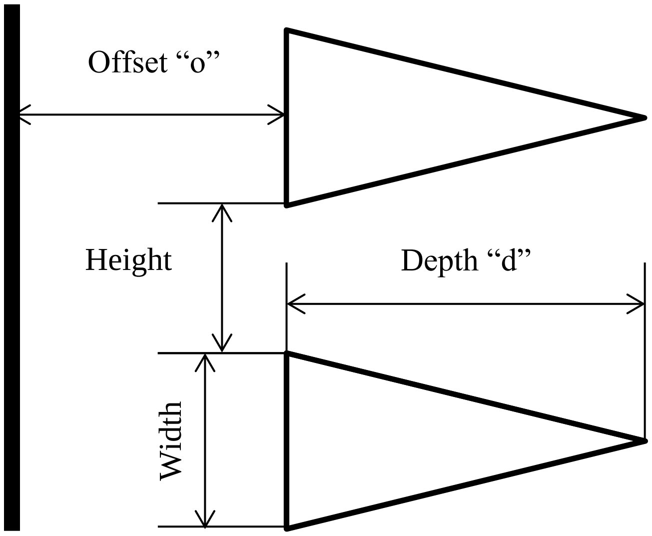


Figure 2.9. Illustration of Each Dynamic Variable

Evaluating the louvers side by side, with all other effects remaining the same, the effects of the louvers and the effects of the variable configurations could be compared directly. Once the simulations for each of the variables sets were complete, the energy results from each variable set could be evaluated. This comparison not only allowed for the least energy intensive louver configuration to be determined, but also created a systematic file of interdependent variables and their energy outputs. With this compilation of outputs, energy demand for continuous variables, outside the finite and discrete number of variable that where run within this work, could be accessed. This research has created an initial prototype software to access any variation of louver configuration within the range of the research. The range of the research was derived primarily from the ability to manufacture the materials and the industry norms for louver technology.

3. EXPERIMENTAL PROCEDURE

3.1 EXPERIMENTAL DESIGN

3.1.1. House Design. The simulated house was designed for the US DOE Solar Decathlon in 2009, by Missouri S&T. This house was the fourth house designed and constructed to compete for that competition by the Missouri S&T team for students. After the competition, this house came to rest, along with the other returned homes, at the Missouri S&T Solar Village. This Solar Village is a community of these four solar homes to be used as an outreach, education, and teaching tool at the university. The homes also serve as faculty and student housing for the campus. The house that this research focused on was the latest and most prominent application of passive solar shading, the Missouri S&T 2009 solar house. Figure 3.1 shows a photo if the original experimental house on its site at the Missouri S&T Solar Village.

Figure 3.1. Photo of the Original Experimental House by Missouri S&T

The 2009, as it’s called, is the only house within the solar village to implement a solar shading louver array. Its array stretches across the entire south façade, across the fenestration surfaces, as well as, the opaque surfaces of the walls. The model of the 2009, seen in Figure 3.2, was constructed to follow, to the best ability, the 2009 building materials, structure, interior spaces, and building shape, size and geometry. These static components of the house all were modeled after the original to best represent, within a virtual space, the effects that the materials had on the internal environment of the home, and the energy requirements of the mechanical systems.

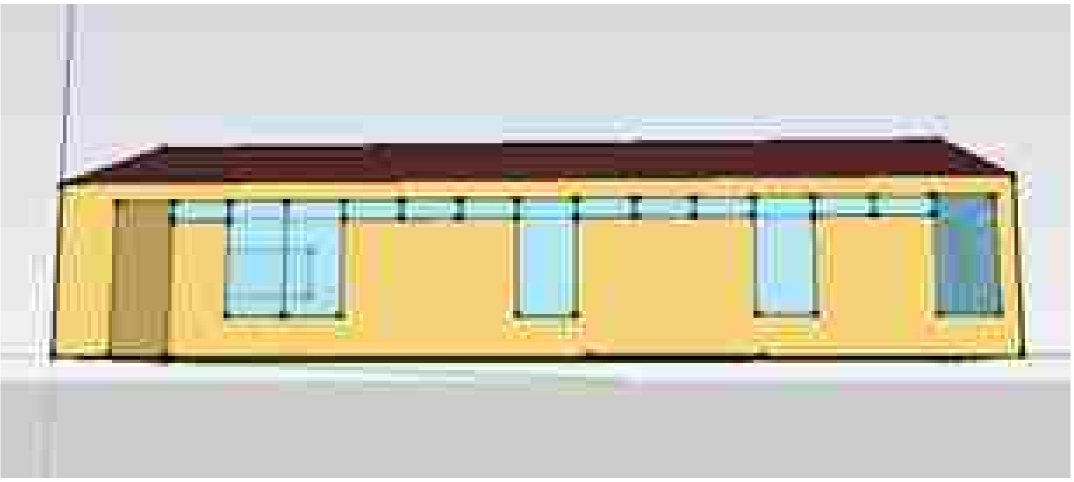


Figure 3.2. Image of the 2009 Simulation Model

3.1.2. Exterior Surfaces. The 2009 house has a simple floor plane that was translated into the model. It consists of a rectangle floor 49 feet long in the East-West direction, or along the positive X coordinate line, assuming an origin point at the lowest, east point of the house. The length of the house, or along the North- South plane of the house, is 15 feet. The input into Energy Plus is an X, Y, Z coordinate system in metric units. The seemingly odd coordinates are due to the conversion from the imperial units used to design and construct the house to metric used within Energy Plus. Table 3.1 illustrates the X, Y, Z coordinates of each vertex to form wall planes within the building's external structure and as well as displays the material objects and Energy Plus construction objects used within the model, from the Energy Plus file.

Table 3.1. Wall Construction and Location

Name	Units	NORTH WALL LOW	NORTH WALL HIGH	EAST WALL	WEST WALL	SOUTH WALL
Surface Type		Wall	Wall	Wall	Wall	Wall
Construction Name		EXTERIOR WALL	EXTERIOR WALL	EXTERIOR WALL	EXTERIOR WALL	EXTERIOR WALL
Zone Name		ZONE 1	ZONE 1	ZONE 1	ZONE 1	ZONE 1
Outside Boundary Condition		Outdoors	Outdoors	Outdoors	Outdoors	Outdoors
Sun Exposure		Sun Exposed	Sun Exposed	Sun Exposed	Sun Exposed	Sun Exposed
Wind Exposure		Wind Exposed	Wind Exposed	Wind Exposed	Wind Exposed	Wind Exposed
View Factor to Ground			autocalculate	autocalculate	autocalculate	
Number of Vertices		4	4	5	5	4
Vertex 1 X-coordinate	m	14.93	14.93	14.93	0.00	0.00
Vertex 1 Y-coordinate	m	4.57	4.57	0.00	4.57	0.00
Vertex 1 Z-coordinate	m	0.00	2.74	0.00	0.00	0.00
Vertex 2 X-coordinate	m	0.00	0.00	14.93	0.00	14.93
Vertex 2 Y-coordinate	m	4.57	4.57	4.57	0.00	0.00
Vertex 2 Z-coordinate	m	0.00	2.74	0.00	0.00	0.00
Vertex 3 X-coordinate	m	0.00	0.00	14.93	0.00	14.93
Vertex 3 Y-coordinate	m	4.57	4.19	4.57	0.00	0.00
Vertex 3 Z-coordinate	m	2.74	4.11	2.74	2.74	2.74
Vertex 4 X-coordinate	m	14.93	14.93	14.93	0.00	0.00
Vertex 4 Y-coordinate	m	4.57	4.19	4.19	4.19	0.00
Vertex 4 Z-coordinate	m	2.74	4.11	4.11	4.11	2.74
Vertex 5 X-coordinate	m			14.93	0.00	
Vertex 5 Y-coordinate	m			0.00	4.57	
Vertex 5 Z-coordinate	m			2.74	2.74	

The floor, roof materials, and construction are also input from characteristics of the actual house. The floor is divided by the interior surface material into the main house floor (Zone 1) and the bathroom floor. Even though the flooring is different, the thermal zone of the model is the same for the building. The difference is due to the flooring material used for each. The main floor is wood flooring. As a wood material, the floor has a low conductivity and as such restricts the flow of energy and heat to and from the house, acting as an insulator. The bathroom floor, however, is a ceramic tile floor and has a reasonably high conductivity for flooring. The tile acts as a conduit for heat and energy to enter and leave the building. Unlike the floor construction within the model, the roof is a single unit made of similar materials. The roof materials characteristics again are derived from the actual materials used from the construction of the home. As a single unit of like materials, the roof extends from the top of the South façade, and closes the zone volume by connecting to the other wall facades. Table 3.2 highlights the construction and locations of both the roof and floor object within the Energy Plus file.

Table 3.2. Roof and Floor Construction and Location

Name	Units	ZONE 1 FLOOR	BATHROOM FLOOR	ROOF
Surface Type		Floor	Floor	Roof
Construction Name		FLOOR ZONE 1	FLOOR BATHROOM	EXTERIOR ROOF
Zone Name		ZONE 1	ZONE 1	ZONE 1
Outside Boundary Condition		Outdoors	Outdoors	Outdoors
Sun Exposure		Sun Exposed	Sun Exposed	Sun Exposed
Wind Exposure		Wind Exposed	Wind Exposed	Wind Exposed
Number of Vertices		4	4	4
Vertex 1 X-coordinate	m	14.93	11.12	0.00
Vertex 1 Y-coordinate	m	0.00	0.00	0.00
Vertex 1 Z-coordinate	m	0.00	0.00	2.74
Vertex 2 X-coordinate	m	0.00	8.38	14.93
Vertex 2 Y-coordinate	m	0.00	0.00	0.00
Vertex 2 Z-coordinate	m	0.00	0.00	2.74
Vertex 3 X-coordinate	m	0.00	8.38	14.93
Vertex 3 Y-coordinate	m	4.57	2.44	4.19
Vertex 3 Z-coordinate	m	0.00	0.00	4.11
Vertex 4 X-coordinate	m	14.93	11.12	0.00
Vertex 4 Y-coordinate	m	4.57	2.44	4.19
Vertex 4 Z-coordinate	m	0.00	0.00	4.11

3.1.3. Fenestration Surfaces. The glazing or fenestration surfaces within the the model are vital to the acceptance of solar gains within the building are also responsible for the majority of heat loss through the exterior surfaces. The 2009 house was set primarily on a three foot grid. Due to this grid style construction, the windows on the south façade were each approximately 3 foot long, in the X direction, and varied from either being an upper window, at roughly 1 foot tall in the Z direction, or a full length window, at roughly six feet tall in the Z direction. The South façade window coordinates were described within Table 3.3. Of the 14 windows on the south façade, four are shown here to conserve space. The full list is available within Appendix A.

Table 3.3. South Façade Window Construction and Locations

Name	Units	SOUTH WINDOW 1	SOUTH WINDOW 2	SOUTH WINDOW 3
Surface Type		Window	Window	Window
Construction Name		WINDOW	WINDOW	WINDOW
Building Surface Name		SOUTH WALL	SOUTH WALL	SOUTH WALL
Multiplier		1.00	1.00	1.00
Number of Vertices		4.00	4.00	4.00
Vertex 1 X-coordinate	m	1.83	2.74	3.66
Vertex 1 Y-coordinate	m	0.00	0.00	0.00
Vertex 1 Z-coordinate	m	2.13	0.61	0.61
Vertex 2 X-coordinate	m	2.74	3.66	4.57
Vertex 2 Y-coordinate	m	0.00	0.00	0.00
Vertex 2 Z-coordinate	m	2.13	0.61	0.61
Vertex 3 X-coordinate	m	2.74	3.66	4.57
Vertex 3 Y-coordinate	m	0.00	0.00	0.00
Vertex 3 Z-coordinate	m	2.44	2.44	2.44
Vertex 4 X-coordinate	m	1.83	2.74	3.66
Vertex 4 Y-coordinate	m	0.00	0.00	0.00
Vertex 4 Z-coordinate	m	2.44	2.44	2.44

Considering that the majority of the energy is gained or lost through the South façade, this research has taken a focus on the windows of this façade. The windows on the East, West and North façade are also modeled within this work within Tables 3.4 and 3.5. The entire list is available in Appendix A. Each of these tables corresponds to the location and material makeup of each of the window on any façade surface.

Table 3.4. West and East Façade Window Construction and Locations

Name	Units	WEST WINDOW 1	EAST WINDOW 1	EAST WINDOW 2	EAST DOOR
Surface Type		Window	Window	Window	Door
Construction Name		WINDOW	WINDOW	WINDOW	DOOR
Building Surface Name		WEST WALL	EAST WALL	EAST WALL	EAST WALL
Multiplier		1.00	1.00	1.00	1.00
Number of Vertices		4.00	4.00	4.00	4.00
Vertex 1 X-coordinate	m	0.00	14.93	14.93	14.93
Vertex 1 Y-coordinate	m	4.42	0.30	1.22	2.74
Vertex 1 Z-coordinate	m	1.22	2.13	2.13	0.00
Vertex 2 X-coordinate	m	0.00	14.93	14.93	14.93
Vertex 2 Y-coordinate	m	2.59	1.22	2.13	3.66
Vertex 2 Z-coordinate	m	1.22	2.13	2.13	0.00
Vertex 3 X-coordinate	m	0.00	14.93	14.93	14.93
Vertex 3 Y-coordinate	m	2.59	1.22	2.13	3.66
Vertex 3 Z-coordinate	m	2.13	2.44	2.44	2.44
Vertex 4 X-coordinate	m	0.00	14.93	14.93	14.93
Vertex 4 Y-coordinate	m	4.42	0.30	1.22	2.74
Vertex 4 Z-coordinate	m	2.13	2.44	2.44	2.44

These static surfaces remained unchanged in all of the simulations regardless of louver configuration. By maintaining these unchanging components within each model, the louver variables were able to be compared independently of extraneous environmental changes.

Table 3.5. North Façade Window Construction and Locations

Name	Units	NORTH WINDOW	NORTH WINDOW HIGH 1
Surface Type		Window	Window
Construction Name		WINDOW	WINDOW
Building Surface Name		NORTH WALL LOW	NORTH WALL HIGH
Multiplier		1.00	1.00
Number of Vertices		4.00	4.00
Vertex 1 X-coordinate	m	2.90	14.71
Vertex 1 Y-coordinate	m	4.57	4.39
Vertex 1 Z-coordinate	m	1.22	3.40
Vertex 2 X-coordinate	m	0.23	13.87
Vertex 2 Y-coordinate	m	4.57	4.39
Vertex 2 Z-coordinate	m	1.22	3.40
Vertex 3 X-coordinate	m	0.23	13.87
Vertex 3 Y-coordinate	m	4.57	4.27
Vertex 3 Z-coordinate	m	2.13	3.84
Vertex 4 X-coordinate	m	2.90	14.71
Vertex 4 Y-coordinate	m	4.57	4.27
Vertex 4 Z-coordinate	m	2.13	3.84

3.1.4. Louver Design. The optimum louver configuration is the goal of this research. By varying the critical characteristics of the louver and the array geometry, the optimum louver can be defined as the system to produce the least energy dependent home, according to the energy model and energy systems output. Each of the characteristics was systematically changed within manufacturer-set upper limits. To this goal, the optimum size louver and its configuration will still be able to be manufactured by the industry today. Those louver and array characteristics are depth, height, offset, and width. Each of the four characteristics was assigned four discrete values within manufacturing ability of the louver. These characteristics were then assembled into all the possible combinations of the variables. These 256 possible combinations of the louver variables were then added to the house simulation and run within the simulation engine to simulate an entire year's worth of solar gain and environmental factors on the house. These 256 discrete data points, associated with the combined heating and cooling loads for each louver array, were collected and compiled to create a view of the least energy intensive louver array for this latitude and climate. The variables within this work were described as a series of four values. Any number series directly described the louver array with its variables in alphabetical order. In other words, the louver array with a depth of one inch, a height of one inch, and offset of zero inches, and width of one inch will be labeled in alphabetical order of its variables; d, h, o, w: 1,1,0,1.

3.1.4.1 Depth. The depth is the component of the louver array that corresponds to the distance between the outermost tip and the center point closest to the structural wall. The depth, in conjunction with the height of louver array, is primarily responsible for the amount of light able to be reflected from the covered surface. In this research the depth of the louver array was divided into four discrete values for possible variables. The variables range from the highest and lowest extremes of the manufacturer ability and two median values of the range. The depth variables considered within this research ranged from the lowest value of 1 inch, to a set of distributed median values of 6 inches and 12 inches, and a highest value normally manufactured at 18 inches.

3.1.4.2 Height. The height is the distance between the center points of the louvers within the array. This variable is responsible for the majority of the light being able to pass through the array without shading. A large height will allow a majority of the energy to pass through the array, and is usually attributed with lower heating loads and higher cooling loads. The height is an array louver variable so does not have a manufacturer designation. The values for the height examined within this research are the ranges generally seen within residential or commercial installations. The height is the critical element that sets the number of louvers that can be within a finite space, as highlighted in Figure 3.3. The allocated space used within this research was the fenestration space utilized on the existing house at 7.5 feet. The highest louver within any array could not be any higher than the top most windows on the South façade.

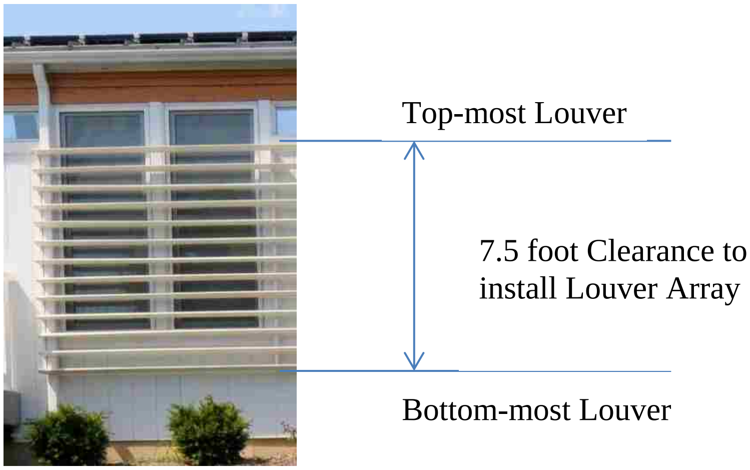


Figure 3.3. Array Restrictions on Height of Array

The height between the louvers directly affected the number of louver that could fit within that space. Table 3.6 describes the value levels of each of the dynamic variable within this work.

Table 3.6. Range Values for Dynamic Variables within the Model

	Low	Low Mid	Mid High	High
Depth inches	1	6	12	18
Height inches	1	4	8	12
Offset inches	0	4	8	12
Width inches	1	2	4	6

3.1.4.3 Offset. The offset describes the distance between the louver's back and the structural wall. This was another louver array variable that is independent of manufacturer specification, as the offset is focused primarily on the installation portion of the configuration. The offset is the variable responsible, in conjunction with height, which affects the amount energy able to pass through the louver. A larger offset variable will equate to a louver array further from the structural wall and generally further from the fenestration surfaces. This larger depth will allow more light to pass throughout the day, when compared to a smaller offset variable. The offset variables considered within this work were taken to represent a zero inch offset, or the louver was against the wall, up to a 12 inch offset, which was considered to be a large residential offset.

3.1.4.4 Width. The width variable of the louver represents the distance between the upper and lower portions of the louver. This variable, with height, affects the number of louver that can fit within a finite amount of space. The width, in addition to the height, set the number of louver that could be installed on the specific façade face. By setting the number of louver, the width was responsible for the amount of energy allowed or blocked at the periphery of the array, and affected the shading zone on the South façade, by increasing the upper portion of the louver.

3.1.5. Simulation Development. Each of the 256 combinations of louver and array configurations simulations were ran in Energy Plus to access the annual energy load of the each of the configurations. The smallest energy demand across the year corresponded to the louver and array design that allowed the greatest amount of solar gain during the heating months, or the winter months, and the greatest amount of shading during the cooling months, or the summer. This delicate balance between heating and cooling cycles disallows the ability in this climate to use a full shade or no shade option, but this combination set of variables contains a group of configuration representative design considerations that assume discrete variable sets across the entire finite range, from an almost full shade configuration of 1 1 0 1, to a configuration predominantly open without shading, like 18 12 12 6. These two extremes can be seen in Figure 3.4.

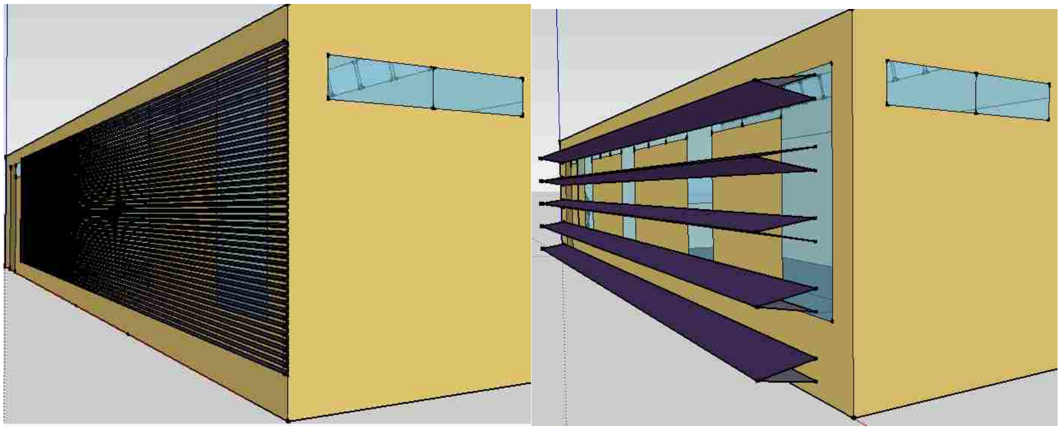


Figure 3.4. Illustration of Louver Configuration Extremes

4. RESULTS AND CONCLUSION

4.1 DATA ANALYSIS

The energy analysis was simulated using the Energy Plus simulation engine, and the annual energy load results of each of the 256 was compiled into a master spreadsheet. This master sheet facilitated the collection and manipulation of the raw Energy Plus data to determine which louver characteristic contributed the most to the energy reduction, in the design of the louver array, as well as, which louver configuration design consumed the least annual energy through the mechanical systems within the house. Once validated against the test cases, the house simulation could be run to test each of the louver configurations in turn. Appendix B highlights the all the combinations on a single figure with the outputs. The graph of total annual energy consumption of the various combinations is presented in Appendix B. Figure 4.1 is a graph of the best performing louver configurations based on the minimal heating and cooling load was determined by the Louver Configuration Input Program.

4.1.1. Annual Energy Results. The focus of this work was on the ideal heating and cooling loads of the Missouri S&T 2009 Solar House on the S&T campus in Rolla, Missouri. These annual calculated loads are representative of the total energy necessary to heat and cool this house in accordance with ASHRAE 55 comfort zone standards. By using this metric as a basis for the energy loading on the mechanical systems of the house, the effect of the each louver configuration could be compared directly to the other configurations, with all other unexamined factors unchanging. Beyond the fact the actual experimentation would be too costly to run, the simulation also allows for the interdependent variables outside the control of the experiment to remain unchanged throughout the simulation process.

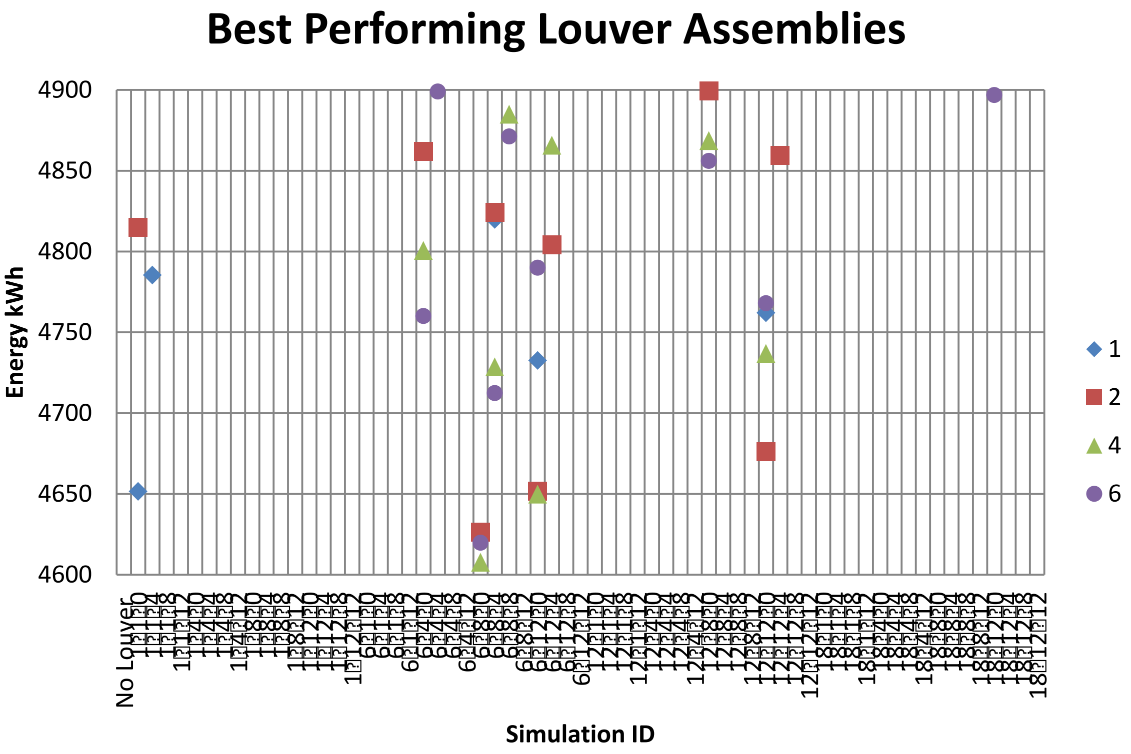


Figure 4.1. Graph of Best Performing Louver Configurations

Appendix B displays both the total annual energy for each louver configuration as well as the heating and cooling loads that make up the total energy load. The total energy loads from all the configurations ranged from 4608 kWh to a maximum to 5442 kWh, not including the baseline house without louver. The baseline house had a total energy load of 5563 kWh. According to this data, any configuration of louvers decreased the energy load of the house, through affecting the heating and cooling systems at a minimum reduction of energy load of 121kWh across the year, and at a maximum reduction for this experiment of 995 kWh.

4.1.2. ANOVA. The effect of any of the variables were considered independent of the others. An Analysis of Variance Factorial Test (ANOVA) was performed to determine the main interactions between the variable within the configurations. The ANOVA produced a Sum of Squares analysis for each variable and the weight of the variable was derived from the variable percent of the total Sum of Squares value. This weight was used to assess the effect of the variable within the weight interpolation of in the Louver Configuration Input Program. The weights of each of the variables were compiled into Table 4.1.

Table 4.1. Weights of the Variable from the ANOVA

	Weights
Depth	46.8%
Height	8.6%
Offset	44.5%
Width	0.1%

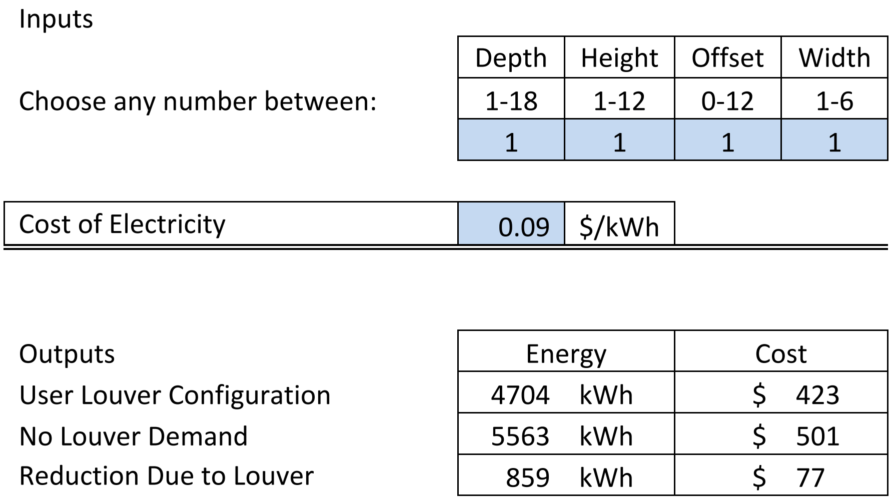
4.1.3. Overall Optimized Louver Configuration. The most effective louvers focused on the reduction of energy were expressed on the Top Performers Graph in Figure 4.1. Table 4.2 highlights the top performing louver configurations with each configuration’s energy loading. Table 4.2 shows that the 6804 series of louvers was the best louver configuration and that the width had little impact on the energy loading. This conclusion follows the data presented from the graph of energy outputs in Appendix B and the ANOVA weight analysis. Of the top ten listed in Table 4.2, configuration 6804 claimed the most effective louver array by facilitating an energy reduction to 4607 kWh, a reduction from the baseline house without louvers of 955 kWh. This louver array and building geometry accounted for a greater than 17% reduction in energy consumed over the course of the year. This data concluded that a louver configuration with a louver six inches deep, and four inches wide, with a height between louver of eight inches, installed directly to the façade it shades is the best applications of louvers to a house like the 2009 Solar House in Rolla, Missouri.

Table 4.2. Top Performing Louver Configurations

	Simulation ID	Total Annual Energy [kWh]
1	6804	4607.7
2	6806	4619.7
3	6801	4626.1
4	6802	4626.5
5	61204	4649.8
6	1101	4651.6
7	61202	4651.7
8	121202	4676.1
9	6846	4712.4
10	6844	4728.6

4.1.4. Louver Configuration Input Program. The output of the this research, beyond the optimized louver configuration for the Missouri S&T 2009 Solar House, was an ability to view homes in the Midwest region of the United States and determine an effective louver array configuration. This research developed a simple input program compiling the results of this research to be able to input any value for the louver design characteristics, within the range of this research, and predict an output for the energy consumption that these louvers would expect under ideal conditions and a reduction from the baseline, “No Louver” case. The program also outputs a two dimensional profile view of two louvers within the louver assembly. The ability to input any continuous value within the research range for the characteristics allows the user to use and understand the effect of a louver array on a building, interactively. The continuous inputs are compared against the two closest discrete variables. The weights of the variables are implemented in regard to their effect on the energy usage of the house due to the louvers. Finally the approximate energy consumption of a house in the Midwest climate using the input louver configuration is output, and compared against the baseline case for energy and electrical cost. The program assumed all the energy used within the house was electricity. It does not account for any other energy and fuel sources in the cost analysis. Table 4.3 and Appendix C showcase the input and output panels for the program and Figure 4.2 illustrated the output profile.

Table 4.3. Input and Output Panel for the Program



Inputs

	Depth	Height	Offset	Width
Choose any number between:	1-18	1-12	0-12	1-6
	1	1	1	1

Cost of Electricity	0.09	$/kWh

Outputs	Energy	Cost
User Louver Configuration	4704 kWh	$ 423
No Louver Demand	5563 kWh	$ 501
Reduction Due to Louver	859 kWh	$ 77

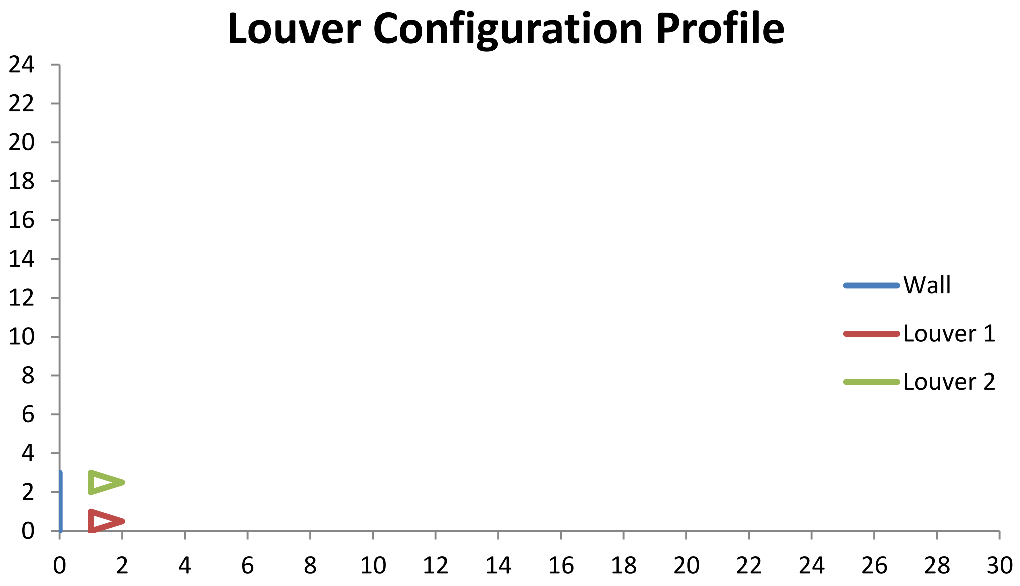


Figure 4.2. Output Profile from Program

5. FUTURE WORK

5.1 ITERATION RESOLUTION

The research on the louver configuration and the combination associated with them in this work were conducted at a fairly high resolution. In other words, the values for each of the louver elements had a wide range between discrete inputs. If this work were to be continued, the resolution of the input values should be reduced to be able to more accurately estimate the continuous output energy from the spreadsheet.

5.2 DEPENDENT FACTOR STATISTICAL ANALYSIS

An in-depth statistical analysis could also highlight the independent variables within the systems, as well as, develop the understanding of the interdependency between the multiple variables like height and depth.

5.3 GEOGRAPHIC LOCATION

The geographic location could be altered to access the effect of a louver array is climates and latitude outside the Midwest of United States. Higher latitudes would test the feasibility and usefulness of louver in colder climates within smaller solar altitudes, while lower latitudes, till approaching the equator, would test the usefulness of louvers for full scale passive solar shading.

APPENDIX A

FAÇADE WINDOW LISTING

Name	Units	SOUTH WINDOW 1	SOUTH WINDOW 2	SOUTH WINDOW 3
Surface Type		Window	Window	Window
Construction Name		WINDOW	WINDOW	WINDOW
Building Surface Name		SOUTH WALL	SOUTH WALL	SOUTH WALL
Multiplier		1.00	1.00	1.00
Number of Vertices		4.00	4.00	4.00
Vertex 1 X-coordinate	m	1.83	2.74	3.66
Vertex 1 Y-coordinate	m	0.00	0.00	0.00
Vertex 1 Z-coordinate	m	2.13	0.61	0.61
Vertex 2 X-coordinate	m	2.74	3.66	4.57
Vertex 2 Y-coordinate	m	0.00	0.00	0.00
Vertex 2 Z-coordinate	m	2.13	0.61	0.61
Vertex 3 X-coordinate	m	2.74	3.66	4.57
Vertex 3 Y-coordinate	m	0.00	0.00	0.00
Vertex 3 Z-coordinate	m	2.44	2.44	2.44
Vertex 4 X-coordinate	m	1.83	2.74	3.66
Vertex 4 Y-coordinate	m	0.00	0.00	0.00
Vertex 4 Z-coordinate	m	2.44	2.44	2.44
Name	Units	SOUTH WINDOW 4	SOUTH WINDOW 5	SOUTH WINDOW 6
Surface Type		Window	Window	Window
Construction Name		WINDOW	WINDOW	WINDOW
Building Surface Name		SOUTH WALL	SOUTH WALL	SOUTH WALL
Multiplier		1.00	1.00	1.00
Number of Vertices		4.00	4.00	4.00
Vertex 1 X-coordinate	m	4.57	5.49	6.40
Vertex 1 Y-coordinate	m	0.00	0.00	0.00
Vertex 1 Z-coordinate	m	2.13	2.13	2.13
Vertex 2 X-coordinate	m	5.49	6.40	7.31
Vertex 2 Y-coordinate	m	0.00	0.00	0.00
Vertex 2 Z-coordinate	m	2.13	2.13	2.13
Vertex 3 X-coordinate	m	5.49	6.40	7.31
Vertex 3 Y-coordinate	m	0.00	0.00	0.00
Vertex 3 Z-coordinate	m	2.44	2.44	2.44
Vertex 4 X-coordinate	m	4.57	5.49	6.40
Vertex 4 Y-coordinate	m	0.00	0.00	0.00
Vertex 4 Z-coordinate	m	2.44	2.44	2.44
Name	Units	SOUTH WINDOW	SOUTH WINDOW	SOUTH WINDOW

		7	8	9
Surface Type		Window	Window	Window
Construction Name		WINDOW	WINDOW	WINDOW
Building Surface Name		SOUTH WALL	SOUTH WALL	SOUTH WALL
Multiplier		1.00	1.00	1.00
Number of Vertices		4.00	4.00	4.00
Vertex 1 X-coordinate	m	7.31	8.23	9.14
Vertex 1 Y-coordinate	m	0.00	0.00	0.00
Vertex 1 Z-coordinate	m	0.61	2.13	2.13
Vertex 2 X-coordinate	m	8.23	9.14	10.06
Vertex 2 Y-coordinate	m	0.00	0.00	0.00
Vertex 2 Z-coordinate	m	0.61	2.13	2.13
Vertex 3 X-coordinate	m	8.23	9.14	10.06
Vertex 3 Y-coordinate	m	0.00	0.00	0.00
Vertex 3 Z-coordinate	m	2.44	2.44	2.44
Vertex 4 X-coordinate	m	7.31	8.23	9.14
Vertex 4 Y-coordinate	m	0.00	0.00	0.00
Vertex 4 Z-coordinate	m	2.44	2.44	2.44
Name	Units	SOUTH WINDOW 10	SOUTH WINDOW 11	SOUTH WINDOW 12
Surface Type		Window	Window	Window
Construction Name		WINDOW	WINDOW	WINDOW
Building Surface Name		SOUTH WALL	SOUTH WALL	SOUTH WALL
Multiplier		1.00	1.00	1.00
Number of Vertices		4.00	4.00	4.00
Vertex 1 X-coordinate	m	10.06	10.97	11.89
Vertex 1 Y-coordinate	m	0.00	0.00	0.00
Vertex 1 Z-coordinate	m	2.13	0.61	2.13
Vertex 2 X-coordinate	m	10.97	11.89	12.80
Vertex 2 Y-coordinate	m	0.00	0.00	0.00
Vertex 2 Z-coordinate	m	2.13	0.61	2.13
Vertex 3 X-coordinate	m	10.97	11.89	12.80
Vertex 3 Y-coordinate	m	0.00	0.00	0.00
Vertex 3 Z-coordinate	m	2.44	2.44	2.44
Vertex 4 X-coordinate	m	10.06	10.97	11.89
Vertex 4 Y-coordinate	m	0.00	0.00	0.00
Vertex 4 Z-coordinate	m	2.44	2.44	2.44
Name	Units	SOUTH WINDOW 13	SOUTH WINDOW 14	SOUTH DOOR

Surface Type		Window	Window	Door
Construction Name		WINDOW	WINDOW	DOOR
Building Surface Name		SOUTH WALL	SOUTH WALL	SOUTH WALL
Multiplier		1.00	1.00	1.00
Number of Vertices		4.00	4.00	4.00
Vertex 1 X-coordinate	m	12.80	13.72	0.91
Vertex 1 Y-coordinate	m	0.00	0.00	0.00
Vertex 1 Z-coordinate	m	2.13	0.61	0.00
Vertex 2 X-coordinate	m	13.72	14.63	1.83
Vertex 2 Y-coordinate	m	0.00	0.00	0.00
Vertex 2 Z-coordinate	m	2.13	0.61	0.00
Vertex 3 X-coordinate	m	13.72	14.63	1.83
Vertex 3 Y-coordinate	m	0.00	0.00	0.00
Vertex 3 Z-coordinate	m	2.44	2.44	2.44
Vertex 4 X-coordinate	m	12.80	13.72	0.91
Vertex 4 Y-coordinate	m	0.00	0.00	0.00
Vertex 4 Z-coordinate	m	2.44	2.44	2.44

Name	Units	NORTH WINDOW	NORTH WINDOW HIGH 1	NORTH WINDOW HIGH 2
Surface Type		Window	Window	Window
Construction Name		WINDOW	WINDOW	WINDOW
Building Surface Name		NORTH WALL LOW	NORTH WALL HIGH	NORTH WALL HIGH
Multiplier		1.00	1.00	1.00
Number of Vertices		4.00	4.00	4.00
Vertex 1 X-coordinate	m	2.90	14.71	13.79
Vertex 1 Y-coordinate	m	4.57	4.39	4.39
Vertex 1 Z-coordinate	m	1.22	3.40	3.40
Vertex 2 X-coordinate	m	0.23	13.87	12.95
Vertex 2 Y-coordinate	m	4.57	4.39	4.39
Vertex 2 Z-coordinate	m	1.22	3.40	3.40
Vertex 3 X-coordinate	m	0.23	13.87	12.95
Vertex 3 Y-coordinate	m	4.57	4.27	4.27
Vertex 3 Z-coordinate	m	2.13	3.84	3.84
Vertex 4 X-coordinate	m	2.90	14.71	13.79
Vertex 4 Y-coordinate	m	4.57	4.27	4.27
Vertex 4 Z-coordinate	m	2.13	3.84	3.84
Name	Units	NORTH WINDOW HIGH 3	NORTH WINDOW HIGH 4	NORTH WINDOW HIGH 5
Surface Type		Window	Window	Window
Construction Name		WINDOW	WINDOW	WINDOW
Building Surface Name		NORTH WALL HIGH	NORTH WALL HIGH	NORTH WALL HIGH
Multiplier		1.00	1.00	1.00
Number of Vertices		4.00	4.00	4.00
Vertex 1 X-coordinate	m	12.88	11.96	11.05
Vertex 1 Y-coordinate	m	4.39	4.39	4.39
Vertex 1 Z-coordinate	m	3.40	3.40	3.40
Vertex 2 X-coordinate	m	12.04	11.12	10.21
Vertex 2 Y-coordinate	m	4.39	4.39	4.39
Vertex 2 Z-coordinate	m	3.40	3.40	3.40
Vertex 3 X-coordinate	m	12.04	11.12	10.21
Vertex 3 Y-coordinate	m	4.27	4.27	4.27
Vertex 3 Z-coordinate	m	3.84	3.84	3.84
Vertex 4 X-coordinate	m	12.88	11.96	11.05
Vertex 4 Y-coordinate	m	4.27	4.27	4.27
Vertex 4 Z-coordinate	m	3.84	3.84	3.84
Name	Units	NORTH WINDOW HIGH 6	NORTH WINDOW HIGH 7	NORTH WINDOW HIGH 8

Surface Type		Window	Window	Window
Construction Name		WINDOW	WINDOW	WINDOW
Building Surface Name		NORTH WALL HIGH	NORTH WALL HIGH	NORTH WALL HIGH
Multiplier		1.00	1.00	1.00
Number of Vertices		4.00	4.00	4.00
Vertex 1 X-coordinate	m	10.13	9.22	8.31
Vertex 1 Y-coordinate	m	4.39	4.39	4.39
Vertex 1 Z-coordinate	m	3.40	3.40	3.40
Vertex 2 X-coordinate	m	9.30	8.38	7.47
Vertex 2 Y-coordinate	m	4.39	4.39	4.39
Vertex 2 Z-coordinate	m	3.40	3.40	3.40
Vertex 3 X-coordinate	m	9.30	8.38	7.47
Vertex 3 Y-coordinate	m	4.27	4.27	4.27
Vertex 3 Z-coordinate	m	3.84	3.84	3.84
Vertex 4 X-coordinate	m	10.13	9.22	8.31
Vertex 4 Y-coordinate	m	4.27	4.27	4.27
Vertex 4 Z-coordinate	m	3.84	3.84	3.84
Name	Units	NORTH WINDOW HIGH 9	NORTH WINDOW HIGH 10	NORTH WINDOW HIGH 11
Surface Type		Window	Window	Window
Construction Name		WINDOW	WINDOW	WINDOW
Building Surface Name		NORTH WALL HIGH	NORTH WALL HIGH	NORTH WALL HIGH
Multiplier		1.00	1.00	1.00
Number of Vertices		4.00	4.00	4.00
Vertex 1 X-coordinate	m	7.39	6.48	5.56
Vertex 1 Y-coordinate	m	4.39	4.39	4.39
Vertex 1 Z-coordinate	m	3.40	3.40	3.40
Vertex 2 X-coordinate	m	6.55	5.64	4.72
Vertex 2 Y-coordinate	m	4.39	4.39	4.39
Vertex 2 Z-coordinate	m	3.40	3.40	3.40
Vertex 3 X-coordinate	m	6.55	5.64	4.72
Vertex 3 Y-coordinate	m	4.27	4.27	4.27
Vertex 3 Z-coordinate	m	3.84	3.84	3.84
Vertex 4 X-coordinate	m	7.39	6.48	5.56
Vertex 4 Y-coordinate	m	4.27	4.27	4.27
Vertex 4 Z-coordinate	m	3.84	3.84	3.84
Name	Units	NORTH WINDOW HIGH 12	NORTH WINDOW HIGH 13	NORTH WINDOW HIGH 14
Surface Type		Window	Window	Window
Construction Name		WINDOW	WINDOW	WINDOW

Building Surface Name		NORTH WALL HIGH	NORTH WALL HIGH	NORTH WALL HIGH
Multiplier		1.00	1.00	1.00
Number of Vertices		4.00	4.00	4.00
Vertex 1 X-coordinate	m	4.65	3.73	2.82
Vertex 1 Y-coordinate	m	4.39	4.39	4.39
Vertex 1 Z-coordinate	m	3.40	3.40	3.40
Vertex 2 X-coordinate	m	3.81	2.90	1.98
Vertex 2 Y-coordinate	m	4.39	4.39	4.39
Vertex 2 Z-coordinate	m	3.40	3.40	3.40
Vertex 3 X-coordinate	m	3.81	2.90	1.98
Vertex 3 Y-coordinate	m	4.27	4.27	4.27
Vertex 3 Z-coordinate	m	3.84	3.84	3.84
Vertex 4 X-coordinate	m	4.65	3.73	2.82
Vertex 4 Y-coordinate	m	4.27	4.27	4.27
Vertex 4 Z-coordinate	m	3.84	3.84	3.84

Name	Units	NORTH WINDOW HIGH 15	NORTH WINDOW HIGH 16
Surface Type		Window	Window
Construction Name		WINDOW	WINDOW
Building Surface Name		NORTH WALL HIGH	NORTH WALL HIGH
Multiplier		1.00	1.00
Number of Vertices		4.00	4.00
Vertex 1 X-coordinate	m	1.90	0.99
Vertex 1 Y-coordinate	m	4.39	4.39
Vertex 1 Z-coordinate	m	3.40	3.40
Vertex 2 X-coordinate	m	1.07	0.15
Vertex 2 Y-coordinate	m	4.39	4.39
Vertex 2 Z-coordinate	m	3.40	3.40
Vertex 3 X-coordinate	m	1.07	0.15
Vertex 3 Y-coordinate	m	4.27	4.27
Vertex 3 Z-coordinate	m	3.84	3.84
Vertex 4 X-coordinate	m	1.90	0.99
Vertex 4 Y-coordinate	m	4.27	4.27
Vertex 4 Z-coordinate	m	3.84	3.84

APPENDIX B

ENERGY OUTPUT KWH

Iteration Combinations				Simulation ID	ZONE 1ZONEHVAC:IDEAL LOADSAIRSYSTEM: Ideal Loads Total Heating Energy [kWh](Run Period)	ZONE 1ZONEHVAC:IDEAL LOADSAIRSYSTEM: Ideal Loads Total Cooling Energy [kWh](Run Period)	Total Annual Energy [kWh]
d	h	o	w				
				No Louver	1968	3594	5563
1	1	0	1	1101	2688	1964	4652
1	1	0	2	1102	2851	1963	4815
1	1	0	4	1104	3088	1911	4998
1	1	0	6	1106	3151	1901	5053
1	1	4	1	1141	2665	2120	4785
1	1	4	2	1142	2822	2147	4969
1	1	4	4	1144	2970	2147	5116
1	1	4	6	1146	3024	2129	5153
1	1	8	1	1181	2604	2322	4926
1	1	8	2	1182	2738	2335	5073
1	1	8	4	1184	2866	2326	5192
1	1	8	6	1186	2911	2304	5216
1	1	12	1	11121	2538	2486	5024
1	1	12	2	11122	2664	2490	5154
1	1	12	4	11124	2767	2467	5234
1	1	12	6	11126	3075	2277	5352
1	4	0	1	1401	2197	2748	4945
1	4	0	2	1402	2343	2626	4969
1	4	0	4	1404	2607	2371	4978
1	4	0	6	1406	2752	2243	4995
1	4	4	1	1441	2214	2843	5057
1	4	4	2	1442	2335	2734	5068
1	4	4	4	1444	2540	2567	5108
1	4	4	6	1446	2714	2380	5095
1	4	8	1	1481	2186	2967	5154
1	4	8	2	1482	2321	2865	5186
1	4	8	4	1484	2487	2709	5196
1	4	8	6	1486	2650	2525	5175
1	4	12	1	14121	2173	3069	5242
1	4	12	2	14122	2291	2973	5263
1	4	12	4	14124	2444	2822	5266
1	4	12	6	14126	2614	2656	5270
1	8	0	1	1801	2105	3090	5194

1	8	0	2	1802	2167	3029	5196
1	8	0	4	1804	2335	2786	5121
1	8	0	6	1806	2424	2666	5091
1	8	4	1	1841	2087	3188	5275
1	8	4	2	1842	2163	3092	5255
1	8	4	4	1844	2331	2826	5157
1	8	4	6	1846	2445	2643	5088
1	8	8	1	1881	2081	3262	5343
1	8	8	2	1882	2157	3174	5331
1	8	8	4	1884	2324	2898	5222
1	8	8	6	1886	2451	2714	5165
1	8	12	1	18121	2072	3317	5389
1	8	12	2	18122	2148	3239	5387
1	8	12	4	18124	2315	2987	5302
1	8	12	6	18126	2450	2812	5263
1	12	0	1	11201	2064	3230	5294
1	12	0	2	11202	2089	3213	5302
1	12	0	4	11204	2277	2892	5169
1	12	0	6	11206	2371	2759	5130
1	12	4	1	11241	2050	3319	5369
1	12	4	2	11242	2128	3187	5315
1	12	4	4	11244	2271	2972	5244
1	12	4	6	11246	2317	2943	5261
1	12	8	1	11281	2045	3370	5415
1	12	8	2	11282	2115	3239	5354
1	12	8	4	11284	2255	3077	5332
1	12	8	6	11286	2271	3049	5319
1	12	12	1	112121	2035	3407	5442
1	12	12	2	112122	2110	3291	5400
1	12	12	4	112124	2227	3150	5377
1	12	12	6	112126	2234	3115	5348
6	1	0	1	6101	3457	1737	5194
6	1	0	2	6102	3442	1753	5195
6	1	0	4	6104	3405	1748	5153
6	1	0	6	6106	3274	1783	5057
6	1	4	1	6141	3417	1784	5202
6	1	4	2	6142	3385	1813	5197
6	1	4	4	6144	3242	1946	5188
6	1	4	6	6146	3124	2021	5145
6	1	8	1	6181	3312	1816	5128
6	1	8	2	6182	3239	1922	5161

6	1	8	4	6184	3097	2134	5231
6	1	8	6	6186	2988	2211	5199
6	1	12	1	61121	3184	1859	5044
6	1	12	2	61122	3096	2054	5150
6	1	12	4	61124	2964	2331	5296
6	1	12	6	61126	2872	2353	5225
6	4	0	1	6401	3024	1901	4925
6	4	0	2	6402	2969	1893	4862
6	4	0	4	6404	2931	1870	4801
6	4	0	6	6406	2905	1855	4760
6	4	4	1	6441	2977	2032	5009
6	4	4	2	6442	2924	2068	4992
6	4	4	4	6444	2818	2116	4934
6	4	4	6	6446	2848	2051	4899
6	4	8	1	6481	2858	2235	5094
6	4	8	2	6482	2827	2273	5100
6	4	8	4	6484	2713	2312	5025
6	4	8	6	6486	2754	2242	4996
6	4	12	1	64121	2756	2426	5182
6	4	12	2	64122	2718	2439	5157
6	4	12	4	64124	2633	2459	5092
6	4	12	6	64126	2692	2398	5090
6	8	0	1	6801	2485	2141	4626
6	8	0	2	6802	2473	2154	4626
6	8	0	4	6804	2534	2074	4608
6	8	0	6	6806	2532	2088	4620
6	8	4	1	6841	2433	2387	4820
6	8	4	2	6842	2444	2380	4824
6	8	4	4	6844	2519	2209	4729
6	8	4	6	6846	2539	2173	4712
6	8	8	1	6881	2386	2573	4959
6	8	8	2	6882	2407	2567	4974
6	8	8	4	6884	2494	2391	4885
6	8	8	6	6886	2533	2338	4871
6	8	12	1	68121	2434	2547	4980
6	8	12	2	68122	2357	2710	5067
6	8	12	4	68124	2465	2554	5019
6	8	12	6	68126	2518	2498	5016
6	12	0	1	61201	2308	2425	4733
6	12	0	2	61202	2322	2330	4652
6	12	0	4	61204	2436	2214	4650

6	12	0	6	61206	2425	2365	4790
6	12	4	1	61241	2263	2666	4929
6	12	4	2	61242	2339	2466	4804
6	12	4	4	61244	2405	2460	4866
6	12	4	6	61246	2360	2616	4975
6	12	8	1	61281	2228	2819	5046
6	12	8	2	61282	2310	2639	4949
6	12	8	4	61284	2362	2653	5016
6	12	8	6	61286	2304	2774	5078
6	12	12	1	612121	2193	2935	5128
6	12	12	2	612122	2290	2791	5081
6	12	12	4	612124	2316	2795	5111
6	12	12	6	612126	2261	2886	5147
12	1	0	1	12101	3507	1667	5173
12	1	0	2	12102	3494	1685	5179
12	1	0	4	12104	3475	1718	5192
12	1	0	6	12106	3465	1722	5188
12	1	4	1	12141	3500	1670	5170
12	1	4	2	12142	3456	1693	5149
12	1	4	4	12144	3457	1740	5198
12	1	4	6	12146	3449	1754	5203
12	1	8	1	12181	3362	1678	5040
12	1	8	2	12182	3336	1716	5052
12	1	8	4	12184	3394	1834	5228
12	1	8	6	12186	3396	1887	5283
12	1	12	1	121121	3309	1697	5005
12	1	12	2	121122	3215	1748	4963
12	1	12	4	121124	3264	1947	5212
12	1	12	6	121126	3285	2075	5361
12	4	0	1	12401	3397	1802	5199
12	4	0	2	12402	3386	1803	5189
12	4	0	4	12404	3352	1807	5159
12	4	0	6	12406	3314	1796	5110
12	4	4	1	12441	3342	1857	5199
12	4	4	2	12442	3325	1901	5226
12	4	4	4	12444	3195	1995	5190
12	4	4	6	12446	3248	1977	5224
12	4	8	1	12481	3197	1964	5161
12	4	8	2	12482	3179	2031	5210
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12	8	4	1	12841	2859	2177	5036
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12	8	4	6	12846	2584	2371	4955
12	8	8	1	12881	2748	2391	5139
12	8	8	2	12882	2738	2394	5132
12	8	8	4	12884	2515	2522	5037
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12	8	12	1	128121	2647	2538	5185
12	8	12	2	128122	2637	2533	5171
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12	12	0	6	121206	2628	2140	4768
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12	12	4	2	121241	2689	2171	4860
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12	12	4	6	121246	2532	2386	4917
12	12	8	1	121281	2451	2545	4996
12	12	8	2	121282	2622	2363	4985
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18	8	4	1	18841	3072	2043	5115
18	8	4	2	18842	3061	2067	5129
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18	8	4	6	18846	2742	2338	5080
18	8	8	1	18881	2934	2226	5160
18	8	8	2	18882	2926	2295	5222
18	8	8	4	18884	2676	2482	5158
18	8	8	6	18886	2655	2475	5131
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18	8	12	2	188122	2811	2483	5294

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18	12	0	1	181201	2877	2059	4936
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18	12	4	2	181242	3008	2099	5107
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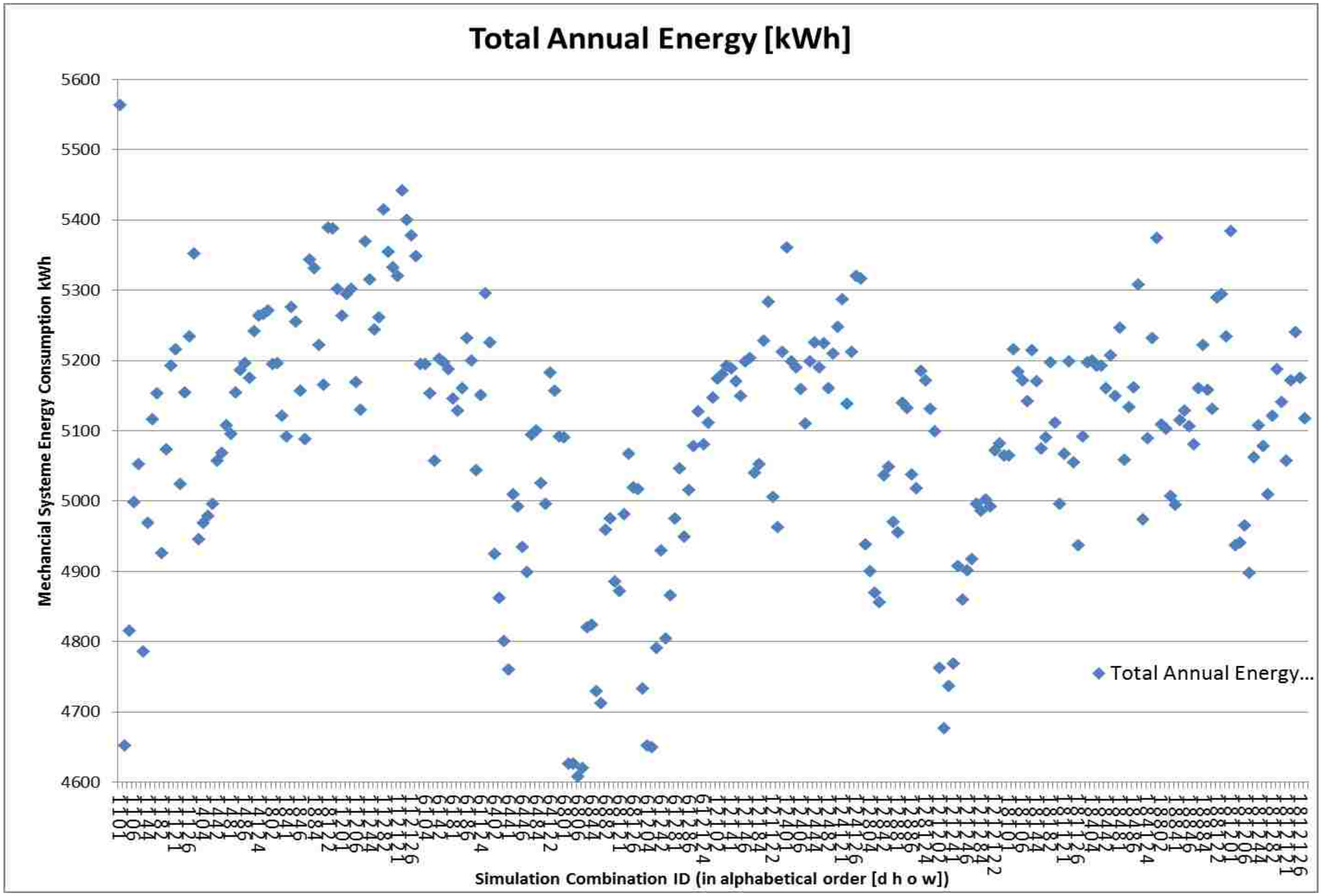
18	12	12	2	1812122	2795	2445	5240
18	12	12	4	1812124	2697	2478	5175
18	12	12	6	1812126	2515	2603	5117


Total Annual Energy [kWh]
Mechancial Systeme Energy Consumption kWh
5600
5500
5400
5300
5200
5100
5000
4900
4800
4700
4600
Simulation Combination ID (in alphabetical order [d h o w])
1101
1106
1144
1182
11121
11126
1404
1442
1481
1486
14124
1802
1841
1846
1884
18122
11201
11206
11244
11282
112121
112126
6104
6142
6181
6186
61124
6402
6441
6446
6484
64122
6801
6806
6844
6882
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68126
61204
61242
61281
61286
612124
12102
12141
12146
12184
121122
12401
12406
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12482
124121
124126
12804
12842
12881
12886
128124
121202
121241
121246
121284
1212122
18101
18106
18144
18182
181121
181126
18404
18442
18481
18486
184124
18802
18841
18846
18884
188122
181201
181206
181244
181282
1812121
1812126
◆ Total Annual Energy...

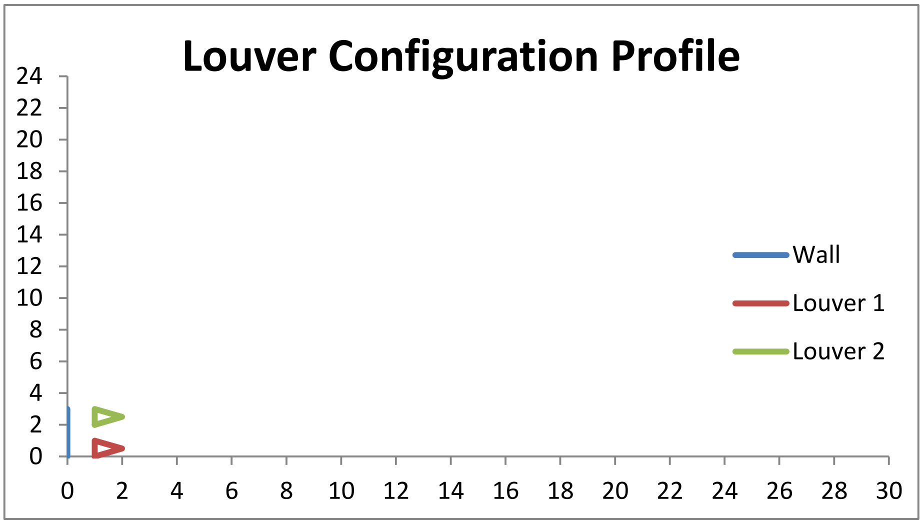
APPENDIX C

USER INPUT PROGRAM EXAMPLE

Choose Any Number Between:	1-18	1-12	0-12	1-6
	1	1	1	1

Cost of Electricity	0.09	$/kWh

Outputs	Energy		Cost	
User Louver Configuration	4704	kWh	423	$
No Louver Demand	5563	kWh	501	$
Reduction Due to Louver	859	kWh	77	$



BIBLIOGRPAHY

Abdulsalam Ebrahimpour, Mehdi Maerefat, Application of advanced glazing and overhangs in residential buildings, Energy Conversion and Management, Volume 52, Issue 1, January 2011, Pages 212-219.

"Buildings Energy Data Book." *Buildings Energy Data Book*. US Department of Energy: Energy Efficiency and Renewable Energy, Web. 26 Oct. 2012. <http://buildingsdatabook.eren.doe.gov/default.aspx>.

Christian Anker Hviid, Toke Rammer Nielsen, Svend Svendsen, Simple tool to evaluate the impact of daylight on building energy consumption, Solar Energy, Volume 82, Issue 9, September 2008, Pages 787-798, ISSN 0038-092X, 10.1016/j.solener.2008.03.001.

Dubois, Marie- Claude. "Solar Architecture." *A Method to Define Shading Devices Considering the Ideal Total Solar Energy Transmittance*. Proc. of Third ISES Europe Solar Congress: Eurosun 2000, Copenhagen, Denmark. Print.

"EnergyPlus Training: EnergyPlus University Course Teaching Material." *EnergyPlus Energy Simulation Software:*. US Department of Energy: Energy Efficiency and Renewable Energy,Web. 26 Oct. 2012. <http://apps1.eere.energy.gov/buildings/energyplus/energyplus_training.cfm>.

"Google Maps." *Google Maps Rolla Missouri*. Web. 25 Oct. 2012. <https://maps.google.com/maps?hl=en>.

Greici Ramos, Enedir Ghisi, Analysis of daylight calculated using the EnergyPlus programme, Renewable and Sustainable Energy Reviews, Volume 14, Issue 7, September 2010, Pages 1948-1958.

H.D. Kambezidis, 3.02 - The Solar Resource, In: Editor-in-Chief: Ali Sayigh, Editor(s)-in-Chief, Comprehensive Renewable Energy, Elsevier, Oxford, 2012, Pages 27-84, ISBN 9780080878737, 10.1016/B978-0-08-087872-0.00302-4.

Janak, Milan. *Whole Building Energy Simulation with Complex External Shading Devices*. Proc. of Eighth International IBPSA Conference 2003, Eindhoven, Netherlands. Print.

Lechner, Norbert. *Heating, Cooling, Lighting: Design Methods for Architects*. 2nd ed. New York: Wiley, 1991. Print.

Maile, Tobias. *COMPARING MEASURED AND SIMULATED BUILDING ENERGY PERFORMANCE DATA*. Diss. STANFORD UNIVERSITY, 2010. Print.

M. David, M. Donn, F. Garde, A. Lenoir, Assessment of the thermal and visual efficiency of solar shades, Building and Environment, Volume 46, Issue 7, July 2011, Pages 1489-1496.

Nysan Solar Control: A Hunter Douglas Contract Company. *Sun Louvers*. Web. 25 Oct. 2012.<http://assets.hunterdouglascontract.com/documents/NysanSunLouversBrochurev2withchange.pdf>.

Offiong, A., and A. U. Ukpoho. "External Window Shading Treatment Effects on Internal Environmental Temperature of Buildings." *Renewable Energy* 29.14 (2004): 2153-165. Web.

Oliveti, Giuseppe, Natale Arcuri, Roberto Bruno, and Marilena De Simone. "An Accurate Calculation Model Of Solar Heat Gain Through Glazed Surfaces." *Energy and Buildings* (2010): Web.

Oliveti, G., M. De Simone, and S. Ruffolo. "Evaluation of the Absorption Coefficient for Solar Radiation in Sunspaces and Windowed Rooms." *Solar Energy* 82.3 (2008): 212-19. Print.

Palmero-Marrero, Ana I., and Armando C. Oliveira. "Effect of Louver Shading Devices on Building Energy Requirements." *Applied Energy* 87.6 (2010): 2040-049. Web.

Pueblo De Taos. Digital image. *National Geographic*. Panoramic Images/ Getty Images, n.d. Web. <http://travel.nationalgeographic.com/travel/world-heritage/pueblo-de-taos/>.

"Station Details: VICHY ROLLA NATIONAL AIRPORT, MO US, GHCND:USW00013997Missouri United States | Climate Data Online (CDO) | National Climatic Data Center (NCDC. NOAA National Climatic Data Center, Web. 25 Oct. 2012. <http://www.ncdc.noaa.gov/cdo-web/datasets/NORMAL_ANN/stations/GHCND:USW00013997/detail>.

Gronbeck, Christopher, "Sustainable By Design :: Hour Angle." *Sustainable By Design :: Hour Angle*. Illustration. Web. 26 Oct. 2012. <http://www.susdesign.com/popups/sunangle/hour-angle.php>.

Stern, David, "The Path of the Sun, the Ecliptic." *The Path of the Sun, the Ecliptic*. NASA. Web. 26 Oct. 2012. <http://www-spof.gsfc.nasa.gov/stargaze/Secliptc.htm>.

US Department of Energy: Energy Efficiency and Renewable Energy. *About EnergyPlus*. 8 March 2011. Website. 1 May 2012. <http://apps1.eere.energy.gov/buildings/energyplus/energyplus_about.cfm>.

VITA

Cory Brennan was born in Belleville, Illinois. His education continued from two bachelor’s degrees in Civil Engineering and Architectural Engineering from Missouri University of Science and Technology, to this Master’s degree in Civil Engineering; also at the Missouri University of Science and Technology. His credits included the project manager of the 2009 Solar House Design while during his undergraduate work at Missouri S&T and Graduate Student Sustainability Coordinator at the Office of Sustainable Energy and Environmental Engagement at Missouri S&T. Research credits include an Opportunity for Undergraduate Research Experience (OURE) implementing parabolic solar trough research, and two projects from the American Public Power Demonstration of Energy Efficient Development program involving energy monitoring and management in residential homes, and a community energy storage and support project.