2012

Evaluation of the thermal performance and cost effectiveness of radiant barrier thermal insulation materials in residential construction

Somayeh Asadi
Louisiana State University and Agricultural and Mechanical College

EVALUATION OF THE THERMAL PERFORMANCE AND COST EFFECTIVENESS OF RADIANT BARRIER THERMAL INSULATION MATERIALS IN RESIDENTIAL CONSTRUCTION

A Dissertation

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

in

The Interdepartmental Program in Engineering Science

by
Somayeh Asadi
B.S., Semnan University, 2003
M.S., Louisiana State University, 2011
August 2012

ACKNOWLEDGEMENTS

My deepest thanks are to my adviser, Dr. Marwa Hassan. She always supported me to explore new ideas, to question common assumptions, and to operationally think about social systems. Her expertise in understanding and analyzing problems and her visionary approach to guiding advisees were invaluable assets for me. In-depth discussions with Marwa sometimes went beyond research, reminding me why we live, what we want, how we can help the public, and why family is the priority. I hope one day I will become as good an adviser as Marwa. I am also thankful to my other committee members, Dr. Isabelina Nahmens, Dr. Ayman Okeil, Dr. Michele Barbato, Dr. Sherif Ishak, and Dr. Carol Taylor.

Throughout the experience, I was nurtured with friendship and love of many friends. I would like to thank them. Some of them are Ali Beheshti, Mohammad Fesanghary, Seyed Mostafa Seyadat Mosavi.

Finally and most importantly, I would like to especially thank my parents who always encouraged me to keep high work standards, stay with the Values they taught me, and devote myself to helping people. I am thankful to my sisters and brothers, for being extremely supportive during the time I was far from my parents.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Reducing heating and cooling systems loads in buildings is a cost effective way to decrease energy consumption in residential houses. This reduction can be achieved in many ways including proper insulation of the building envelope. In recent years, considerable attention was given to the use of radiant reflective insulating barriers. Over the past years, reflective barrier insulation companies nationwide have experienced significant growth resulting in an industry average growth rate of 26.8%. This significant growth is expected to continue as a result of increased cooling demands and pressure from the energy sector and the economy. Growth is also predicted to be prevalent amongst the southern regions of the United States in efforts to reduce high cooling energy costs, which are expected to prevail. This significant growth has not been felt by the radiant barrier industry in Louisiana. This is mainly due to the lack of knowledge and amount of research available in quantifying radiant barriers thermal effectiveness for hot and humid climatic conditions widely encountered in the State. In order to improve the competitiveness of the reflective insulation industry, the primary goal of this research is to develop a simple estimating tool that may be used by homeowners, state agencies, and contractors to assess the effectiveness and economic benefits of radiant barrier insulation systems under the climatic conditions encountered in United States.

Current research achieved this objective by adopting a multi-dimensional research approach that developed this estimating tool over three main phases and then combined results of these phases to provide an overall assessment tool for this technology. In the first phase, the energy saving benefits of radiant barrier was quantified experimentally for the climatic conditions and construction practices prevalent in United States. A transient heat transfer finite element (FE) model was developed to predict the ceiling heat gain or loss through the attic space

in residential buildings and to accurately estimate savings in cooling and heating loads produced by the radiant barrier application. Validity of the models was established by comparing their prediction with experimental data. In the second phase, economic effectiveness of radiant barrier technology was evaluated. In the third phase, development of the estimating tool and dissemination of the results was achieved. Results showed that radiant barrier can reduce heat flux transferred from roof to the condition space significantly.

CHAPTER 1: INTRODUCTION

Energy consumption in the buildings is one of the major issues in the United States. In 2009, the residential sector consumed approximately 22% of the annual nation's energy consumption among the different sectors. 13% of the residential sector energy consumption is used for water heating and 43% is used to satisfy heating and cooling housing requirements [DOE 2009]. More than 60% of the residential sector energy needs originate from thermal power plants using nonrenewable sources of energy such as coal and natural gas [DOE 2009]. Therefore, a nationwide attempt to improve the thermal efficiency of buildings could help to decrease heating and cooling energy use.

Reducing heating and cooling loads in buildings is a cost effective method to decrease energy consumption in residential construction. This reduction can be achieved in many ways including proper insulation of the building envelope. Heat is transferred through the building envelope in three different ways, conduction, convection, and radiation. However, 65 to 80% of all heat loss or gain in buildings occurs through a radiation mechanism (TVM 2001). Since a roof is the primary component exposed to solar radiation during all hours of daylight, heat flow through roof is often more critical than through walls, especially in hot climates where cooling loads dominate. Thus, the amount of heat flux through a roof to the inside of building should be minimized (TVM 2001). There are four ways to reduce this heat flux: (1) by adding more insulation in the roof to decrease conduction, (2) using certain cooling systems such as water spray, (3) ventilation of the attic, and (4) using radiant barriers (Yarbrough 1991).

Radiant barrier is a thin layer of aluminum with low emissivity between 0.03-0.05, facing airspace that attached on one or both sides of the plywood, Kraft paper and etc. (RIMA 2002). While most traditional insulation materials resist heat flow through convection and conduction

by restricting air movement, reflective insulation materials target the main source of heat transfer, which is radiation. The use of a single reflective surface may reduce heat flow by as much as 95% of the infrared rays and addition of bubble packing between two reflective layers allows to resist both radiation and convection heat transfer mechanisms (Yarbrough 1991). Radiant barriers can be installed on the roof beams (Truss Radiant Barrier) or horizontally on the ceiling (Horizontal Radiant Barrier).The horizontal radiant barrier decreases the rate of heat transfer by nearly 5% in comparison to the truss radiant barrier, but dust accumulation will decrease the efficiency of a horizontal radiant barrier (RIMA 2002).

Despite all the promising benefits mentioned above, nearly half of the homes in the US have insufficient insulation due to poor construction practices and in an attempt to save in the initial investment. Hence, the primary objective of this research is to develop a simple estimating tool that may be used by homeowners, state agencies, and contractors to assess the effectiveness and economic benefits of radiant barrier insulation systems under the different climatic conditions in the United States. The results of the research will be summarized in a fact sheet and represented in a simple tool to increase the competitiveness of the radiant barrier insulation industry in the United States.

1.1 Problem Statement

The question to insulate buildings or not is no longer debatable whereas the question is refocused on how. The effects of many variables on the thermal efficiency of the building envelope including material properties, climate, and the adopted insulation strategy are not well understood for the different climatic conditions in US. Quantitative comparison of different insulation materials and methods to find the optimal solution is timely and is critically needed to ensure that buildings only use the energy that is needed for their operation.

In hot and humid climates, the greatest thermal gain occurs through the roof. Hence, the use of thermal radiation barrier may minimize the heat flux through the roof. In recent years, considerable attention was given to the use of radiant reflective insulating barrier. As a result, reflective barrier insulation companies nationwide have experienced significant growth resulting in an industry average growth rate of 26.8%. This significant growth has not been felt by all the radiant barrier industry in the US. This is mainly due to the lack of knowledge and amount of research available in quantifying radiant barriers thermal effectiveness for hot and humid climatic conditions. In order to improve the competitiveness of the reflective insulation industry in US, the primary goal of this research is to develop a simple estimating tool that may be used by homeowners, state agencies, and contractors to assess the effectiveness and economic benefits of radiant barrier insulation systems under the different climatic conditions in US.

1.2 Objectives

To address the aforementioned problem and in order to improve the economic competitiveness of the reflective insulation industry in US, the primary goal of this research is to develop a simple estimating tool that may be used by homeowners, state agencies, and contractors to assess the effectiveness and economic benefits of radiant barrier insulation systems under the different climatic conditions in US. The results of the research will be summarized in a fact sheet and represented in a simple tool to increase the competitiveness of the radiant barrier insulation industry in US.

1.3 Research Approach

The proposed research will achieve this objective by adopting a multi-dimensional research approach that will develop this estimating tool over three main phases and will then combine results of these phases to provide an overall assessment tool for this technology.

- Phase I: Effectiveness of Radiant Barrier System
    - Task 1 – Development of Finite Element (FE) Models to Simulate Radiant Barrier Heat Flow
    - Task 2 – Model Verification and Validation
    - Task 3 – Parametric Study in Order to Optimize the Design Variables and Predict Thermal Performance

      Task 3-1-Sensitivity Analysis

      Task 3-2-Simulation Design
    - Task 4 – Quantification of Energy Savings
- Phase 2: Economic Evaluation of Radiant Barrier System
- Phase 3: Development of a Simple Estimating Tool

The objective of the first phase is to quantify the energy saving benefits of radiant barrier technology. To achieve this objective, a numerical FE approach was developed and validated based on experimental measurements. The developed model was then used to determine the energy savings and cooling load reduction provided by radiant barriers for a wide range of operating conditions expected in US. Experimental testing of radiant barrier is time consuming and expensive and may not allow to consider all operating conditions expected in the field. Therefore, evaluation of the effectiveness of radiant barriers was conducted using a three-dimensional FE approach. The developed model simulated coupled conduction, natural convection, and thermal radiation modes of heat transfer. The developed models fitted any set of weather and operational conditions, time, and location through linkage to weather measurement data obtained from typical meteorological files (TMY2). The models were multidimensional and

time-dependent in order to simulate real field conditions. To achieve this goal, ABAQUS FE software version 6.9 was used in the modeling process (ABAQUS 2009). Two 3D FE models were developed to simulate the case where radiant barrier is used and a conventional case without radiant barrier.

The second task was carried out with the support of the local industry and our research partners. A number of projects utilizing radiant barrier insulation in Louisiana provide real time data through installed sensors. Two projects were instrumented with t-type thermocouples and heat flux transducers, one site with radiant barrier insulation and one site with conventional insulation. T-type thermocouples were continuously monitored the temperature field in the system. Data was collected over a variety of weather conditions, ranging from cloudy and overcast days to sunny hot days, selected over an eight month monitoring period. The geometry, material properties, and climatic conditions, for the corresponding field conditions were simulated in the developed FE models and accuracy of the predicted heat flow was established by comparing measured and predicted thermal performance. Developed FE models were adjusted and modified until an accurate prediction of the temperature distribution in the system is achieved. Results of our measurements were used to assess the thermal efficiency of the radiant barrier insulation system as compared to conventional insulation system. As many factors affect the calculated temperature distributions and heat flux in the roof, the validity of the FE model was evaluated by comparing finite element simulation results with experimental data.

Task 3 identified the significance of the design and operational variables and their influence on the performance of the radiant barrier insulation system based on FE analysis. Initially, factors affecting thermal performance are divided into two main categories:

- Design variables such as emissivity of the material, thickness of the air space, orientation of the air space, number of reflective layers, and direction of heat flow.
- Operational Parameters such as solar radiation, wind speed and direction, radiation angle, and temperature differences between the inside and the outside of the building.

Design parameters were systematically varied until optimum conditions were identified in order to maximize thermal performance of the radiant barrier insulating system. Graphing the variation of one parameter at a time against the temperature profile used to quantify its impact on system performance. Based on this analysis, thermal performance of the developed system and its variation with operational parameters is evaluated and reported for utilizing in the estimating tool.

In task 3.1 sensitivity analysis was carried out to quantify the variations of an output parameter of a system with respect to changes imposed to some input parameters. Sensitivity analysis is used to understand which factor among design and operational parameters has the greatest effect on the performance of radiant barrier. The design and operational parameters are shown in Table 1.

In task 3.2 fractional factorial design was performed to investigate the influence of design and operational parameters on the heating and cooling load in residential buildings. Three levels (low [0], intermediate [1], and high [2]) were considered for each factor as shown in Table 1.2. The required total number of runs is calculated from the definition of the factorial design, $3^{(k-p)}$; where k is the number of factors and p is one representing the half fraction. There are 81 combinations with six replicates to account for variability. The model can be represented in the form of $Y = f(x_1, x_2 \ldots, x_k)$, where $x_1, x_2 \ldots, x_k$ are input factors and Y is the model output. In

this study Y represents the temperature of the insulation. Related input factors which are the design and operational parameters are shown in Table1.

Table 1: Design and operational parameters

Emissivity of Asphalt Shingle
Emissivity of Aluminum
Thickness of Air space
Orientation of air space
Number of reflective layers
Direction of heat flow & ventilation
Insulation
Thickness of Aluminum
Solar radiation
Wind speed and direction
Radiation angle
Temperature difference between inside and outside of the house
Type of Ventilation

Table 2: The range of design and operational parameters

Parameters	Range of variation		
	Low Level (0)	Intermediate Level (1)	High Level (2)
Shingle emissivity	0.75	0.8	0.97
Radiant barrier emissivity	0.03	0.04	0.05
Insulation emissivity	0.2	0.3	0.4
Air gap thickness	0	0.75	5
Radiant barrier orientation	Full	East-West	North-South
Attic flow rate	0.1	1.3	5
Wind speed	0	3.5	14
Solar radiation	0	875	1310
Outside temperature	-24	17	34

To obtain enough data for the statistical analysis and more accurate results, the simulation runs were based on typical days in each season (spring, summer, fall, and winter). In task 4, results of tasks 1 through 3 are used to determine the amount of energy savings provided by

radiant barriers. Energy savings quantified on a monthly basis over an entire year based on the building cooling and heating loads reduction. Reported savings was expressed in terms of the operational conditions and factors affecting the performance of radiant barriers that identified along with recommended ranges for maximum benefits from the insulating system.

The second phase was to assess the economic performance of radiant barrier system based on a whole-life cycle cost approach. Economic performance evaluated by determining the costs for purchase, installation, maintenance, replacement and disposal at the end-of-life. All future costs discounted to their equivalent present values. Performance of radiant barrier system was obtained from the results of Phase I and used to determine the energy savings benefits of this technology. By summation of equivalent present values, a total economic score was obtained. A lower score indicates a technology that is more cost effective and economic over the entire design service life of the construction product. To quantify the added social values to the consumer and to the society, a benefit-cost analysis model was incorporated into the life-cycle cost analysis framework. In this approach, the ratio of social benefits of the radiant barrier insulating system, expressed in monetary terms, relative to its costs was calculated. All benefits and costs were expressed in discounted present values.

The third and final phase was to develop a simple estimating tool that may be used by homeowners, state agencies, and contractors to assess the effectiveness and economic benefits of radiant barrier insulation systems under the climatic conditions in US. While the theoretical basis behind this tool is robust and accurate, it is envisioned that the developed tool is simple, flexible, and user-friendly to encourage its use among practitioners and homeowners with minimal background about this system. The developed tool is based on the results of the FE models by implementing these results into a set of regression equations that may predict the thermal and

economic performances of radiant barriers under a wide range of operating conditions. Accuracy of the models was assessed by the coefficient of determination, (R2), and root mean square error (RMSE). Based on this simple design tool, the user was able to enter data corresponding to the specific design in mind, such as the geometrical shape of the roof, the thermal properties of the materials used, and climatic trends specific to the location. From the data, the models predict the efficiency of the reflective barrier insulation and its cost effectiveness. Users may run repeated trials to find the optimal design solution based on their needs.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

The depletion of non-renewable fuels, global climate change, and consciousness of the impact of harmful emissions on health and the environment has resulted to an increased interest in renewable energy and energy efficiency applied to every major energy sector. However, the most energy and environmental benefits can be attained by focusing efforts on improving the energy efficiency and building practices in residential and commercial buildings. According to the Energy Information Administration, buildings consume 37% of the energy in the United States and 53% of that energy is used by residential buildings (Department of Energy 2011). Most of this energy is for supplying the energy for lighting, heating, cooling, and ventilation. Increased awareness of the environmental impact of Carbon Dioxide (CO_2) and Nitrogen Oxide (NOx) emissions triggered a renewed attention in environmentally friendly cooling and heating innovative technologies (Urban Land Institute 2008).

Buildings are important consumers of energy and thus important contributors to the emission of Green House Gases (GHG) into the atmosphere. The development and integration of appropriate renewable energy technologies in buildings has an important role to play. However, issues of cost, investment and ownership along with technical risk provide disincentives to the uptake of embedded energy technologies. Governments have adopted a number of approaches to encourage these new and often expensive technologies, including energy price subsidies, capital grants and supply side obligations (Day et al. 2009). Another way of reducing building energy consumption is to correctly design the buildings, which will be more economical in their use of energy and energy efficiency.

A large portion of residential building energy consumption is attributed to space heating and cooling which differs with climate conditions (Department of Energy 2011). Due to the large energy consumption by residential buildings, efforts to decrease energy use and negative environmental impact are an important national issue. There are two major problems to achieve sustainability in residential buildings. One is the technology and its associated cost. The energy efficiency of appliances, lighting, HVAC, and building materials must improve and it should be able to compete economically with traditional building materials and practices. Second problem is that homeowners and residential contractors do not have enough information and knowledge about new available materials and technologies, or have concern about cost or ease of installation. Both of these concerns should be considered to achieve a positive impact in residential buildings.

2.2 Building Energy Consumption

Nowadays, our society must deal with two major issues of this century: the progressive exhaustion of fossil fuels (carbon, oil, gas and coal), which provides currently more than 80% of the primary energies marketed in the world and the climate change. Greenhouse gas emissions are considered to be the main reason of the climatic warming for the last fifty years and a progressive concern about this matter has been observed (Elani et al. 1996).

Energy is essential for socio-economic progress both in developing and industrialized countries and the demand for energy will increase with the global population, currently growing at a rate of 250,000 people per day (Abdeen 2008). In the year 2001, the use of fossil fuels released about 23.7 Gigatonnes of CO2 into the atmosphere with a continuous increase compared to previous periods (International Energy Agency 2004).

Figure 1 shows the energy consumption, production, imports, and exports in the U.S. over the past several years. As can be seen, there is an upward trend in energy consumption from 1960 to 2010 while energy production trend was roughly constant from 1970 to 2010 which required the U.S. to import energy from other countries.

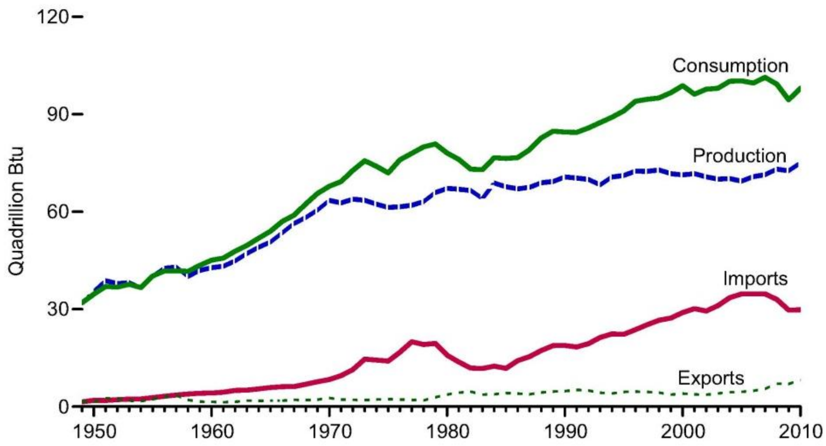


Figure 1: U.S Energy Consumption, Production, Imports, and Exports (1 Quadrillion Btu = 1015BTU) (Adapted from Department of Energy 2011)

Figure 2 shows the primary energy production by source. As can be seen, fossil fuels still is the largest source of energy production in the U.S. The renewable energy sources and nuclear electric power show a very slight upward trend from 1980 to 2010.

Figure 3 shows a breakdown of the U.S. energy consumption by sectors from 1950 to 2010. There is an upward trend in energy consumption in all the sectors. The industrial sector still accounts for the majority of energy consumption, but residential and transportation sectors are growing rapidly. As can be seen, industrial sector consumes the largest portion of energy in the U.S. Residential sector consumes 23% of the total energy in the U.S. In most of the cases in the early phases of a project, parametric studies have to be performed to find an optimum solution among a large variety of parameters.

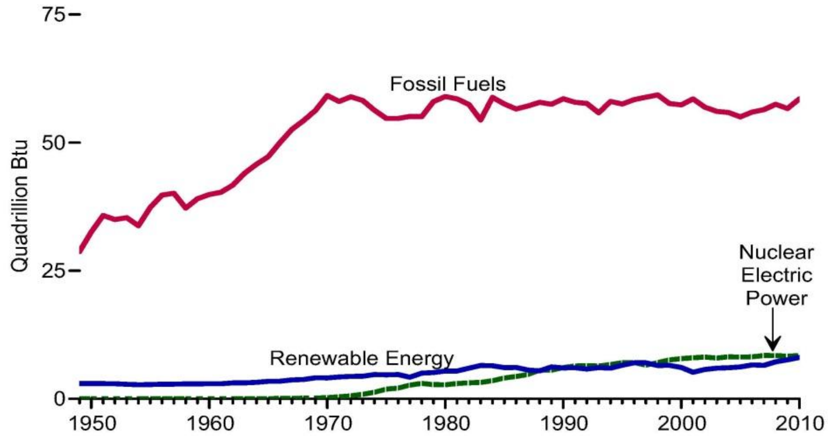


Figure 2: Primary Energy Productions by Source (Adapted from Department of Energy 2011)

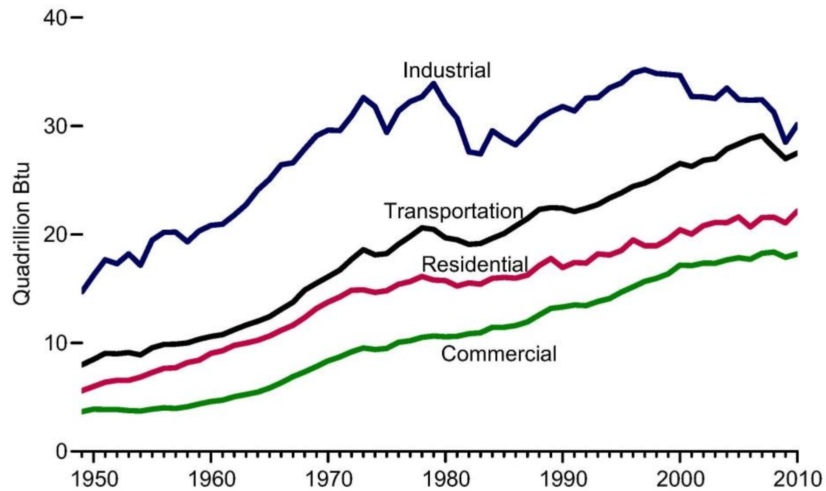


Figure 3: U.S energy consumption by different sectors (Adapted from Department of Energy 2011)

Using passive measures on solar heat gain or natural ventilation can significantly decrease primary energy consumption. Promoting innovative renewable sources and highlighting the RES market will contribute to perpetuation of the environment by reducing production of

emissions at local and global levels. These measures show a large benefit by replacing conventional fuels with green energies that produce no air pollution or greenhouse gases.

A number of energy saving measures can be used for buildings in order to decrease the energy consumption and to be environmentally friendly (Glickman et al 2001):

• Good thermal insulation of the building

• Better use of day-lighting

• Natural/hybrid ventilation

• Passive solar heating

• Passive cooling

• Use of renewable energies (wind energy use, solar heating, solar electricity, use of geothermal energy or biomass)

2.3 Building Energy Demand

In the U.S., the building industry is responsible for 30% of greenhouse emission gases and 36% of total energy consumption, making it as one of the biggest consumer of energy across all of the economy sectors (Energy Information Administration 2011). In the U.S., the energy spent for heating and cooling of the occupied spaces in the residential sector represents more than 43% from the total energy demand (U.S. energy Efficiency and Renewable Energy 2008).

A major energy reduction can be attained if a building is properly designed by engineers and architects. In particular, the use of renewable energy is considered as the solution of the future. The prediction of the energy savings would be a good indicator for the choice between different energy solutions according to the building features and the local climate. But this

savings are hard to predict because the efficiency of the system is directly influenced by the heating-cooling demand. Moreover, predicting building energy demand is a complex problem since it is practically impossible to model a correct level of occupancy, lighting, and equipment loadings. Therefore, making a model to predict accurate energy consumption is very difficult. So, we need accurate and easy-to-use estimating tools.

Various simplified methods have been developed to assess the heating and cooling demand, such as the degree-day method (Santamouris 2005). These methods are not sufficiently accurate and in most cases they are over assessing the required energy without considering important aspects such as the true thermal inertia. The degree-day method is a traditional method that has been in use for decades, in both the academic and industrial worlds. The concept mainly shapes on the temperature difference between indoor temperature and the outdoor temperature, multiplied by the duration of the temperature difference. This method does not consider the solar gains or internal gains effect on the energy demand (Santamouris 2005).

In fact, the most dependable solutions are the simulation energy tools to predict the effect of design parameters and better recognize the design problems with respect to energy performance. Simulation tools such as Energy Plus (Energy Plus review 2009), Simbad (Simbad 2001) or Trnsys 16 (Trnsys 2005) are good methods to simulate and analyze the building and the systems. The disadvantage of these softwares is that they need a significant amount of detailed input data and time from even an experienced user. Before or during the design of a project, multiple solutions should be suggested and evaluated but the lack of time and the complex data inputs stop this process of optimization and analysis.

A method to balance between simple and complicated models of assessing the heating and cooling demand is to utilize energy estimation models that can predict accurate results from

the model to the data obtained from simulations or experimental measurements. The main research goal of this section concerns with the development of a simple estimating tool to predict the required monthly/annual heating and cooling load for houses in different climates, with the aim to be used by homeowners, contractors, designers, and architects as a support tool in the design state of a project.

The energy estimation models that were achieved in this dissertation research work simplify the parametrical studies in order to find a better design approach to reduce energy consumption versus environmental or financial criteria.

2.4 Estimating Heating and Cooling Load

Different estimating models have been suggested by several researchers including Fourier series models (Dhar et al. 1998); regression models (Sullivan et al 1985, Sullivan et al 1984, Sander et al. 1993, O'Neill et al. 1991, Kreider and Wang 1992) and neural network (NN) models (Andersson et al. 1996, Kawashima 1994, Aydinalp et al. 2002, Aydinalp et al. 2004, Kreider and Wang 1997, Anstett and Kreider 1993, Stevenson 1994, Kreider et al. 1995, Ruano et al. 2006, Dong 2005, Yang et al. 2005, Young and Kang 2007, Datta et al. 2000, Chlela 2008). Ruano et al. (2006) used NN technique to predict building's temperature based on the environmental data. Building energy consumption was predicted based on the new NN algorithm and data collected from four commercial buildings in tropical regions in Singapore by Dong et al. (2005). Later, Yang et al. (2005) presented and tested two adaptive artificial NN algorithms to estimate building energy consumption. The major benefits of artificial NN are that they are able to adapt themselves to unexpected pattern changes in the incoming data.

When working with a particular pattern, it is possible to utilize multiple regression analysis to get accurate models but it is needed to have a database to predict the model variables

and the suitability of the statistical methods (Young et al. 2007) applied to develop the equation. In another study, Datta et al. (1997) compared NN techniques to linear regression techniques and, verified that a simple linear regression model functions very poorly in comparison with a simple NN. Chela.F (2008) developed polynomial models that were based on numerical simulations with the goal to predict the required energy and summer thermal comfort for commercial buildings. There was a good agreement between the methodology results and the numerical simulation results. The existing literature suggests that there is a high interest on this subject with major potential and substantial advantages for the research community and industry. This research work can be considered as a continuation of the previous research works by focusing on the residential construction and considering different climate and the building design.

An additional estimation method is the Cooling Load Temperature Difference/Cooling Load Factor (CLTD/CLF) method. This method was suggested in ASHRAE 1997 handbook (ASHREA 1997). However, in the new versions of ASHRAE handbook, this method is not discussed anymore and has been replaced by the heat balance method and radiant time series (RTS) method which is a simplified version of heat balance method with some limitations. In the CLTD method, the cooling load due to external heat gains (roofs, walls, and fenestration) and internal heat gains (lights, people, and equipment) are calculated separately and added to the heat gain due to infiltration to obtain the total zone cooling load (ASHREA 2001, ASHREA 2005).

Another simplified method which is widely used in the U.S. is the Manual J, published by the Air-Conditioning Contractors of America. This method has been in use for decades and has undergone periodic updates. The Manual J is a component-based procedure – formulas and tables specify the load contribution per unit area of a wide range of residential construction

assemblies, taking into account design conditions and surface orientation. Given these factors, designated heat transfer multipliers (HTMs), the envelope load calculation is simply sum of component area multiplied by the HTM. Additional gains are added to heat from appliances, occupants, and infiltration (ASHREA 2005).

In 2001, the ASHRAE and ACCA undertook a research project: Updating the ASHRAE/ACCA Residential Heating and Cooling Load Calculation Procedures and Data (1199-RP). This project modified the heat balance method for residential applications (Barnaby et al. 2004, Barnaby et al. 2005). The resulting Residential Heat Balance (RHB) method is a 24-hour procedure that can be performed on any day of the year with any design conditions. Hourly loads are calculated via rigorous energy balances and the design load is simply the peak of the overall daily profile. Xiao (2006) presents an extensive evaluation of RHB.

2.5 Energy Efficient Building Design

It is evident that energy efficiency in buildings is vital for many reasons. In order to have energy efficient buildings, it is important to focus on the basic principles that have impact on energy efficiency. According to previous studies, the following parameters have the main effect on the energy efficiency in buildings.

2.5.1 Building Shape

Shape of the building is an important factor that can affect required heating-cooling demand in an occupied space. The shape of a building has also an important impact on the construction costs but most importantly on the energy consumption and implicitly on the energy costs (Pessenlehner and Mahdavi 2003). Depecker et al. (2001) have studied the relation between the form of the building and its energy consumption. For that, they analyzed 14 buildings which were created from the same basic cell.

A simplified analysis method have developed by Ourghi et al. (2007) to estimate the effect of morphology of an office building on its annual cooling demand. This method was carried out based on detailed simulation using several scenarios of building geometry, glazing type, window area and climate. A direct correlation has been found between relative compactness and total building energy consumption as well as the cooling energy demand. They also concluded that in addition to the relative compactness, the glazing has an effect on the building total energy consumption. In Kuwait, AlAnzi (2009) performed a similar study on an office building but with an extended database and special building shapes (i.e. H-shape). The simplified method that they found is appropriate for architects during first design phase to evaluate the effect of shape on the energy efficiency of office buildings. Jedrzejuk and Marks (2002) optimized the shape and the functional structure of energy-saving buildings. The objective of their study was to present rational multi-criteria methods to optimize the shape along with the optimization of heat sources considering some energy criteria.

Givoni (1998) found that building form mainly depends on whether the building is intended to be air-conditioned or if it is planned to rely on natural ventilation. He proposed a compact shape for the building that is determined to use air conditioners and open forms for naturally ventilated buildings. Compactness of the building reduces the surface area of the building envelope, resulting in a reduction of the heat gain through the envelope.

2.5.2 Building Orientation

Building orientation determines the buildings relationship with the sun's path. This determines solar gain characteristics of the building. Hence, the sun's apparent path should be carefully observed to decide an efficient orientation of the given building in a given area or site. Properly oriented buildings can take advantage of solar radiation and prevailing wind. In order to

get minimum solar heat gain by the building envelope, the longer axis of the building should lie along east-west direction (Gut and Ackerknecht 1993).

A field measurement and computational energy simulations were carried out by Wong and Li (2007) to investigate the effectiveness of passive climate control methods such as building orientation in residential buildings of Singapore. Their results showed that the best orientation for a building in Singapore with its tropical climate is placing the longer axis of the building along east-west direction. They also found that the cooling load for a residential building can be reduced to 8% -11% by following this orientation.

The passive design feature suggested by Wong and Li (2007) is not always possible, especially because of actual orientation of the site which results in on orienting the longer axis of the building towards east- west direction. In other words, when the site itself is longer on the west and east sides, these cases are outside the control of the architect. In such cases, the west frontage needs more attention because it heats up in the afternoon and increases the temperature of bedrooms that are generally used later during the day when residents return from office. Since the east side only heats up during the morning, it is not as problematic as west side. Therefore, kitchen and staircase should not place in the west frontage and if they cannot be avoided, they should be sufficiently shaded by using verandahs. It is better to locate the auxiliary spaces in the west side.

It should also be considered that the orientation requirement for wind flow can differ with the requirement for solar protection. Mowla (1985) remarked that solar geometry cannot be changed; expert application of elements such as roof overhang or wall-projecting wing can change the direction of air flow and also give shade.

Watson and Labs (1983) have suggested that to have an energy efficient house, we should somehow take advantage of solar orientation and prevailing wind direction. However, they did not determine how much energy saving is possible through such planning. Givoni (1998) proposed that cross-ventilation can be applied to allow faster cooling and better ventilation. He stated that building layout which makes good potential for cross-ventilation is more suitable for developing countries in hot-humid regions where the massive majority of people cannot pay for air conditioners.

2.5.3 Landscaping

The valuable effects of trees were proved in a study by Raeissi and Taheri (1999). They stated that plantation of trees can result in energy saving, reduction of noise and pollution, modification of temperatures and relative humidity and psychological benefits on humans. According to their study, proper tree plantation can reduce cooling load in a house by 10-40%. They also mentioned that trees can perform complementary to window overhangs which result in better blocking of sun in the morning and afternoon sun. In a study by Simpson and Macpherson (1996), it is shown that tree shades can decrease annual cooling energy by 10-50% which was in agreement with Raeissi and Taheri (1999).

2.5.4 Building Envelope

The building envelope is considered to be everything about the building that separates the living space from the outdoors. It contains the wall and roof assemblies, insulation, windows, doors, finishes, weather-stripping, and air/vapor retarders. One of the main factors that affect energy consumption in buildings is its envelope. For the different climatic conditions, different design plans are recommended, therefore specific designs and materials can take advantage of or provide solutions for the given climate. The second important factor that affects energy demand

is what happens inside the building. If the activity and appliances inside the building produce a significant amount of heat, the thermal loads may be mainly internal rather than external. This influences the rate at which a building gains or loses heat.

2.5.4.1 External wall

Walls are essential in buildings in order to separate spaces into areas of convenient size and also keep out dust and rain from inside. The most common materials utilized for walls are stone, concrete, burnt clay, and wood. One the main objectives in building design is reducing the direct heat gain by radiation through openings and reduction of internal surface temperature. In order to achieve this objective, the building should be designed with protected openings and walls (Gut, and Ackerknecht 1993).

The main factor in choosing wall material when considering energy consumption is the thermal mass of the wall. For different climate conditions, different types of walls are needed (Straaten 1967). Mathur and Chand (2003) suggested that thermal resistance of a wall can get better by adding an air cavity. In another study, Mallick (1996) emphasized that changing the wall thickness can create significant difference in comfort level of houses in tropical climates. He stated that, a building material with high thermal mass and adequate thickness delays the effect of temperature changes from the outside wall on the wall’s interior.

In hot and humid climates, where nighttime temperatures do not fall significantly below daytime temperatures, light materials with little thermal capacity are chosen. In some hot and humid climates, materials such as masonry, which functions as a desiccant, are common. Walls should be covered by overhangs. Large openings protected from the summer sun should be placed primarily on the north and south sides of the envelope (Cheung et al. 2005).

2.5.4.2 Foundations and Floor

Foundation walls and slabs can be also insulated as walls. Since the temperature of soil is different from the room temperature, un-insulated foundations can cause a negative impact on the building energy consumption and comfort. Materials such as plastic and ceramic floor finishing with low thermal conductivity are desirable to decrease the heat loss through the floor.

2.5.4.3 Window

Application of proper glazing type and shading devices in residential buildings can cause a substantial contribution in decreasing heating and cooling loads. Several studies have carried out about glazing and shading device systems (Arasteh et al. 1985, Pletzer et al. 1987, Dubrous 1991, McCluney et al. 1993, Soebarto et al. 1994, Sullivan et al. 1994, Carpenter et al. 1998, Anello et al. 2000, Farrar-Nagy et al. 2000, Tsangrassoulis et al. 2001, Capeluto 2003).

The size, location, shape, and orientation of glazed areas in a building have a significant effect on heat gains and solar gains of a building. The reason is that glazed areas have the highest heat gain per unit area and the major proportion of solar gains is also through windows. Gut and Ackerknecht(1993) proposed that windows should be large and fully operable, with inlets of a similar size on opposite walls for proper cross-ventilation in tropical climates. Liping et al. (2007) stated that ventilation and indoor air quality can be enhanced by increasing the window to wall ratios (WWR), but it would also increase solar heat gain. Liping et al. (2007) also performed a comprehensive assessment using building simulation and indoor Computational fluid dynamics (CFD) simulation in order to get a precise prediction of indoor thermal environment for naturally ventilated buildings in the hot-humid climate of Singapore. The window size in this coupled simulation was changing from WWR= 0.1 to WWR= 0.4 for all orientations. Their results indicated that the optimum window to wall ratio is equal to 0.24 and

horizontal shading devices are required for the four orientations, especially for large windows for further improvement in indoor thermal comfort.

A study performed by Ossen et al. (2005) to evaluate and compare the impact of horizontal shading devices in decreasing unwanted solar heat gain and the amount of natural light penetration into the building.

The effect of climate on the design and location of windows in buildings in Bangladesh was studied by Ossen et al. (2005). Their results showed that the orientation of windows should aim at rejecting solar infiltration. They also stated that windows should not locate on western walls as it is practically impossible to shade it in all seasons. Liping et al. (2007) also highlighted on avoiding east or west facing rooms for the purpose of thermal comfort and energy consumption.

Three shading devices were defined by Watson and Labs (1983) including solar transmittance of glazing materials, interior shading and exterior window shades. Solar transmittance is defined as the heat admitting or rejecting characteristic of the glazing materials. They said that the absorbed heat can be uncomfortable to occupants because it increases the temperature of the interior by conduction and thermal radiation. Another disadvantage of heat absorbing and heat reflecting glazing types is that they do not allow solar gain enter to the building in winter and summer. According to the study that conducted by Gut and Ackerknecht (1993), most of these glasses are not enough effective because their own temperature is raised, which increases the heat convected and reradiated into the internal space, or they tend to decrease light rather than heat.

The impact of shading devices along with five other passive design plans on the cooling load for an apartment was studied by Cheung et al. (2005). Their results suggested that the longer

the shading, the greater the reductions in both annual required cooling energy and peak cooling load. They concluded that by using these shading, the annual required cooling energy will reduce by 5%. Though, according to Mowla (1985), the length of shading devices depends on the orientations, width of the opening, height of the openings, horizontal shadow angle and vertical shadow angle. Therefore, it is not sound to conclude that shading devices should have arbitrary lengths in general for all orientations.

2.5.4.4 Roof

The roof is considered as an important element of design when it comes to conserving energy because this part of the building receives most of the solar radiation and its shading is not easy. Vijaykumar et al. (2007) stated that Indian concrete roofs in single or two story buildings with 150 mm thickness of reinforced cement concrete (RCC) and a weathering course (WC) having 75–100 mm thick lime brick mortar, account for about 50%- 70% of total heat transferred into the occupant zone and are in charge for the major portion of electricity bill in air-conditioned buildings. Tang and Etzion (2004), Vijaykumar et al. (2007) and Alvarado and Martinez (2008) concluded that the heat incoming into the building structure through roof is the main cause for discomfort in case of non-air-conditioned building or the main load for the air-conditioned building. However, Gut and Ackerknecht (1993) stated that this is true for single storied buildings and the top floor of multi-storied buildings.

Regarding roof shape, Gut and Ackerknecht (1993) noticed that warm-humid regions should have pitched roofs to drain off heavy rains. They also suggested that roofs should have large overhangs to keep the walls and openings from radiation and precipitation; they should be made of lightweight materials with a low thermal capacity and high reflectivity.

Alvarado and Martinez (2008) studied the effect of a simple and passive cooling system in reducing thermal loads of one- storied roofs. Their results showed that the alumunium–polyurethane insulation system with an optimal orientation decreases significantly the midpoint temperature of a cement-based roof. The results also demonstrated that the roof insulation system can decrease the typical thermal load by over 70% while effectively controlling thermal variations. However, Garde et al. (2004) and Suehrcke et al. (2008) have different views. Garde et al. (2004) stated that in tropical climates, intermediate roof insulation can only reduce the air temperature inside a dwelling by few degrees. Suehrcke et al. (2008) concluded that roof insulation may delay the desired night-time cooling.

In another study, Vijaykumar et al. (2007) has shown that passive roof cooling systems like coating the rooftop with highly reflective coatings can decrease the heat transmission through the roof by 20% –70%. However, the durability of roof coating reflectivity over time is a major issue. Levinson et al. (2005) proposed that washing the dirt off from the reflective roofs can almost completely reinstate its original reflectivity.

Green roofs have been progressively studied in order to determine how they could improve the quality of the urban environment. Teemusk and Mander (2009) have defined green roofs as containing of the following layers: a water- proofing membrane, a drainage layer, a filter membrane, a substrate layer and plants ; the composition and thickness of this substrate layer is decisive.

The shape of the roof is an important factor in sunny climate. A flat roof obtains solar radiation continuously throughout the day, at a rate that increases in the early morning and decreases in the late afternoon due to changes in both solar intensity and angle of the sun. Therefore, pitching or arching the roof has several advantages over a flat structure. First, the

height of part of the interior is increased, thus providing a space far above the heads of the inhabitants for warm air that rises or is transferred through the roof. Second, for most of the day, part of the roof is shaded from the sun, at which time it can perform as a radiator, absorbing heat from the sunlit part of the roof and the internal air, and transmitting it to the cooler outside air in the roof's shade.

Venting roofs is also another method to decrease heat gain through roofs. In hot climates, the temperature of the space between the roof and ceiling (attic) is higher than the outside and inside environments; hence making a vent through the roof or ceiling to the outside will decrease the heat gain through the roof. This hole will help in flowing out the air at higher temperature to the outside.

2.5.5 Infiltration and Ventilation

Infiltration is defined as the uncontrolled movement of air through unintended openings such as cracks in the walls and ceilings and through the gaps of windows and doors forced by wind, temperature difference, and internal persuaded pressures. The amount of infiltrated air depends on several factors including pressure difference; the number, the size, and the shape of the cracks; the number, the length, and the width of the gaps of windows and doors; and the nature of the flow in the crack of gap. Infiltration from outside air to the inside temperature is considered as an important contributor and it is a good idea to retain it out. Outside air can penetrate into a building around poorly sealed doors, windows, electrical outlets, and through openings in exterior walls (Straaten 1967).

The infiltrating air has to be cooled to the anticipated space temperature and this enhances a cooling load to the building. Therefore reducing the infiltrated air will decrease the cooling load of the building. It is possible to reduce infiltration through appropriate sealing of

cracks, closing of openings like doors and windows. Once the building is sealed to avoid air leaks, it is essential to run controlled ventilation (Merritt et al. 2001). This can be attained through natural or forced ventilation.

Natural ventilation depends on only natural air movement, thus decreasing the need for mechanical ventilations and air conditioning. Ventilation in general helps enhance good indoor air quality and avoid the accumulation of moisture in the indoor air (Michael et al 2002).

Wong and Huang (2004) carried out a comparative study in order to investigate the effect of the natural ventilation on the indoor air quality in bedrooms of residential buildings in Singapore. They observed that CO2 levels of bedrooms utilizing air conditioners are significantly higher than those using natural ventilation. Thermal comfort comparison of the air-conditioned bedrooms and naturally ventilated bedrooms designate that the air-conditioned bedrooms are usually considerably overcooled which result in very high Percentage People Dissatisfied (PPD). While, in natural ventilated bedrooms, the use of fans was adequate to get the essential thermal comfort. They also found that occupants using air conditioners showed more sick building syndrome (SBS) symptoms than those using natural ventilation. Liping et al. (2007) also stated that natural ventilation is a good alternative to decrease the associated problems with air-conditioned buildings because natural ventilation has potential benefits such as reduced operation costs, improved indoor air quality and satisfactory thermal comfort.

Hirano et al. (2006) studied the possible impacts that a porous building model may have on the natural ventilation performance and cooling load reductions in hot and humid climates. Two types of residential building models were studied. One of these models had 0% void ratio and the porous one had 50% void ratio. The model with a void ratio of 50% has 50% of its capacity occupied by voids, and the model with a void ratio of 0% is simply a shaped residential

building without voids. CFD analysis and thermal and airflow network analysis of the two models show that the model with a void ratio of 50% has a better performance than the model with a void ratio of 0% in terms of air change rate.

2.5.5.1 Energy Recovery Ventilation Systems

Energy recovery ventilation systems provide a controlled way of ventilating a home while minimizing energy loss. They reduce the costs of heating ventilated air in the winter by transferring heat from the warm inside air being exhausted to the fresh (but cold) supply air. In the summer, the inside air cools the warmer supply air to reduce ventilation cooling costs. There are two types of energy-recovery systems: heat-recovery ventilators (HRV) and energy-recovery ventilators (ERV). ERVs provide a controlled way of ventilating a home while minimizing energy loss (ASHREA 2009). The operation principle is simple: using a heat exchanger, an ERV allows the exhaust air being ventilated from the home to exchange energy with the air being drawn into the system. ERVs are especially effective for tightly sealed homes as such structures often require forced ventilation in order to maintain proper indoor air quality (Liping et al. 2007).

Energy recovery ventilators require little maintenance and very little energy to operate. Unlike HRVs that simply recover the latent heat associated with the exhaust air, ERVs allow for the transfer of moisture between the air streams, which helps to maintain a better humidity balance in the conditioned space and can also help reduce problems associated with water freezing in the ERV unit. ERVs are best suited for climates that experience extreme winters and summers and have high fuel costs; in mild climates the cost of energy consumed by the system may exceed the energy savings from not conditioning the intake air (Liping et al. 2007).

2.5.6 Air Conditioning Systems

These systems consume more energy, cost more to function, and are more complicated than other energy systems in the building. Decreasing the cooling load demand in the building allows for the installation of a smaller cooling system. But they need to be correctly sized because a system that is not appropriately sized can raise the cost of the cooling system in addition to the cost of operation. Design and installation of ducts are considered as a main aspect of the efficacy of conditioning systems. Ducts must be correctly insulated and leak off (Jones, 1994).

2.5.7 Lighting and Appliances

Lighting equipment is considered as one of the sources of load to air conditioning system so that should consider using energy efficient lighting bulbs. Turning lights off during day time when enough natural light is available should be considered as an advantage. Rio de Janeiro performed simulation runs over a year with hourly data to investigate the efficiency of lighting system. Results indicated that application of proper daylight control system can significantly decrease artificial lighting by 60-80% and at the same time reduce the cooling load of the buildings (Energy Efficient Lighting 2010).

Only 10% of the energy that incandescent lighting use is for lighting and the rest will convert to heat energy which constitute to cooling load. Therefore, natural daylighting should be considered to illuminate the building and consider switching to compact fluorescent lamps. These consume about 75% less energy than incandescent lamps, and emit 90% less heat for the same amount of light (Energy Efficient Lighting 2010).

Krarti et al. (2005) carried out a simplified analysis method to assess the potential of day lighting to save energy associated with electric lighting use in commercial buildings.

Performance of day lighting were studied for several combinations of building geometry, window opening size, and glazing type for four geographical locations in the United States. The results showed that daylighting save 13% of total annual energy consumption from the artificial lighting system.

2.6 Thermal Insulation performance

Thermal insulation hinders conductive, convective and/or radiative heat transfer (ASHREA 2001). Providing insulation for walls and roof in a building increases their thermal resistance and limits conductive heat flow through the building envelope. The building envelope insulation is a main component because it plays a major function in the energy consumption. The building's roof, windows, walls and floors lead the flow of energy between the indoor and the outdoor of the building. The envelope insulation is very important, and it is the best solution in order to have an efficient and less consuming energy building. Both new and old building is trying to reduce their energy consumption by improving the air tightness and increasing the thickness of insulation (Taylor and Imbabi 1998).

It should be considered that insulation can have a negative impact on buildings when the internal heat gain from lights, people and equipment is greater than the heat gain from the external sources such solar and infiltration. In this case the insulation will stop heat loss from the building which will increase the cooling load.

ORNL (2002) provided guidelines for choosing the type and level of insulation for different envelope components in residences in different U.S. climates. For a gas-heated wood frame house with a slab-on-grade floor in a hot and humid climate, it is suggested that an insulation level of R-11 to R-15 be provided for wall cavities, R-38 for attics and cathedral ceilings, and R-4 for slab perimeters.

According to Bolatturk (2008), thermal insulation is considered as one of the most useful energy preservation measures for cooling and heating in buildings because it decreases heat transfer to and from the buildings. However, this opinion represented by Bolatturk (2008) appears to conflict with those of Gut and Ackerknecht (1993) and Yang and Hwang (1993). They believed that thermal insulation is not very significant in warm–humid climates due to free flow of air. The ambient air temperature inside and outside the buildings is similar. Gut and Ackerknecht (1993) stated that that thermal insulation has a dual nature. It decreases daytime the extra heat that come to a building, but prevents the building from cooling down at night. Based on their study, this dual nature makes insulation inappropriate for buildings with natural climate control. Perhaps the solution is to first define the cooling load at the design phase and then making decision whether this cooling load would be decreased by applying thermal insulation in the building or by using passive means of control (Gut and Ackerknecht 1993).

Many studies have also quantified the energy savings from improved insulation. Ternes et al. (1994) showed that by retrofitting exterior masonry wall insulation from R-3 to R-13, energy consumption reduces by 9 -15% in Arizona. A study of a typical uninsulated masonry house in the hot and humid climate of Bangkok, Thailand by Chulsukon (2002) indicated 3-4% annual energy savings from light-weight walls with R-11 batt insulation and from cement tile roof with R-11 batt insulation. Another study of a similar house in Bangkok, Thailand showed 8% of total energy reduction from light-weight concrete block walls with R-10 exterior insulation, and 9% reduction from similar wall construction with R-10 interior insulation (Rasisuttha and Haberl 2004). Tham (1993) Studied different energy conservation strategies and found that wall insulation does not significantly affect reducing heating and cooling load in buildings. He stated that adding 50 mm of polystyrene as wall insulation only causes in 1.7 %

reduction in total energy consumption. He also proposed that if savings in operation cost were compared to the cost of installation, wall insulation would not be economically practicable.

These studies propose that high R-values and low air infiltration loss could be achieved with advanced construction techniques, which can result in significant energy savings. However, high cooling energy savings are expected in residences in hot and humid climates.

2.6.1 Building Insulation

Insulation performs by reducing heat as it moves through the material. The amount of required depends on the building design and location. When choosing insulation products, several performance features are important. Some of them are: insulating capacity, fire resistance, moisture control, weight, convective heat loss, settling and loss of insulating capacity, and cost. Insulation is evaluated in terms of its resistance to heat flow, called R-value. The higher the R-value, the greater is its thermal resistance. The R-value of thermal insulation depends on the type of material, its thickness, and density. Insulation is available in a variety of materials and forms (ORLN 2002):

- Fiber glass insulation
- Cellulose insulation
- Mineral wool insulation
- Rigid insulation
- Sprayed foam insulation
- Radiant Barriers and Reflective Insulations

2.6.1.1 Fiber Glass Insulation

The most commonly used insulation in modern buildings is fiberglass. Fiberglass is chemically stable, will not decay and is nonflammable. It does melt with enough heat, so it offers

no fire retardant properties to the building. It is also porous and will freely absorb moisture, making it a poor choice in damp or wet locations. Fiberglass insulation is produced in a number of useful forms such as fiber glass rolls, fiber glass batts, fiber glass blankets, and fiber glass loose-fill (ORLN 2002).

2.6.1.2 Cellulose Insulation

Cellulose insulation is a byproduct of the paper industry, using up to 75% recycled newsprint. Cellulose and fiberglass have similar R-values at typical temperatures, but cellulose has larger insulating properties at lower temperatures than fiberglass or mineral wool which makes it better insulation choice in colder climates. Cellulose is also less porous to air movement than fiberglass and is less affected by packing and fluffing. Therefore, it is a better insulation for blowing into uninsulated walls or other building cavities. They are available as loose-fill products and they have none of the irritating properties of fiberglass, and so far have not been revealed to have any deleterious impacts (ORLN 2002).

2.6.1.3 Mineral Wool

Mineral wool, also known as rock wool, is an insulation material produced from steel slag. The slag, a byproduct of steel manufacturing containing of dirt and limestone, is combined with other chemicals, heated and turned into a fibrous material that is a good insulator. It defined as a permanent insulation because it does not rot; burn or melt, and it does not absorb moisture, and does not maintain mold or mildew. It is available in batts or as a loose-fill product that can be blown into walls and ceilings. It can also be installed between wall studs by using a mesh screen across one side of the studs, letting floor to ceiling filling with a technique virtually the same as with blown-in cellulose. Because of its greater density and water resistant properties,

mineral wool performs as a vapor barrier and, unlike fiberglass, does not need an additional vapor barrier to be effective (ORLN 2002).

2.6.1.4 Rigid Foam and Foam Boards Insulation

Foam insulation normally is more expensive than fiber insulation. In buildings with space limitations and where higher resistance is required, it is very applicable. Foam insulation R-value is approximately 2 times greater than most other insulating materials of the same thickness. Foam insulation is often made with one of three materials: molded expanded polystyrene (MEPS), extruded expanded polystyrene (XEPS) or polyurethane, polyisocyanurate, or a related chemical mixture.

Although batts are normally utilized between studs or floor joists, rigid foam boards should be considered as an alternate approach. These boards are lightweight, and supply structural support and acoustical insulation. Rigid boards can also be added to basement walls, exposed foundations, cathedral ceilings, exterior walls, and attic access. Such boards may be covered with a reflective foil that decreases heat flow when is in contact with an air space. Foam insulation can be spoiled if they are exposed to direct sunlight; therefore it is better to keep them using a rubber or plastic especially in roofs. Foam insulations are toxic when burnt. So they are not suggested to be use in residential buildings.

2.6.1.5 Spray Foam Insulation

Foam insulation can be sprayed into building cavities or directly onto the surfaces. Spray foams have higher R-values than fiberglass, cellulose or mineral wool. It is an inert product that resists rot and mildew and due to its strong bond that it makes with structural members, it increases the efficiency of the building. They can be added into concrete or masonry walls by injecting loose foam beads into masonry blocks or pouring liquid foam into the hollow block

cores. In hot climates foam insulation can be utilized in combination with fiberglass insulation (ORLN 2002).

2.6.1.6 Radiant Barriers or Reflective Insulations

Radiant barriers are defined as a thin layer of aluminum that can be attached to different materials such as Kraft paper, plastic film, polyethylene bubbles, or cardboard that works differently than insulation but has a similar impact. These reflective insulation systems are usually installed directly under the roof rafters in order to decrease heat gain from the sun. They can also be very effective when used for walls that absorb direct sunlight, particularly if an effective roof overhang is not applied. They showed better performance in hot climates than in cool climates due to intense solar radiation. Radiant barrier insulations have a low emissivity (0.1 or less) and high reflectance (0.9 or more). Most of them in the market today have about the same emissivity values. Therefore, choice is made by considering other features such as strength, flammability, availability, and cost.

2.7 Active Solar Techniques

Using renewable energy as an energy source is another option to reduce the consumption of non-renewable energy. Active solar energy systems can provide electricity generation, hot water and space conditioning. In residential buildings, solar energy has been utilized for space heating and domestic hot water using active solar collector systems and for generating electricity using photovoltaic (PV) systems. Active solar techniques use PV panels, pumps, and fans to convert sunlight into useful outputs. Active solar collection techniques consist of flat plate collection, concentrating collection, and PV collection. Each type has some advantages and disadvantages that need to be considered before it is selected for a specific application (Payne et al. 2001):

2.7.1 Flat plate solar collectors

Flat plate solar collectors are considered as the most economical, active method of solar energy collection (Duffie and Backman 1991). They consist of a dark flat-plate absorber of solar energy, a transparent cover that allows solar energy to pass through but reduces heat losses, a heat-transport fluid to remove heat from the absorber, and a heat insulating backing. The cover performs three functions: preventing convection losses, decreasing thermal radiation losses, and shielding the absorber plate against environmental hazards. While the absorber is a coated plate upon which the sun's energy is converted to heat, the insulation prevents back losses. Flat plate collectors utilize the absorber to heat air or water, which can then be used or stored for later use. They are usually used for applications requiring moderate heat gain (ASHREA 1999).

2.7.2 Concentrating Solar Collectors

Concentrating solar energy refers to the use of reflecting or refracting optical devices to focus or redirect incoming solar radiation onto a receiver, usually to improve performance and/or economics. Concentrating collectors are basically evacuated tubular collectors that remove convection losses. They deflect sunlight from a large area into a smaller region where the concentration of light can be used to produce temperatures higher than those obtainable from flat plates. Concentrating solar thermal (CST) collectors allow greater levels of radiation to be collected by smaller receivers, enabling higher receiver temperatures and decreasing surface area over which heat loss occurs. Systems of CST collectors can be scaled to provide large quantities of heat and designed to achieve a wide range of temperatures, well-suited to various industrial or power generation processes (Winston et al. 2005).

2.7.3 Photovoltaic collectors or PV

PV is defined as a technology in which sunlight is converted into electrical power. It is best known as a method for generating power using solar cells packaged in photovoltaic modules, often electrically connected in multiples as solar photovoltaic arrays, to convert energy from the sun into electricity. PV requires little to no maintenance, makes no pollution, and does not deplete materials. In some cases, it is possible to generate enough electricity from PV to power an entire building (Payne et al. 2001). A diagram of the power system can be seen in Figure 4.

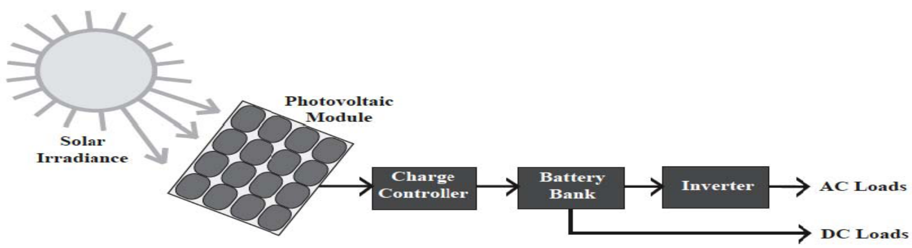


Figure 4: Photovoltaic System Diagram (Adapted from Winston et al. 2005)

A solar hot water heating system can be used to supply the residence with hot water. Solar radiation is absorbed by the collector and heats a glycol-water antifreeze mixture that is pumped through the collector. The antifreeze mixture is necessary to prevent the water in the collector from freezing. The heated antifreeze solution travels to a heat exchanger that transfers energy between the antifreeze solution and the potable water used in the home. A traditional

natural gas hot water tank is used to store the potable hot water and supply auxiliary heat when necessary (Lutz et al. 1996). A scheme of the system is shown in Figure 5.

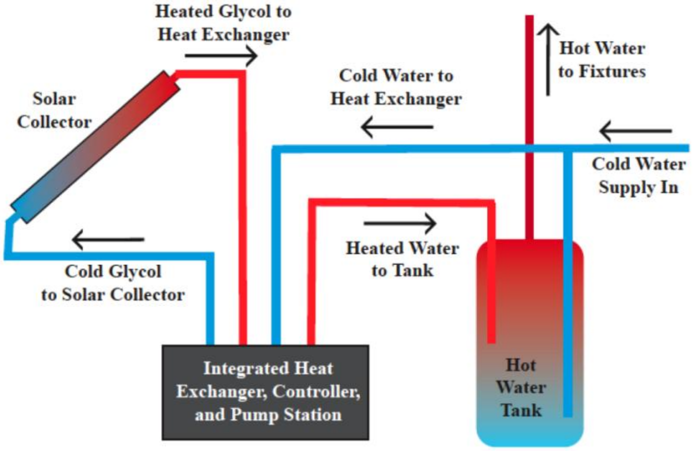


Figure 5: Solar Hot Water Heating System Scheme (Adapted from Lutz et al. 1996)

2.7 Attic Insulation and Radiant Barrier

2.7.1 Introduction

The roof is the most important element to control heat gain/ loss and usually easiest and cheaper place to improve insulation performance of new or existing buildings. Wall insulation is not as important for heating and cooling as attic insulation because outdoor temperatures are not as hot as attic temperatures. Also, floor insulation has little or no impact on cooling.

Attic insulation and radiant barriers have been considered to be an important component in decreasing heating and cooling loads in residential buildings. Using materials with low emissivity to block the radiation heat transfer in building has been common for more than half a century. Initial interest in reflective insulation materials began in the 1916, initiated by Dickinson and VanDusen (1916) at the U.S. Bureau of Standards. They reported the effects created by using bright tin surfaces placed between two air spaces within wall cavities (Dickinson and VanDusen 1916). Using these materials with low emissivity reduce the required energy for cooling load across the wall (Goss and Miller 1989). Several studies were carried out during the 1930's which reported research dealing with reflective insulation materials. According to Wilkes, the most common low emissivity surface used in the 1930's were aluminum foil attached to different materials such as paper, corrugated cardboard, and plasterboard.

2.7.2 Radiant Barrier Installation Methods

There are three methods to install radiant barrier in the attic. In the first method radiant barrier can be pre-applied to the roof decking. If the radiant barrier has only one reflective side, this side faces up toward the air space. In the second method, the radiant barrier is attached to either the faces or bottoms of the rafters or top chords of the roof trusses. Under this installation method an extra air space is created between the radiant barrier and roof deck. If the radiant barrier has only one reflective side, it can be faced either to the deck or beneath the barrier without making much difference. In the last method the radiant barrier is laid out on the attic floor over the top of the existing attic insulation (Department of Energy 2010).

2.7.3 Effect of Radiant Barrier on heating and cooling load

Early studies on heat transfer mechanism that occurs in the attic of buildings showed that radiation is a significant portion of the total heat transfer in attics. Joy (1958) was a pioneer in

using reflective insulation materials on top of the insulation material and found a significant increase of overall thermal resistance in the attic. Joy performed a series of steady state experiments in a simulated attic of a 4 m by 3.7 m plan area. Radiant barrier was placed over the ceiling insulation that was made of 50 mm semi-rigid fiber. Joy's result showed that the heat flux through the ceiling was reduced 50% under summer condition by applying radiant barrier. Joy's studies produced the basis of the "Table of Effective Resistance of Ventilated Attics" found in the ASHREA Handbook of Fundamentals (Joy 1958).

Fairey (1983, 1985) carried out two studies, using a small scale hot box and full scale attic tests using radiant barrier insulation under summer conditions. In the full-scale tests, controlled conditions were maintained inside the simulated conditioned space. On the other hand, the hot box experimental results using a single foil layer with a two-sided foil surface and including airspace on the other side reduced heat transfer through the ceiling by 29% without insulation, and by 44% by using 150 mm fiberglass insulation. The attic airflow rate reported was 2.4 (l/sec)/m2 of attic floor. Fairey in his last study developed a simplified model based on the ASHREA procedure for predicting radiant barrier performance. It was calibrated against Joy's data for flat roof parallel- air flow attics. The parametric analysis represented that the surface emissivity and the vent air inlet temperature into the attic are very important parameters in determining the performance of attic radiant barrier system (Fairy 1983, 1985).

Katipamula and O'Neal (1986) studied the performance of radiant barrier under different installation methods. The first method was installing the radiant barrier directly on the ceiling. This showed the heat reduction of 43% during daylight hours. In the second method, radiant barrier was draped over the trusses facing downward which resulted in 33% reduction in ceiling

load. Finally, when the radiant barrier was placed under roof sheathing, the heat reduction was 31%.

Levins and Karnitz (1986) conducted several experimental studies during summer and winter in Karns, Tennessee. Three of the houses were unoccupied ranch-style with dimensions of 12.2 m by 9.2 m. They studied the effect of two methods of radiant barrier installation: horizontal installation over the ceiling insulation (HRB) and attached to the underside of the roof (TRB). It was found that an attic radiant barrier system laid horizontally on the insulation with R= 1.94 m^2. K/W (R-11) can reduce ceiling cooling load by 16% during the summer in comparison with control house. Increasing the insulation from R= 1.94 to 5.28 m^2. K/W (R-11 to R-30) in combination with radiant barrier in the attic reduced the cooling load by 16%. They concluded that radiant barrier system performs better when installed horizontally instead of attached to the underside of the roof. Although they found that radiant barriers reduced heat transfer in the attic but their model had some problems. First, significant variation was seen in the measured cooling load between the test houses even though the houses were identical. Without installing radiant barrier in the attic, there was 50% difference in energy use in houses. They assumed that this difference was due to dissimilarity in the envelope construction such as different coefficient of performance of the air conditioners and air leakage rate. In order to minimize this problem, they developed a normalization procedure.

Levins and Karnitz (1986, 1987a, 1987b, 1988) studied the performance of radiant barrier in winter condition. They found that energy savings were less significant in winter than summer. They concluded that moisture build up can be a reason for this problem.

Hall (1986) studied the performance of radiant barrier under heating and cooling condition using small test cells. He found that radiant barrier can reduce the cooling load by 30 to 40 %.

According to his study, roof deck temperature in hot days was only 8 °F higher when radiant barrier was used.

Lear et al (1987) studied the performance of radiant barriers in side-by-side experiments at the university of Florida Energy Research and Education Park (EREP) in Gainesville. Both houses had the same area of 116 m^2 and the attics had fiberglass insulation with a resistance value of 3.88 m^2K/W (R-22). Both attics had natural ventilation. The control attic had soffit-gable ventilation and the test attic had ridge-soffit ventilation. The radiant barrier that they used was kraft paper faced on one side and aluminum faced on the other side and was installed against the rafters with the reflective side facing down. The time period used in the estimation of the ceiling heat flux reduction was 12 hours from 10 a.m. to 10 p.m. The result showed that the test house had 40% lower ceiling heat flux in comparison with the control house.

Lotz (1964) was the first person who studied the effect of dust on radiant barrier performance. He found that dust can accumulate at the rate of 28.6% area coverage per year, with an estimated full coverage in approximately 5 years. The emissivity of radiant barrier was not measured due to dust accumulation but degradation was quantified as energy savings related to dust accumulation. He concluded that in a case of dust accumulation of 0.54 mg/cm^2, the radiant barrier performance degradation was 30%. For a dust accumulation of 1.61 mg/cm^2, the radiant barrier performance degradation was 60%. The local and seasonal condition can affect dust accumulation.

Yarbrough et al. (1989) studied the relationship between dust accumulation and radiant barrier emissivity. They developed an exponential curve fit for an emissivity as a function of dust loading. Fairey et al. (1988) said that Yarbrough's data (1989) did not show any significant

sensitivity to dust particular size, but later works (Levins and Karnitz 1990, Hall 1988b) proved that the dust accumulation was strongly affected the emissivity of radiant barrier.

Wilkes (1988) developed a model based on the heat balance to simulate the attics with and without radiant barrier in residential constructions. He formulated the heat transfer equations for conduction, convention, and radiation. In order to solve the system, the Gauss-Jordan elimination method was applied without any convergence problem. The program result was validated with experimental data and showed a good agreement. Upon validation, the model could be used to extrapolate the experimental results to long term analysis.

Ober et al. (1988) carried out detailed tests in a Central Florida location using two identical houses with the area of $85m^2$. The ceiling was covered with R= 3.32 m^2/KW (R-19) fiberglass insulation and the slope of the attic was 6:12 (26.6°). Radiant barrier insulation with an emissivity of 0.03 was installed on the rafters. The result showed that radiant barrier insulation system in combination with attic ventilation reduced ceiling heat flux by 20%.

Hall (1988a) evaluated the performance of radiant barrier with different levels of insulation materials. Results showed that different insulation materials such as glass fiber, cellulous or rock wool with the same R-value had a similar reduction. He concluded that the efficiency of radiant barrier is not dependent on the type of the insulation materials. He also found an indirect relationship between the ceiling load reduction and the R-value of insulation. In a side-by-side testing, he found that dust accumulation on the radiant barrier surface did not degrade its performance. The general conclusion of this study was a reduction of 30% in ceiling heat flux during the summer when using radiant barrier system in combination with R = 1.94 and 3.32 m^2.K/W (R-11 and R-19).

In another study, Hall (1988b) assessed the effect of dust accumulation, attic ventilation, and ceiling insulation on the performance of radiant barrier. Results showed that radiant barrier with emissivity of 0.5 reduced heat flow by 20%. According to his study, different attic ventilation rates did not have significant impact on the performance of radiant barrier. Results indicated that R-11 insulation with radiant barrier in the attic performed nearly as well as R-30 insulation without radiant barrier. Large increases in attic ventilation only made a small reduction in attic with or without radiant barrier.

Wilkes (1988) with collaboration of Oak Ridge National Laboratory developed an automated code to model attic radiant barrier insulation system. He simulated all the heat transfer mechanism that occur in an attic and validated his model based on the experimental data. The model allowed the radiant barrier surfaces to have different levels of emissivity but dust accumulation was not considered.

Levins and Hall (1990) evaluated the performance of radiant barrier installed on the ceiling insulation due to the dust accumulation. This study did not consider the size of the dust on radiant barrier performance or emissivity. Results showed that dust increased radiant barrier emissivity and therefore reduced its efficiency. However, performance degradation was much less sensitive to dust accumulation than emissivity. Even with a large amount of dust, radiant barriers still significantly reduced ceiling heat flux.

Moujaes (1992), Moujaes et al. (1995), and Brickman et al. (1996) developed a model to simulate attic heat transfer in houses. Their model was validated with experimental data and showed a good quantitative agreement. Results indicated 25% ceiling cooling load reduction in the attic with R= 3.32 m^2.K/W (R-19) and the horizontal radiant barrier system.

Bourne et al. (1990) utilized a detailed hourly building simulation to model attic heat transfer in a house with radiant barrier and without radiant barrier in six U.S. cities. Results indicated a significant cooling demand and energy savings variation between the six cities.

Fairey (1990) assessed the performance of attic radiant barrier system in different seasons. The study showed a simplified method of estimating the performance data from side-by-side attic tests conducted in Florida. He found a simple correlation between the measured weather conditions and the measured relative thermal performance in the attic with radiant barrier and control attic.

Levins and Herron (1990) carried out radiant barrier field tests in an Army housing unit in Georgia. Their study indicated that radiant barrier save energy in both heating and cooling conditions of HVAC operations. According to this study, radiant barrier can save energy from 3% to 17% in a year. Annual savings from the application of radiant barriers in relatively mild Georgia heating season were estimated to range from 11% to 18%.

Medina et al. (1992) tested the performance of radiant barriers under full weather conditions in central Texas using a side-by-side comparison of two test houses with identical floor plans and thermal characteristics. The ceiling heat flux was reduced as a result of retrofitting with radiant barriers by approximately 34% when the attics were vented, and 28%when the attics were not vented. The ceiling cooling load reductions translated to an approximately 2-4%space cooling reduction. Parker (1998) carried out a similar study on an attic space. He developed an attic model using the DOE-2 simulation program in order to calculate the possible savings in cooling electricity consumption according to the amount of insulation and ventilation of attics in Florida. The author found an average savings of 19%.

Ashely et al. (1994) investigated the effects of radiant barrier system in Southern Texas during summer. This study was conducted in a single family house with an area of 600 ft^2 to evaluate the performance of radiant barrier. In this study they measured the ceiling heat flux, attic air temperatures, indoor air temperatures, ambient air temperatures, roof temperatures, and solar radiation.

Winiarski and O'Neal (1996) developed a steady state model to predict attic heat transfer in the house with radiant barrier insulation. The input of the model was hourly weather data and the output was hourly ceiling heat flux in the house. The model predicted that in a typical summer, attic radiant barrier system reduced ceiling heat flux between 35 to 43% depending on the insulation level.

Al-Asmar et al. (1996) studied the experimental performance of attic radiant barriers in a simulated attic that was built inside a 24 ft. by 24 ft. environmental chamber. They carried out a total of 72 steady-state experiments. Roof temperature changed from 120°F to 160°F, ventilation varied from 0 to 2 cfm/ft^2. They used two levels of insulation including R-11 and R-19. The radiant barrier was placed on the attic insulation. Results showed reduction in attic heat gains ranging from 17% to 26% with no ventilation and from 24% to 42% in the ventilated attic. The radiant barrier reduced attic temperature from 10°F to 15°F under typical conditions.

Medina et al (1992) studied the effect of attic ventilation on the performance of radiant barrier system. Ceiling heat flux and space cooling load were measured to quantify how attic ventilation would affect the performance of a radiant barrier. Two identical houses with an area of 13.38 m^2 were selected for this study and radiant barrier systems were tested for two months. Results showed that radiant barrier effectiveness was not sensitive to airflow variations past

1.3(l/sec)/m^2 of attic floor. The effect of dust accumulation on the performance of radiant barrier insulation was insignificant.

Medina (2000) investigated the performance of radiant barriers in combination with different attic insulation levels. In order to achieve this objective, experiments and computer simulation were carried out to assess the performance of radiant barrier. The experimental part was conducted in central Texas in two houses with identical floor plans and thermal profile. Results showed an indirect relationship between the ceiling heat flux and attic insulation resistance. According to his result, on average, the experimental ceiling cooling load reductions produced by the radiant barrier in combination with attic insulation resistance levels of 1.94, 3.35, and 5.28 m^2.K/W(R=11, 19, and 30) were 42%, 34%, and 25%, respectively.

Moujaes and Alsaiegh (2000) developed a two-dimensional, steady-state finite-element model to simulate the thermal effect of attic radiant barrier system inside a ventilated residential attic. The ambient temperature and solar radiation on the outer surfaces of the attic were considered as main functions for the model. Results showed that attic radiant barrier system reduced heat transfer through the ceiling by 25-30%. They recommended a three dimensional transient model in order to show more details about the performance of attic radiant barrier system.

Although Radiant Barrier System (RBS) have been well studied, both from a theoretical and an experimental point of view, the evaluation of the influence of climate variables on their performance was still missing; recently, a study conducted in the U.S. has led to interesting conclusions in this subject (Medina and Young, 2006); based on numerical simulations of a standard attic using a transient heat and mass transfer model, several values of performance indicator were obtained for each of the nine defined climates for the U.S.. In terms of percentage

reduction of ceiling heat flux, it was shown that climate parameters having first order effects were local ambient air temperature, humidity, cloud cover index and altitude, while the amount of local solar radiation had no significant influence. Moreover, the sample summer integrated percent reduction ranged from 2.3% for Mediterranean climate to 38.5% for the humid subtropical one. The used expression for the calculation was the following:

$$Percent\ Reduction = \frac{\int_{Evaluation\ Period} q''_{WRB}\ .dt - \int_{Evaluation\ Period} q''_{RB}\ .dt}{\int_{Evaluation\ Period} q''_{WRB}\ .dt} \tag{2.1}$$

Where q''_{RB} is the ceiling heat flux in the presence of radiant barrier in the attic and q''_{WRB} the ceiling heat flux when there is no radiant barrier in the attic.

2.8 Theoretical Basis for the Attic Heat Transfer Model

2.8.1 Introduction

Buildings are exposed to continually changing boundary conditions such as outdoor temperature solar radiation, and wind conditions. Since the building envelope has the capability to store some amount of heat (i.e. thermal mass); these unsteady boundary conditions are controlled by the envelope with a time lag. For example a drop in outdoor temperature may not be felt at the inside surface of a wall for several hours. Consequently, steady state calculations will not provide an accurate evaluation of building energy requirement. Therefore, to calculate the temperature distribution in the roof, attic and ceiling, a transient heat transfer model is needed.

2.8.2 Conduction Heat Transfer

2.8.2.1 Thermal Conductivity

Conduction heat transfer in buildings occurs thorough building envelops such as walls, roofs, floors, doors and windows. Thermal conductivity is the property of a material which determines the heat flow in unit time by conduction through a unit thickness of a unit area of the

material across a unit temperature gradient. The thermal conductivity differs with the density, porosity, moisture content and absolute temperature. There is a greater thermal conductivity at the higher moisture content. The thermal conductivity is greater at high temperature than low temperature.

In calculations, it is often common to use the thermal resistivity which is the reciprocal of the thermal conductivity. The thermal resistance is a measure of the resistance to heat flow of a material or a combination of materials. The thermal resistance may be considered as the time required for the transmission of one unit of quantity of heat through one unit area of material when the temperature difference between surfaces perpendicular to the direction of heat flow is one degree of temperature. If the thickness of the material is increased there is a corresponding proportional increase in its thermal resistance. If some materials are located together in layers the total thermal resistance of the wall may be found by adding the resistances for each component. All of the boundary surfaces in the roof are subject to the conduction heat transfer, which is a transient phenomenon since the temperatures on all of the surfaces change with time.

2.8.3 Radiation Heat Transfer

Radiant heat transfer is a heat transfer mechanism in which heat is transferred by electromagnetic waves. Heat transfers by radiation in buildings through transparent building envelops and from internal heat sources to the building envelope. The main source of radiant heat in a building is windows and glass doors which transmit solar radiation directly to the building. The external surface of any opaque material has three properties that determine its performance with respect to the radiant heat exchange, namely its absorptivity, reflectivity and emissivity. The color of a surface is the most important factor that determines these properties for solar radiation. The absorptivity reduces and the reflectivity increases with lightness of color;

being completely absorbed by a perfectly back surface and completely reflected by a perfect reflector. Most surfaces, however, absorb only part of the incident radiation, reflecting the rest. If the absorptivity is stated by ‘a’ and the reflectivity by ‘r’, then, r = 1-a.

The emissivity (ε) is defined as the materials property that emits radiant energy. For any particular wavelength, absorptivity and emissivity are numerically equal. Every surface emits radiation with a spectral distribution and intensity which depend on its temperature.

2.8.3.1 Solar Radiation on Attic exterior Surfaces

Solar radiation is the one of the sources that increases the temperature of the exterior roof surface in a range of 60-70 °C in summer. Solar heat is ultimately conducted through the roof layers, and then it reaches the attic floor by radiation. Thus, it can be considered as the most important factor that raises the space cooling load of the residence. To prevent moving the most of this energy from the outer surfaces to the attic floor, radiant barrier systems are used. Therefore, solar energy is one of the energy sources responsible for increasing space cooling in residential construction. Since, most of the weather stations measure the radiation on a horizontal surface; the exact amount of solar radiation on each surface of the attic (South, North, East, and West) should be calculated. In order to solve this problem, the horizontal solar radiation data measured by weather station was used to estimate the solar load on each surface. Both the direct component as well as the diffuse component was separated so that the direct component of global radiation could be multiplied to the respective angle describing the orientation of the surface and its relationship to the sun. The diffuse component remains unchanged regardless of surface orientation (Duffie and Backman 1974, Medina et al. 1992).

The geometric relationship between any plane in any orientation and the sun is described in terms of the angles. Figure 6 shows theses angles and their relationships. The surface tilt angle

is the angle between the surface normal and the vertical axis. The surface azimuth angle is the angle between the south and the horizontal projection of the surface normal. The same sign convention is used for the surface azimuth angle as is used for the solar azimuth angle, i.e. Ψ is negative for a surface that faces east of south and positive for a surface that faces west of south. The azimuth angle for a horizontal surface is undefined.

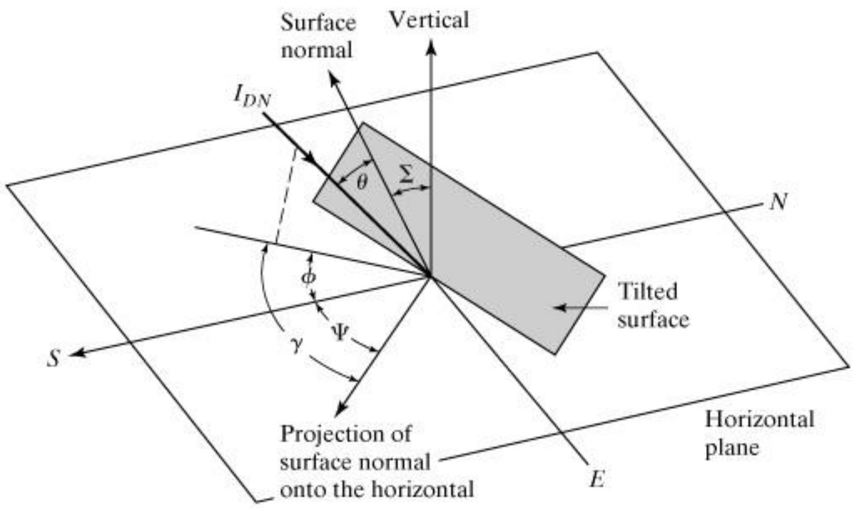


Figure 6: Surface azimuth, surface tilt, and surface-solar azimuth angles (Adopted from ASHREA 2009)

In this figure θ is the angle of incidence of the beam radiation which is measured between the beam and the normal to the plane. The angle γ, the surface azimuth angle, is the deviation of the normal to the surface from the local meridian (the zero point being due to south). β is the angle between the horizontal and plane.

The correlations were expressed as relationships of the ratio of the hourly diffuse radiation to the hourly global radiation and of the ratio of the hourly global radiation to the hourly extraterrestrial radiation as follows (Duffie and Backman 1974, Medina et al. 1992):

$$\frac{I_d}{I} = a_1 + a_2 K_T + a_3 K_T^2 + a_4 K_T^3 + a_5 K_T^4 \tag{2.2}$$

Where

$\frac{I_d}{I}$ = Ratio of hourly diffuse radiation to hourly total global radiation on a horizontal surface;

$K_T = \frac{I_{HOR}}{I_{ET}}$ = The ratio of hourly total global radiation (horizontal) to hourly extraterrestrial radiation (horizontal);

a_1, a_2, a_3, a_4, a_5 = constant;

In Equation 2.2, K_T is an indicator of relative clearness of the atmosphere.

To determine which fraction of the solar irradiation is beam and which fraction is diffuse, the clearness index (k_T) was used as follows (Medina et al. 1992):

$$k_T = \frac{I_{glo,H}}{I_{o,H}} \tag{2.3}$$

Where the $I_{glo,H}$ is the global solar irradiation on a horizontal surface, as provided by any weather station, and the $I_{o,H}$ is the extraterrestrial solar irradiation incident on a horizontal surface.

The ratio of I_d *to* $I_{glo,\,H}$ is estimated as follows:

$$\frac{I_d}{I_{glo,H}} = \begin{cases} 1.0 - 0.09k_T \quad for\ 0 \leq k_T \leq 0.22 \\ 0.9511 - 0.1604k_T + 4.388 \quad k_T^2 - 16.638k_T^3 + 12.336k_T^4 \quad for\ 0.22 \leq k_T \leq 0.80 \\ 0.165 \quad for\ 0.8 \leq k_T \end{cases} \tag{2.4}$$

$$I_{glo,H} = I_b + I_d \tag{2.5}$$

The position of the sun in the sky is a function of many factors, including location on the earth's surface, time of day, and day of year. In order to determine solar position at a specified time, time must be converted from the one that a clock shows to the time a solar time sundial shows, known as apparent solar time or solar time. Whereas a civil day is precisely 24 hours, a solar day is slightly different due to irregularities of the earth's rotation, obliquity of the earth's

orbit and other factors. The difference between Local Solar Time (LST) and Local Civil Time (LCT) is called the Equation of Time, E.

The factors described above can be included into a single equation, which relates solar time and clock time:

$$I_{glo,\ H} = I_b + I_d \quad (2.6)$$

Where:

LST = Local Solar Time [hr];

CT = Clock Time [hr];

L_{std} = Standard Meridian for the local time zone [degrees west];

L_{loc} = Longitude of actual location [degrees west];

E = Equation of Time [hr];

DT = Daylight Savings Time correction (DT = 0 if not on Daylight Savings Time, otherwise DT is equal to the number of hours that the time is advanced for Daylight Savings Time, usually 1hr);

$$E = 0.165 Sin 2B - 0.126 Cos B - 0.025 Sin B \quad (2.7)$$

Where

$$B = \frac{360(n - 81)}{364} \quad (2.8)$$

Where n is the day of the year. The value of n for any day of the month "D" can be easily found from Table 3.

Once Local Solar Time is established, the solar hour angle, h can be calculated:

$$h = 15(LST - 12) \quad (2.9)$$

The sun's declination angle, d, is the angular distance of the sun's rays north (or south) to the equator (Duffie and Backman 1974):

$$d = 23.45 Sin\left[\frac{360}{365}(284+n)\right] \quad (2.10)$$

Table 3: Variation in "n" throughout the year

Month	Day of the month	Month	Day of the month
January	D	July	181 + D
February	31 + D	August	212 + D
March	59 + D	September	243 + D
April	90 + D	October	273 + D
May	120 + D	November	304 + D
June	151 + D	September	334 + D

Therefore, at any point in time, the extraterrestrial solar radiation on a horizontal plane was calculated using:

$$I_{ET} = I_{SC}\left[1 + 0.033\cos\left(\frac{360n}{365}\right)\right]\cos(\theta_z) \quad (2.11)$$

Where

I_{SC} = Solar constant (1353 W/m^2, 429 Btu/hr-ft^2); and

$$Cos(\theta_z) = \cos(\delta)\cos(\phi)\cos(\omega) + \sin(\delta)\sin(\phi) \quad (2.12)$$

Where

Φ = Latitude angle;

δ = Declination angle;

ω = Hour angle;

Once the extraterrestrial radiation on horizontal surface was calculated and K_T had been obtained, Equation 2.13 dictated how much of the total fraction was diffuse and how much of it was direct radiation. The total radiation on a tilted surface was then calculated by (Duffie and Backman 1974, Medina et al. 1992):

$$I_{Tilted} = I_d + I_b R_b \quad (2.13)$$

$$R_b = \frac{\cos\theta}{\cos\theta_H} \quad (2.14)$$

$$Cos\theta = \sin(\delta)\sin(\phi)\cos(\beta) - \sin(\delta)\cos(\phi)\sin(\beta)\sin(\gamma)$$
$$+ \cos(\delta)\cos(\phi)\cos(\beta)\cos(h) + \cos(\delta)\sin(\phi)\sin(\beta)\cos(\gamma)\cos(h)$$
$$+ \cos(\delta)\sin(\beta)\sin(\lambda)\sin(h) \quad (2.15)$$

Where

I_d = diffuse solar radiation [W/m^2, Btu/ hr-ft^2];

I_b = beam (direct) solar radiation [W/m^2, Btu/ hr-ft^2];

γ = surface azimuth angle;

β = slope;

2.8.3.2 Radiation in the Roof

The amount of solar radiation as obtained from Eq. 2.13 was used in the simulation as the heat load on the outside surfaces of the roof. In the attic space, every surface exchanges heat with every other surfaces through radiation. The radiation heat transfer inside the attic depends on view factors that are the measure of relative radiative interaction between the surfaces of the cavity space. The cavity is considered as an ensemble of element faces corresponding to the finite element discretization. These element faces can be treated as elementary areas and, accordingly, simple elemental view factors are calculated using an "area-lump" method as given in the following equation (Sparrow and Chess 1978):

$$A_i F_{ij} = \frac{A_i\, Cos\alpha_i\, A_j\, Cos\alpha_j}{\pi\, R_{ij}^2} \quad (2.16)$$

where,

A_i, A_j = elementary areas exchanging heat;

α_i,= Angle between R_{ij} and surface A_i;

α_j = Angle between R_{ij} and surface A_j;

R_{ij}=Distance between two areas A_i, A_j;

2.8.4 Convection Heat Transfer

Convection heat transfers that occur in buildings are of two types: natural and forced. In buildings natural convection is caused by the movement of air due to pressure difference. This pressure difference is caused by wind (speed and direction) and temperature difference across the building which drives the air to flow from higher to lower pressure in either side of the building. Forced convection is caused due to the movement of air with the help of mechanical systems like ventilation.

2.8.4.1 Convection Heat Transfer in Attic

Energy movements in residential attics are influenced to a degree by the amount of heat which is transported by means of convection. At every surface of the roof, attic, and ceiling, convection heat transfer can be significant. The forced and natural convection coefficient of exterior and interior surfaces can be calculated based on the temperature of the surface and the air, direction of heat flow, surface area, and the surface orientation. Correlations for both laminar and turbulent flows are used, with the choice depending upon the magnitude of the Rayleigh number for natural convection and Reynolds number for forced convection. To calculate the Nusselt number for the external flow over a surface, the following relationships was used (Holman 2002):

$$Nu_F = 0.664\ Pr^{1/3}\ Re^{1/2} \qquad \text{for } Re < 5\times10^5 \qquad (2.17)$$

$$Nu_F = Pr^{1/3}\ (0.37\ Re^{4/5} - 850) Pr^{1/3} \qquad \text{for } Re > 5\times10^5 \qquad (2.18)$$

where,

Nu_F= Nusselt number for forced convection;

Pr= Prandtl number for air;

Re= Reynolds number;

For calculating the natural convection for each surface, depending on the heat flow direction the following equations apply (Cooper 1969):

Horizontal surface, upward heat flow:

$Nu_n = 0.54\ Ra\ ¼$ for $Ra < 8 \times 106$ (2.19)

$Nu_n = 0.15\ Ra\ 1/3$ for $Ra > 8 \times 106$ (2.20)

where,
Nu_n= Nusselt number for natural convection;

Ra= Raynolds number;

Horizontal surface, downward heat flow:

$Nu_n = 0.58\ Ra\ 0.2$ (2.21)

Tilted surface, downward heat flow:

$Nu_n = 0.56\ (Ra \sin(\beta))\ 1/4$ (2.22)

Tilted surface, upward heat flow:

$Nu_n = 0.56\ (Ra \sin(\beta))\ 1/4$ for $Ra/Pr < Gr$ (2.23)

$Nu_n = 0.14\ (Ra\ 1/3 – (Gr\ Pr)1/3\ ) +0.56\ (Gr\ Pr \sin(\beta))\ ¼$ for $Ra/Pr > Gr$ (2.24)

where,

Gr= Grashof number;

B= Tilt angle ;

$Gr= 1\times 106$ for $\beta <15°$ (2.25)

$Gr= 10\ (\beta / (1.1870 + 0.087 * \beta))$ for $15° < \beta < 75°$ (2.26)

$Gr= 5 \times 109$ for $\beta >75°$ (2.27)

The Nusselt number for mixed convection regime is calculated as follows (Chen et al., 1986):

$$Nu_x^3 = Nu_F^3 \pm Nu_N^3 \tag{2.27}$$

where,

Nux= Nusselt number for mixed convection

Finally, the natural, forced or mixed convection coefficient can be calculated using the Nusselt number for the corresponding convection regime based on the following formula:

$$h = \frac{Nu\, k}{L} \tag{2.28}$$

h = convection heat transfer coefficient;

k= thermal conductivity;

L= length of plate;

Nu= Nusselt number;

2.8.5 Ventilation

Attic ventilation reduces excess heat buildup during the summer time and it reduces moisture accumulation during winter. There are two different types of ventilation including natural and forced ventilation. In this study natural ventilation was used and analyzed (soffit–ridge). In residential attics, ventilation air flowing throw the attic is the product of two forces: thermal which is a temperature-dependent effect and pressure which is a wind speed-dependent effect. The pressure force is the dominant one because the volume of ventilation air changes mainly as a function of wind speed.

Wind influence on a structure can be characterized by wind speed, wind direction, local obstructions due to other buildings and/or nearby trees. Most of the weather stations measure the

wind speed and its direction. The air flow rate due to the wind is given by ASHREA as (ASHREA 1979, ASHTREA 2009, Mitalas and Stephenson 1967):

$$Q_p = 88 C_v A V \tag{2.29}$$

Where:

Q_p = Air flow rate due to pressure (ft^3/min);

C_v = Effectiveness opening;

A = Free area of inlet opening (ft^2);

V = Wind speed (mi/hr);

Burch and Treado (1978) had calculated the constant effectiveness opening for different vent combinations. The effectiveness opening for soffit/ridge combination is 0.38, for soffit/gable vent combination is 0.54 and for soffit/soffit vent combination is $\left(0.089 + 0.132 Sin^{2.5}(D)\right)$ where D is the wind speed direction.

ASHRAE had proposed the following formulas to calculate the attic air flow rate due to thermal effect:

$$Q_T = 60.K.A.\left[2.g.\Delta z_{NPL} \frac{(T_{air} - T_0)}{T_{air}}\right]^{0.5} \quad \text{When } T_{air} \geq T_0 \tag{2.30}$$

$$Q_T = 60.K.A.\left[2.g.\Delta z_{NPL} \frac{(T_0 - T_{air})}{T_0}\right]^{0.5} \quad \text{When } T_0 \geq T_{air} \tag{2.31}$$

Where:

Q_T = Air flow rate due to thermal effects (ft3/min);

A = free area of inlet opening (ft^2);

K = discharge coefficient for opening (0.65);

Δz_{NPL} =Height from lower opening;

ASREA offers the following equation to calculate the Δz_{NPL} :

$$\Delta z_{NPL} = \frac{H}{(1 + (\frac{A_i}{A_0})^2 \frac{T_{air}}{T_0}} \quad \text{When } T_{air} \geq T_0 \tag{2.32}$$

$$\Delta z_{NPL} = \frac{H}{(1+(\frac{A_i}{A_0})^2 \frac{T_0}{T_{air}}} \qquad \text{When } T_0 \geq T_{air} \qquad (2.33)$$

Where:

H: difference in elevation between inlet and outlet vents (ft);

A_i = net free area of inlet vents (ft^2);

A_0 = net free area of outlet vents (ft^2);

2.9 Finite Element Model

The finite element method (FEM) is a numerical technique for finding approximate solutions of partial differential equations (PDE) as well as integral equations (Zienkiewicz and Taylor, 2005). Applications range from deformation and stress analysis to field analysis of heat flux, fluid flow, magnetic flux, seepage and other flow problem. In this method of analysis, a complex region defining a continuum is discretized into simple geometric shapes called finite elements (Zienkiewicz and Taylor 2005). In more simplistic terms, the finite element method is analogous to a mosaic, in which very small segments are assembled into a discrete representation of a picture. Each element, like a tessera in a mosaic may be a different shape; for instance, straight lines are often utilized in one-dimensional problems, triangles or quadrilaterals in two dimensional problems, and tetrahedra in three dimensional problems. These elements are interconnected at a certain number of discrete points along their boundaries, known as nodes. In addition to these boundary nodes, an element may have additional nodes either along its edge or interior; these nodes contain properties (such as material strength properties) that are specific only to that particular element. In the finite element method, the value of different unknown variable(s) (displacement, stress, temperature, etc.) are computed at every node location; as such, an increase in nodes results in a more refined solution which will more closely approximate the actual behavior. However, it is also important to assess the unknown variable at intermittent

points; to do this, one must interpolate between the values at adjacent nodes by defining what are known as interpolation or shape functions. Interpolation functions assume certain local dependence of the unknown (dependent variable) on the domain (independent variable). This relationship may be represented by a linear, quadratic, or higher order polynomial function. The degree of the polynomial depends on a number of factors such as the number of nodes assigned to the element, the degrees of freedom associated with each node, and continuity requirements imposed at the nodes (see Figure 7). While higher order functions generally let for a more precise representation of the element behavior, they are also noticeably more expensive with respect to computation time (Bau 2006, Bau 2009).

After nodes have been recognized and the interpolation functions defined, they are then substituted into the original differential equation, or a trial solution in the form of an equivalent integral representation. The equation is then integrated over each individual element and later assembled into a matrix; this matrix, referred to as the local stiffness matrix, is fundamentally a summary of the properties related with that element.

Because the values of adjacent elements are shared at common nodes, these local stiffness matrices can then be combined into a global matrix that defines the behavior of the entire system. Once the global stiffness matrix is assembled, it can be modified to account for boundary conditions by imposing known loads and displacement conditions at the nodes. When completed, the set of simultaneous algebraic equations can be solved by a computer and the results manipulated in order to compute additional parameters of interest (Brauer 2009). However there are a number of methods for defining the properties and unknown values related with the elements. The solution of a continuum problem by the finite element always follows the systematic process described above. To summarize, the following steps are performed:

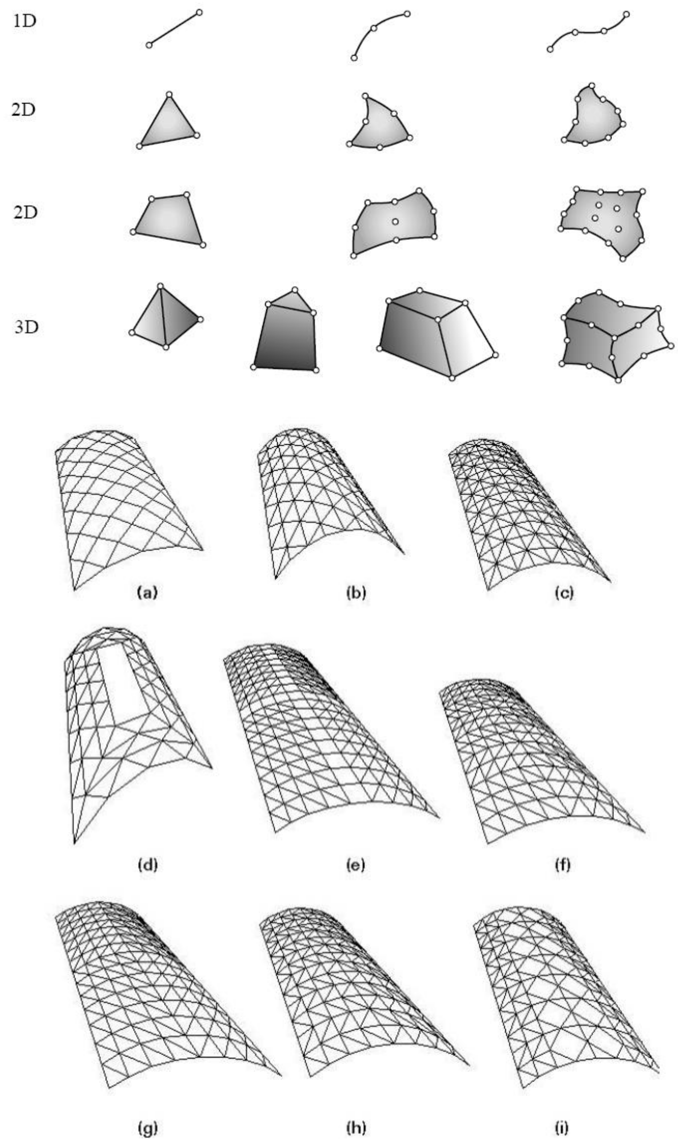


Figure 7: Above: One, two and three dimensional element types (adapted from Bau, 2006) Below: Different meshing options for cylindrical vaults (adapted from University of Ljubljana, 2000)

1. Discretize the continuum into individual elements;
2. Select appropriate shape or interpolation functions;
3. Determine the element properties and assemble the local stiffness matrices;
4. Assemble the global stiffness matrix;
5. Impose applicable boundary conditions;

6. Solve the set of simultaneous algebraic equations;
7. Extrapolate data from the results.

2.10 Existing Software Design Tools

The consumption of energy in buildings involves many complex physical processes taking place at the same time. Several models with different levels of complexity have been developed in order to simplify these processes and the most advanced models are needed to get very accurate results. There are some simulation and design tools available to help designers and architecture in the sustainable design process. The scope of these programs is very wide. Some of them applying computational fluid dynamic and calculates very detailed hourly energy simulation while on the other hand, some of them are very simplified. Cordero (2001) provided a list of these tools in her study. Some of tools that simulate energy savings and energy- efficient design are discussed below:

Department of Energy released some energy simulation tools such as Energy Plus (2000), DOE 2 (1982), and Power DOE (1990). Also, National Renewable Energy Laboratory developed Energy 10 simulation tool. Many of these programs that simulate the whole energy buildings need detailed information from user and provide enough accurate results. Although these programs are very suitable for HVAC people designer, but their application is restricted during initial design because they require too many information about the building in order to run the simulation. The main problem is that user is often not able to understand the effect of changing a specific parameter without doing a complicated setup of building variables. Energy Plus and DOE 2 do not have a user interface and they work based on text file input-output. In order to learn these types of programs, people should spend too much time and they can be used by people who are specialist in building energy simulation. Power DOE and Energy 10 have user

interfaces and are much less complicated than Energy Plus and DOE 2. However, they still need detailed information and there is substantial learning curve. Although programs that carry out energy simulation are beneficial in many design applications, many of them do not provide much help when rough approximation of energy impact of certain parameter are needed during the theoretical design of a building.

On the other hand, the green building advisor is a program that has very limited user input and only gives general recommendations. These recommendations contain a variety of resources such as case studies and technical articles to help designers in the design step. Cordero gives the following list of output related to energy consumption: building envelope, heating, cooling, ventilation, lighting, appliances, equipment, water heating, and energy sources. This information is useful in the design phase of the project. However, it cannot give an actual assessment of energy savings and opportunities for a specific building in a given climate.

The building design advisor 3.0 is considered as a simplified design tool. This tool is connected to DOE-2, a recognized set of simulation tools for energy performance. It will also connect to other tools for airflow, daylighting, and CAD modeling. There is a graphical format to show the results and it is easy to understand but the input is still complex. This program shows promise of being very beneficial when all the bugs are solved. It applies several tools that are already available and performs a simplified building analysis.

Although there are many software packages that carry out energy analysis for buildings, many of them need inclusive input from the user and try to carry out very precise analysis. But many of these parameters are not known for designers and architectures at the design phase which result in little practical application. Although heat transfer is a complex mechanism, simple models can be developed with relatively little information to provide first order

approximations of building performance. The development of estimating tools that need little information from user and producing meaningful output based on the different design parameters will be useful for building designers and architectures. In order to be useful, these tools should have simple output in order to be understood and interpreted easily. A software package that need little design information and produce easy output will advantage designers by notifying them of energy related consequences of the decisions that they have to make early in the design process.

CHAPTER 3: EVALUATION OF THE THERMAL PERFORMANCE OF A ROOF- MOUNTED RADIANT BARRIER IN RESIDENTIAL BUILDINGS: EXPERIMENTAL STUDY AND FIELD MEASUREMENTS

3.1 Introduction

3.1.1 Energy Sector in United States

According to the U.S. Department of Energy's (DOE) Energy Information Administration (EIA), energy consumed by the typical U.S. home has more than doubled since 1980 (Department of Energy, 2010). Moreover, analysts at the U.S. Department of Energy (DOE) estimate that the electricity consumption will increase through 2030 at a rate of 0.8% per year. This trend means that electric power consumption and the associated infrastructure to create and transport electricity will be about 43% greater in 2030 than it is today (Department of Energy, 2010).

Since the residential sector is the fastest growing consumer of electric energy in the United States, new concerns in particular depletion of non-renewable fuels, have promoted an interest in improving energy efficiency in residential buildings. Data collected by the Energy Information Administration indicates that buildings use 37% of the energy in the United States, and residential buildings consume 53% of that energy. A significant increase in electricity demand is expected over the next few years with a growth rate over 10% (Department of Energy, 2010).

3.1.2 Energy Consumption in Louisiana

Electricity consumption in Louisiana is increasing at 1.5% per year, which is two-thirds of the national average. However, the population is increasing at only 0.3% per year, which is one-third of the national average. As a result, per capita electricity consumption is rising quickly.

According to the Department of Energy, Louisiana had the third rank in the U.S. in total energy consumption per capita after Wyoming and Alaska in 2009.

In Louisiana, residential sector consumes the highest amount of energy in comparison with other sectors, which is 37% (28,654 million kW). Per capita consumption of electricity in Louisiana homes was 6,373 Kwh in 2005, which is ranked 6th in the nation. One of the major electricity consumers in the Louisiana's home is air conditioner. Since Louisiana is characterized by a hot and humid climate, this requires extensive use of air conditioner in the summer. According to the National Climate Data Center, Louisiana has 2852 (degree F-Day) cooling days, which is ranked 5th in the nation.

Therefore, there is a critical need for energy-efficient buildings that minimize energy consumption and optimize the performance of individual systems and components of the building. To achieve energy efficiency in residential buildings, several methods are available; notable among them is the use of radiant barrier insulation materials. However, there is a need to quantify its benefit and its application in the attic of residential buildings for the climatic and operating conditions encountered in Louisiana.

To this end, the objective of this study is to quantify the reduction in heating and cooling loads due to the use of radiant barrier and to identify important environmental parameters such as ambient air temperature, solar radiation, relative humidity, and wind speed that may influence its performance. In order to achieve this objective, an experimental study was conducted in Zackary, Louisiana. Two identical houses were selected and instrumented with several thermocouples to capture the hourly temperature in each layer of the roof and ceiling. These houses were exactly identical in terms of geometry, material properties, and climate conditions. The only difference between them was the installation of a radiant barrier in one of the houses while the second one

had a conventional insulation system. Data were collected for eight months to determine the amount of energy savings gained by installing the radiant barrier in the attic. The ceiling heating and cooling loads and the percentage reduction due to the use of radiant barrier were calculated in each month.

3.2 Background

Recently, many studies have been performed to calculate the required heating and cooling loads and energy consumption in buildings (Santamouris et al. 2001, Hassid et al. 2000, Synnefa et al. 2006, Akbari et al. 1997, Sullivan et al. 1985, Synnefa et al. 2007, Rock 2009, Budaiwi et al. 2002). In addition, research has been conducted to evaluate the energy-saving potentials of radiant barrier insulation materials in residential constructions (Soubdhan et al. 2005, Petrie et al. 2000, Al-Asmar et al. 1996, Fairey 1985, Hall 1985, Baldinelli 2010). Medina et al. (1998a, 1998b) tested the performance of radiant barriers under various weather conditions in central Texas using a side-by-side comparison of two test houses with identical floor plans and thermal characteristics. The ceiling heat flux was reduced as a result of retrofitting with radiant barriers by approximately 34% when the attics were vented and 28% when the attics were not vented. Winiarski and O'Neal (1996) developed a steady state model to predict attic heat transfer in the house with radiant barrier insulation. The input of the model was hourly weather data and the output was hourly ceiling heat flux in the house. The model predicted that in a typical summer, attic radiant barrier system would reduce ceiling heat flux between 35 to 43% depending on the insulation level.

Moujaes and Alsaiegh (1995) developed a two-dimensional steady state finite element model to simulate attic heat transfer in houses. The model was validated with experimental data and showed acceptable quantitative agreement. Results indicated 25% ceiling cooling load

reduction in the attic with R=3.32 m^2.K/W (R-19) and the horizontal radiant barrier system. Although radiant barrier system have been well studied, both from a theoretical and an experimental point of view, the evaluation of the effects of climate parameters on their performance was still missing. Recently, a study has evaluated the performance of radiant barrier for nine climatic conditions in the United States based on numerical analysis (Medina and Young 2006). According to the ceiling heating and cooling load percentage reductions, it was determined that climatic parameters that have significant effects were local ambient air temperature, humidity, and altitude. The amount of local solar radiation had no significant effect. Furthermore, the summer integrated percent reduction varied from 2.3% for Mediterranean climate to 38.5% for the humid subtropical one. They used the following expression for the percentage reduction:

$$Percentage\ Reduction = \frac{\int_{Evaluation\ Period} q''_{WRB}\ .dt - \int_{Evaluation\ Period} q''_{RB}\ .dt}{\int_{Evaluation\ Period} q''_{WRB}\ .dt} \tag{3.1}$$

where q''_{RB} is the ceiling heat flux in the presence of radiant barrier in the attic and q''_{WRB} the ceiling heat flux when there is no radiant barrier in the attic.

Ober et al. (1988) carried out a detailed test program in central Florida using two identical houses with the area of 85m^2. The ceiling was covered with R= 3.32 m2/K.W (R-19) fiberglass insulation and the slope of the attic was 6:12(26.6°). The radiant barrier insulation with an emissivity of 0.03 was installed on the rafters. The result showed that radiant barrier insulation system in combination with attic ventilation reduced ceiling heat flux by 20%.

3.3 Experimental Study

The experimental study consisted of two single-family houses with an area of 148 m^2 located in Zachary, Louisiana, latitude 30º N and longitude 90º S. Both houses had the same floor plan, elevations, and cardinal orientation. The tilted roof was made from asphalt shingle,

plywood, and felt, with angle of 33.6°. The attic of one house was covered with radiant barrier that was attached to plywood but the other house had only conventional insulation (control house). The ceiling of both houses was covered with R-30 polyurethane insulation. The attics were originally built with soffit-ridge ventilation, which provided natural ventilation.

Both houses were fully-instrumented, integrating sensors for the measurement of surface temperature of the asphalt shingle, plywood, radiant barrier, attic air, insulation, and gypsum. All the temperatures were measured by T-type thermocouples attached to the surface. These thermocouples were calibrated at the site and their absolute error was estimated to be ± 0.5°C. A data logger, ACR Samar Reader, was used to connect the thermocouples and record the temperatures with 4 minutes intervals and integrated hourly (see Figure 8). A weather station, Davis 6152 Wireless Vantage Pro shown in Figure 8, was installed to measure and store meteorological data including ambient air temperature, relative humidity, wind speed, wind direction, relative humidity, precipitation (rainfall and rain rate), and horizontal solar radiation with 4 minutes intervals and integrated hourly.

The experimental study was conducted for 8 months from December to July 2010, to cover both summer and winter seasons. Some typical meteorological data are presented in Table 4 Zackary has a hot and humid climate, which is a warm and rainy climate with no distinct dry season. The relative humidity of this area is about the average for the southeastern region, which is above the average for the country as a whole.

3.4 Results and Discussion

3.4.1 Temperature Data

As previously mentioned, temperature data were collected at various locations in both houses. Roof shingle temperatures, attic air temperatures, and insulation temperature are shown

in Figures 9-12. Although the performance of the attic radiant barriers was evaluated continuously, for clarity, only 5 days in summer and 5 days in winter are shown

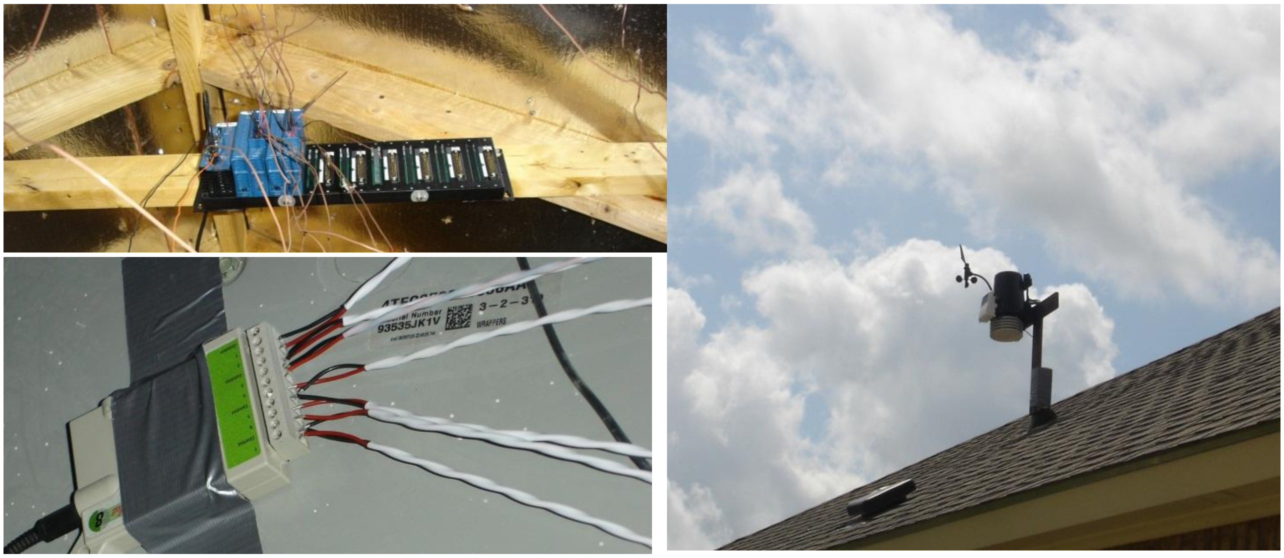


Figure 8: Thermocouples and weather station

Table 4: Typical meteorological data for Zachary, Louisiana

Climate Parameters	Month							
	Jan	Feb	Mar	Apr	May	June	July	Dec
Ambient Air Temperature (°C)	10.3	11.0	17.0	19.8	24.3	26.2	27.1	9.7
Solar Radiation (W/m^2)	101.8	138.5	175.7	224.7	234.1	248.4	252.1	106.8
Wind Speed (m/s)	3.6	3.8	3.8	3.0	2.7	3.1	2.4	2.7
Humidity (%)	75.4	73.6	75.4	73.6	73.9	70.5	79.4	75.9

The data are plotted for the time period between June 8^{th} and 12^{th} 2010 (summer season) and between February 2^{nd} to 6^{th} 2010 (winter season). Based on the temperature data, June 8^{th} was the hottest day during the monitoring period and February 3^{rd} was the coldest day. As shown in Figures 9 and 10, at peak hour, the temperature of asphalt shingles in the control house was approximately 65°C and in the house with radiant barrier was approximately 67°C. For the peak

hour on June 8th, the temperature of asphalt shingles in the house with radiant barrier was 2°C higher than the temperature of asphalt shingles in the house without radiant barrier. There is a notable difference between the temperature of attic air and insulation in the house with radiant barrier and the control house. Attic air temperature in the control house was 6°C higher than in the house with radiant barrier. The lower temperature of attic air in the house with radiant barrier and higher temperature of asphalt shingle show the important role of radiant barrier as a reflector of solar radiation.

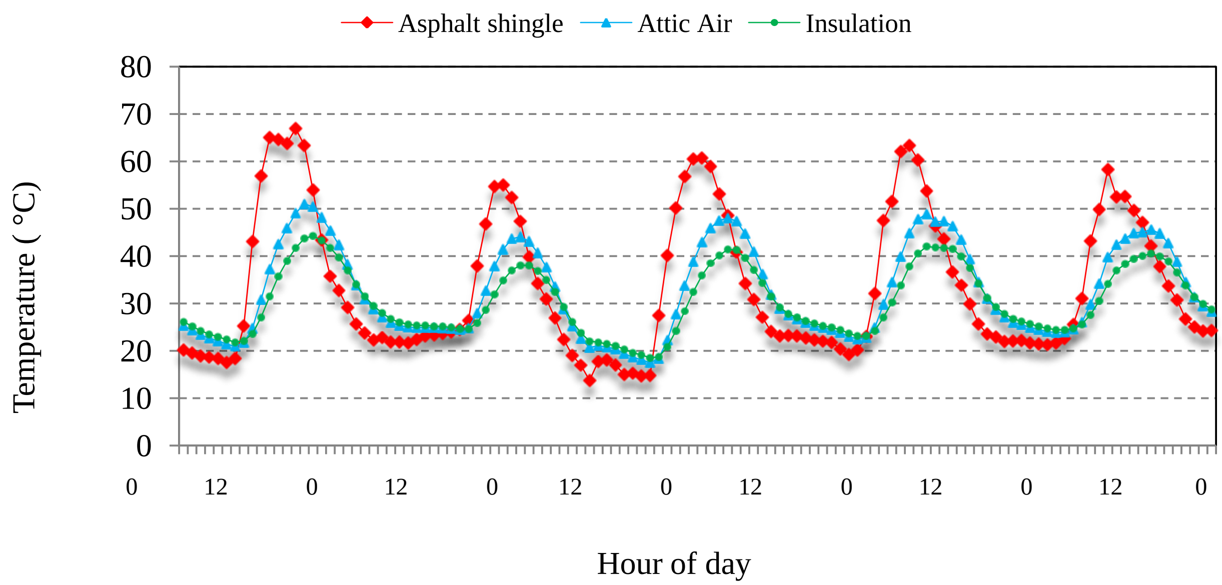


Figure 9: Various Temperature in the house with radiant barrier in summer

Winter in Louisiana is short and mild. As shown in Figures 11 and 12, the difference between the attic air and insulation temperature in the house with radiant barrier and the control house is relatively small. On cold winter days, the temperature of asphalt shingle increases due to solar radiation, which result in positive heat flux into the conditioned space. However, the radiant barrier blocks some of this heat and does not allow it to enter the house.

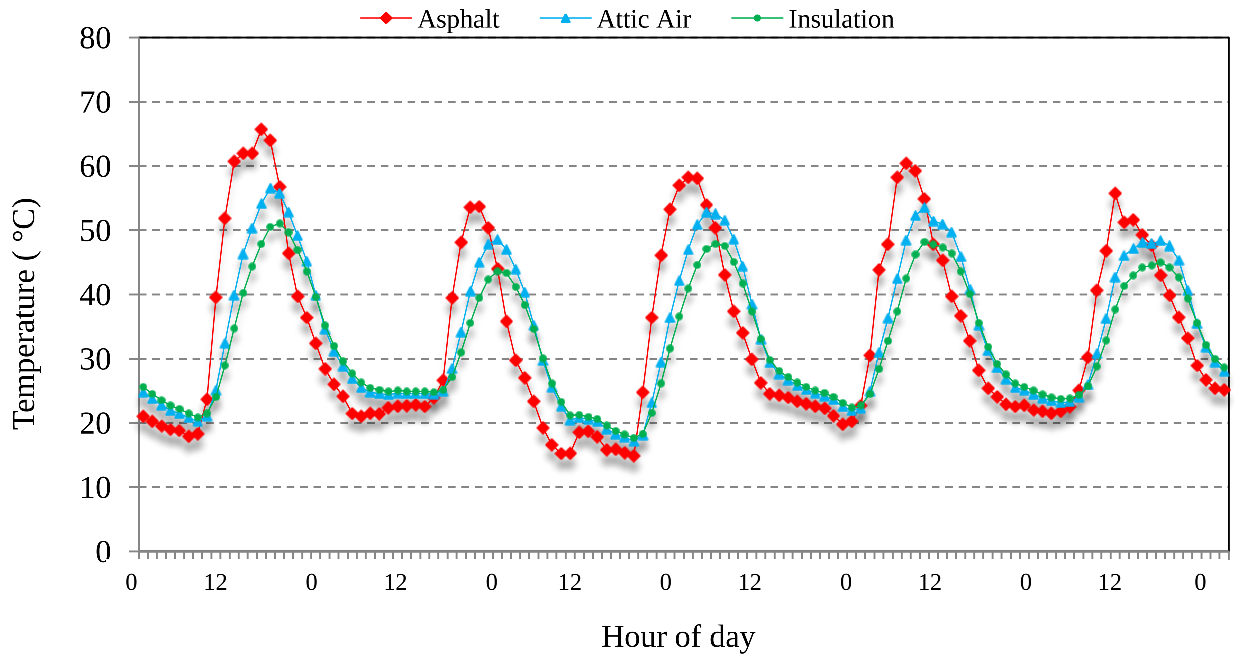


Figure 10: Various Temperature in the house without radiant barrier in summer

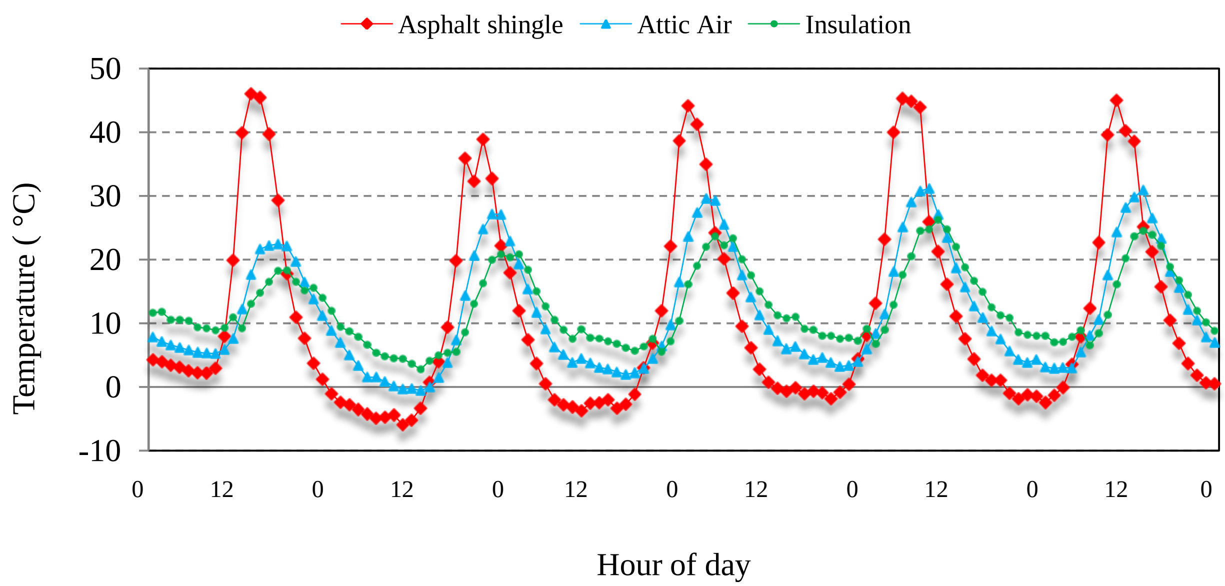


Figure 11: Various Temperature in the house with radiant barrier in winter

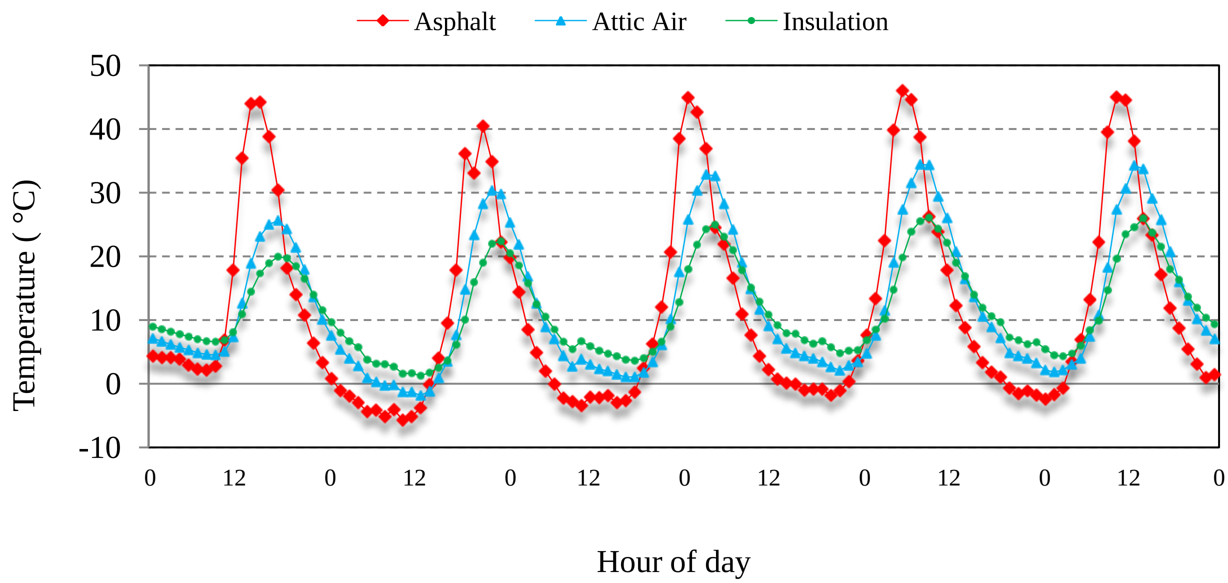


Figure 12: Various Temperature in the house without radiant barrier in winter

3.4.2 Heat Flux Data

Sample profile of hourly ceiling heat fluxes is presented, which describes the performance of radiant barrier. The profile serves as a useful tool to understand how radiant barrier functions. Figures 13 and 14 compare the required hourly ceiling heat flux for 5 days in the summer (June 8th to 12th, 2010) and in the winter (February 2nd to 6th, 2010) in the house with radiant barrier and house without radiant barrier. Since both houses are identical and are subjected to the same weather conditions, any changes occurring in the ceiling heating and cooling loads were attributed to the radiant barrier. In order to calculate the ceiling heat flux, inside temperature was set to 21°C for the winter and 24°C for the summer season. In this climate, radiant barrier is mainly useful during the hour between 11 a.m. and 9 p.m., but it still somewhat contributes in reducing the heat transfer rate during night and early mornings.

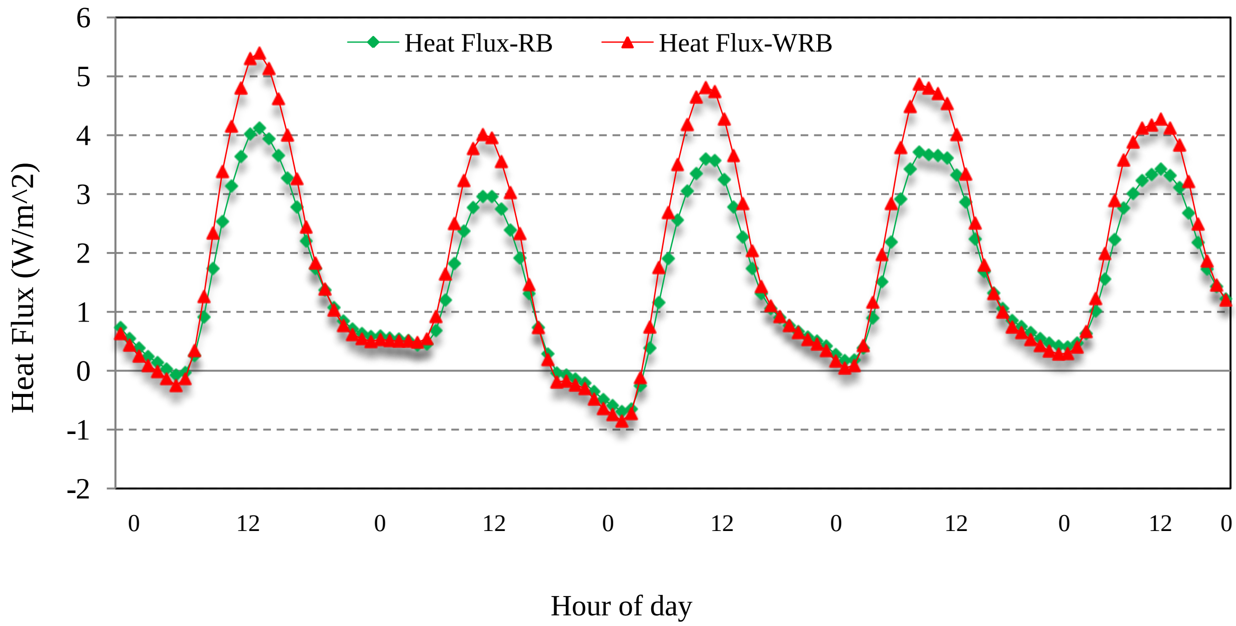


Figure 13: Hourly ceiling heat flux in summer

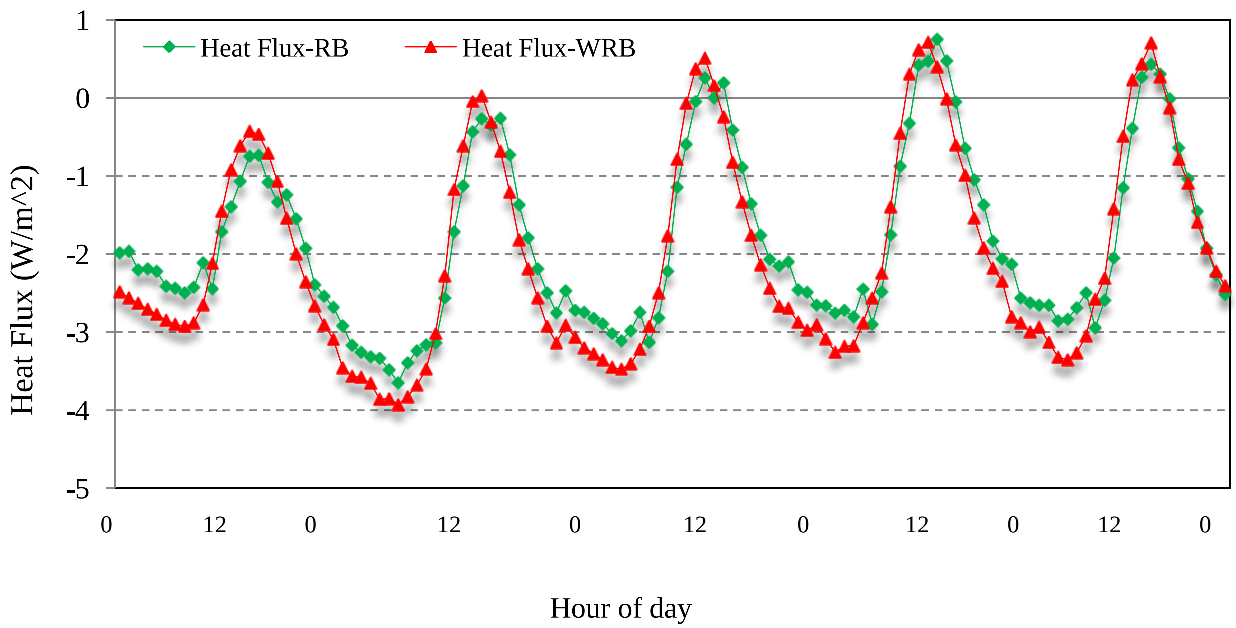


Figure 14: Hourly ceiling heat flux in winter

The best possible performance is achieved during the periods of high solar radiation. In humid climates such as Louisiana, an evaporation procedure occurs in the attic surfaces due to the

deposited moisture. Evaporation results in a cooling effect in the attic surfaces, which appears to be larger in the attic with radiant barriers. This causes the largest difference in ceiling heat fluxes between the attic with radiant barrier and the control case.

Figure 14 shows the ceiling heat flux in the house with radiant barrier and house without radiant barrier in winter. As shown in this figure, radiant barrier can reduce ceiling heat flux from the heated space to the attic. These reductions were approximately between 8 to 11% depending on the climatic conditions.

3.4.3 Effect of Climatic Parameters

Several parameters influence the performance of attic radiant barrier system in residential construction. Since a measure of the performance of an attic radiant barrier is its ability to reduce the heat flux that can be transferred into the conditioned spaces of buildings, it is necessary to investigate whether there are correlations between climatic parameters and the percentage reduction in ceiling heat flux.

The parameters investigated in this study are environmental variables including local ambient air temperature, relative humidity, global horizontal solar radiation, wind speed, and sky cloud cover. Finding these relationships are valuable because they can reveal which climatic parameters have the highest effect on the performance of radiant barrier. This part of the study shows the correlations between the monthly percentage reduction in ceiling heat flux and environmental parameters. The percentage ceiling heat flux reduction was calculated for 8 months of experimental study. Mean hourly values of the weather parameters were used since these are good indicators of climate that prevails in an area. In each case, the mean hourly values show the average over the entire month.

3.4.3.1 Effect of Ambient Air Temperature

Figure 15 presents the relationship between ambient air temperature and monthly percentage reduction in ceiling heat flux.

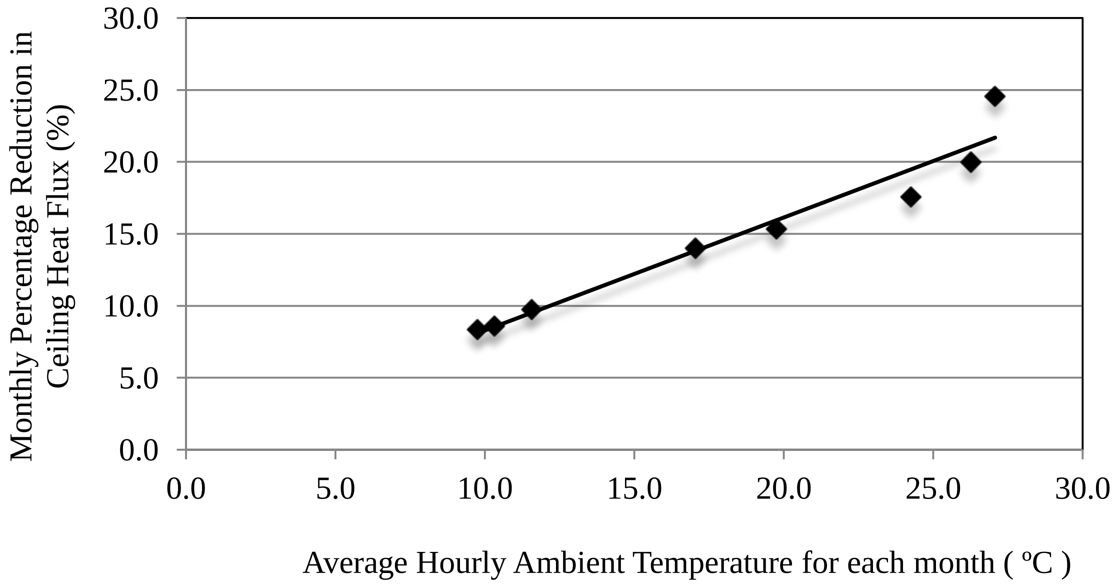


Figure 15: Effect of ambient air temperature on attic radiant barrier performance

As shown in this figure, there is a linear correlation between ambient air temperature and percentage reduction in ceiling heat flux. Attic radiant barrier system performs better at higher ambient air temperatures. It can be concluded from these results that attic radiant barrier would be more beneficial in warmer months than colder months. Moreover, Figure 15 indicates that the performance of attic radiant barrier is considerably affected by the ambient air temperature.

3.4.3.2 Effect of Relative Humidity

Figure 16 shows the relationship between the relative humidity and monthly percentage reduction in ceiling heat flux. According to this figure, the range of relative humidity in Louisiana is between 70 and 80%. Due to the small fluctuation in relative humidity, no clear correlation can be detected between monthly ceiling heat flux and relative humidity. This can

also be attributed to the strong effect of other parameters such as ambient air temperature on the performance of radiant barrier.

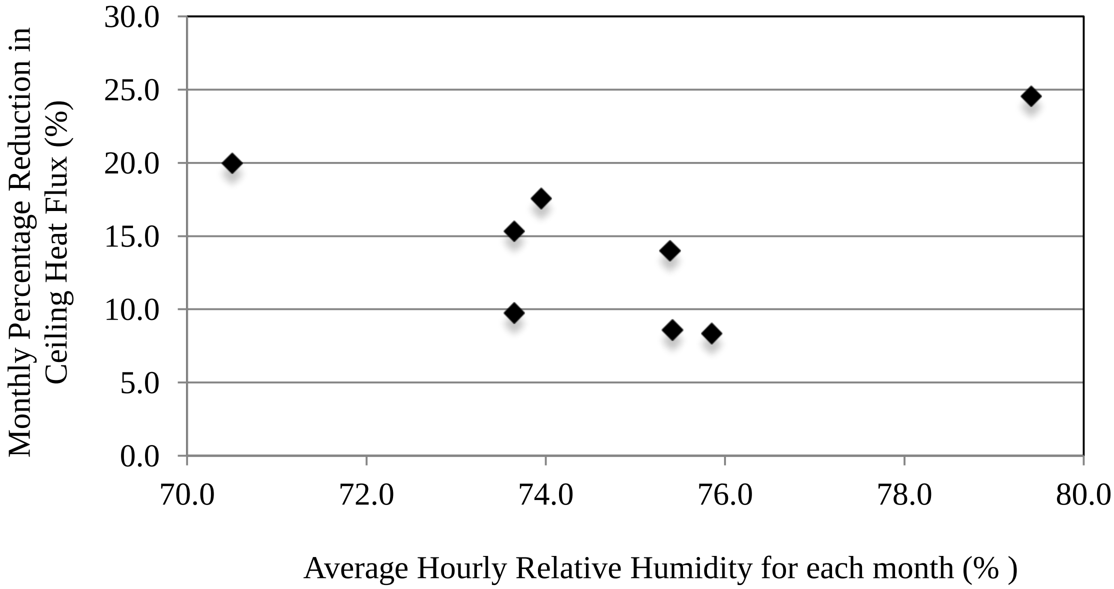


Figure 16: Effect of relative humidity on attic radiant barrier performance

3.4.3.3 Effect of Global Horizontal Solar Radiation

The global horizontal solar radiation is composed of direct and diffuse radiation that reaches horizontal surface. Figure 17 shows the effect of the global horizontal solar radiation on the monthly percentage reduction due to application of radiant barrier insulation system. As shown in this figure, there is a linear relationship between the global horizontal solar radiation and monthly percentage reduction. At the lower level of global horizontal solar radiation, the effect of the radiant barrier is low while at the average solar radiation of 250 W/m^2, higher reduction in ceiling heat flux was observed.

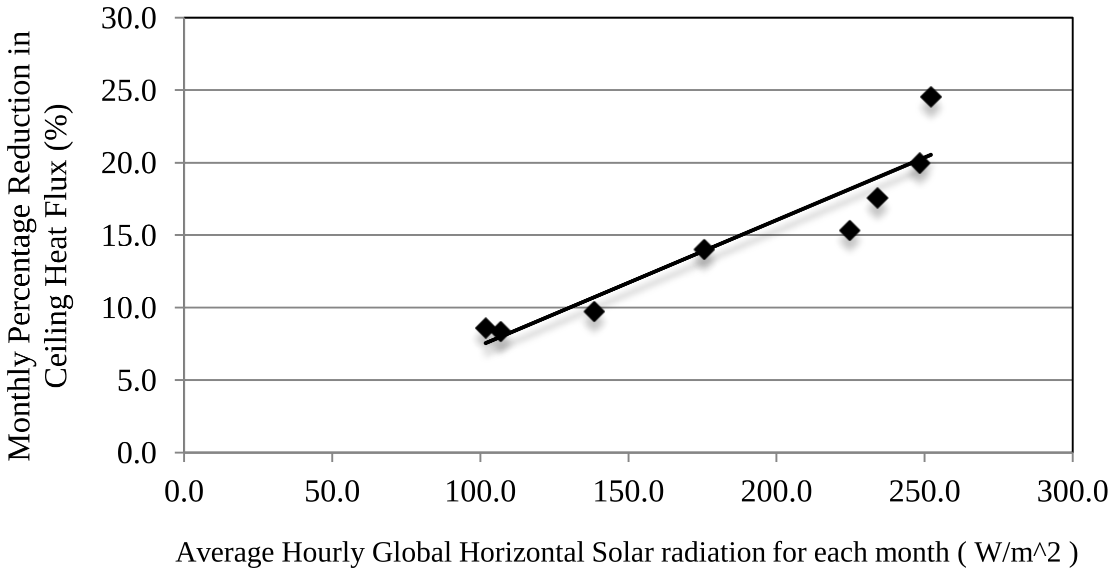


Figure 17: Effect of global horizontal solar radiation on attic radiant barrier performance

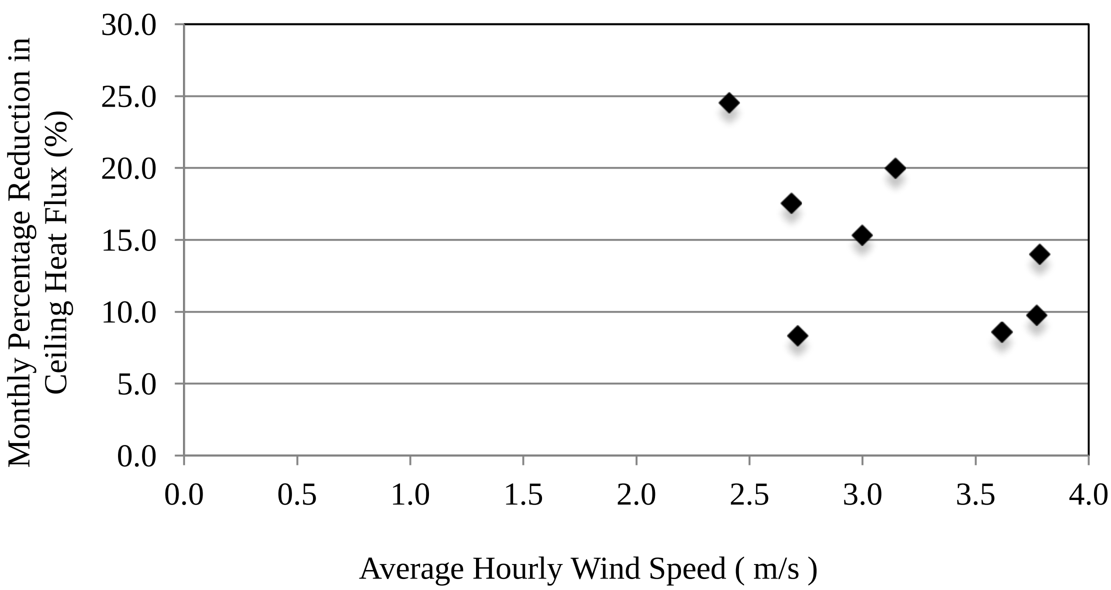


Figure 18: Effect of wind speed on attic radiant barrier performance

3.4.3.4 Effect of Wind Speed

Figure 18 demonstrates the effect of wind speed on attic radiant barrier performance. Similar to relative humidity, this figure shows that the wind speed does not correlate well with radiant

barrier performance. Generally, at low wind speed, the percentage reduction is higher. According to Table 1, the higher wind speed in the monitoring period occurred during cold months, which had low ambient air temperature and solar radiation.

3.4.3.5 Effect of Sky Cloud Cover

Figure 19 illustrates the relationship between sky cloud cover and the ceiling heat flux percentage reduction in each month. These results do not show a clear correlation between sky cloud cover and the reduction in ceiling heat flux. Most of the data points are distributed around a cloud cover index of 0.47 to 0.65 where the monthly percentage reduction in ceiling heat flux was between 9 to 25%. However it should be emphasized that attic radiant barrier would not be beneficial in very cloudy areas. The reason is that in very cloudy areas, the beam component that creates the greater part of the terrestrial solar radiation is considerably decreased during the period of solar heating. Therefore, only a small fraction of the solar radiation reaches the roof. The locations that have moderate values of sky cloud cover or partly cloudy areas will benefit the most from radiant barrier throughout the day. Clouds are recognized for their scattering, absorption, and reflection abilities of solar radiation.

However, when the radiation attains the outer surface of the roof, it becomes difficult for the roof to emit back the stored heat energy to the sky. The reason is that clouds will stop it by reflecting part of the radiation back, scattering part, and also absorbing part and emitting back to the roof. Therefore, the clouds could help in radiation heat transfer exchanges with the roof.

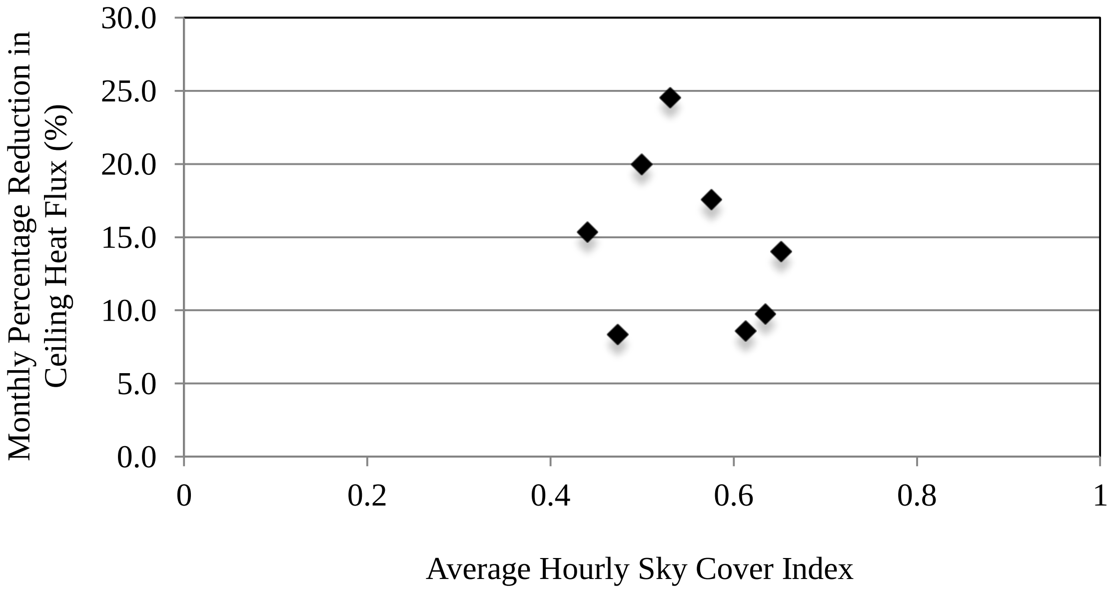


Figure 19: Effect sky cloud cover on the radiant barrier performance

3.5 Conclusions

Residential buildings are considered as one of the largest energy consumption sectors in the US. During the cooling season, heat transfer from the attic space into the conditioned areas of the residence represents a significant portion of the total envelope heat transfer. Consequently, there is a critical need for energy-efficient buildings that minimize energy consumption and optimize the performance of individual systems and components of the building. The objective of this study is to quantify the reduction in heating and cooling loads that would occur with a radiant barrier and to identify important environmental parameters that influence this reduction.

Experimental results showed a notable difference between the temperature of the attic air and insulation in the house with radiant barrier and the control house in the summer. Attic air temperature in the control house was 6°C higher than the house with radiant barrier. The lower temperature of attic air in the house with radiant barrier shows the important role of radiant barrier as a reflector of solar radiation. The difference between attic air and insulation temperature in the house with radiant barrier and control house in winter was relatively small.

The required ceiling heating and cooling loads were determined in the house with and without radiant barrier. Radiant barrier performance profile demonstrates the usefulness of the technology in Louisiana as it helps in decreasing the ceiling heat gains, which increase during periods of high solar activity. Radiant barrier also reduces the infrared radiation from the attic deck to the top of the insulation on the attic floor because of its low emissivity and absorptivity. Results showed that radiant barrier is mainly useful during the hours between 11 a.m. through 9 p.m., but it may still be beneficial in reducing the heat transfer rate during night and early mornings. According to the heat flux results, radiant barrier can reduce energy loads in winter by a factor ranging from 8 to 11% depending on the prevailing climatic conditions.

Results of the experimental program were also used to investigate the sensitivity of ceiling heat flux reduction to environmental parameters such as local ambient air temperature, relative humidity, global horizontal solar radiation, wind speed, and sky cloud cover. It was concluded that among these parameters, ambient air temperature and solar radiation had the highest effects on the ceiling heat flux reduction in residential buildings in Louisiana.

CHAPTER 4: PERFORMANCE EVALUATION OF AN ATTIC RADIANT BARRIER SYSTEM USING THREE-DIMENSIONAL TRANSIENT FINITE ELEMENT METHOD

4.1 Introduction

Energy consumption is generally classified into four different sectors including industry, transportation, building and agriculture. The residential and commercial building sector is considered to be the largest energy consumer (Gordon and Holness, 2008). According to the Department of Energy, residential buildings are responsible for 22% of the total energy use in the US (US Department of Energy, 2006). Specifically, heating and cooling systems account for 54% of the total energy consumption in residential buildings. Therefore, in a modern energy-conscious society, the reduction of energy consumption in air conditioning systems is identified as an effective way to save energy. This reduction can be achieved in many ways including the proper insulation of the building envelope. The attic space between the roof and the ceiling of a building is responsible for a substantial portion of heat transfer. Hence, the application of energy-efficient technologies in design of the attic for residential buildings is deemed necessary.

One method to reduce the heat flux in the attic is to utilize radiant reflective insulating barriers. While most traditional insulation materials resist heat flow through convection and conduction, reflective insulation targets radiation, which is the main source of heat transfer in residential buildings. Radiant barrier insulation system represented only a small portion of the insulation market nationwide. However, owing to the increasing demand for more energy-efficient insulations, the market for the reflective barrier insulations has experienced a significant growth of 27% in recent years (Midwest Roofing Contractors Association [MRCA],

2006). Accordingly, the performance analysis of the radiant barrier insulation systems, as well as quantifying the influence of different design parameters are of critical important for the design and construction of modern residential buildings.

There are several studies dealing with the efficacy assessment of reflective insulation systems in residential buildings (Joy, 1958;Peavy, 1979;Faireym, 1985;Katipamula and O'Neal, 1986;Levins and Karnitz, 1987;Goss and Miller, 1989;Hall, 1989;Chen et al., 1992;Nebeker and Tong, 1992;Medina et al., 1998a;Medina et al., 1998b;Moujaes and Alsaiegh, 2000;Medina and Young, 2006;Roels and Deurinck, 2011). The pioneering work of Joy (1958) involved developing a single steady-state equation by assuming a flat roof and constant ventilation rate, convection and radiation heat transfer coefficients. His work forms the basis for the effective attic resistance tables recommended by ASHRAE. Later, considering different ventilation conditions, Peavy (1979) carried out a numerical simulation to predict ceiling heat transfer in an attic of a residential house with three surfaces including two roofs and a ceiling floor. In a noteworthy contribution, Medina et al. (Medina et al., 1998a) developed a transient heat and mass transfer model to predict the ceiling heating and cooling loads and to estimate the heat flux reduction due to the radiant barrier in residential houses. The model showed a good agreement with the ceiling heat flux experimental results (Medina et al., 1998b). Using this model, Medina and Young (2006) evaluated the influence of the climate and local environmental variables on the performance of attic radiant barriers in the United States. With the advence of fast computers in recent years, numerical techniques such as the Finite Element (FE), have emerged as an accurate alternative method for analysis of large domains with time-dependent and complex boundary conditions. In an interesting effort, Moujaes and Alsaiegh (2000) developed a two dimensional, steady state FE model to investigate the performance of attic radiant barrier system

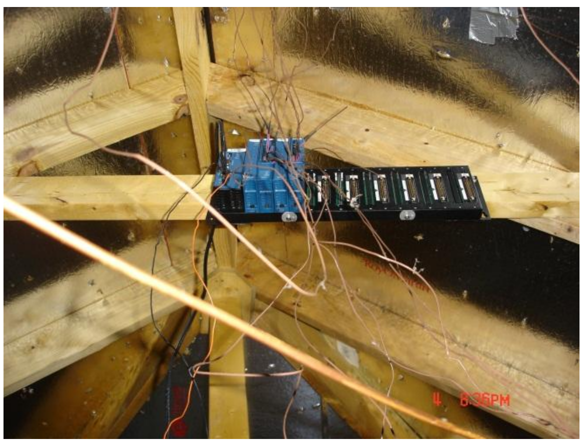
in residential buildings. Results indicated that attic radiant barrier system (ARBS) can reduce the ceiling cooling loads by 25% to 30%.

The objective of the present study is to simulate the heat transfer mechanisms in a residential building attic that features a radiant barrier system, by means of the three-dimensional (3D) transient FE method. The developed model overcomes limitations of previous models that either adopted a two dimensional approach or assumed steady-state conditions. This model considers a whole roof configuration and is capable of simulating each side of the roof individually as each side—depending on its location and orientation—can be exposed to different environmental conditions and different levels of solar radiation. The accuracy of the FE model was validated by comparing the predicted roof temperatures with experimental measurements. Subsequently, the results of the FE model were used to assess the thermal efficiency of the radiant barrier insulation system as compared to the conventional systems. In addition, the design variables and their influence on the performance of the radiant barrier insulation system were investigated based on FE analysis.

4.2 Experimental Procedure

The experiments were carried out in Zachary, Louisiana. This location is characterized by a humid subtropical weather. Two houses were selected, each having 148 m^2 area, and which were exactly identical in terms of their geometry, building materials, and climate conditions. The only difference between these two houses was the use of radiant barrier in one of them whereas the second one had a conventional insulation system, referred to as the control house hereafter. Radiant barrier was made of a thin layer of highly reflective aluminum that was attached to plywood, i.e. the inner side of the roof. The outer surfaces of the roofs were covered with dark asphalt shingles, which are considered as low reflective materials. The ceilings were covered

with polyurethane insulation (R-30). The houses were built with soffit-ridge ventilation. Each house was instrumented with various thermocouples to capture the temperatures in each layer of the roof and the ceiling. A data logger, ACR Samar Reader shown in Figure 20.a, was installed to record the temperatures every 4 minutes. A weather station, Davis 6152 Wireless Vantage Pro shown in Figure 20.b, was employed to measure and store the ambient air temperature, relative humidity, wind speed, wind direction, barometric pressure, precipitation (rainfall and rain rate), and solar radiation every 4 minutes.



a. Data logger

b. Weather Station

Figure 20: Data logger and weather station

4.3 Finite Element Model

To calculate the temperature distribution in the roof, attic and ceiling, a 3D transient finite element model was developed using the finite element commercial software ABAQUS 6.9 (Dassault Systèmes, 2009). Shown in Figure 21, is the sketch of an attic representing various heat transfer mechanisms that take place in the attic. The five-sided attic, which is geometrically symmetric with respect to XY and YZ planes, was simulated. The attic had two pitched roof sections, two vertical gable-end sections, and one horizontal ceiling frame. This configuration is

typical for houses constructed in the southern regions of the US. In order to investigate the impact of the radiant barrier system on the heating and cooling load, two finite element models were developed. One model represented the roof with the radiant barrier and the other one represented the roof without the radiant barrier in the attic. The radiant barrier, which was made from aluminum was simply modeled as an extra layer on the inner side of the roof which was in contact with the attic air (see Figure 21). Although the physical model was symmetric, the amount of solar radiation differed from one side of the roof to the other depending on the surface orientation and inclination. Thus, in order to conduct an accurate analysis, the entire configuration of the roof was simulated in the FE model (see Figure 22). The material properties including the thickness of the each layer are provided in Table 5.

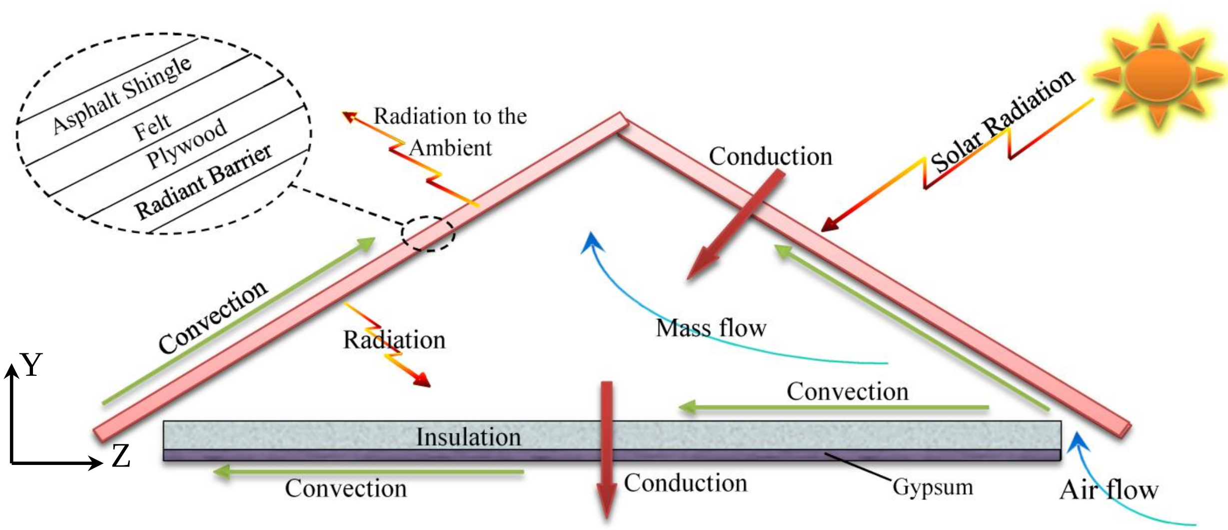


Figure 21: Schematic of the heat transfer mechanisms in the house roof

It is worth noting that in order to obtain mesh independent results, a mesh convergence technique was conducted and the final mesh size was selected considering both the computational efficiency and accuracy aspects.

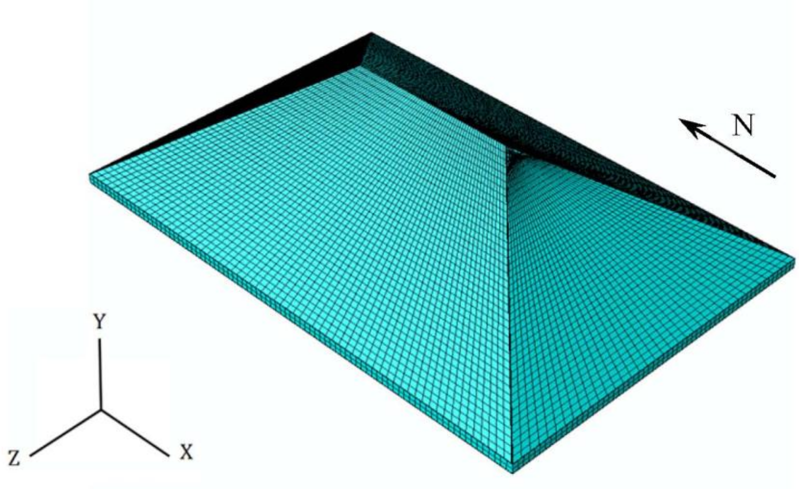


Figure 22: Finite element mesh

Table 5: Material properties used in the FE model

Material	Conductivity (w/m-°c)	Density (kg/m^3)	Specific heat (J/kg-°K)	Thickness (mm)	Emissivity
Asphalt Shingle	0.121	1121.29	1260	10.2	0.97
Aluminum	250	2800	900	0.001	0.03
Felt	0.173	800.9	0.0837	1.3	-
Plywood	0.130	640.7	1507	12.7	0.8
Insulation	0.016	24	1590	25.4	0.7
Gypsum	0.159	799.3	1089	12.7	0.82

The mesh density was increased by a factor of 2 iteratively until the resulting change in the nodal temperature became negligible. Twenty four steps were required to capture the hourly temperature variation during a day. As stated before, all of the experimental data were recorded every 4 minutes. Consequently, in order to use them as an input in the model, they were averaged over an hour period. The implementation technique for each of the heat transfer mechanism in the FE model is presented in the following sections.

4.3.1 Conduction Heat Transfer

All of the bounding surfaces in the attic are subjected to the conduction heat transfer, which is a transient phenomenon since the temperatures on all of the surfaces change with time. To model the conduction heat transfer mechanism in the roof and the ceiling, approximately 49,000 DC3D8 elements were used. Featuring a hexahedron shape with 8 nodes, these linear heat transfer elements were used for all of the materials except the air.

4.3.2 Radiation Heat Transfer

The outer surfaces of the roof are exposed to solar radiation. Heat flux due to solar radiation for a given day was obtained experimentally from the solar sensors. Since it is difficult to measure solar radiation on the inclined surfaces, e.g., the attic surfaces, the global radiation on a horizontal surface was obtained from the weather station. According to the following formulas (Duffie and Beckman, 1974), the exact amount of solar radiation received by each roof surface depends on a variety of parameters such as inclination, orientation and geographical location and is given by:

$$I_{Tilted} = I_d + R_b I_b \tag{4.1}$$

where,

I_{Tilted} = Total radiation for the tilted surface

I_d= Diffuse irradiation

I_b= Beam irradiation

and

$$R_b = \frac{Cos\theta}{Cos\theta_z} \tag{4.2}$$

where,

θ= Incidence angle

θ_z= Zenith angle

and

$$Cos\ \theta = Sin\ (\delta)\ Sin\ (\phi)\ Cos\ (\beta) - Sin\ (\delta)\ Sin\ (\phi)\ Cos\ (\beta)\ Sin\ (\gamma) + Cos\ (\delta)\ Cos\ (\phi)\ Cos\ (\beta)\ Cos\ (\omega) + Cos(\delta)\ Sin(\phi)\ Sin(\beta)\ Cos\ (\gamma)\ Cos\ (\omega) + Cos\ (\delta)\ Sin(\beta)\ Sin(\gamma)\ Sin\ (\omega) \qquad (4.3a)$$

$$Cos\theta_z = Sin(\delta)Sin(\phi) + Cos(\delta)Cos(\phi)Cos(\omega) \qquad (4.3b)$$

where,

δ=Declination angle;

ϕ= Latitude;

β=Tilt angle;

γ=Surface azimuth angle;

ω=Hour angle;

The amount of solar radiation as obtained from Eq. 4.1 was used in the simulation as the heat load on the outside surfaces of the roof. In the attic space, every surface exchanges heat with every other surfaces through radiation. The radiation heat transfer inside the attic depends on view factors that are the measure of relative radiative interaction between the surfaces of the cavity space. In order to model the heat transfer due to the radiation in the enclosure (attic space), the cavity option in ABAQUS was used. In this approach, ABAQUS automatically calculates view factors for three-dimensional models. The cavity is considered as an ensemble of element faces corresponding to the finite element discretization. These element faces can be treated as elementary areas and, accordingly, simple elemental view factors are calculated using an "area-lump" method as given in the following equation (Sparrow and Cess, 1978):

$$A_i F_{ij} = \frac{A_i\ Cos\alpha_i\ A_j\ Cos\alpha_j}{\pi\ R_{ij}^2} \qquad (4.4)$$

where,

A_i, A_j = elementary areas exchanging heat;

$\alpha_{i,}$= Angle between R_{ij} and surface A_i;

α_j = Angle between R_{ij} and surface A_j;

R_{ij}=Distance between two areas A_i, A_j;

4.3.3 Convection Heat Transfer

At every surface of the roof, attic, and ceiling, convection heat transfer can be significant. To calculate forced and natural convection for exterior and interior surfaces, a user subroutine was developed that calculates the forced and natural convection coefficient based on the temperature of the surface and the air, direction of heat flow, surface area, and the surface orientation. Correlations for both laminar and turbulent flows are used, with the choice depending upon the magnitude of the Rayleigh number for natural convection and Reynolds number for forced convection. To calculate the Nusselt number for the external flow over a surface, the following relationships were used (Holman, 2002):

$$Nu_F = 0.664\, Pr^{1/3}\, Re^{1/2} \qquad \text{for } Re < 5 \times 10^5 \qquad (4.5a)$$

$$Nu_F = Pr^{1/3}\,(0.37\, Re^{4/5} - 850) Pr^{1/3} \qquad \text{for } Re > 5 \times 10^5 \qquad (4.5b)$$

where,

Nu_F= Nusselt number for forced convection

Pr= Prandtl number for air

Re= Reynolds number

For calculating the natural convection for each surface, depending on the heat flow direction the following equations apply (Holman, 2002):

Horizontal surface, upward heat flow:

$Nu_n = 0.54\, Ra^{1/4}$ for $Ra < 8 \times 10^6$ (4.6a)

$Nu_n = 0.15\, Ra^{1/3}$ for $Ra > 8 \times 10^6$ (4.6b)

where,

Nu_n= Nusselt number for natural convection;

Ra= Raynolds number;

Horizontal surface, downward heat flow:

$Nu_n = 0.58\, Ra\ 0.2$ (4.7)

Tilted surface, downward heat flow:

$Nu_n = 0.56\, (Ra \sin(\beta))^{1/4}$ (4.8)

Tilted surface, upward heat flow:

$Nu_n = 0.56\, (Ra \sin(\beta))^{1/4}$ for $Ra/Pr < Gr$ (4.9a)

$Nu_n = 0.14\, (Ra^{1/3} - (Gr\, Pr)^{1/3}) + 0.56\, (Gr\, Pr \sin(\beta))^{1/4}$ for $Ra/Pr > Gr$ (4.9b)

where,

Gr= Grashof number

B= Tilt angle

$Gr = 1 \times 10^6$ for $\beta < 15°$ (4.10a)

$Gr = 10^{(\beta / (1.1870 + 0.087 * \beta))}$ for $15° < \beta < 75°$ (4.10b)

$Gr = 5 \times 10^9$ for $\beta > 75°$ (4.10c)

The Nusselt number for mixed convection regime is calculated as follows (Chen et al., 1986):

$$Nu_x^3 = Nu_F^3 \pm Nu_N^3 \quad (4.11)$$

where,

Nu_x= Nusselt number for mixed convection;

Finally, the natural, forced or mixed convection coefficient can be calculated using the Nusselt number for the corresponding convection regime based on the following formula:

$$h = \frac{Nu\,k}{L} \tag{4.12}$$

h = convection heat transfer coefficient;

k= thermal conductivity;

L= length of plate;

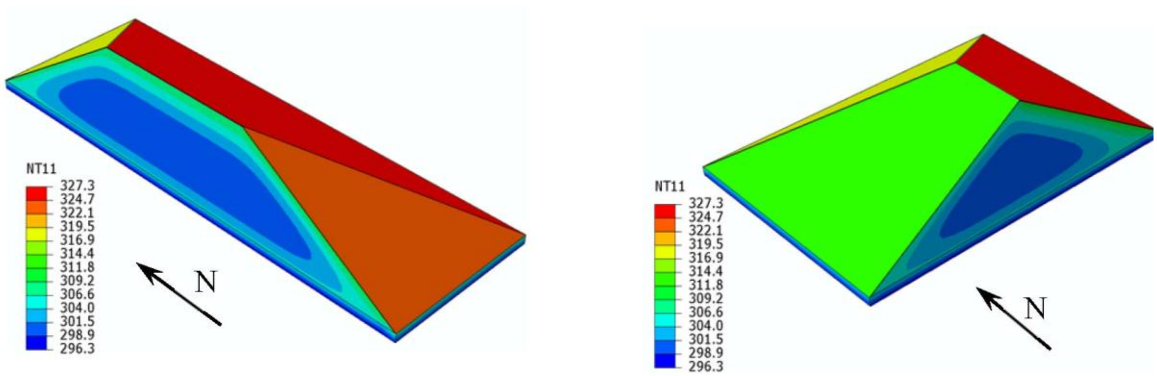
Nu= Nusselt number;

To model the advection, i.e., bulk motion of the air in the attic, the convection/diffusion option in ABAQUS were utilized by means of 8-node DCC3D8 elements with forced convection/diffusion capabilities. The total number of aforementioned elements was approximately 73,000. In addition, forced convection inside the roof was simulated by means of the mass heat transfer option in ABAQUS.

4.4 Results and Discussion

Using the developed finite element model, the temperature distribution in the roof, attic, and ceiling were estimated for summer and winter at different hours in a day. For instance, Figure 23 illustrates the 3D temperature distribution in the house with radiant barrier at 1 PM in a typical summer day. XY and YZ plane cuts are made to illustrate the internal distribution of temperature. As seen in this figure, the maximum temperature occurs on the asphalt-singles, which are exposed to considerable amount of solar radiation. The amount of solar radiation received by the roof surfaces depends on roof sides' orientation with respect to the sun at each hour of the day. The roof side facing East receives the maximum solar radiation at sunrise while the side facing South receives the maximum solar radiation in the afternoon. Therefore, at 1 PM,

the sides facing toward east and south have the maximum temperature fields (327°K and 324°K, respectively) as shown in Figure 23 (N indicates North).



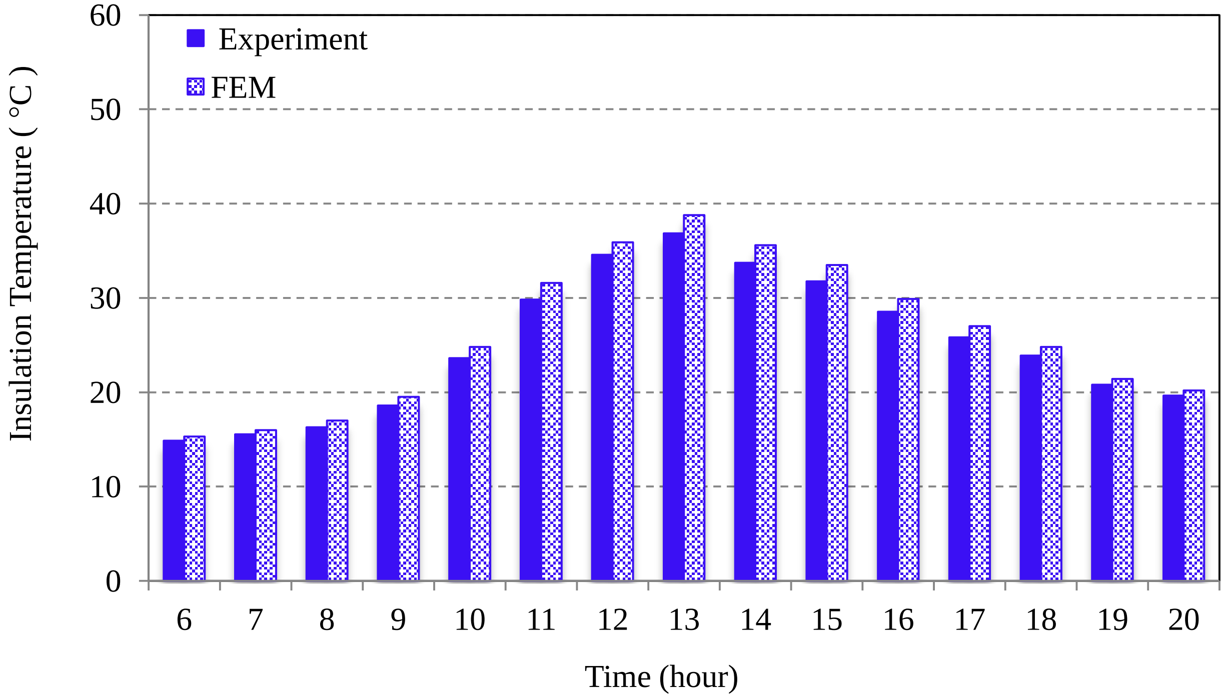
cut

(a) (b)

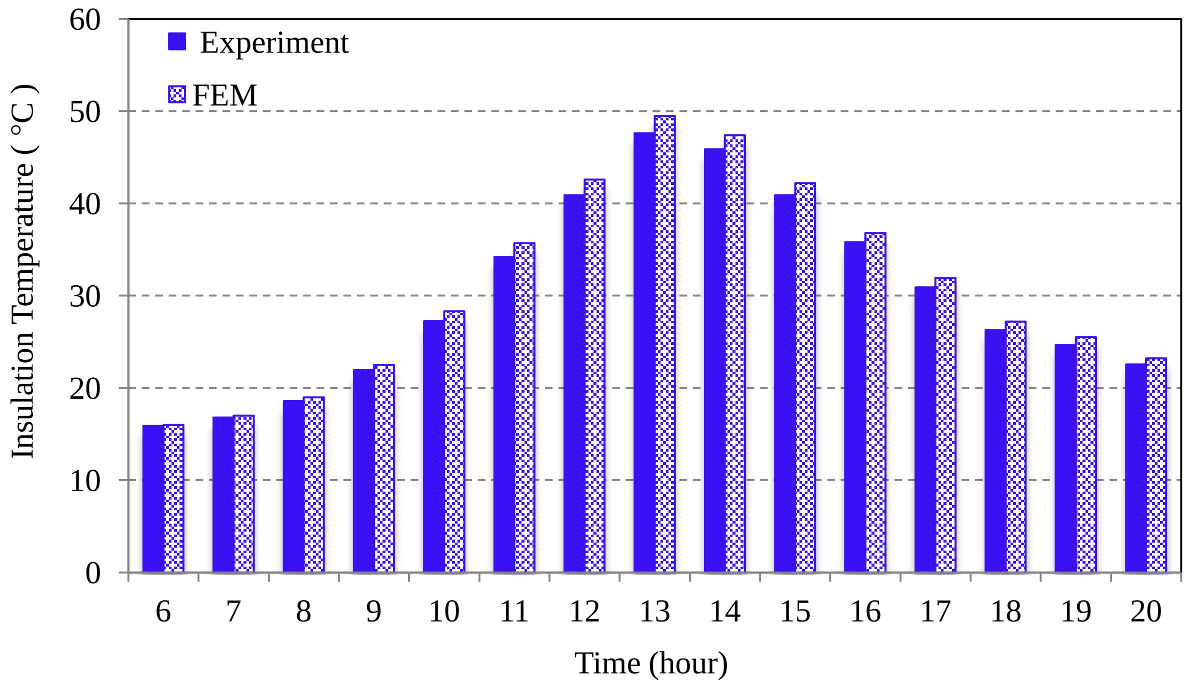
Figure 23: Contour of temperature (°K) distribution (a) XY plane cut and (b) YZ plane

4.4.1 Model Validation

As many factors affect the calculated temperature distributions and the heat flux in the roof, the validity of the FE model was evaluated by comparing finite element simulation results with experimental data. Figures 24 and 25 compare the results of the FE model with experimental data in a typical day in summer and winter. For brevity, the results are only presented for the insulation temperature and are given for two cases: the house with radiant barrier and the control house. As shown in these figures, there is a good agreement between the FE model prediction and experimental measurements during both peak and peak off time. However, the FE model predictions deviated more from the experimental values in the heating season than during the cooling season. One possible reason for this difference might be the moisture transport process. In fact, high levels of saturation are believed to affect the sensors output. However, the difference between the predictions and experiments is less than 5% for most cases.

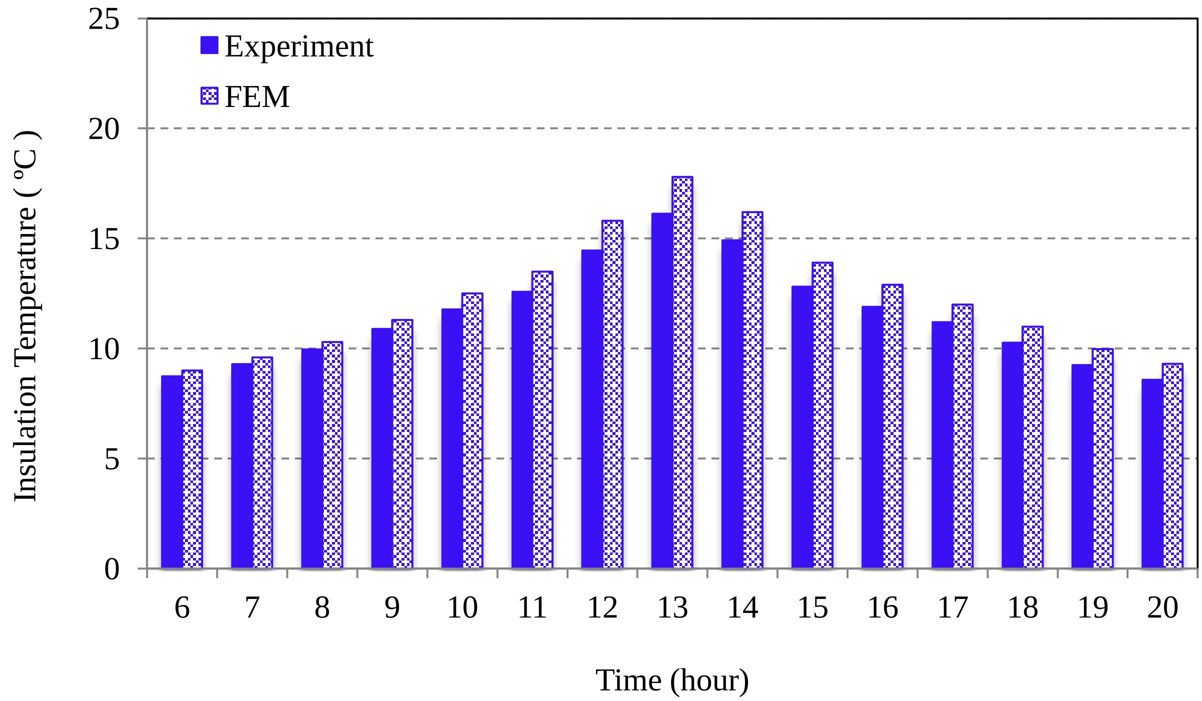


(a)

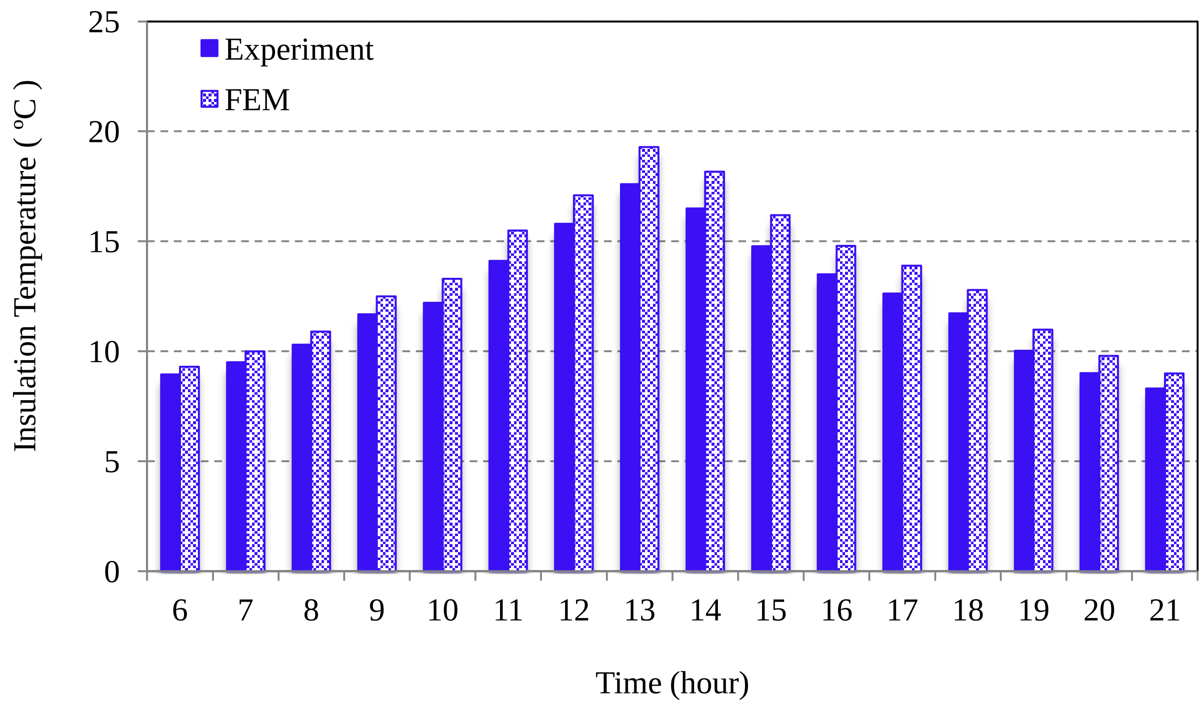


(b)

Figure 24: Insulation temperature in summer (a) in the house with radiant barrier and (b) in the control house



(a)



(b)

Figure 25: Insulation temperature in winter (a) in the house with radiant barrier and (b) in the control house

4.4.2 Effect of Radiant Barrier Insulation

Comparing the temperatures presented in Figures 24 and 25, it is noted that employing a radiant barrier (RB) in the attic has a significant effect on the insulation temperature since it prevents the attic surfaces from emitting heat waves toward insulation. As shown in these figures, during the peak hour, the temperature of the insulation in the house with radiant barrier in the summer is almost 10°C lower than the house without radiant barrier. Figure 26 compares the required ceiling heating-cooling loads based on FE in the house with radiant barrier and the control house in a typical day of each month for a year. RB-FEM shows the result based on the finite element model for the house with radiant barrier and WRB-FEM shows the result for the house without radiant barrier (control house). The peak of the ceiling heat flux in the control house and the house with radiant barrier were approximately 12 W/m^2 and 9 W/m^2, respectively, showing 21% reduction due to application of radiant barrier. In addition, based on these results, it is determined that the radiant barrier system decreases the annual required ceiling cooling load in the house by 18%.

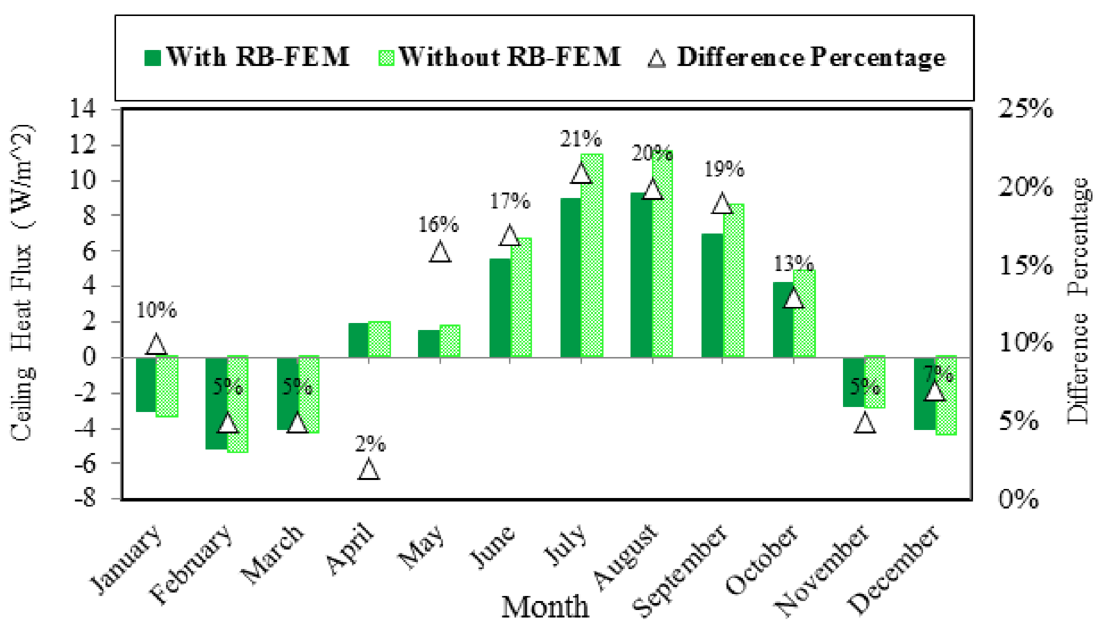


Figure 26: Performance of radiant barrier system based on FE model

4.4.3 Parametric Study

Upon validation of the model, the effect of radiant barrier on the insulation temperature was evaluated based on FE analysis. Also investigated, were the influence of design variables on the performance of the RB insulation system. In order to understand which design factors have the highest effect on the performance of RB, a parametric study was carried out by changing one parameter at a time while keeping the others constant at the low level. These parameters and the range of corresponding values are summarized in Table 6.

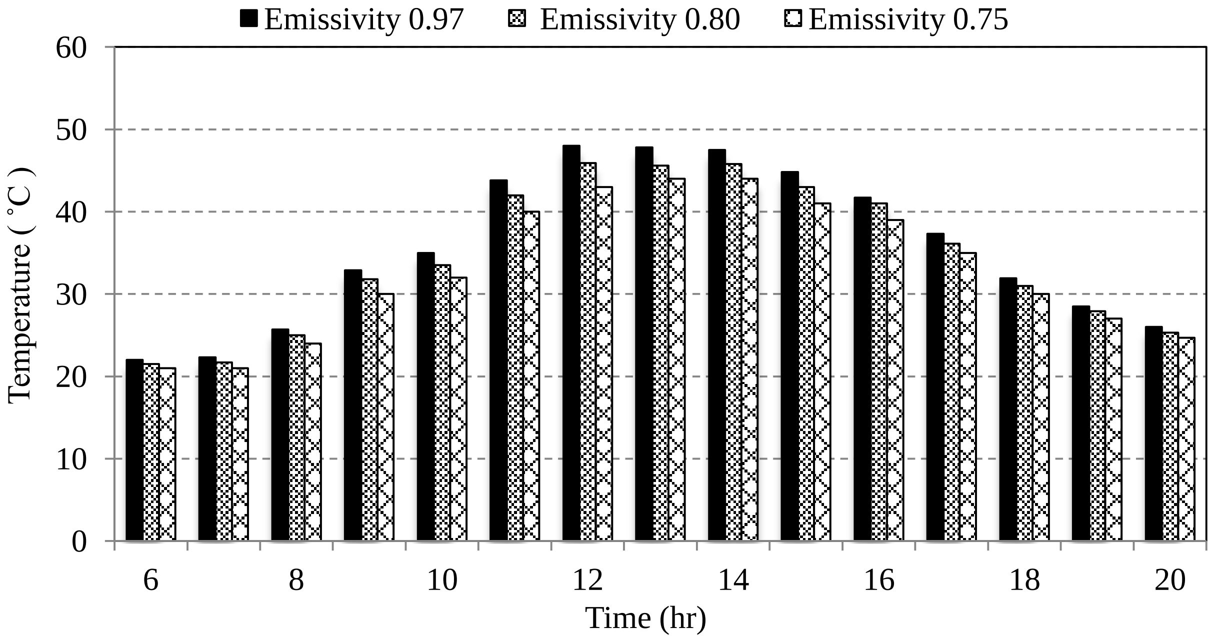
Table 6: Level of factors for parametric study

Factor	Level		
	Low	Medium	High
Shingle emissivity	0.75	0.80	0.97
Air gap thickness	0	0.75	5
Radiant barrier emissivity	0.03	0.04	0.05
Radiant barrier coverage	Full	North-South	East-West

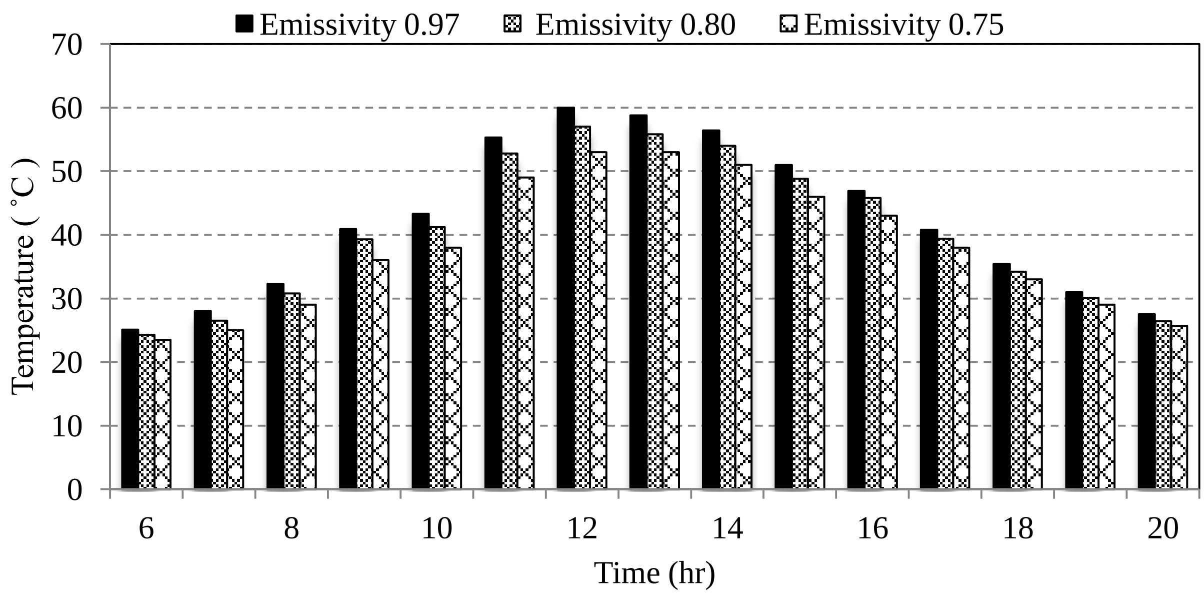
4.4.3.1 Effect of Asphalt Shingle Emissivity

The emissivity of the exterior surfaces is considered to be an important factor on heat gain or loss in buildings especially in places where the amount of solar radiation is significant. Figure 27 shows the effect of asphalt shingle emissivity on performance of the radiant barrier for a typical day in summer. Figure 28 shows the insulation temperature in the house with radiant barrier and control house at the different level of asphalt shingle emissivity at different hours of a typical day in summer.

Increasing the emissivity of asphalt shingle results in more solar radiation absorption. This leads to higher temperature in the attic upper surfaces (plywood surface). Consequently, the radiation from these surfaces on the insulation intensifies, rendering the role of radiant barrier, as a heat block, more critical.



(a)



(b)

Figure 27: Effect of shingle emissivity on the insulation temperature (a) in the house with radiant barrier (b) in the house without radiant barrier

As expected, during the cooling season, by increasing the emissivity of the shingle, the insulation temperature increases. However, as it can be seen, at the emissivity of 0.75 the

temperature in the house with radiant barrier at the peak hour is 10°C lower than the temperature in the control house while this difference is approximately 12°C at the 0.97 emissivity.

4.4.3.2 Effect of Air Gap Thickness

The second parameter evaluated in this study was the thickness of the air gap between the plywood and the radiant barrier. The thickness of the air gap has a significant effect on the heat gain or loss in the attic. Owing to its low thermal conductivity, the air gap serves to block the transfer of heat into the attic.

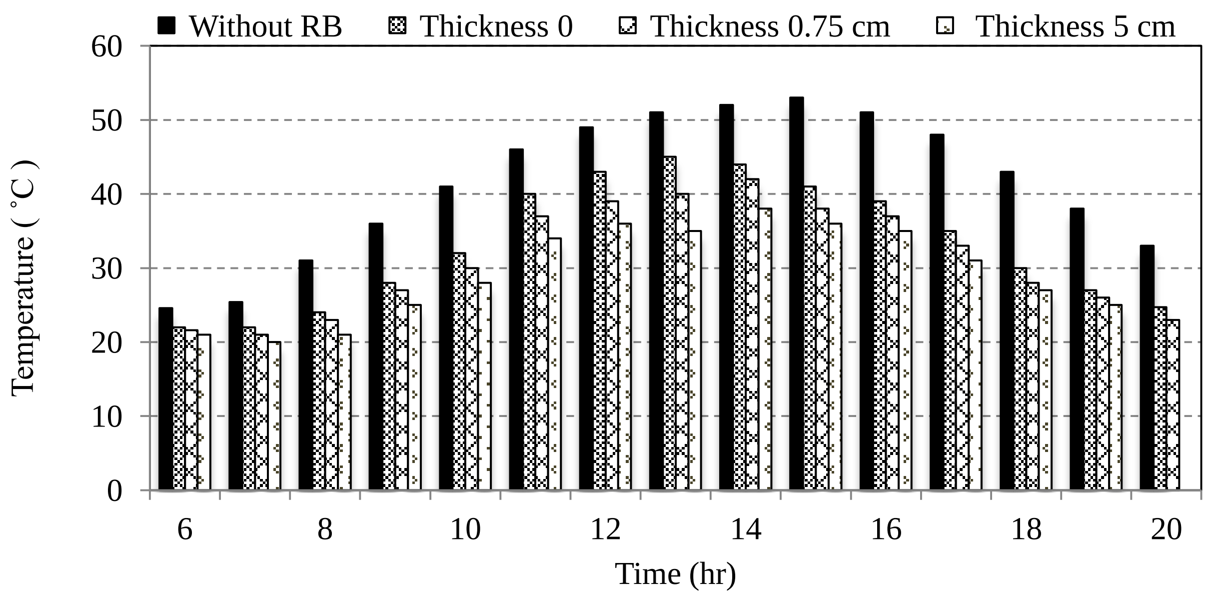


Figure 28: Effect of the air gap thickness on the insulation temperature

Figure 28 shows the effect of the air gap thickness on the insulation temperature in cooling season. It is evident that by increasing the thickness of the air gap, the attic air temperature will significantly decrease during the cooling season. As shown in Figure 28, increasing the thickness of the air gap from 0 to 5 cm, results in the temperature decrease from 44°C to 39°C during the peak hour. It can be seen that at the 5 cm air gap, radiant barrier can reduce the temperature by 26%.

4.4.3.3 Effect of Radiant Barrier Emissivity

The third parameter investigated in this study is the emissivity of the radiant barrier as it affects the insulation temperature. In addition to the air gap thickness, the emissivity of the radiant barrier can be considered as another important parameter to control the amount of infrared radiation in the attic of a building. The emissivity of typical radiant barriers varies from 0.03 to 0.05. Based on this range, radiant barrier can reflect 95 to 97% of solar radiation. Figure 29 demonstrates the effect of emissivity of radiant barrier on the insulation temperature. As shown in this figure, the effect of radiant barrier emissivity was relatively small (due to small variation of emissivity). However, it is evident that decreasing the emissivity of the radiant barrier leads to further reduction of the attic air temperature.

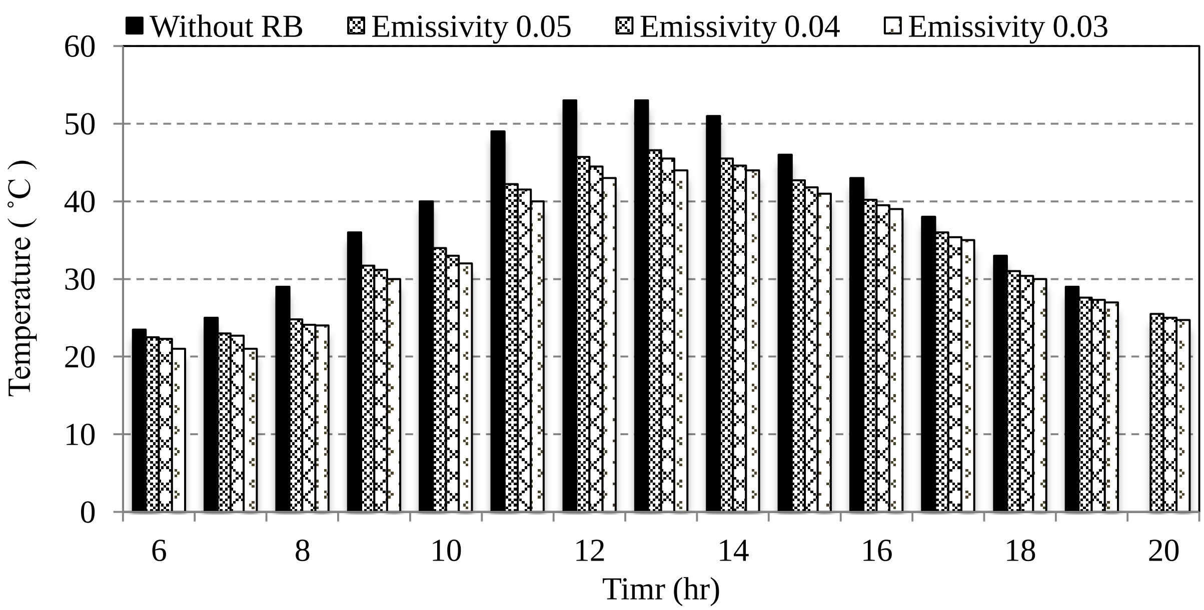


Figure 29: Effect of radiant barrier emissivity on the insulation temperature

4.4.3.4 Effect of Radiant Barrier Location

Figure 30 shows the effect of the location of radiant barrier in the attic on the insulation temperature. In the current study, the longer roof sides faced towards East-West. As shown, by changing the radiant barrier coverage from full coverage, to East-West coverage, and then North-

South coverage, the insulation temperature increases from 43°C to 48°C and 53°C during the cooling season. Therefore, the maximum benefit with the radiant barrier is achieved when the entire roof is covered with the radiant barrier insulation system.

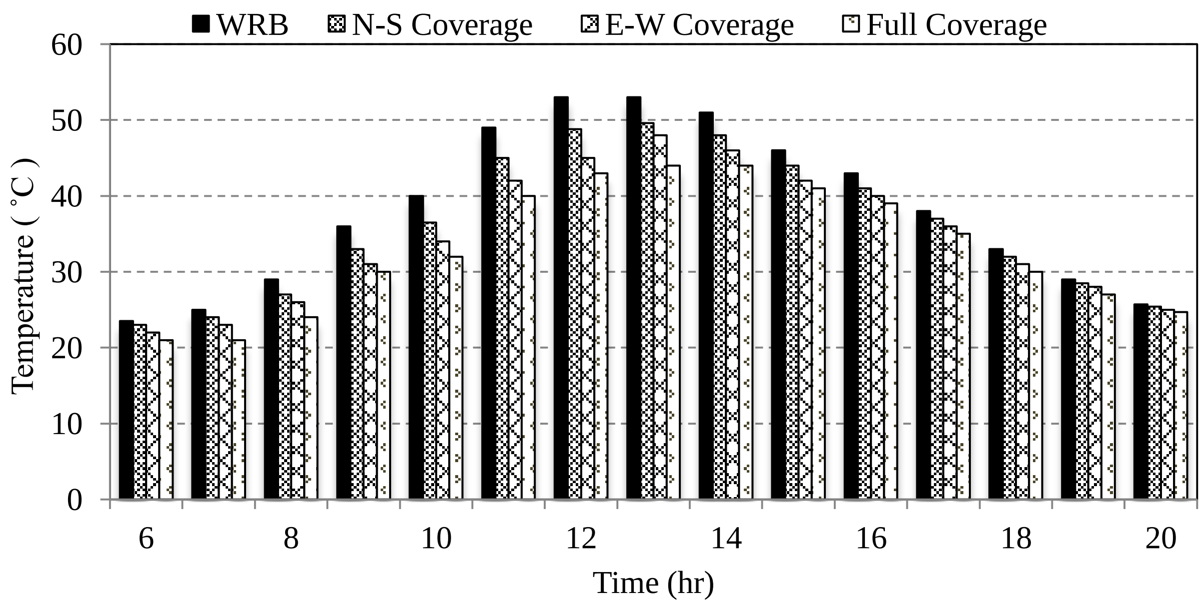


Figure 30: Effect of radiant barrier coverage in the roof on the insulation temperature

4.5 Conclusions

The objective of this study was to develop a three-dimensional transient FE model of the heat transfer processes in residential attic spaces to determine the possible energy savings gained by the use of the radiant barrier. Models for the thermal analysis of attics with and without radiant barrier were developed and analyzed using ABAQUS 6.9 software. Solar loads on outer attic surfaces are also calculated. The hourly temperatures predicted by the finite element model were compared to experimental measurements and showed good agreement with the experimental data. The error was less than 5% in most cases.

For a typical day in cooling season and during peak hour, the temperature of the insulation in the house with radiant barrier is 10°C lower than the house without radiant barrier. The simulation indicates that the application of the RB reduces the ceiling cooling load similar to

other experimental studies about 21%. A parametric study was conducted to evaluate the performance of radiant barrier as a function of shingle emissivity, thickness of air gap, radiant barrier emissivity, and location of radiant barrier in the roof. Based on the parametric study, it was also determined that the thickness of air gap had a significant effect on the performance of radiant barrier.

CHAPTER 5: DEVELOPMENT AND VALIDATION OF A SIMPLE ESTIMATING TOOL TO PREDICT HEATING AND COOLING DEMAND FOR ATTICS OF RESIDENTIAL BUILDINGS

5.1 Introduction

The US Green Building Council reported that buildings are responsible for 36% of total energy use, 65% of electricity consumption, and 30% of greenhouse gas emissions (ULI 2008). With the high amount of energy used by buildings, there will be a greater need for non-renewable energy sources such as coal. By 2030, an estimated 80% more coal will be needed, shifting the US to have to import coal from other countries (ULI 2008). Since buildings represent the largest energy consumption sector, efforts to reduce energy use and negative environmental impacts are important issues.

Several experimental and numerical studies have been carried out to identify the energy savings of radiant barriers in attics during summer and winter seasons (Soubdhan and Feuillard 2005, Petrie et al. 2000, Al-Asmar et al. 1996, Fairey 1985, Hall 1985, Baldinelli 2010). A transient heat and mass transfer model was developed by Medina et al. (1998a, 1998b) to predict hourly ceiling heat/gain in residential construction, with the aim of estimating heating-cooling load reduction produced by radiant barriers. Using this model, Medina and Young (2006) evaluated the influence of the climate and local environmental variables on the performance of attic Radiant Barrier System (RBS) in the US. Later, Miranville et al. (2008) studied the thermal performance of radiant barriers based on dynamic simulations and field measurements. A test cell equipped with a standard roof was used for the field measurements. Results demonstrated that the overall thermal performance of the roof was controlled by convective heat transfer in the lower air layer and that the thermal bridges had little effect on roof thermal performance. The efficiency of different types of radiant barriers available in civil construction market was studied

by Michaels et al. (2008). More recently, the thermal resistance of a roof-mounted multi-reflective radiant barrier was evaluated experimentally for tropical and humid conditions. The thermal performance of multi-reflective radiant barrier was determined based on the mean energy method. Results showed that this method is able to predict the thermal performance of multi-reflective radiant barrier given the prevailing climatic conditions (Miranville 2012).

Energy–conscious consumers deal with the decision of whether or not to install a radiant barrier in their home, and if so, what type of radiant barrier to install. Therefore, the objective of this study is to develop a simple estimating tool that may be used by homeowners, state agencies, and contractors to assess the effectiveness and economic benefits of radiant barrier insulation systems under different climate conditions in the US. This tool can help demonstrate how important design decisions can impact building energy performance. To achieve this objective, a series of FE simulations based on a partial factorial design were conducted to investigate the influence of different design and operational parameters on the performance of radiant barrier. Results of the FE models were then implemented into a set of regression equations to predict the thermal and economic performances of radiant barriers under a wide range of operating conditions. The tool calculates annual heating-cooling loads for any type of building inputs provided by the user. It is anticipated that the developed tool will facilitate the integration of energy efficiency in residential design and construction. This tool was designed based on the following principles: ease of use, minimization of required inputs, and simplicity and practicality of outputs.

5.2 Methodology

The flowchart of the methodology adopted in the development of the estimating tool is illustrated in Figure 31. As illustrated in this figure, this study consisted of two steps: an

experimental study and a numerical study. The experimental part of this study was carried out in Louisiana. Two identical houses were selected for this study. One of the houses had radiant barrier insulation system in its attic while the second one had conventional insulation. The experimental study lasted for 8 months in order to collect data in the winter and summer seasons. In the numerical study, 3D transient finite element models were developed to simulate the heat transfer mechanism in the attic. The developed models were validated based on experimental measurements. After validation, a fractional factorial design study was carried out to evaluate the effect of different design and operational parameters on the performance of radiant barrier system. Based on the results of the fractional factorial design, regression equations were developed and verified for different cases. These equations were used to build the simple estimating tool to predict annual heating-cooling load and total cost savings in different climate conditions in the US.

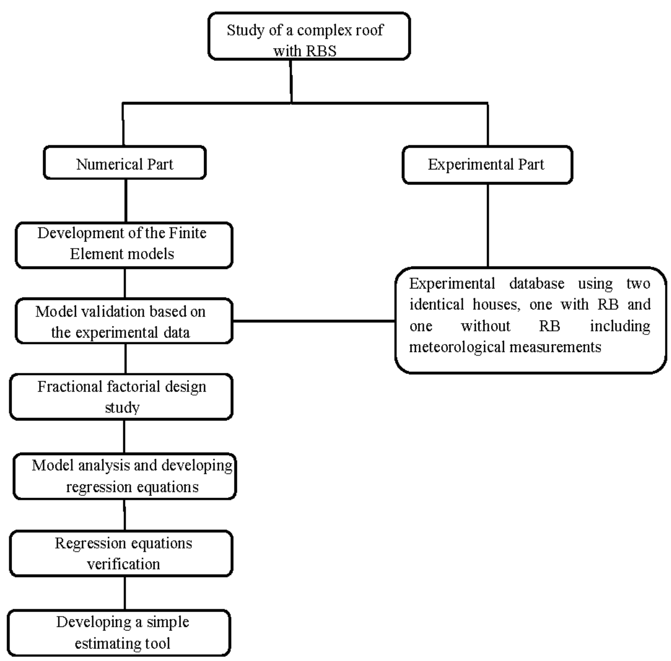


Figure 31: Methodology used for the present study

5.2.1 Description of the Finite Element Model

Three dimensional transient finite element heat transfer models for an attic with and without radiant barrier system were developed to evaluate the thermal performance of radiant barrier under different design and environmental conditions in the US. Figure 32 illustrates the various heat transfer mechanisms that take place in the attic. A five-sided attic, which is geometrically symmetric with respect to XY and YZ planes, was simulated.

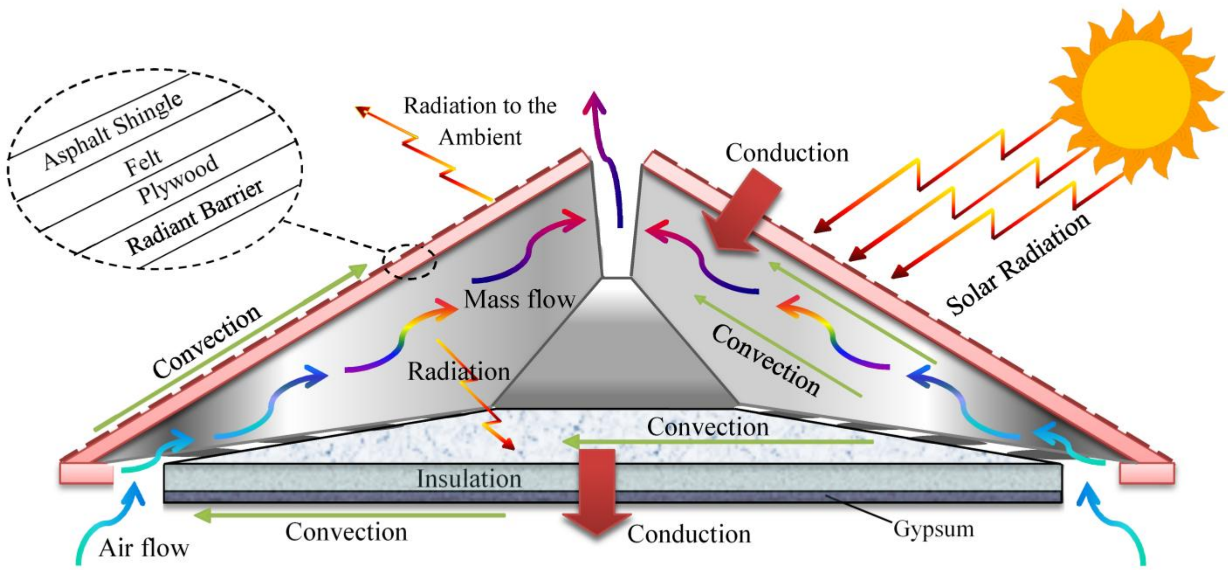


Figure 32: Schematic of the heat transfer mechanisms in the roof

The attic had two pitched roof sections, two vertical gable-end sections, and one horizontal ceiling frame. The model considered all the heat transfer mechanisms that may occur within the space.A full description of the model and its validation against experimental data is found in Refs (Asadi et al. 2012, Asadi and Hassan 2011).

Three separate finite element models were developed in order to evaluate the effects of different air gap thicknesses on the performance of radiant barrier. A finite element model was

also built to simulate the heat transfer mechanism in a similar house without radiant barrier. The inputs to the FE model included the emissivity of radiant barrier, emissivity of asphalt shingle, emissivity of insulation, attic flow rate, longitude, latitude, and time zone of the locations. Hourly climate data, including ambient temperature, solar radiation, wind speed, wind direction, and relative humidity, were used in the simulation. Typical Meteorological Year 2 (TMY2) weather files were used to provide local hourly climate data (NREL 1995). Figure 33 describes the finite element method procedure. The analysis approach adopted in this study was to calculate heat convection coefficients and solve the three dimensional (3D) transient heat transfer problems in an iterative sequence, using the output of one simulation as an input of the following one.

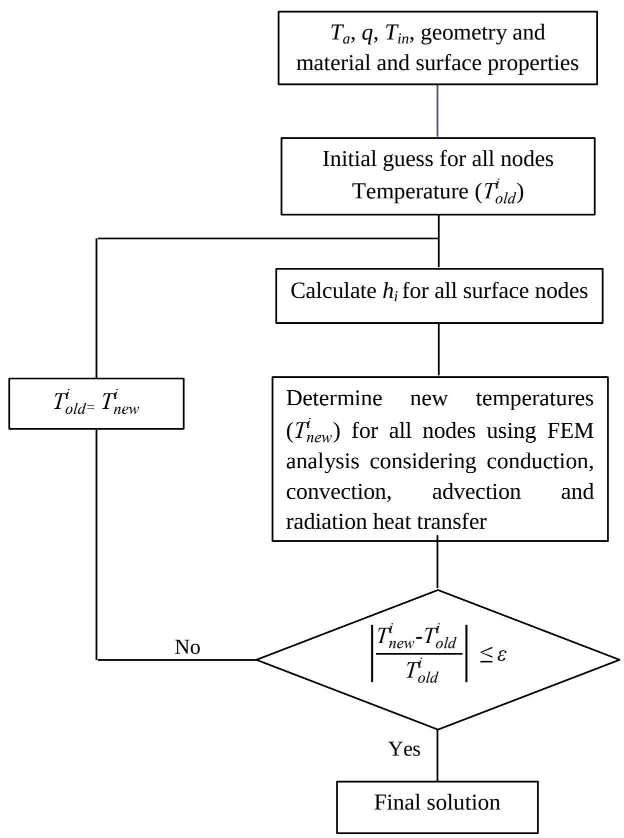


Figure 33: Finite element analysis procedure

This means that at each time and step, the surface temperature is first assumed and is used to calculate the heat convection coefficients. The heat convection coefficients are then tabulated in ABAQUS (2009). The simulation was then conducted and a new temperature distribution was obtained. The new temperature distribution is then used to calculate heat convention coefficients for each surface node. The procedure was repeated until the surface temperature and the heat convection coefficients converge to single values in that time step.

It is worth noting that in order to obtain reliable and accurate results, a mesh convergence sensitivity analysis was conducted using different mesh sizes. Final mesh size was selected after considering both computational efficiency and accuracy. Twenty four steps, one in each hour, were required to model the transient heat transfer mechanisms taking place during the day.

5.3 Climatic Zones in the United States

The climates of the United States are categorized as cool, temperate, hot-arid, and hot-humid as shown in Figure 34. The cool climate is cold with cool summers and humid winters. The temperate region has a cold climate with warm and humid summer. The hot humid is a warm and rainy climate with no distinct dry season. Hot arid has high temperature and low humidity. In these climates, the months between April and July are very dry.

Table 7: Average annual weather data

Climate	Average Dry Bulb Temperature (ºC)	Average Relative Humidity (%)	Average Solar Radiation (W/m^2)	Average Wind Speed (m/s)
Cool	3.8	72.6	138.9	4
Temperature	13.2	64.6	169.9	3.9
Hot-Arid	20.3	72.9	185.7	3.4
Hot-Humid	22.2	75.2	206.7	3.2

Table 7 provides typical weather data including solar radiation, ambient temperature, wind speed, and relative humidity for the four climatic regions found in the continental United States.

Figure 34: US climatic regions (Department of Energy 2010)

5.4 Regression Equations Development

A fractional factorial design was conducted to investigate the influence of design and operational parameters on the heating and cooling loads in residential buildings. These parameters are shown in Table 8. Three levels (low [0], intermediate [1], and high [2]) were considered for each factor. The resulting total number of runs required is calculated from the definition of the factorial design, $3^{(k-p)}$; where k is the number of factors and p is one representing the half fraction. The operational parameters such as ambient temperature, solar radiation, wind

speed, wind direction, and relative humidity were varied hourly (Law 2007). To obtain accurate data for the statistical analysis, the simulation runs were conducted based on a typical day per month for each climatic condition.

Table 8: The range of design parameters

Parameters	Range of variation		
	Low Level (0)	Intermediate Level (1)	High Level (2)
Shingle emissivity	0.75	0.8	0.97
Radiant barrier emissivity	0.03	0.04	0.05
Insulation emissivity	0.2	0.3	0.4
Air gap thickness	0	0.75	5
Radiant barrier orientation	Full	East-West	North-South
Attic flow rate	0.1	1.3	5

To simplify heating and cooling load calculation in residential buildings, statistical regression equations were developed. The results of the FE models were implemented in to a set of regression equations to predict the thermal and economic performances of radiant barriers under a wide range of operating conditions. The estimating equations developed for predicting insulation temperature were based on multiple-linear regression analysis. Multiple-linear regression is a method of demonstrating that a response (dependent) variable, Y, varies with a set of independent variables, X_1 to X_n. Multiple regression shares all the assumptions of correlation: linearity of relationships, the same level of relationship throughout the range of the independent variable, interval or near-interval data, absence of outliers, and data whose range is not truncated. To develop regression equations, it is necessary to generate a large database by conducting several parametric studies and then create a simple equation by using regression analysis (Freund 2008).

5.4.1 Regression Models and Accuracy

Several models were tested to achieve the best fit between the simulated data and the model results and it was found that linear models are the most appropriate solution for the problem. The regression equations were developed based on varying the different installation as well as varying the type of radiant barrier insulation system. According to this flowchart, if radiant barrier exists in the attic, three options are available: (1) radiant barrier can be attached to plywood without any air gap between them; (2) bubble radiant barrier can be installed to achieve a 0.75 cm air gap; (3) radiant barrier can be installed on the rafters with a 5 cm air gap. Using multiple linear regression method, 16 regression equations were developed to simulate the different scenarios.

Based on the conducted regression analysis, the developed models for predicting the insulation temperature for each climate zone and radiant barrier installation method are presented.

Cool Climate Zone

Attached to Plywood (air gap = 0)

$$\mathrm{T_{Insulation}} = 36.3 + 0.88 \times T_a + 0.12 \times V - 0.024 \times h - 0.37 \times \lambda + 0.018 \times (q_s \times \varepsilon_a) + 20.7 \times \varepsilon_{RB} + 0.82 \times \varepsilon_i$$

Bubble Radiant Barrier (air gap = 0.75cm)

$$\mathrm{T_{Insulation}} = 37.6 + 0.87 \times T_a + 0.19 \times V - 0.025 \times h - 0.37 \times \lambda + 0.013 \times (q_s \times \varepsilon_a) + 20 \times \varepsilon_{RB} + 0.042 \times \eta$$

Install on Rafters (air gap = 5)

$$\mathrm{T_{Insulation}} = 37.5 + 0.88 \times T_a + 0.17 \times V - 0.025 \times h - 0.36 \times \lambda + 0.013 \times (q_s \times \varepsilon_a) + 19 \times \varepsilon_{RB} + 0.036 \times \eta$$

Without Radiant Barrier

$$T_{\text{Insulation}} = 23.9 + 0.93 \times T_a + 0.033 \times V - 0.042 \times h + 0.022 \times (q_s \times \varepsilon_a) + 0.042 \times \eta + 0.9 \times \varepsilon_i$$

<u>Temperature</u> <u>Climate</u> <u>Zone</u>

Attached to Plywood (air gap = 0)

$$T_{\text{Insulation}} = 45.4 + 0.87 \times T_a + 0.07 \times V - 0.06 \times h + 0.012 \times (q_s \times \varepsilon_a)$$

Bubble Radiant Barrier (air gap = 0.75cm)

$$T_{\text{Insulation}} = 45.5 + 0.87 \times T_a + 0.099 \times V - 0.064 \times h + 0.009 \times (q_s \times \varepsilon_a)$$

Install on Rafters (air gap = 5)

$$T_{\text{Insulation}} = 45.79 + 0.87 \times T_a + 0.13 \times V - 0.06 \times h + 0.006 \times (q_s \times \varepsilon_a)$$

Without Radiant Barrier

$$T_{\text{Insulation}} = 21.7 + 0.949 \times T_a + 0.04 \times V - 0.05 \times h + 0.0189 \times (q_s \times \varepsilon_a)$$

<u>Hot-Arid</u> <u>Climate</u> <u>Zone</u>

Attached to Plywood (air gap = 0)

$$T_{\text{Insulation}} = -26.4 + 1.1 \times T_a + 0.38 \times V - 0.006 \times h + 0.009 \times (q_s \times \varepsilon_a)$$

Bubble Radiant Barrier (air gap = 0.75cm)

$$T_{\text{Insulation}} = -24 + 1.09 \times T_a + 0.43 \times V - 0.01 \times h + 0.005 \times (q_s \times \varepsilon_a) + 10 \times \varepsilon_{RB}$$

Install on Rafters (air gap = 5)

$$\mathrm{T}_{\mathrm{Insulation}} = -23.02 + 1.08 \times T_a + 0.47 \times V - 0.012 \times h + 0.003 \times (q_s \times \varepsilon_a) + 13.4 \times \varepsilon_{RB}$$

Without Radiant Barrier

$$\mathrm{T}_{\mathrm{Insulation}} = -28.7 + 1.1 \times T_a + 0.26 \times V + 0.015 \times (q_s \times \varepsilon_a)$$

Hot-Humid Climate Zone

Attached to Plywood (air gap = 0)

$$\mathrm{T}_{\mathrm{Insulation}} = 35.2 + 0.9 \times T_a + 0.24 \times V - 0.07 \times h + 0.014 \times (q_s \times \varepsilon_a) - 3.78 \times \varepsilon_i$$

Bubble Radiant Barrier (air gap = 0.75cm)

$$\mathrm{T}_{\mathrm{Insulation}} = 33.7 + 0.91 \times T_a + 0.28 \times V - 0.079 \times h + 0.01 \times (q_s \times \varepsilon_a) - 3.74 \times \varepsilon_i$$

Install on Rafters (air gap = 5)

$$\mathrm{T}_{\mathrm{Insulation}} = 31.7 + 0.92 \times T_a + 0.31 \times V - 0.08 \times h + 0.008 \times (q_s \times \varepsilon_a) - 3.9 \times \varepsilon_i$$

Without Radiant Barrier

$$\mathrm{T}_{\mathrm{Insulation}} = -44.5 + 1.18 \times T_a - 0.09 \times V - 0.07 \times h + 0.01 \times (q_s \times \varepsilon_a) - 0.73 \times \varepsilon_i$$

where,

$T_{Insulation}$= Insulation temperature (ºC);

T_a = Ambient temperature (ºK);

V = Wind speed (m/s);

h = Relative humidity (%);

λ = Radiant barrier coverage (Full coverage =3, East-West coverage = 2, North-South coverage = 1);

q_s = Global horizontal solar radiation (W/m^2);

ε_a = Emissivity of asphalt shingle;

ε_i = Emissivity of insulation;

ε_{RB} = Emissivity of radiant barrier; and

η = Attic flow rate.

Accuracy of the models was assessed by the coefficient of determination (R^2) and the Root Mean Square Error (RMSE) [18]. Table 9 shows the coefficient of determination (R^2), and the Root Mean Square Error (RMSE) of each equation in each climatic zone. As shown in Table 8, the R^2 of all developed models were acceptable and the root mean square error was not significant.

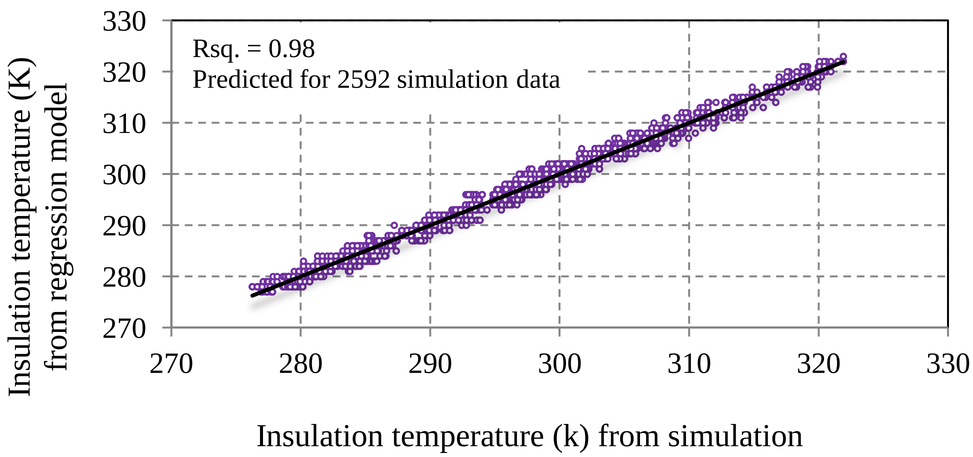


Figure 35: Goodness of fit for hot- humid climate zone and zero air gap by regression model

Figure 35 compares the predicted insulation temperatures from one of the regression models for the hot-humid climate zone with zero air gap to the insulation temperatures determined from the FE analysis. As shown in this figure, the results from the model are well correlated with the data from the FE simulation. The analysis of residuals was also carried out to assess the suitability of the models to fit the data. It was found that the residuals were randomly

distributed around zero and do not show any specific pattern or any relationship to the value of the independent variable.

Table 9: and Root Mean Square Error of each Model

Climate	Design Case	R^2	RMSE
Cool Zone Climate	Attached to plywood	0.99	1.3
	Bubble radiant barrier	0.99	1.2
	Installed on rafters	0.99	1.3
	Without radiant barrier	0.99	1.2
Temperature Climate Zone	Attached to plywood	0.99	0.98
	Bubble radiant barrier	0.98	1.1
	Installed on rafters	0.98	1.2
	Without radiant barrier	0.99	1.2
Hot-Arid Climate Zone	Attached to plywood	0.97	1.0
	Bubble radiant barrier	0.95	1.1
	Installed on rafters	0.94	1.2
	Without radiant barrier	0.98	0.96
Hot-Humid climate zone	Attached to plywood	0.98	1.2
	Bubble radiant barrier	0.98	1.3
	Installed on rafters	0.98	1.3
	Without radiant barrier	0.99	1.0

5.5 Development of the Estimating Tool

The main objective of this study was to develop a simple estimating tool that may be used by homeowners, state agencies, designers, and contractors to assess the effectiveness and economic benefits of radiant barrier insulation systems under different climate conditions in the US. The aim of the estimating tool is to provide estimates to the users in order to help them identify which design parameters have the highest impact on building energy consumption. This tool was designed based on the following principles: ease of use, minimization of required inputs, and simplicity and practicality of outputs.

Visual Basic programming language was used to create the interface design of the estimating tool. The program calculates annual heating-cooling loads for different building inputs by the user. The input page is designed in three parts by categorizing the questions into logical groups related to building information, heating–cooling load information, and roof information (see Figure 36). Several combo boxes and text boxes were defined for users to easily enter their input parameters. A question mark was provided for a number of inputs to provide more information to the users by connecting them to the related websites. The output page shows the monthly heating-cooling load in the house with radiant barrier, monthly heating–cooling load in the house without radiant barrier, annual cooling cost savings, annual heating cost savings, and the total cost savings in a year as shown in Figure 37.

The program first opens the user interface. The user can then input the required information and start running the program by clicking on the button 'calculate.' The program then starts reading user input variables such as location, type of the building, and conditioned floor area and set corresponding variables. Based on the selected location, it connects to the weather database and read weather data file and set weather variables such as ambient temperature, relative humidity, solar radiation, and wind speed. In the next step, the program initializes all the building variables that the user entered in the last step.

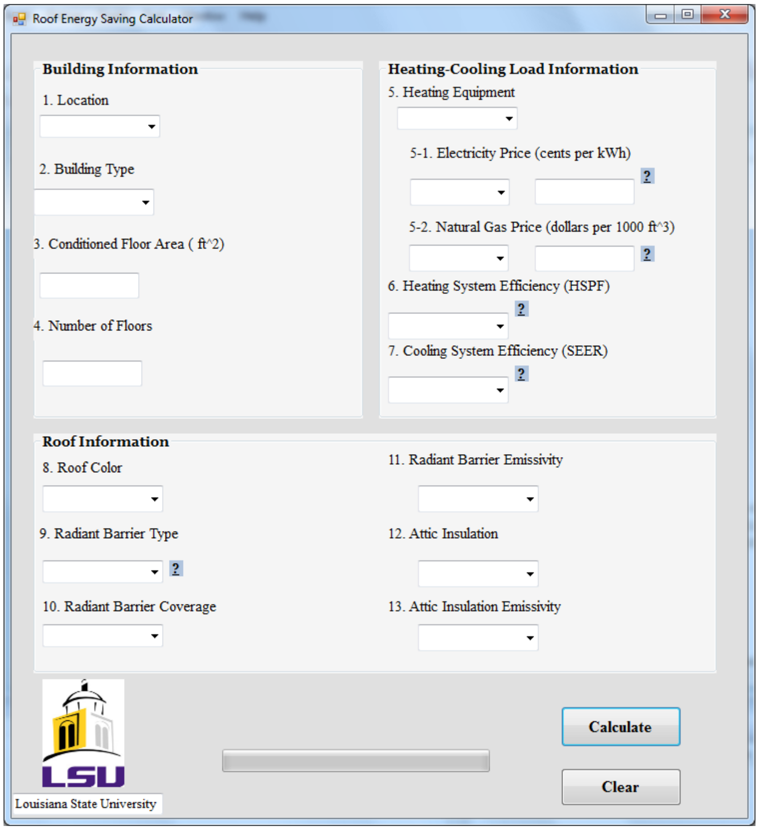


Figure 36: Input Page

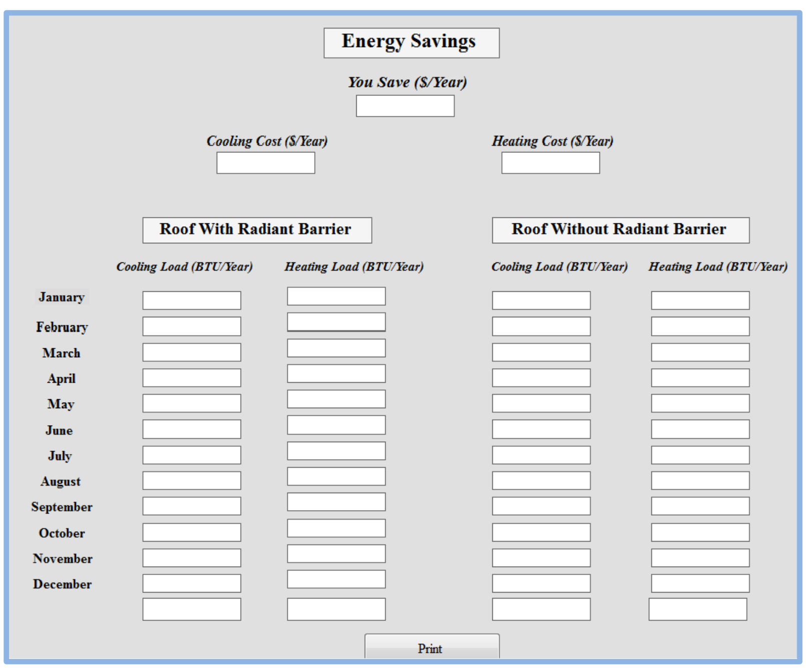


Figure 37: Output Page

Based on the regression equations, the program then calculates the heat flux hourly, daily, monthly, and yearly. In order to convert heating-cooling loads savings to cost savings, the fuel prices of each state and typical HVAC system efficiencies were applied based on the department of energy standards. The program then calculates heating-cooling costs in the house with radiant barrier and for the control house. The cost of heating and cooling load and the total cost savings in a year display in the output page. At the end, the user can click on the clear button and start a new estimation.

5.6 Results

5.6.1 Model Verification

Model verification is considered one of the most important steps when developing a model, particularly when dealing with multiple parameters. Verifying and analyzing cases that were not included in the data set used to create the model is essential and will show the accuracy of the model when it deals with cases different than the ones considered in the development phase. In order to ensure that the estimating tool produces reasonable results, several building cases were simulated based on the finite element model and estimating tool. Figure 38 and 39 compare the temperature and heat flux obtained based on the regression model and finite element method in the house with radiant barrier and control house. It can be observed that the results obtained by the regression models are similar with the ones obtained by the finite element model with acceptable errors of 5% or less.

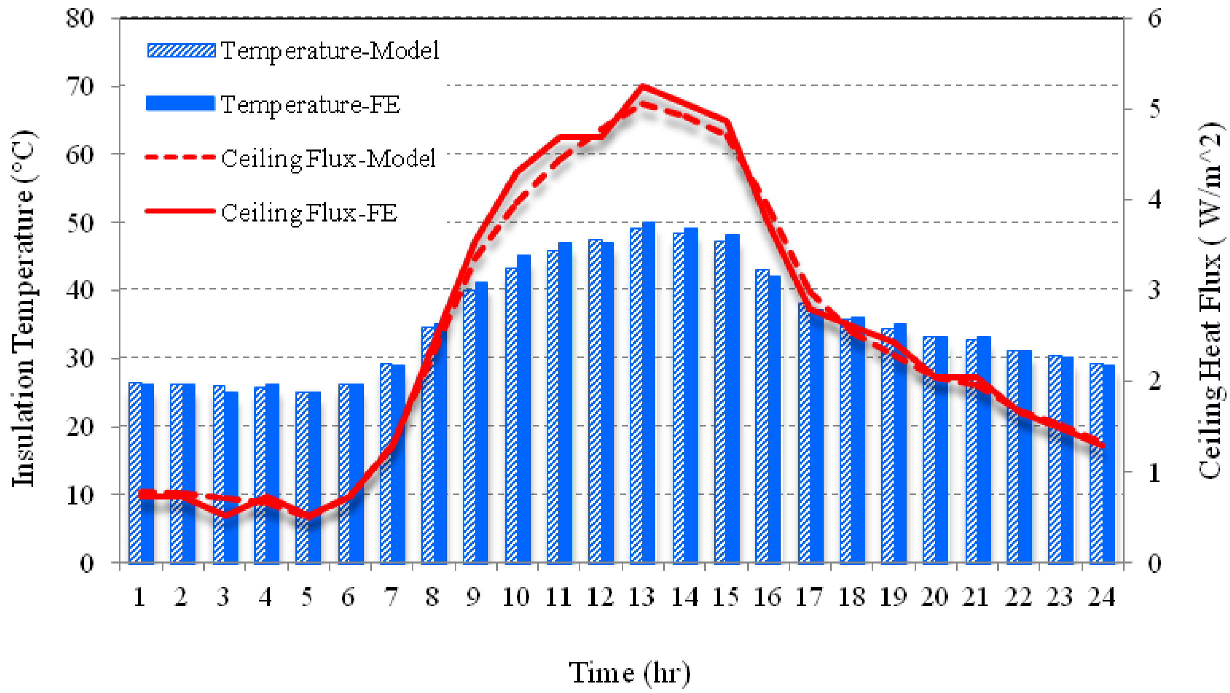


Figure 38: Insulation temperature and heat flux in the house with radiant barrier

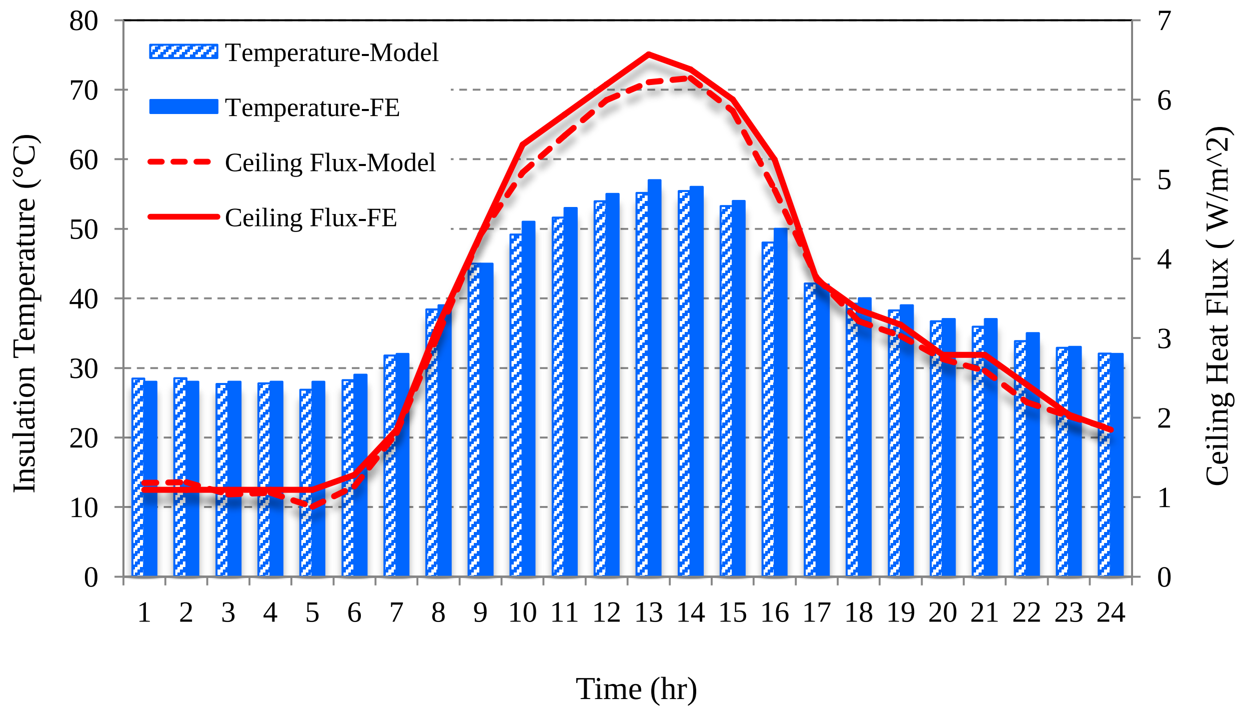


Figure 39: Insulation temperature and heat flux in the house without radiant barrier

5.6.2 Ceiling Heating-Cooling Load

Figures 40 and 41 represent the required annual ceiling heating-cooling load in the house with radiant barrier and control house (without radiant barrier) in 8 states. Ceiling was covered with R-19 insulation and the air gap thickness was zero. As shown in these figures, the annual ceiling heating-cooling load in the house without radiant barrier was larger than in the house with radiant barrier in all cases. This reduction in heat flux proves the usefulness of this technology in these climates. In some states such as Louisiana, Arizona, and Florida, the annual cooling load is larger than the annual heating load while in some states such as Minnesota and Montana due to their local climate, the annual heating load is larger than the cooling load.

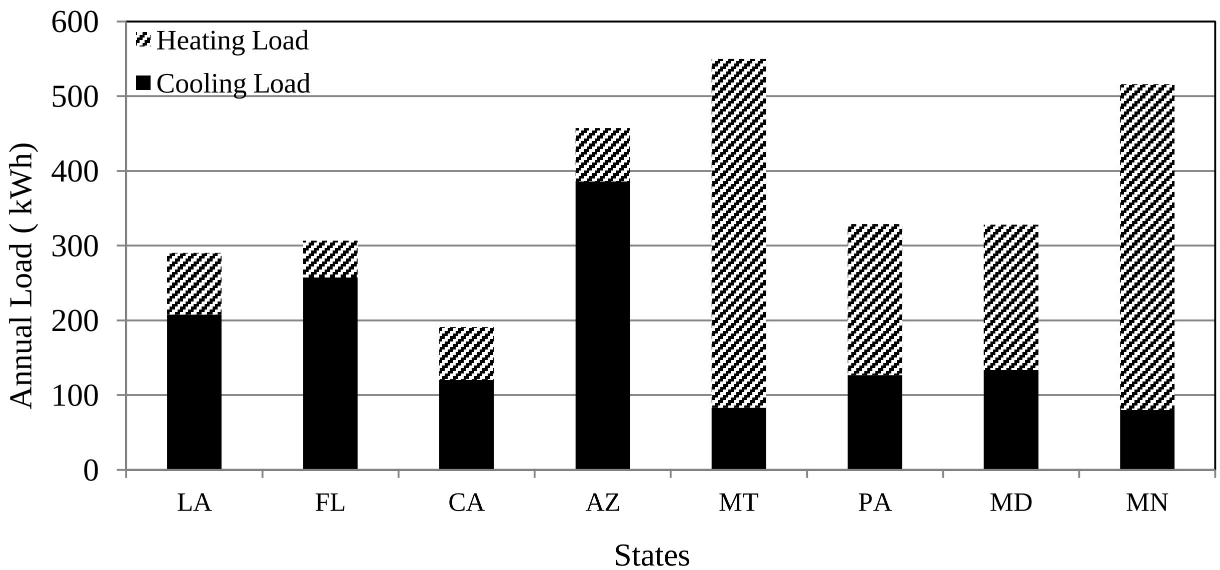


Figure 40: Annual ceiling heating-cooling load in the house with radiant barrier

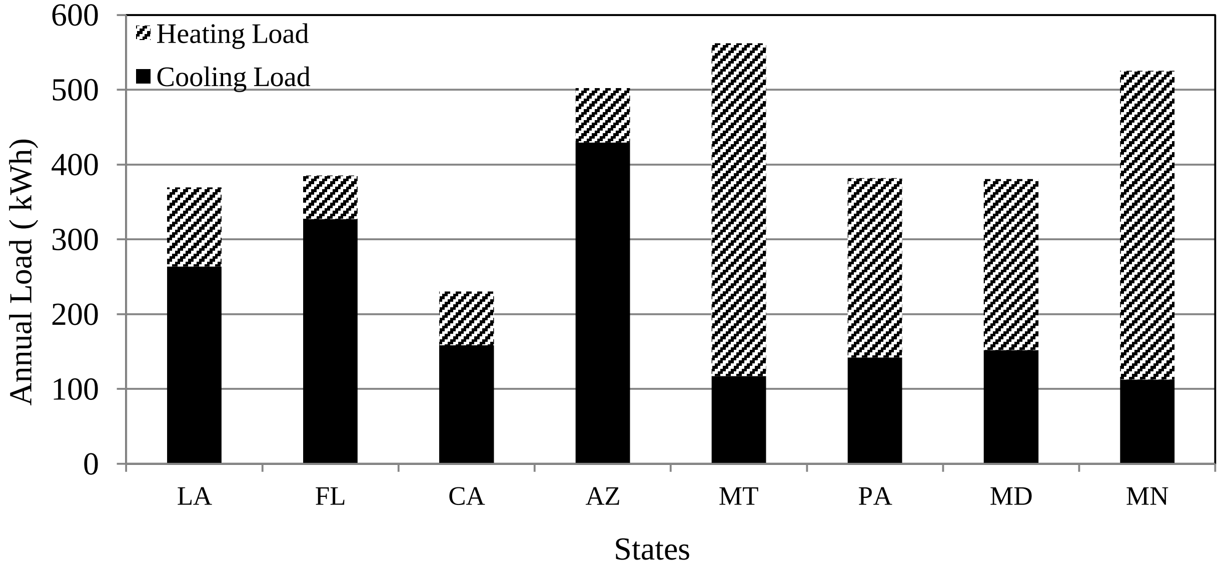


Figure 41: Annual ceiling heating-cooling load in the house without radiant barrier

5.6.3 Potential Cost Savings

To calculate the potential cost savings due to the application of radiant barrier in the attic, the fuel prices of each state in 2011 and typical HVAC system efficiencies were applied. The standards of the Department of Energy were used for heat pump and air conditioners. According to these standards, a Seasonal Energy Efficiency Ratio (SEER) of 13 and a Heating Season Performance Factor (HSPF) of 7.7 were used to convert energy savings to electricity savings. Table 4 shows the electricity prices used for each analysis location.

Results indicate that the saving estimates are very sensitive to the climate. Figure 42 presents the annual cost savings for a house with area of 148m^2 (1600ft^2) for the case with zero air gap thickness (i.e., radiant barrier was attached to plywood) and three levels of insulation resistance 1.94, 3.35, and 5.28 m^{2}K/W (R-11, R-19, and R-30) as compared to the house without radiant barrier. It is observed that the influence of climate is significant. States such as Arizona, Florida, and Louisiana are showing the highest cost savings due to the use of radiant barrier and

in Minnesota, the cost saving is small. Another factor that affects the saving estimates is the level of insulation. The higher cost savings were observed at the lower level of insulation.

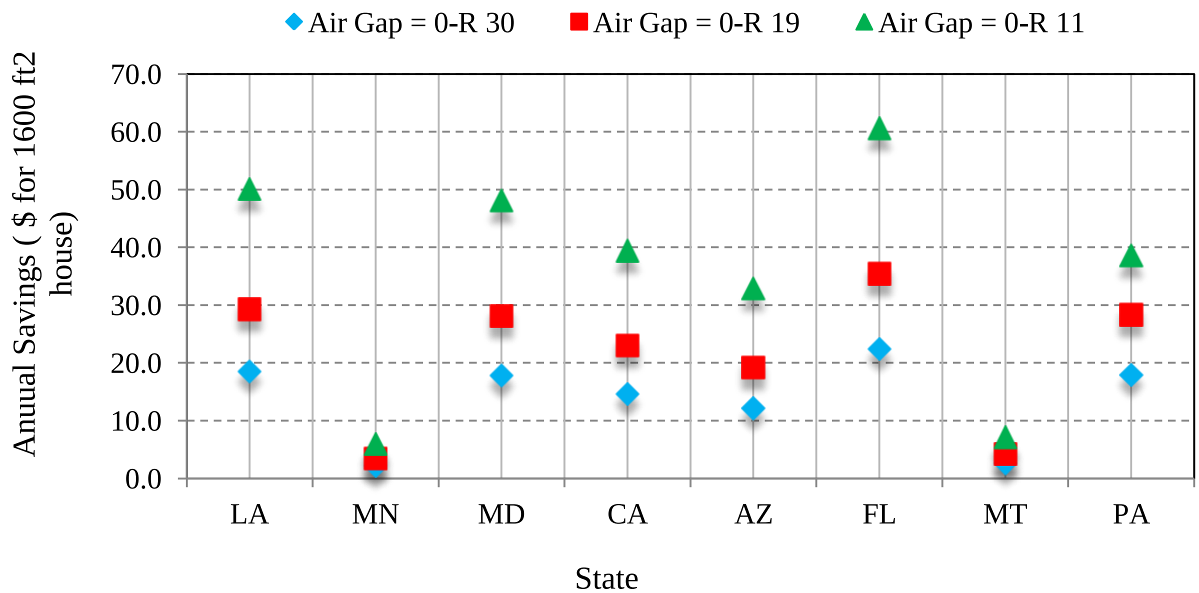


Figure 42: Cost savings in different states (air gap thickness=0)

Figures 43 and 44 present the influence of air gap thickness on the annual cost savings in different states. Figure 44 shows the annual cost saving when the air gap thickness is 0.75cm (i.e., the bubble radiant barrier was used) and Figure 44 shows the annual cost saving when the radiant barrier was installed on the rafters. Both figures compare the annual cost savings at three levels of insulation. By comparing Figures 42 to 44, it is evident that by increasing the thickness of the air gap, cost saving will increase. The thickness of the air gap had a significant effect on the heat gain or loss in the attic. Owing to its low thermal conductivity, the air gap serves to block the transfer of heat into the attic. As shown in Figures 42 to 44, at the lower amount of insulation, the higher percentage of reduction is achieved by the radiant barrier. This is attributed to the fact that increasing the insulation level causes an increase in the surface temperature of the radiant barrier as well as the other parts of the attic. This results in the radiation exchange that

occurs at higher temperatures and consequently, causing the smaller reduction of relative heat flow.

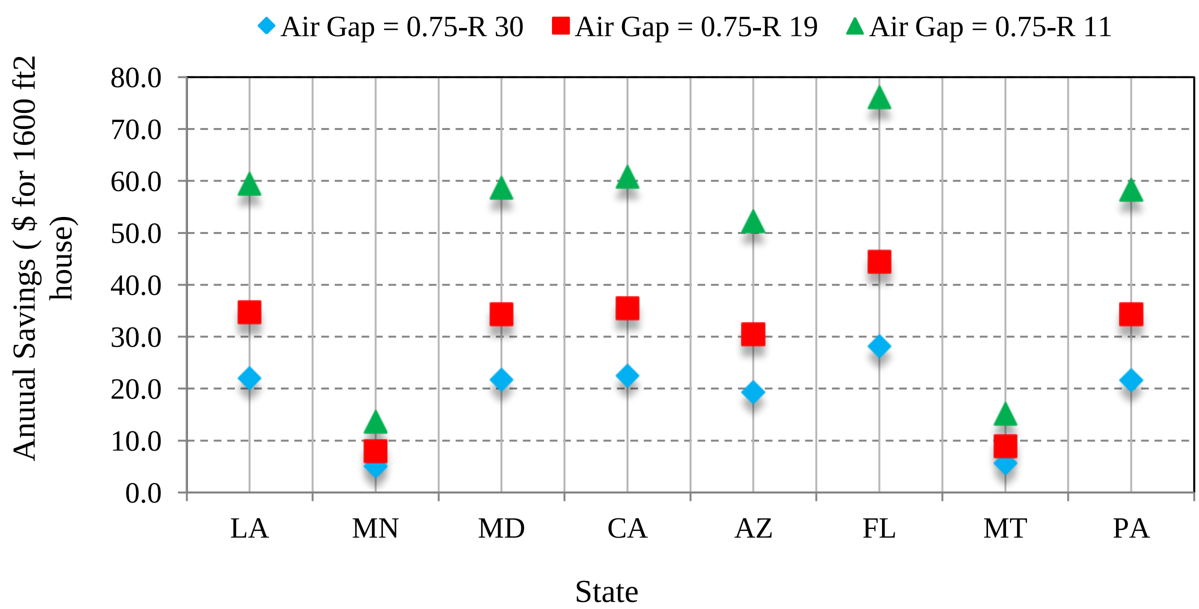


Figure 43: Cost savings in different states- air gap thickness = 0.75 cm

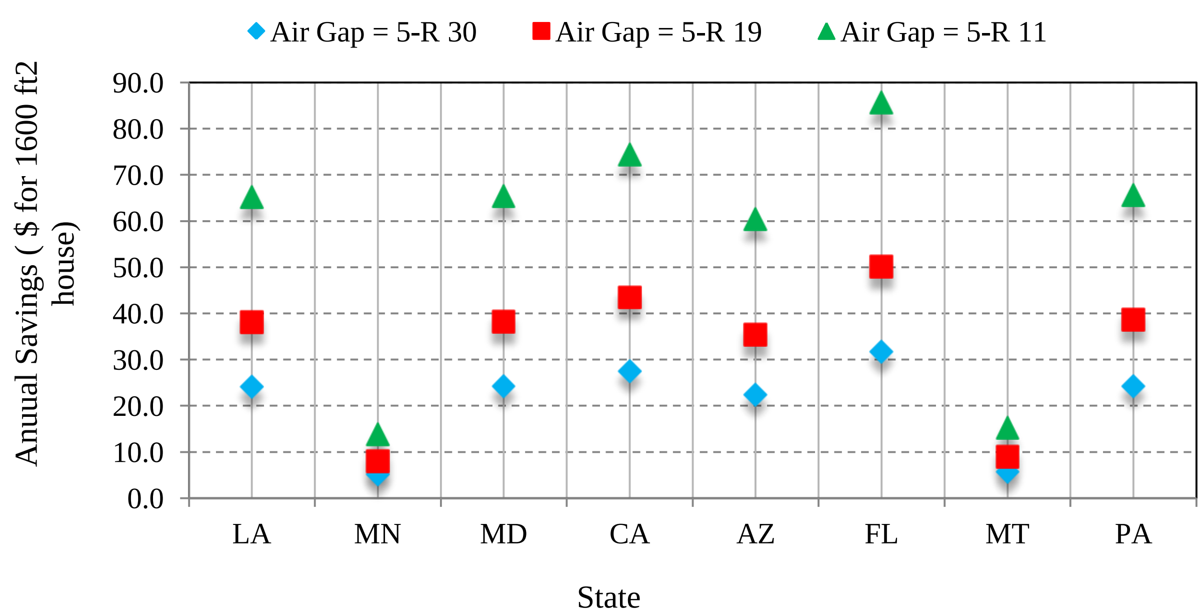


Figure 44: Cost savings in different states- air gap thickness =5cm

In order to investigate the performance of attic radiant barrier in each state in the four climate regions, the annual cost savings in 50 cities in each state of the U.S. was calculated. Figure 45 shows the annual cost savings for a 148m^2 (1600 ft^2) single family house for the case with zero air gap thickness (i.e., radiant barrier was attached to plywood) in 50 cities in the US. The ceiling of the attic was covered with insulation resistance of 3.35 m^{2}K/W (R-19). The influence of climate is evident with higher savings in hot and humid climates than in cold climates. As shown in Figure 45, Honolulu (Hawaii) had the highest annual savings, $86 per year and in cold states such as Main, New Hemisphere, and Alaska, the annual saving was zero. According to this map, the greatest cost savings occur in the south and southeastern regions.

5.6.4 Cost of Radiant Barrier

The cost of reflective insulation materials consists of two main components: the cost of buying materials and the cost of installation. Single-sided radiant barrier costs 10 ¢/ft^2 and double-sided radiant barrier costs 15 ¢/ft^2. The installation of radiant barrier is considered as Do It Yourself (DIY), therefore, the installation cost was considered zero in this study. The LCC was calculated for a typical single family house with area of 148m^2 (1600ft^2). It was found that for this typical house, the cost of the single-sided radiant barrier was $160 and $240 for double-sided.

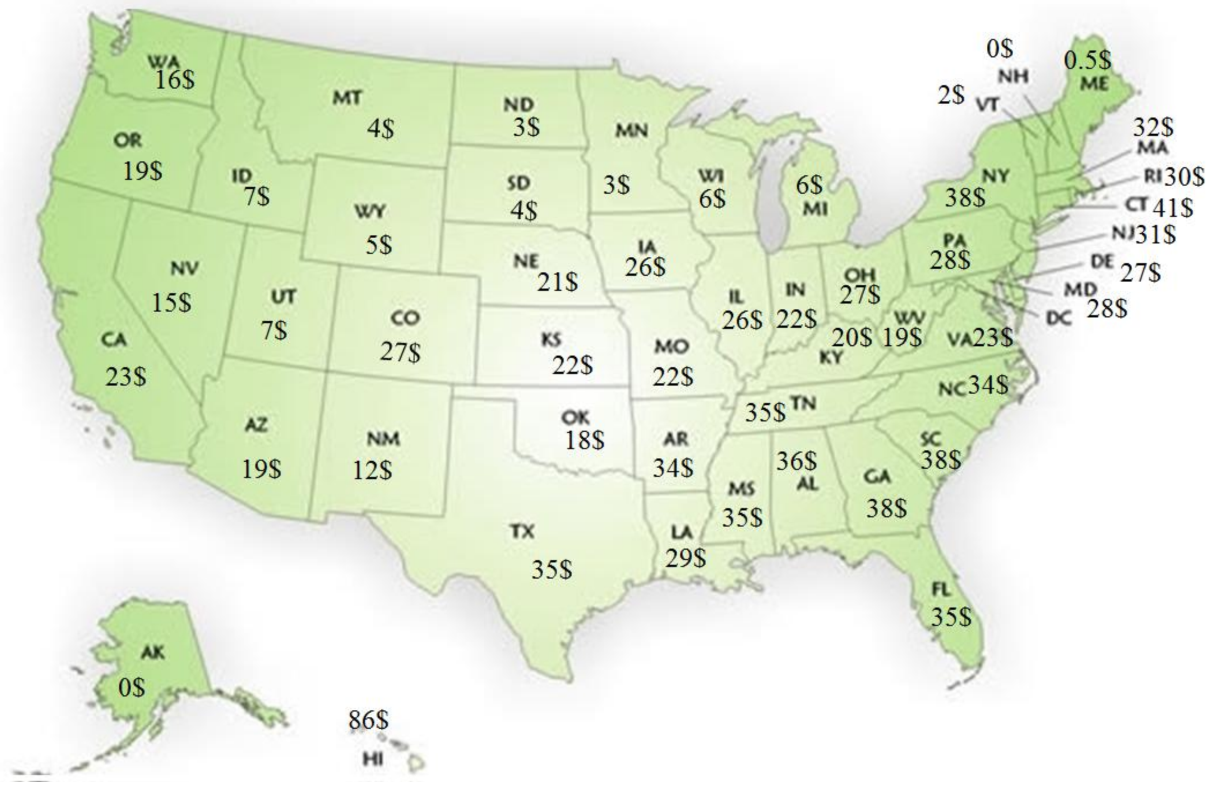


Figure 45: Potential cost saving in 50 states in 2011

5.7 Conclusions

Energy–conscious consumers are faced with the decision of whether or not to install a radiant barrier in their home, and if so, what type of radiant barrier to install. Therefore, the objective of this study was to develop a simple estimating tool that may be used by homeowners, state agencies, and contractors to assess the effectiveness and economic benefits of radiant barrier insulation systems under different climate conditions in the US. To achieve this objective, a series of transient 3D FE models were built and run based on a partial factorial design to investigate the influence of different design and operational parameters on the performance of radiant barrier. The results of the FE models were then implemented into a set of regression equations to predict the thermal and economic performances of radiant barriers under a wide

range of operating conditions. Accuracy of the models was assessed by the coefficient of determination (R^2), and Root Mean Square Error (RMSE). According to the residual analysis, the results from the model are well correlated with the data from FE simulation. The regression equations were also verified against experimental measurements it showed less than 5% error in all cases.

The required ceiling heating and cooling was calculated for 8 states having four different defined climate conditions in the U.S. Results indicated a strong relationship between the local climate parameters and energy consumption. Also the potential cost savings due to the use of radiant barrier in the attic were calculated for these states under different thickness of air gap and insulation levels. It is evident that by increasing the thickness of the air gap, cost saving will increase. The thickness of the air gap has a significant effect on the heat gain or loss in the attic. Owing to its low thermal conductivity, the air gap serves to block the transfer of heat into the attic. Also, at the lower amount of insulation, the higher percentage of reduction is achieved by the radiant barrier. This is attributed to the fact that increasing the insulation level causes an increase in the surface temperature of the radiant barrier as well as the other parts of the attic. This results in the radiation exchange that occurs at higher temperatures and consequently, causing the smaller reduction of relative heat flow.

The potential cost savings due to the application of radiant barrier was calculated separately for each state. Results showed that Hawaii had the highest cost savings and in northern regions, the cost savings was very low. According to these results, the greatest cost savings is expected in the south and southeastern regions of the US.

CHAPTER 6: CONCLUSION AND FUTURE WORK

Summary:

The main Objective of the dissertation was to develop a simple estimating tool that may be used by homeowners, state agencies, and contractors to assess the effectiveness and economic benefits of radiant barrier insulation systems under the different climatic conditions in US. In order to achieve this objective, the dissertation was divided in to three phases: the first phase was dedicated to the effectiveness of radiant barrier system; the second one to evaluate the economic benefit of radiant barrier system; and the third phase was to develop a simple estimating tool.

6.1 Conclusion

Based on this study, the following conclusions can be drawn:

- Experimental results showed a notable difference between the temperature of attic air and insulation in the house with radiant barrier and the control house in the summer. Attic air temperature in the control house was 6°C higher than the house with radiant barrier. The lower temperature of attic air in the house with radiant barrier shows the important role of radiant barrier as a reflector of solar radiation. The difference between attic air and insulation temperature in the house with radiant barrier and control house in winter was relatively small.
- The required ceiling heating and cooling loads were determined experimentally in the house with and without radiant barrier. Radiant barrier performance profile demonstrates the usefulness of the technology in Louisiana as it helps in decreasing the ceiling heat gains, which increase during periods of high solar activity. Radiant barrier also reduces the infrared radiation from the attic deck to the top of the insulation on the attic floor because of its low emissivity and absorptivity. Results showed that radiant barrier is

mainly useful during the hours between 11 a.m. through 9 p.m., but it may still be beneficial in reducing the heat transfer rate during night and early mornings. According to the heat flux results, radiant barrier can reduce energy loads in winter by a factor ranging from 8 to 11% depending on the prevailing climatic conditions.

- Results of the experimental program were also used to investigate the sensitivity of ceiling heat flux reduction to environmental parameters such as local ambient air temperature, relative humidity, global horizontal solar radiation, wind speed, and sky cloud cover. It was concluded that among these parameters, ambient air temperature and solar radiation had the highest effects on the ceiling heat flux reduction in residential buildings in Louisiana.
- The hourly temperatures predicted by the finite element model were compared to experimental measurements and showed good agreement with the experimental data. The error was less than 5% in most cases.
- A parametric study was conducted to evaluate the performance of radiant barrier as a function of shingle emissivity, thickness of air gap, radiant barrier emissivity, and location of radiant barrier in the roof. Based on the parametric study, it was also determined that the thickness of air gap had a significant effect on the performance of radiant barrier.
- The hourly temperatures predicted by the regression model were compared to the data obtained from finite element simulation. The regression equations were also verified against experimental measurements it showed less than 5% error in most cases.
- The required ceiling heating and cooling was calculated for 8 states of four defined climate conditions in the U.S. Results indicated a strong relationship between the local

climate parameters and energy consumption. Results showed that among the 8 states, Montana had the highest demand for ceiling heating load and Arizona had the highest demand for ceiling cooling load.

- Also the potential cost savings due to the use of radiant barrier in the attic were calculated for these states under different thickness of air gap and insulation levels. It is evident that by increasing the thickness of the air gap, cost saving will increase. The thickness of the air gap had a significant effect on the heat gain or loss in the attic. Also, at the lower level of insulation, the higher percentage of reduction is achieved by the radiant barrier. This is attributed to the fact that increasing the insulation level causes an increase in the surface temperature of the radiant barrier as well as the other parts of the attic. This results in the radiation exchange that occurs at higher temperatures and consequently, causing the smaller reduction of relative heat flow.
- The potential cost savings due to the application of radiant barrier was calculated separately for each state. Results showed that Hawaii had the highest cost savings and in northern regions, the cost savings was very low. According to these results, the greatest cost savings is expected in the south and southeastern regions of the US.

6.2 Recommendations and Future Work

This study only quantifies the performance of attic radiant barrier system in residential construction with specific geometry. Based on the above conclusions of this study, the following future research is recommended:

- Future research is needed to study the effect of different shape of attic on the performance of radiant barrier system.

- Studies should be conducted to evaluate the performance of radiant barrier insulation systems in the walls of buildings.
- Research is needed to quantify the performance of attic radiant barrier insulation system in commercial construction.

REFERENCES

ABAQUS. ABAQUS User Manual. 6.9 ed: Dassault Systems Simulia Corp.; 2009.

Abdeen M.O., Energy, environment and sustainable development, Renewable and Sustainable Energy Reviews, 2008, 12:2265–2300.

Abdeen M.O., Energy, environment and sustainable development, Renewable and Sustainable Energy Reviews, 2008, 12:2265–2300.

Ahmed, Z.N. 1987. The Effects of Climate on the Design and Location of Windows in Bangladesh. Ph.D.thesis. Department of Building Science, Sheffield University.

Akbari, H., S. Bretz, D. Kurn, J. Hanford, (1997). Peak power and cooling energy savings of high-albedo roofs, Energy and Buildings, (25), 117–126.

AlAnzi A. et al., Impact of building shape on thermal performance of office buildings in Kuwait, Energy Conversion and Management, 50 (2009) 822–828.

Al-Asmar H.R., B.W. Jones, D.K. Matteson, (1996). Experimental evaluation of attic radiant barriers (RP-577) ASHRAE Transactions, vol. 102, ASHRAE Inc., Faxon Finder, pp. 297–306, ISSN: 0001-2505.

Al-Asmar, H.R., Jones, B.W., Matteson, D.K., “Experimental Evaluation of Attic Radiant Barriers, “ASHREA Transactions, June 1996, Vol.102, pp. 589-597.

Aldawoud, A. & Clark, R. 2008. Comparative Analysis of Energy Performance Between Courtyard and Atrium in Buildings. Energy and Buildings, 40 (3): 209-214.

Alvarado, J.L., Martı´nez E. 2008. Passive Cooling of Cement-Based Roofs in Tropical Climates. Energy and Building, 40 (3): 358-364.

Andersson S., Olofsson T., Ostin R., Predictions of energy demand in buildings using neural network techniques on performance data, Proceedings of the 4th Symposium on Building Physics in the Nordic Countries, 1996, Espoo, Finland, Vol. 1, pp. 5l-58.

Anello, M.T., D.S. Parker, J.R. Sherwin, and K. Richards. 2000. Measured impact of advanced windows on cooling energy use. Proceedings of the 2000 ACEEE Summer Study 1: 29-38.

Anstett M. and Kreider J.F., Application of Neuronal Network Models to Predict energy use, ASHRAE Transactions, 1993, 3672:505-517.

Arasteh D., R. Johnson, S. Selkowitz, and D. Connell. 1985. Cooling energy and cost savings with daylighting in a hot and humid climate. 2nd Symposium on Improving Building Systems in Hot and Humid Climate 1-7.

Asadi, S. Hassan, M. (2011), Evaluation of the Thermal Performance of Radiant Barrier in Heating and Cooling Load Reduction of Residential Buildings, Integrating Sustainability Practices in the Construction Industry, ASCE Proceeding.

Asadi, S. Hassan, M. Beheshti, A. (2012), Residential Attic with Radiant Barrier System: Finite Element Simulation and Parametric Study, 48th ASC Annual International Conference Proceedings.

Ashley, R., Garcia, O., Medina, M.A., and Turner, W.D., 1994, "Effect of Radiant Barrier Technology on Summer Attic Heat Load in South Texas," Proceedings- 9th Symposium on Improving Building Systems in Hot and Humid Climates, pp.121-124.

Ashrae Handbook Heating, Ventilation and Air Conditioning Applications, ASHRAE Inc., Atlanta, (1999), 32.6-32.21.

Ashrae, 1979, Handbook of Fundamentals, American Society of Heating, Refrigeration, and Air Conditioning Engineers.

Ashrae, 2009, Handbook of Fundamentals, American Society of Heating, Refrigeration, and Air Conditioning Engineers.

Ashrae. 1997. Handbook of Fundamentals

Ashrae. 2001. Handbook of Fundamentals.

Ashrae. 2001a. 2001 ASHRAE Handbook—Fundamentals. Atlanta, GA: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.

Ashrae. 2005. Handbook of Fundamentals.

Ashre, 1989, Handbook of Fundamentals, American Society of Heating, Refrigeration, and Air Conditioning Engineers, Atlanta, GA.

Aydinalp M., Ugursal V.I., Fung A.S., Modelling of the space and domestic howater energy consumption in the residential sector using neural networks, Applied Energy, 2004, 79(2):159–178.

Aydinalp M., V.I. Ugursal, A.S. Fung, Modelling of the appliance, lighting, and space cooling energy consumption in the residential sector using neural networks, Applied Energy, 2002, 71(2):87–110.

Baldinelli, G., (2010). A methodology for experimental evaluations of low-e barriers thermal properties: field tests and comparison with theoretical models, Building and Environment 45 (4),1016–1024.

Barnaby, C. S., J. D. Spitler, and D. Xiao. 2004. Updating the ASHRAE/ACCA Residential Heating and Cooling Load Calculation Procedures and Data. 1199-RP final report. ASHRAE, Atlanta, GA.

Barnaby, C. S., J. D. Spitler, and D. Xiao. 2005. The Residential Heat Balance Method for Heating and Cooling Load Calculations (1199-RP). ASHRAE Transactions 111(1), ASHRAE, Atlanta, GA.

Bau, H.H. © ENM 427/ MEAM 527, Class Notes, "Chapter 1: Introduction to Finite

Bau, H.H. ©, MEAM 427 Class Notes, "Chapter 2: Interpolation" 21 August 2006.

Bolatturk, A. 2008. Optimum Insulation Thicknesses for Building Walls with Respect to Cooling and Heating Degree-Hours in the Warmest Zone Of Turkey. Building and Environment, 43 (6): 1055–1064.

Bourne, Marc A. Hoeschele and Richard. 1990, "Climate. Influence on Attic Radiant Barrier Energy and Demand Savings "American Council for an Energy- Efficient Economy Summer Study on Energy Efficiency in Buildings, pp 1.5-1.31.

Budaiwi, I. , A. Abdou, and M. Al-Homoud, (2002), Variations of Thermal Conductivity of Insulation Materials Under Different Operating Temperatures: Impact on Envelope-Induced Cooling Load, ASCE Journal of Architectural Engineering, December 2002.

Burch D.M and Treado , S.J 1978 , Ventilation Residence and their attics for energy conservation, experimental study'' in summer attic and whole house ventilation.NBS special publication 548, pp 73-104.

C. Michels, R. Lamberts, S. Guths, Evaluation of heat flux reduction provided by the use of radiant barriers in clay tile roofs, Energy and Buildings 40 (2008) 445–451

Capeluto, I.G. 2003. Energy performance of the self-shading building envelope. Energy and Buildings 35(3): 327-336.

Carpenter, S.C., A.G. McGowan, and S.R. Miller. 1998. Window annual energy rating systems: what they tell us about residential window design and selection. ASHRAE Transactions 104(1): 1360-1375.

Chen, H., Larson, T. & Erikson, R. W. 1992. The performance of an attic radiant barrier for a simulated Minnesota winter. *Proceedings of the thermal performance of the exterior envelopes of buildings conference.*

Chen, T. S., ARMALY, B. F. & RAMACHANDRAN, N. 1986. Correlations for Laminar Mixed Convection Flows on Vertical, Inclined, and Horizontal Flat Plates. Journal of Heat Transfer-Transactions of the ASME, 108, 835-840.

Chen, T. S., Armaly, B. F. & Ramachandran, N. 1986. Correlations for Laminar Mixed Convection Flows on Vertical, Inclined, and Horizontal Flat Plates. *Journal of Heat Transfer-Transactions of the Asme,* 108**,** 835-840.

Cheung, C.K., Fuller, R.J. & Luther, M.B. 2005. Energy-Efficient Envelope Design for High-Rise Apartments. Energy and Buildings, 37 (1): 37-48.

Cheung, C.K., Fuller, R.J. & Luther, M.B. 2005. Energy-Efficient Envelope Design for High- Rise Apartments. Energy and Buildings, 37 (1): 37-48.

Chlela F., Développement d'une méthodologie de conception de bâtiments à basse consommation d'énergie, doctoral thesis, April 2008.

Chulsukon, P. 2002. Development and Analysis of a Sustainable, Low Energy House in a Hot and Humid Climate. Ph.D. Dissertation. College Station, TX: Texas A&M University.

Cooper, P .I, "The Absorbtion of Solar Radiation in Solar Stills'' Solar Energy Journal, Vol. 12, 1969.

Cordero, Elizabeth, 2001, sustainability in Architecture.MS Thesis, Massachusetts Institute of Technology, Cambridge, MA, pp. 45-61.

Crawley D. B., Lawrie L. K., Pedersen C. O., and Winkelmann F. C. (2000). "Energy plus: energy simulation program." ASHRAE Journal, 42(4), 49-50.

Dassault Systèmes 2009. Abaqus User Manual : version 6.9. Providence, RI: Dassault Systèmes/Simulia Corp.

Dassault Systèmes 2009. ABAQUS User Manual: version 6.9. Providence, RI: Dassault Systèmes/Simulia Corp.

Dassault Systèmes 2009. ABAQUS User Manual: version 6.9. Providence, RI: Dassault Systèmes/Simulia Corp.

Datta D., Tassou S.A., Marriott D., Application on Neural Networks for the pre diction of the energy consumption in a Supermarket, Proceedings of Clima 2000 Conference, Brussels, August 3 0 to September 2 1997.

Day A.R. et al., The use of the planning system to encourage low carbon energy technologies in buildings, Renewable Energy (2009), doi:10.1016/j.renene.2009.02.003.

Day A.R. et al., The use of the planning system to encourage low carbon energy technologies in buildings, Renewable Energy (2009), doi:10.1016/j.renene.2009.02.003.

Department of Energy (DOE), 2010. Radiant Barrier fact sheet.

Department of Energy, (2009), Buildings Energy Data Book: 1.2 Residential Sector Energy Consumption.

Department of Energy, US Energy Information Administration, Annual Energy Review (2010). DOE/EIA-0384(2010) | October 2011.

Depecker P., Menezo C., Virgone J., Lepers S., Design of building shape and en-ergetic consumption, Building and Environment, 2001, 36:627–635.

Dhar A., Reddy T.A., Claridge D.E., Modelling hourly energy use in commercial buildings with Fourrier series functional form, ASME, Journal of Solar Energy neering, 1998, (120)3:217-223.

Dickinson, H.C., and Van Disen, M.S. 1916 "The Testing of Thermal Insulators," American Society of Refrigerating Engineering, Vol. 3, No.2, pp. 5-25.

DOE-2 Engineers Manual. (1982). Los Alamos National Laboratory, Los Alamos, Version 2.1A.

Dong B., Cao C., Siew Eang L., Applying support vector macines to predibuilding energy consumption in tropical region, Energy and Buildings, 2005, 37:545-553.

Dubrous, F.M. 1991. A new computer package for rating window performance. ASHRAE Transactions 97(2): 694-700.

Duffie J. A. and Beckman W. A. 1991. Solar Engineering of Thermal Processes, Wiley, New

Duffie, J. A. & BECKMAN, W. A. 1974. Solar energy thermal processes, New York; London, Wiley-Interscience.

Duffie, J. A. & Beckman, W. A. 1974. *Solar energy thermal processes*, New York ; London, Wiley-Interscience.

Elani U.A., Alawaji S.H., Hasnain S.M., The Role of Renewable Energy in En-ergy Management and Conservation, WREC, 1996.

Elani U.A., Alawaji S.H., Hasnain S.M., The Role of Renewable Energy in En-ergy Management and Conservation, WREC, 1996.

Elements and Applications." 9 Sept 2009.

Energy Plus review, U.S. Department of Energy, Available on http://apps1.eere.energy.gov/buildings.

Erbs, D.G., 1982, Estimation of the diffuse Radiation Fraction fro, Hourly, Daily, and Monthly average Global Radiation, Solar Energy, Vol. 28, pp. 293-302.

F. Miranville, H. Boyer, P. Lauret, F. Lucas, A combined approach for determining the thermal performance of radiant barriers under field conditions, Solar Energy 82 (2008) 399–410.

F. Miranville, H. Fakra, A.H. Boyer, P. Lauret, F. Lucas, Bigot, D. Evaluation of the thermal resistance of a roof-mounted multi-reflective radiant barrier for tropical and humid conditions: Experimental study from field measurements, (2012), doi:10.1016/j.enbuild.2012.01.013.

Fairey P.W., 1983, “Effect of infrared Radiation Barriers on the Effective Thermal Resistance of Building Envelopes,” Proceedings, ASHREA/DOE Conference on Thermal Performance of the exterior envelopes of buildings II, ASHREA SP 38.

Fairey P.W., 1985, “The Measured Side by Side Performance of Attic Radiant Barrier Systems in Hot, Humid Climates, “Proceedings, 19th International Thermal Conductivity Conference, Cookeville, TN.

Fairey, P,. “Seasonal Prediction of Roof-Mounted Attic Radiant Barrier System Performance from Measured Test Data, 1990,” American Council for an Energy- Efficient Economy Summer Study on Energy Efficiency in Buildings, pp. 1.103-1.114.

Fairey, P., (1985),The measured side-by-side performance of attic radiant barrier systems in hot and humid climates, in: Nineteenth International Thermal Conductivity Conference, Cookville, Tenn., pp. 481–496.

Faireym, P. W. The Measured Side-by-side Performance of Attic Radiant Barrier Systems in Hot, Humid Climates. Proceedings of the 19th international thermal conductivity conference, 1985.

Fairy, P., Swami, M. and Beal, D., 1988, “Radiant barrier system technology: Task 3 Report,” Draft report, FSEC-CR-211-88, Florida Solar Energy Center, Cape Canaveral, FL., April 1988.

Farrar-Nagy, S., P. Reevers, and R. Anderson. 2000. Impacts of shading and glazing combinations on residential energy use in a hot dry climate. Proceedings of the 2000 ACEEE Summer Study 1: 63-76.

Freund, R.J., and Littell, R.C., 2000, SAS system for regression (3rd ed.): Cary, N.C., 235 p.

G. Baldinelli, A methodology for experimental evaluations of low-e barriers thermal properties: field tests and comparison with theoretical models, Building and Environment 45 (4) (2010) 1016–1024.

Garde, F., Adelard,L., Boyer, H. & Rat, C. 2004.Implementations and Experimental Survey of Passive Design Specifications Used in New Low-Cost Housing Under Tropical Climates. Energy and Buildings, 36 (4): 353–366.

Givoni, B. 1998. Climate Considerations in Building and Urban Design. New York: Van Nostrand Reinhold.

Glicksman L.R., Norfold L.K, Garden L.V, 2001, Energy Consumption in Chinese Residential Buildings: Progress and Opportunities in Design and Policy. Annual Review of Energy and Environment, 28: 83-115.

Gordon , V. R. & Holness, R. E. 2008. Improving Energy Efficiency in Existing Buildings. *ASHRAE Journal*, 50**,** 12–26.

Goss, W. P. & Miller, R. G. 1989. Literature review and predictions of reflective building insulation system performance. *ASHRAE Transaction.*

Goss, W.P. and Miller R.G., 1989, “Literature Review and Predictions of Reflective Building Insulation System Performance”, 1900-1989, ASHREA Transactions.

Gut, P. & Ackerknecht, D. 1993. Climate Responsive Building: Appropriate Building Construction in Tropical and Subtropical Regions. Switzerland: SKAT.

H.R. Al-Asmar, B.W. Jones, D.K. Matteson, Experimental evaluation of attic radiant barriers (RP-577) ASHRAE Transactions, vol. 102, ASHRAE Inc., Faxon Finder, 1996, pp. 297–306, ISSN: 0001-2505.

Hall, J,. 1986, “ Performance Testing of Radiant Barriers, “ Third annual symposium on improving building energy efficiency in hot and humid climates, Texas A&M University, Energy Management Group, Department of Mechanical Engineering.

Hall, J. A. Performance testing of radiant barriers (RB) with R-11, R-19, and R-30 cellulose and rock wool insulation Proceedings of the fifth annual symposium on improving building energy efficiency in hot and humid climates, 1989. 174–185.

Hall, J., 1988(a), “ Performance testing of radiant barriers with R 11, R 19, and R30 Cellulose and rock wool insulation,” fifth annual symposium on improving building energy efficiency in Hot and Humid climates, Texas A & M University, Energy management group, Department of mechanical engineering.

Hall, J., 1988(b), “Radiant Barrier testing to assess effects of dust accumulation, attic Ventilation, and other key variables,” TVA/OP/EDT-88/25, DE89 006441, Tennessee Valley Autorithy.

Hall, J., 1988(b), “Radiant Barrier testing to assess effects of dust accumulation, attic Ventilation, and other key variables,” TVA/OP/EDT-88/25, DE89 006441, Tennessee Valley Authority.

Hall, J.A. (1985), Performance testing of radiant barriers, in: Third Annual Symposium on Improving Building Energy Efficiency in Hot and Humid Climates, Arlington, Texas, , pp. 55–77.

Hassid, S., M. Santamouris, N. Papanikolaou, A. Linardi, N. Klitsikas, C. Georgakis, D.N. Assimakopoulos(2000), The effect of the Athens heat island on air conditioning load, Energy and Buildings 32 131–141.

Hiranoa,T., Katoa,S., Murakamib, S., Ikagac, T. & Shiraishi, Y. 2006. A Study on a Porous Residential Building Model in Hot and Humid Regions: Part 1-The Natural Ventilation Performance and the Cooling Load Reduction Effect of the Building Model. Building and Environment, 41 (1): 21-32.

Holman, J. P. 2002. *Heat transfer*, Boston [Mass.] ; London, McGraw-Hill.

Holman, J. P. 2002. Heat transfer, Boston [Mass.]; London, McGraw-Hill.

http://www.eere.energy.gov/consumerinfo/factsheets/eelight.html, Energy Efficient Lighting.

http://www.rio02.de/proceedings/pdf/159_Grimme.pdf, Michael Laar and Friedrich Wilhelm Grimme, Sustainable Buildings in the Tropics.

International Energy Agency, 30 years of energy use in IEA countries. Oil crisis and climate challenges, IEA-OECD, 2004.

International Energy Agency, 30 years of energy use in IEA countries. Oil crisis and climate challenges, IEA-OECD, 2004.

J.A. Hall, Performance testing of radiant barriers, in: Third Annual Symposium on Improving Building Energy Efficiency in Hot and Humid Climates, Arlington, Texas, 1985, pp. 55–77.

Jedrzejuk H., Marks W., Optimization of shape and functional structure of build-ings as well as heat source utilization. Basic theory, Building and Environment 2002, 37:1379–1383.

Jedrzejuk H., Marks W., Optimization of shape and functional structure of buildings as well as heat source utilisation example, Building and Environment, 2002, 37: 1249-1253.

Jones, W.P., Air Conditioning Engineering , Fourth Edition, Edward Arnold member of Hodder Headline Plc , London , 1994.

Joy, F. A. 1958. Improving Attic Space Insulating Values. ASHRAE Transaction, 64, 251-266.

Joy, F. A. 1958. Improving Attic Space Insulating Values. *ASHRAE Transaction,* 64**,** 251-266.

Katipamula, S. & O'neal, D. L. An evaluation of the placement of radiant barriers on their effectiveness in reducing heat transfer in attics. Proceedings of the third annual symposium on improving building energy efficiency in hot and humid climates, 1986. 68–77.

Katipamula, S., and O'Neal , D.L., 1986, " An evaluation of the placement of radiant barriers on their effectiveness in reducing heat transfer in attics," Third annual symposium on improving building energy efficiency in Hot and Humid climates, Texas A & M University, Energy management group, Department of mechanical engineering.

Katipamula, S., Tuner, W. D., Murphy, W. E. and O'Neal , D.L., 1985, "Influence of Infrared Radiation on attic heat transfer,'' second annual symposium on improving building energy efficiency in Hot and Humid climates, Texas A & M University, Energy management group, Department of mechanical engineering.

Kawashima M., Artificial neural network back propagation model with three-phase annealing developed for the building energy predictor shootout, ASHRAETransactions, 1994, 100(2):1095–1103.

Krarti, M., Erickson, P.M. & Hillman, T.C. 2005. A Simplified Method to Estimate Energy Savings of Artificial Lighting Use from Day Lighting. Building and Environment, 40 (6): 747-754.

Kreider J.F. and Wang X.A., Artificial Neural Network demonstration for auto-mated generation of energy use predictors for commercial buildings, ASHRAE Tranactions, 1997, 2:775-779.

Kreider J.F. and. Wang X.A, Improved artificial neural networks for commercial Building energy use prediction, Solar Engineering ASM 1, 1992, pp. 361–366.

Kreider J.F., Claridge D.E., Curtiss P., Dodier R., Haberl J.S., Krati M., Build- ing energy use prediction and system identification using recurrent neural networks, Solar Energy Journal, 1995, 117:161-166.

Law, A.M., Simulation Modeling and Analysis, 4^{th} Edition, 2007, Mc Grow Hill.

Lear, W.E., Barrup, T.E., and Davis. K.E., 1987, " Preliminary Study of a Vented attic Radiant Barrier System in Hot, Humid climates Using Side-by-Side, Full-Scale Test Houses," Proceedings of the Fourth Annual Symposium in Improving Building Energy Efficiency in Hot and Humid Climates, Houston, TX., pp. 195-198.

Levins, W. P. & Karnitz, M. A. 1987. Heating Energy Measurements of Unoccupied Single-Family Houses with Attics Containing Radiant Barriers *ORNL/CON-213.* Oak Ridge National Laboratory.

Levins, W. P. and Kernitz,M. A., 1988, " Heating energy measurements of single- family houses with attics containing radiant barriers in combination with R-11 and R-30 ceiling insulation," Oak Ridge National Laboratory, ORNL/M-1067, February, 1990.

Levins, W.P. and Hall, J. A., 1990, "Measured Effect of Dust on the Performance of Radiant Barriers Installed in Top of Attic Insulation." Presented at the ASHREA Summer Meeting St. Luis Missouri, June 24-28, 1990, CONF 9006117-3. DE 90-008911.

Levins, W.P. and Herron, D.L., "Radiant Barrier Field Tests in Army Family Housing Units at Fort Benning, Georgia," ASHREA Transactions, June, 1990 npt.2, pp. 589-597.

Levins, W.P. and Karnitz, M.A., 1987(a). "Heating energy measurements of unoccupied single- family houses with attics containing radiant barriers," Oak Ridge National Laboratory, ORNL/CON-213, January, 1987.

Levins, W.P. and Karnitz, M.A., 1987(b). "Cooling energy measurements of unoccupied single- family houses with attics containing radiant barriers," Oak Ridge National Laboratory, ORNL/CON-226, May, 1987.

Levins, W.P. and Karnitz, M.A.,and Knight D.K., 1986, " Cooling Energy Measurements of Houses with Attic Containing Radiant Barriers". Third annual symposium on improving building energy efficiency in Hot and Humid climates, Texas A & M University, Energy management group, Department of mechanical engineering.

Levins, W.P., Karnitz, M.A. and Hall, J. A., 1990," Cooling season energy measurements of dust and ventilation effects on radiant barriers," Oak Ridge National Laboratory, ORNL/M-1067, February, 1990.

Levinson, R.,Berdahl,P.,Berhe, A. & Akbari, H. 2005. Effects of Soiling and Cleaning on the Reflectance and Solar Heat Gain of a Light-Coloured Roofing Membrane. Atmospheric Environment, 39 (40): 7807–7824.

Liping, W., Hien,W.N & Shuo, L. 2007. Facade Design Optimization for Naturally Ventilated Residential Buildings in Singapore. Energy and Buildings, 39 (8): 954-961.

Liping, W., Hien,W.N & Shuo, L. 2007. Facade Design Optimization for Naturally Ventilated Residential Buildings in Singapore. Energy and Buildings, 39 (8): 954-961.

Lotz, F.J., 1964, "The Effect of Dust on the Efficiency of Reflective Metal Foil Used as a Roof Ceiling Insulation." National Building Research Institute Bulletin 33, Council for Scientific and Industrial Research Report #212, Pretoria, South Africa.

Lutz, J. D., Liu, X., McMahon, J. E., Dunham, C., & McGrue, Q. T., 1996, "Modeling Residential Hot Water Use Patterns," No. LBL-37805, Lawrence Berkeley National Laboratory.

Mallick, F.H. 1996. Thermal Comfort and Building Design in the Tropical Climates. Energy and Buildings, 23 (1996): 161-167.

Marcel Dekker Inc. New York, NY. 1993.

Mathur,V. K. & Chand, I. 2003. Climatic Design for Energy Efficiency in Buildings. IE (I) Journal-AR, 84 (2003): 33-39.

McCluney, R. and L. Mills. 1993. Effect of interior shade on window solar gain. ASHRAE Transactions 99(2): 565-570.

Medina, M. A. & Young, B. (2006). A Perspective on the Effect of Climate and Local Environmental Variables on the Performance of Attic Radiant Barriers in the United States. Building and Environment, 41, 1767-1778.

Medina, M. A. & Young, B. (2006). A Perspective on the Effect of Climate and Local Environmental Variables on the Performance of Attic Radiant Barriers in the United States. Building and Environment, 41, 1767-1778.

Medina, M. A. & YOUNG, B. 2006. A Perspective On the Effect of Climate and Local Environmental Variables On the Performance of Attic Radiant Barriers in the United States. Building and Environment, 41, 1767-1778.

Medina, M. A. & Young, B. 2006. A Perspective On the Effect of Climate and Local Environmental Variables On the Performance of Attic Radiant Barriers in the United States. *Building and Environment,* 41**,** 1767-1778.

Medina, M. A. & Young, B. 2006. A Perspective on the Effect of Climate and Local Environmental Variables on the Performance of Attic Radiant Barriers in the United States. Building and Environment, 41, 1767-1778.

Medina, M. A., O'neal, D. L. & Turner, W. D. (1998a). A Transient Heat and Mass Transfer Model of Residential Attics Used to Simulate Radiant Barrier Retrofits, Part I: Development. Journal of Solar Energy Engineering-Transactions of the Asme, 120, 32-38.

Medina, M. A., O'neal, D. L. & Turner, W. D. (1998b). A Transient Heat and Mass Transfer Model of Residential Attics Used to Simulate Radiant Barrier Retrofits, part II: Validation and simulations. Journal of Solar Energy Engineering-Transactions of the ASME, 120, 39-44.

Medina, M. A., O'neal, D. L. & Turner, W. D. 1998a. A Transient Heat and Mass Transfer Model of Residential Attics Used to Simulate Radiant Barrier Retrofits, Part I: Development. *Journal of Solar Energy Engineering-Transactions of the Asme,* 120**,** 32-38.

Medina, M. A., O'neal, D. L. & Turner, W. D. 1998a. A Transient Heat and Mass Transfer Model of Residential Attics Used to Simulate Radiant Barrier Retrofits, Part I: Development. Journal of Solar Energy Engineering-Transactions of the ASME, 120, 32-38.

Medina, M. A., O'neal, D. L. & Turner, W. D. 1998b. A Transient Heat and Mass Transfer Model of Residential Attics Used to Simulate Radiant Barrier Retrofits, part II: Validation and simulations. *Journal of Solar Energy Engineering-Transactions of the Asme,* 120**,** 39-44.

Medina, M. A., O'neal, D. L. & Turner, W. D. 1998b. A Transient Heat and Mass Transfer Model of Residential Attics Used to Simulate Radiant Barrier Retrofits, part II: Validation and simulations. Journal of Solar Energy Engineering-Transactions of the ASME, 120, 39-44.

Medina, M.A., 2000, “On the Performance of Radiant Barriers in Combination with Different Attic Insulation Levels,” Journal of Energy and Buildings, Vol. 33, pp. 31-40.

Medina, M.A., O'Neal, D.L., and Turner, W.D., 1992, " Effects of Radiant Barrier Systems on Ventilated Attics in a Hot and Humid Climates, Proceedings- 8th Symposium on Improving Building Systems in Hot and Humid Climates, pp.47-52.

Medina, M.A., O'Neal, D.L., and Turner, W.D., 1992, "Effect of Attic Ventilation on the Performance of Radiant Barriers," Journal of Solar Energy Engineering, November 1992, Vol.114, pp.234-239.

Medina,M., Development of the Transient Heat and Mass Transfer Model of Residential Attics To Predict Energy Savings Produced by the Use of Radiant Barriers, PhD Dissertation, Texas A&M University, December 1992.

Merritt, F.S and Ricketts, J.T, Building Design and Construction Handbook, Sixth Edition, McGraw-HILL, New York, 2001.

Midwest Roofing Contractors Association(MRCA) 2006. Reflective Industry Continues to Grow.

Mitalas, G.P., and Stephenson, D.G., 1967, "Room Thermal Response Factors," ASHRAE Transactions, Vol. 73, Part I.

Moujaes, S. F. & Alsaiegh, N. T. 2000. Numerical Heat Transfer Attic Model Using a Radiant Barrier System. *Journal of Energy Engineering-ASCE,* 126**,** 32-51.

Moujaes, S.F., and Alsaiegh, N.T., 2000, " Numerical Heat Transfer Attic Model Using a Radiant Barrier System", Journal of Energy Engineering, April 2000, pp. 32-50.

Moujaes. S., 1996, "Use of Passive Radiant Barriers in Ventilated Attics." ASHREA Transactions, 102(1): 307-314.

Moujaes. S., and Brickman.R., (1995), "Simulation and Evaluation of Passive Energy Technology in Residential Space.", Energy Sources, 17(N2): 153-160.

Moujaes. S., and Brickman.R., 1995, "Simulation and Evaluation of Passive Energy Technology in Residential Space.", Energy Sources, 17(N2): 153-160.

Moujaes. S.,1992, A parametric Study of the effect of roof Attic Radiant Barrier System (ARBS) Emissivities, Roof Orientation, and Wind Speed on Ceiling Cooling Load Through Modeling. In Proc of the International Symposium ECOS 92. Organized by University of Zaragoza. Spain. With ASME Advanced Energy Systems Division. PP 689-696.

Mowla, Q.A. 1985. An Analytical Study of Sun-Building Interaction. Roorkee. Master's thesis. Department of Architecture and Planning.University of Roorkee.

Mowla, Q.A. 1985. An Analytical Study of Sun-Building Interaction. Roorkee. Master's thesis. Department of Architecture and Planning.University of Roorkee.

National Renewable Energy Laboratory. (1995). “User’s manual for TMY2 (Typical Meteorological Years).” NREL/SP-463-7668, and TMY2s, typical meteorological years derived from 1961-1990 national solar radiation data base, Golden, Colo.

Nebeker, B. M. & Tong, T. W. 1992. Heat Transfer in Rectangular Reflective Insulation Systems. *Journal of Building Physics,* 16**,** 50-65.

O’Neill P.J, Crawley D.B., Schliesing J.S., Using regression equations to deter mine the relative importance of inputs to energy simulation tools, Proceedings of the Building Simulation ’91 Conference, 20-22 August 1991, Sophia-Antipolis, Nice, France, pp. 283-289.

Ober, D.G., and Volckausen, T.W., (1988).Radiant Barrier Insulation Performance in Full Scale Attic with Soffit and Ridge Ventilation 5th Annual Symposium on Improving Building Energy Efficiency in Hot and Humid Climates, 169-173.

Ober, D.G., and Volckausen, T.W., 1988.Radiant Barrier Insulation Performance in Full Scale Attic with Soffit and Ridge Ventilation 5th Annual Symposium on Improving Building Energy Efficiency in Hot and Humid Climates, 169-173.

Ornl. 2002. DOE Insulation Fact Sheet. DOE/CE-0180/ with Addendum 1. Oak Ridge, TN: Oak Ridge National Laboratory.

Ossen, D.R., Ahmad, M.H. & Madros, N.H. 2005. Optimum Overhang Geometry for Building Energy Saving in Tropical Climates. Journal of Asian Architecture and Building Engineering, 4(2): 563-570.

Ourghi R., Al-Anzi A., Krarti M., A simplified analysis method to predict the impact of shape on annual energy use for office buildings, Energy Conversion an Management , 2007, 48:300–305.

P. Fairey, The measured side-by-side performance of attic radiant barrier systems in hot and humid climates, in: Nineteenth International Thermal Conductivity Conference, Cookville, Tenn., 1985, pp. 481–496.

Parker, D. 1998. Measured energy savings of a comprehensive retrofit in an existing Florida residence. Proceedings of the 1998 ACEEE Summer Study on Energy-Efficient Buildings 1: 235-253.

Payne, A., R. Duke, and R.H. Williams., 2001: Accelerating residential PV expansion: supply analysis for competitive electricity markets. Energy Policy, 29, pp. 787-800.

Peavy, B. A. 1979. A Model for Predicting the Thermal Performance of Ventilated Attic, Summer Attic and Whole House Ventilation *NBS special publication,* 548**,** 119-149.

Pessenlehner W, Mahdavi A., A building morphology, transparency, and energy performance, 8th international IBPSA conference proceedings, Eindhoven, Nethelands, 2003.

Petrie, T.W., K.E. Wilkes, P.W. Childs, J.E. Christian, (2000),Effect of radiant barriers and attic ventilation on residential attics and attic duct systems: new tools for measuring and modelling, in: ASHRAE Transactions, , pp. 1175–1192.

Pletzer, R.K., J.W. Jones, and B.D. Hunn. 1987. Energy savings resulting from shading devices on single family residences in Austin, Texas. Foruth Annual Symposium on Improving Building Energy Efficiency in Hot and Humid Climate: 112-121.

Power DOE, (1990). Los Alamos National Laboratory, Los Alamos, Version 2.1A

Raeissi,S. & Taheri, M. 1999. Energy Saving by Proper Tree Plantation. Building and Environment, 34(1999): 565-570.

Rasisuttha, S. and J. Haberl. 2004. The Development of Improved Energy Efficient Housing for Thailand Utilizing Renewable Energy Technology. Presented at SimBuild 2004, First National Conference of IBPSA-USA. Boulder, CO.

Reflective Insulation Manufacturer's Association (RIMA). (2002). "Understanding and Using Reflective Insulation, Radiant Barrier and Radiation Control Coatings." Available at www.rima.net.

Rock, B, (2009), Thermal and Economic Evaluation of Slab-on-Grade Insulation in Wood-Framed Buildings, ASCE Journal of Architectural Engineering, March 2009.

Roels, S. & Deurinck, M. 2011. The Effect of a Reflective Underlay on the Global Thermal Behaviour of Pitched Roofs. *Building and Environment,* 46**,** 134-143.

Ruano A.E., Crispim E.M., Conceição E.Z.E., Lúcio M.M.J.R., Prediction of building's temperature using neural networks models, Energy and Buildings, 2006, 38:682-694.

Sander D.M. et al, Development of a simple model to relate heating and cooling energy to building envelope thermal characteristics, Proceedings of the Building Simulation '93 Conference, 16-18 August 1993, Adelaide, Australia, pp. 223-230.

Santamouris M., Energy performance of residential buildings: A practical guide for energy rating and efficiency, 2005, Earthscan, 195 pages.

Santamouris, M., N. Papanikolaou, I. Livada, I. Koronakis, C. Georgakis, A. Argiriou, D.N. Assimakopoulos, (2001). On the impact of urban climate on the energy consumption of buildings, Energy and Buildings,(70), 201– 216.

Sikora, Jeannie Leggett (2002). Profit from Building Green. Washington, D.C.: BuilderBooks.

Simbad, SIMBAD Building and HVAC toolbox, Version 3.1.0., 2001, CSTB, France.

Simpson, J.R. & McPherson, E.G. 1996. Potential of Tree Shade for Reducing Residential Energy Use in California. Journal of Arboriculture, 22 (1): 23-31.

Soebarto, V.I. and L.O. Degelman. 1994. Effectiveness of external window attachments based on daylight utilization and cooling load reduction for small office buildings in hot and humid climate. In Proceedings of the 9th Symposium on Improving Building Systems in Hot and Humid Climates: 110-114.

Soubdhan, T., T. Feuillard, F. Bade, (2005), Experimental evaluation of insulation material in roofing system under tropical climate, Solar Energy, (79) 311–320.

Sparrow, E. M. & Cess, R. D. 1978. Radiation heat transfer, Washington [D.C.]; London, Hemisphere; New York; London: McGraw-Hill.

Sparrow, E. M. & Cess, R. D. 1978. *Radiation heat transfer,* Washington [D.C.] ; London, Hemisphere ; New York ; London : McGraw-Hill.

Stevenson W.J, Using Artificial Neuronal Networks to predict building energy parameters, ASHRAE Transactions, 1994, 100(2):1081.

Suehrcke, H., Peterson , E.L. & Selby. N. 2008. Effect of Roof Solar Reflectance on the Building Heat Gain in a Hot Climate. Energy and Buildings, 40 (12): 2224-2235.

Sullivan R, Nozari S, Johnson R, Selkowitz S. Commercial building energy per-formance analysis using. multiple regression ,ASHRAE Transactions, 1985, 91:337–53.

Sullivan, R. and Nozaki, S. A., Multiple regression techniques applied to fenestra-tion effects on commercial building energy performance, ASHRAE Transactions,1984, 90 (Part 1A):116-123.

Sullivan, R., K.J. Frost, D.K. Arasteh, and S. Selkowitz. 1994. Window U-factor effects on residential cooling load. ASHRAE Transactions 100(2): 50-58.

Sullivan, R., S. Nozari, R. Johnson, S. Selkowitz, (1985), Commercial building energy performance analysis using multiple regression, ASHRAE Transactions, (91) 337–353.

Synnefa A, Santamouris M, Akbari H. (2007); Estimating the effect of using cool coatings on energy loads and thermal comfort in residential buildings in various climatic conditions. Energy Build, 39(11):1167–74.

Synnefa, A., M. Santamouris, I. Livada, (2006). A study of the thermal performance of reflective coatings for the urban environment, Solar Energy 80, 968–981.

T. Soubdhan, T. Feuillard, F. Bade, Experimental evaluation of insulation material in roofing system under tropical climate, Solar Energy 79 (2005) 311–320.

T.W. Petrie, K.E. Wilkes, P.W. Childs, J.E. Christian, Effect of radiant barriers and attic ventilation on residential attics and attic duct systems: new tools for measuring and modelling, in: ASHRAE Transactions, 2000, pp. 1175–1192.

Tang, R. & Etzion, Y. 2004. On Thermal Performance of an Improved Roof Pond for Cooling Buildings. Building and Environment, 39 (2): 201-209.

Taylor B.J and Imbabi M.S , The application of dynamic insulation in buildings, Renewable Energy, 1998, pp. 377-382.

Teemusk, A. & Mander, U. 2009. Green Roof Potential to Reduce Temperature Fluctuations of a Roof Membrane: A Case Study from Estonia. Building and Environment, 44 (3): 643-650.

Ternes, M.P., K.E. Wilkes and A. McLain. 1994. Cooling Benefits from Exterior Masonry Wall Insulation. Home Energy Magazine 11(2): 33-35.

Tham, K.W. 1993. Conserving Energy without Sacrificing Thermal Comfort. Building and Environment, 28 (3): 287-299.

Trnsys 16, A Transient System Simulation Program, Solar Energy Laboratory, 2005, University of Wisconsin Madison, USA.

Tsangrassoulis, A., C. Pavlou, M. Santamouris, W. Pohl, and C. Scheiring. 2001. A new value of average beam solar heat gain coefficient for innovative daylighting systems. Energy and Buildings. 33(6): 519-524.

TVM Building Products, (2001), Engineered Reflective Insulation Products.

U.S. Department of Energy, Energy Efficiency and Renewable Energy, http://www.energysavers.gov/your_home/landscaping/index.cfm/mytopic=11920.

U.S. Department of Energy, U.S. Energy Information Administration, Electric Power Monthly February 2012 with Data for December 2011, DOE/EIA-0226 (2012/02).

U.S. Department of Energy, U.S. Energy Information Administration, Electric Power Monthly February 2012 with Data for December 2011, DOE/EIA-0226 (2012/02).

U.S. energy Efficiency and Renewable Energy, Energy Efficiency Trend in Residential and Commercial Buildings, October 2008.

U.S. Energy Information Administration, Annual Energy Review, 2010.Department of Energy. DOE/EIA-0384(2010) | October 201.1.

ULI-the Urban Land Institute (2008). ULI Community Catalyst Report Number 7: Environmentally Sustainable Affordable Housing. Washington, D.C.: URI- the Urban Land Institute.

ULI-the Urban Land Institute (2008). ULI Community Catalyst Report Number 7: Environmentally Sustainable Affordable Housing. Washington, D.C.: URI- the Urban Land Institute.

ULI-the Urban Land Institute (2008). ULI Community Catalyst Report Number 7: Environmentally Sustainable Affordable Housing. Washington, D.C.: URI- the Urban Land Institute.

US Department Of Energy 2006. Buildings energy data book.

Van Straaten, J.F., Thermal Performance of Buildings, Elsevier Publishing Company, London, 1967.

Van Straaten, J.F., Thermal Performance of Buildings, Elsevier Publishing Company, London, 1967.

Vijaykumar, K.C.K., Srinivasan, P.S.S. & Dhandapani, S. (2007). A Performance of Hollow Clay Tile (HCT) Laid Reinforced Cement Concrete (RCC) Roof for Tropical Summer Climates.Energy and Buildings, 39 (8): 886-892.

Watson, D. & Labs, K. 1983. Climatic Building Design: Energy-Efficient Building Principles and Practice. New York: McGraw-Hill.

Watson, D. & Labs, K. 1983. Climatic Building Design: Energy-Efficient Building Principles and Practice. New York: McGraw-Hill.

Wilkes, K.E., 1988, " Modeling of residential attics with radiant barriers," fifth annual symposium on improving building energy efficiency in Hot and Humid climates, Texas A & M University, Energy management group, Department of mechanical engineering.

Wilkes, K.E., 1988, "Thermal Modeling of Residential Attics with Radiant Barrier: Comparison with Laboratory and Field Data." CONF-891202-2, DE89019287, Presented at the Conference of Thermal Performance of the Exterior Envelope Of Buildings IV Orlando, Florida, December 4-7, 1989.

Winiarski W. D and O'Neal, D.L., (1996), "Quasi-Steady Model of Attic Heat Transfer, Energy and Buildings, pp. 183-194.

Winiarski W. D and O'Neal, D.L., 1996, "Quasi-Steady Model of Attic Heat Transfer, Energy and Buildings, pp. 183-194.

Winston, R., Miñano, J. C., Benítez, P., 2005, Nonimaging Optics, Elsevier Academic Press, Burlington, MA, USA.

Wong, N.H. & Li, S. 2007. A Study of the Effectiveness of Passive Climate Control in Naturally Ventilated Residential Buildings in Singapore. Building and Environment, 42 (3): 1395-1405.

Wong, N.K. & Huang, B. 2004. Comparative Study of the Indoor Air Quality of Naturally Ventilated and Air-Conditioned Bedrooms of Residential Buildings in Singapore. Building and Environment, 39 (9): 1115-1123.

Xiao, D. 2006. Inter-model, Analytical, and Experimental Validation of a Heat Balance Based Residential Cooling Load Calculation Procedure. Ph.D. thesis, Oklahoma State University.

Yang J, R. Hugues, Zmeureanu R., On-line building energy prediction using adaptive artificial neural networks, Energy and Buildings, 2005, 37:1250-1259.

Yang, K. H. & Hwang, R. L. 1993. The Analysis of Design Strategies on Building Energy Conservation in Taiwan. Building and Environment, 28(4): 429-438.

Yarbrough, D., Cook, J. and Wilkes, K., 1989, "Contamination of reflective foils in horizontal applications and its effect on thermal performance," ASHRAE Conference, Vancouver, BC, Canada, June 25-28, 1989.

Yarbrough, D.W. (1991). "Thermal Resistance of Air Ducts with Bubble pack Reflective Insulation." Journal of Thermal Insulation, Vol. 15, 137-152.

Young-Sub K., Kang-Soo K., Simplified energy prediction method accounting for part-load performance of chiller, Building and Environment, 2007, 42:507–515.

Zienkiewicz, O.C. and Taylor R.L,The Finite Element Method, 6th Edition, Elsevier.

APPENDIX A

Hot-Humid Region

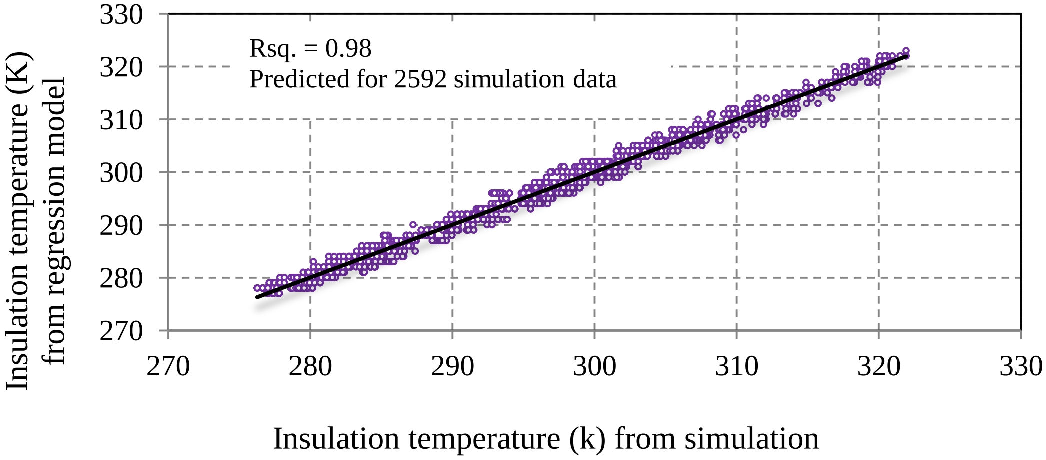


Figure 46: Goodness of fit – With Radiant Barrier - air gap = 0

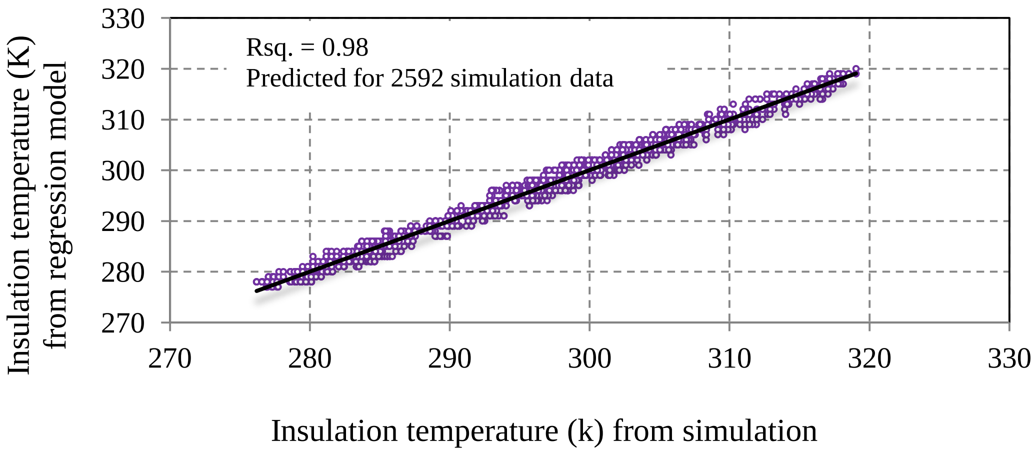


Figure 47: Goodness of fit – With Radiant Barrier - air gap = 0.75

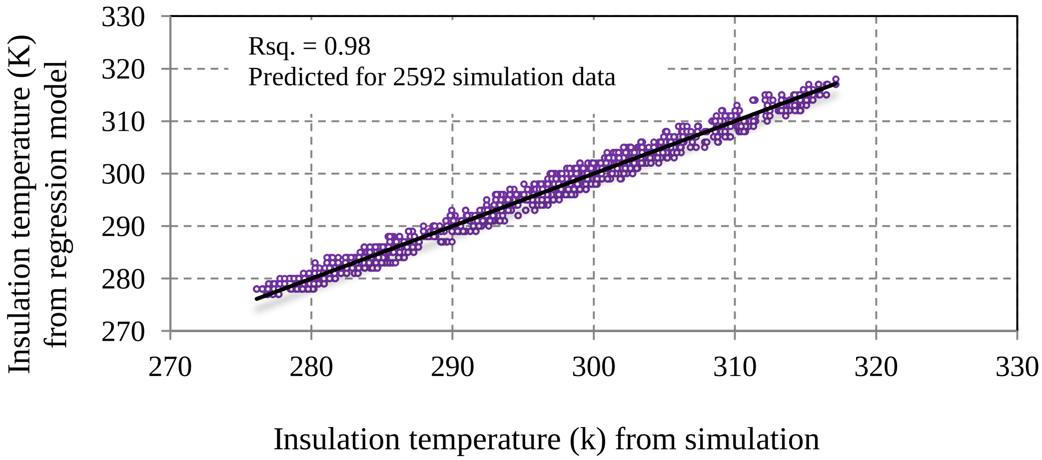


Figure 48: Goodness of fit – With Radiant Barrier - air gap = 5

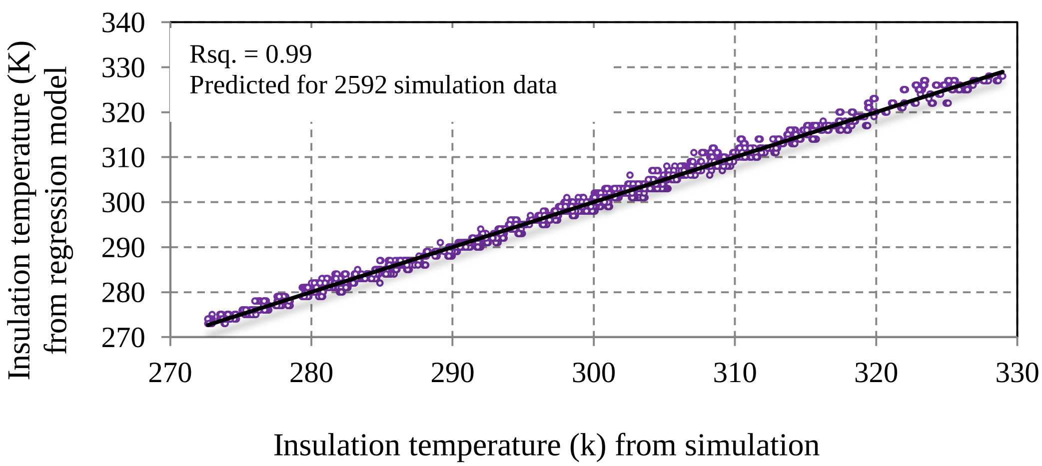


Figure 49: Figure A.4 Goodness of fit – Without Radiant Barrier

Temperature Region

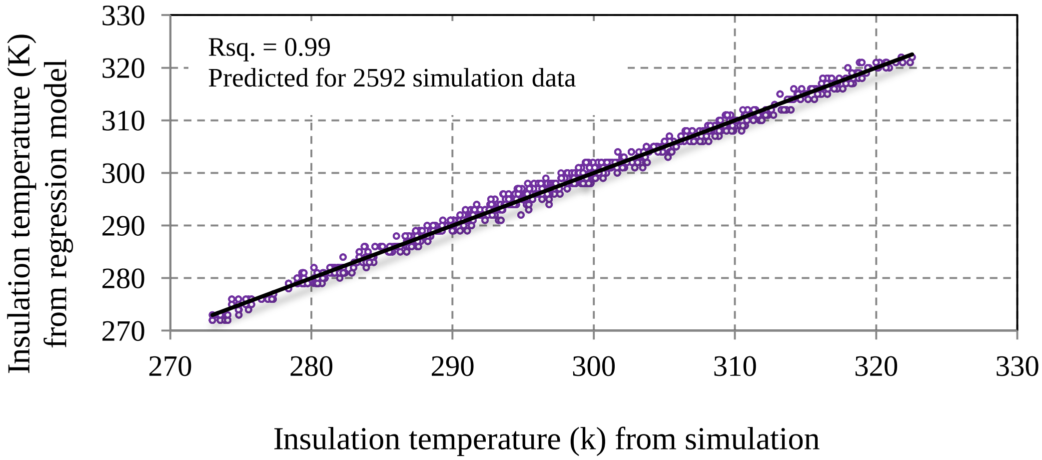


Figure 50: Goodness of fit – With Radiant Barrier - air gap = 0

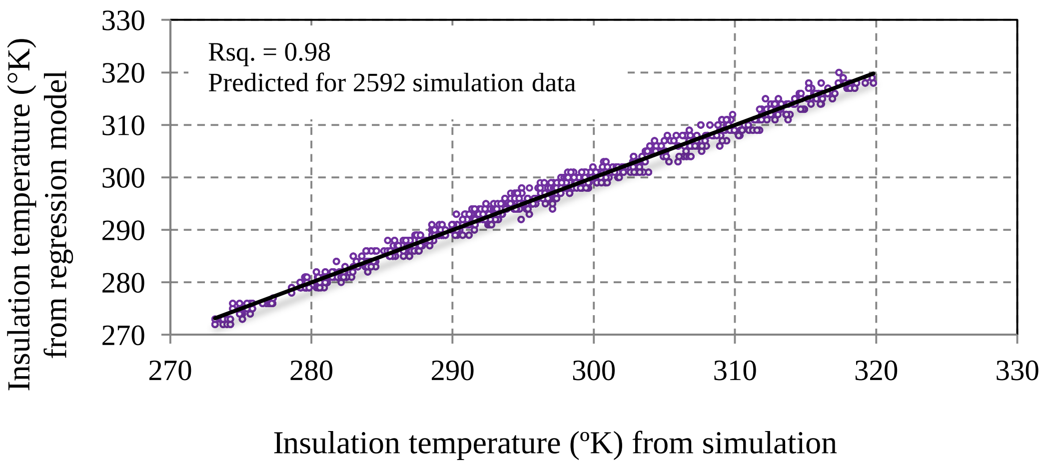


Figure 51: Goodness of fit – With Radiant Barrier - air gap = 0.75

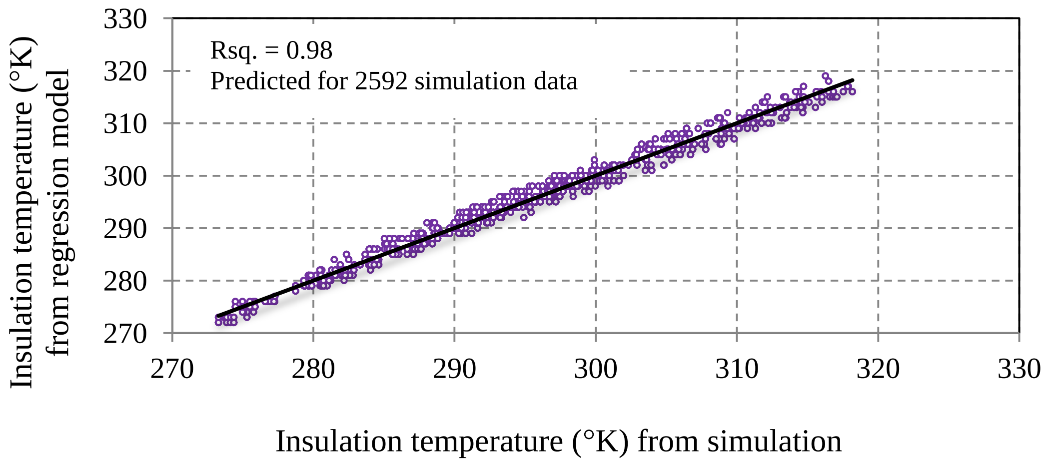


Figure 52: Goodness of fit – With Radiant Barrier - air gap = 5

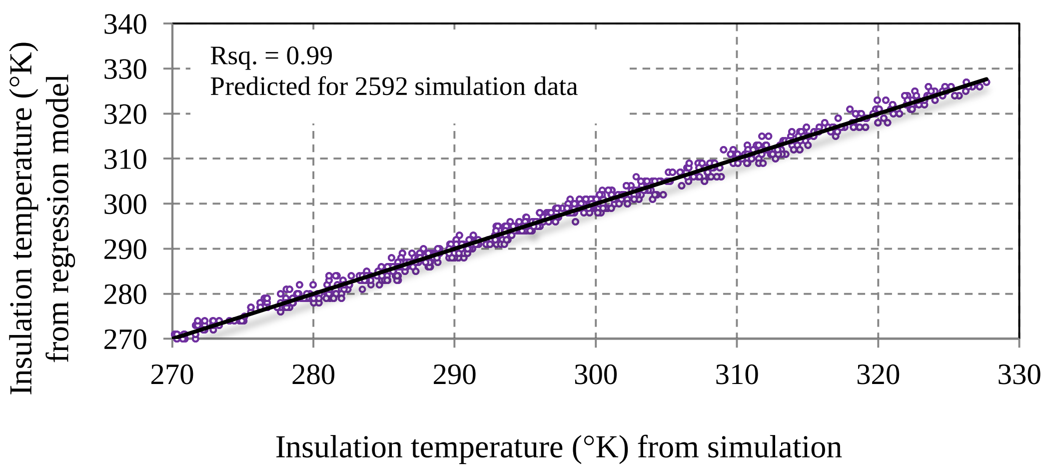


Figure 53: Goodness of fit – Without Radiant Barrier

Hot-Arid Temperature

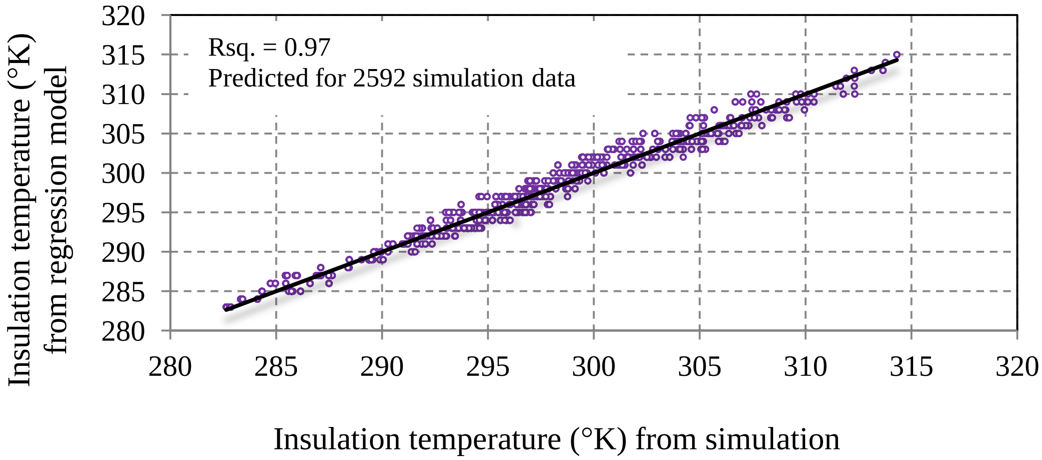


Figure 54: Goodness of fit – With Radiant Barrier - air gap = 0

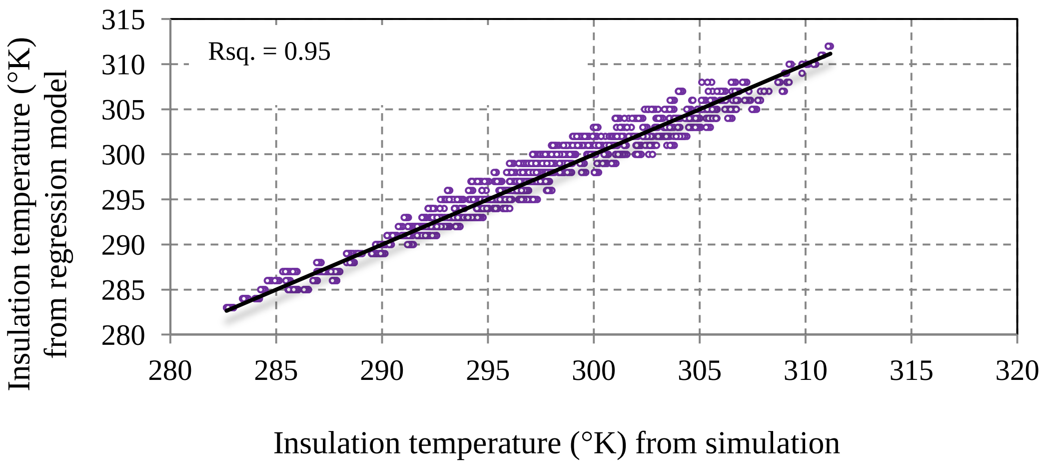


Figure 55: Goodness of fit – With Radiant Barrier - air gap = 0.75

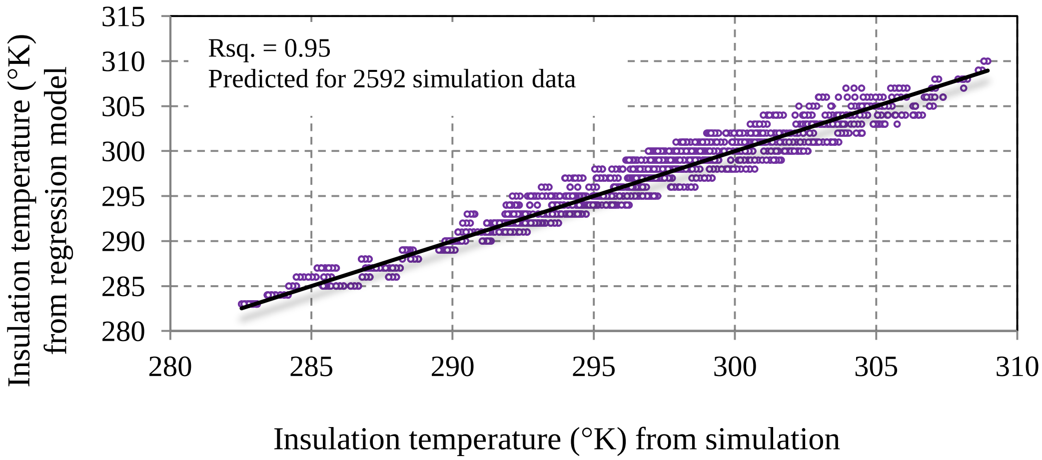


Figure 56: Goodness of fit – With Radiant Barrier - air gap = 5

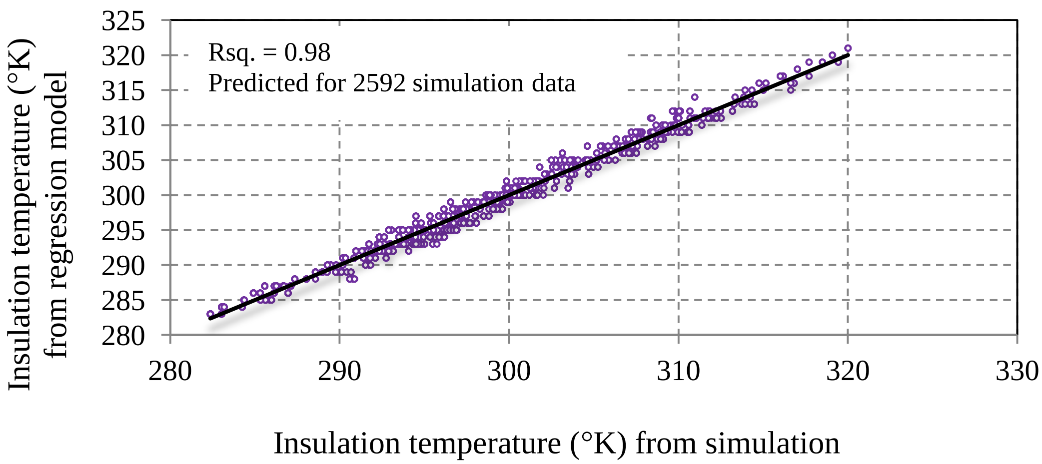


Figure 57: Goodness of fit – Without Radiant Barrier

Cool Temperature

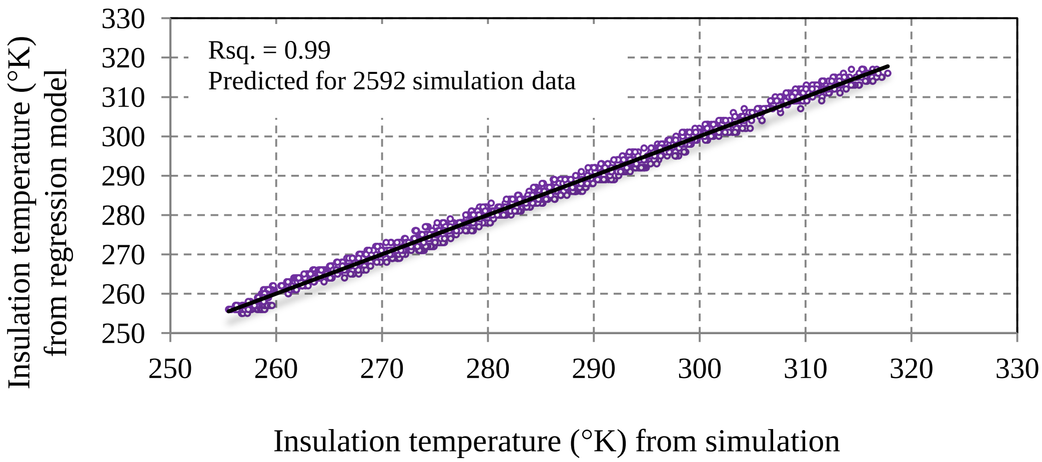


Figure 58: Goodness of fit – With Radiant Barrier - air gap = 0

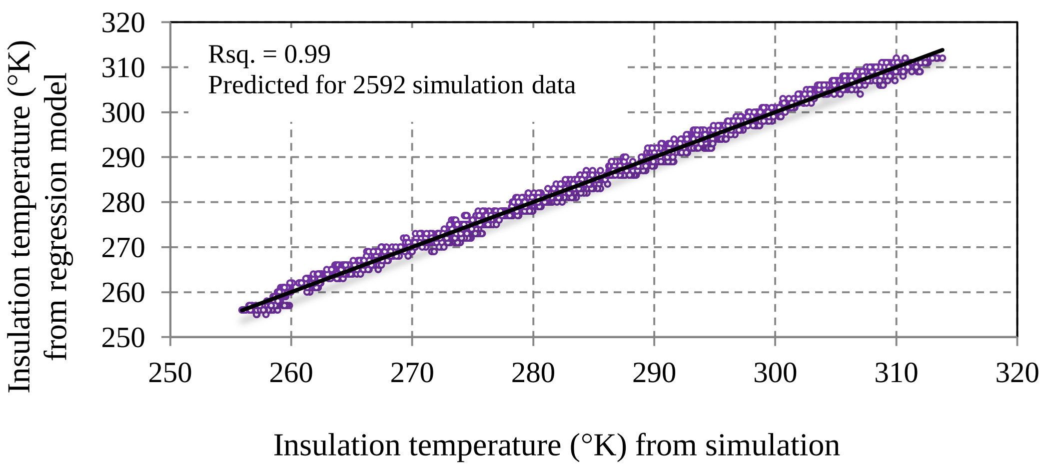


Figure 59: Goodness of fit – With Radiant Barrier - air gap = 0.75

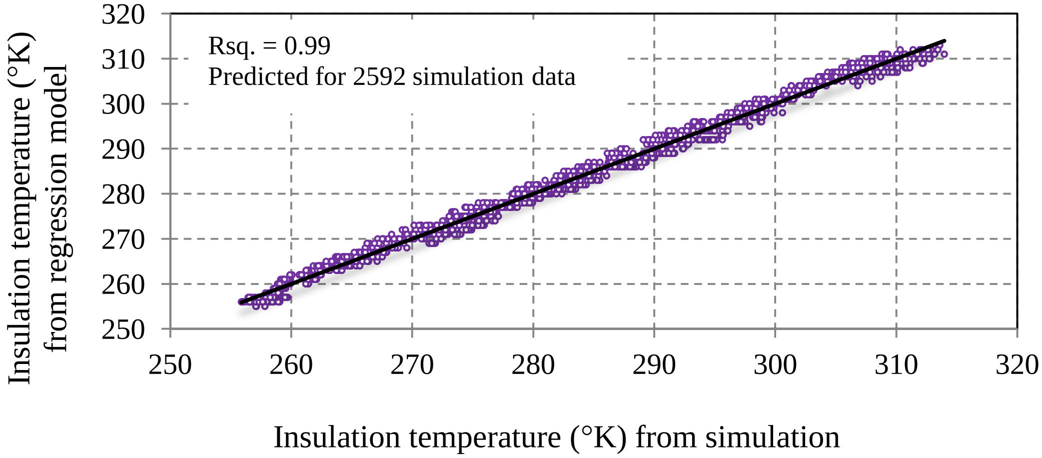


Figure 60: Goodness of fit – With Radiant Barrier - air gap = 5

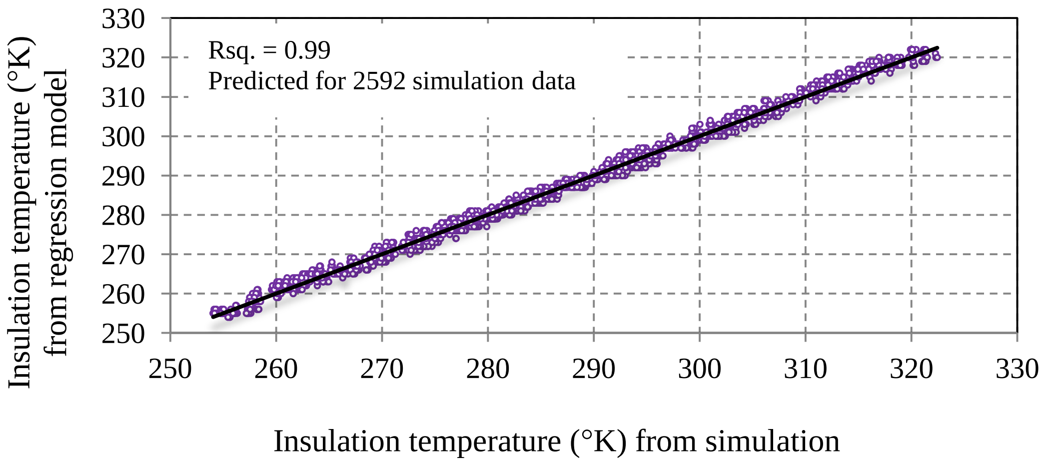


Figure 61: Goodness of fit – Without Radiant Barrier

Regression Model Verification

Hot-Humid Region

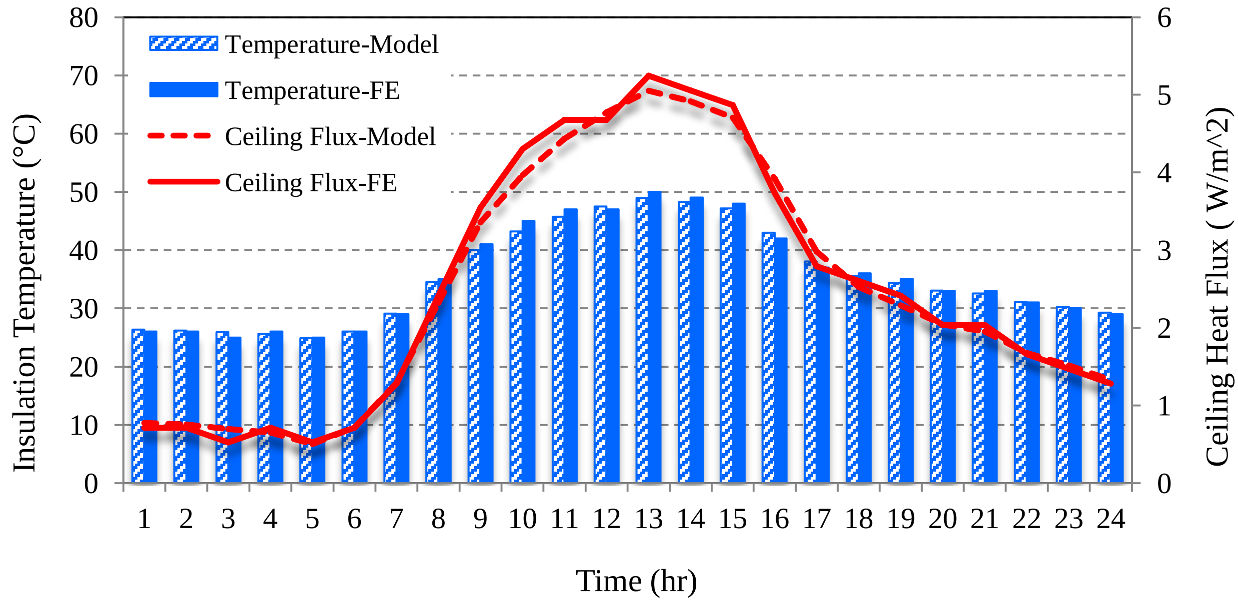


Figure 62: Insulation temperature and heat flux in the house with radiant barrier in summer-airgap thickness = 0

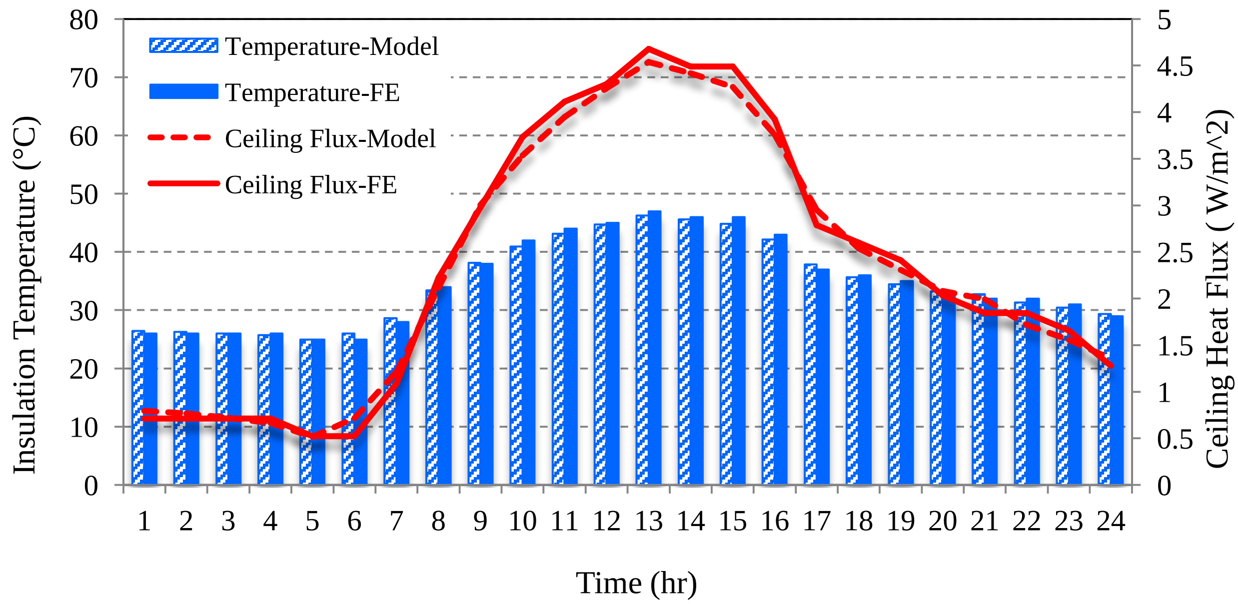


Figure 63: Insulation temperature and heat flux in the house with radiant barrier in summer – airgap thickness = 0.75

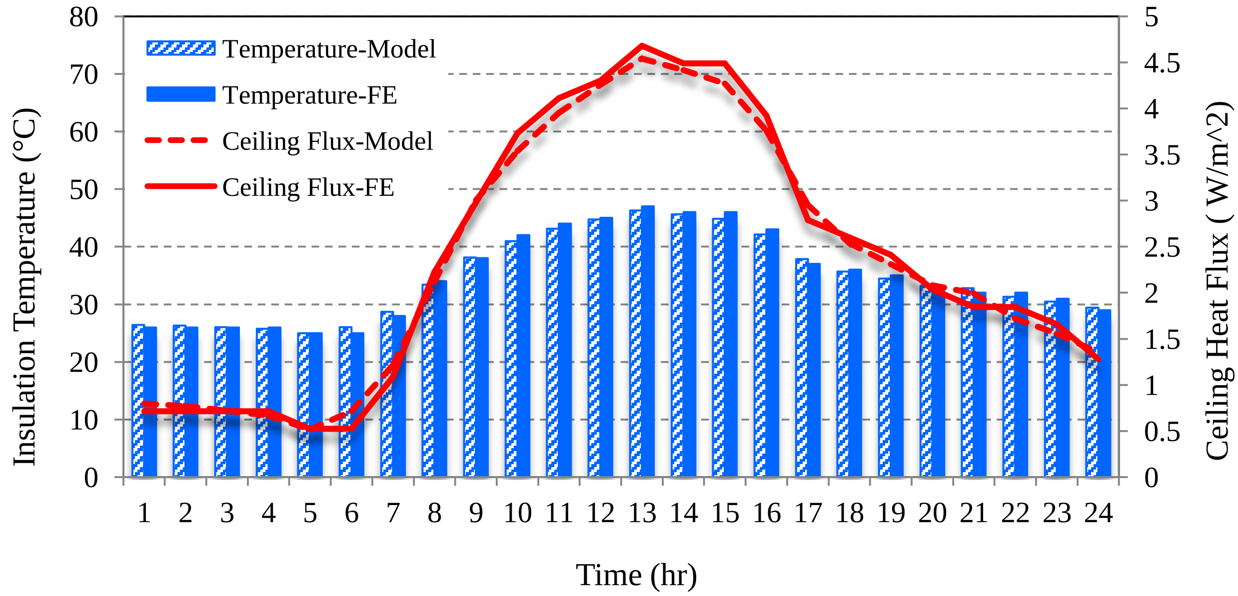


Figure 64: Insulation temperature and heat flux in the house with radiant barrier in summer – airgap thickness = 5

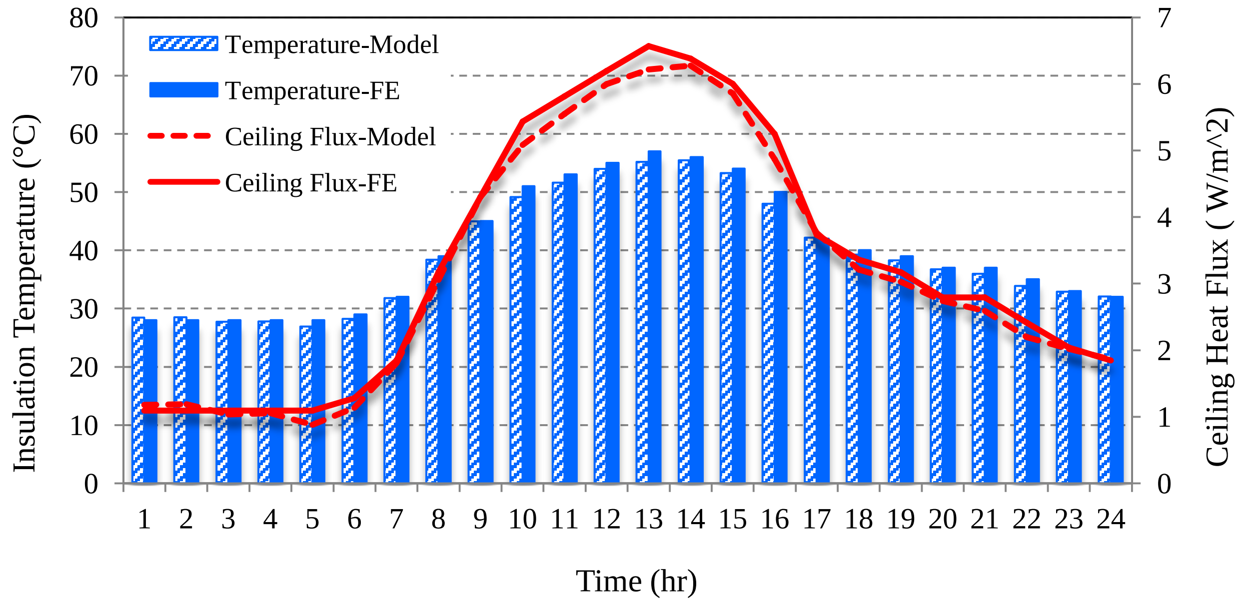


Figure 65: Insulation temperature and heat flux in the house without radiant barrier in summer

Temperature Region

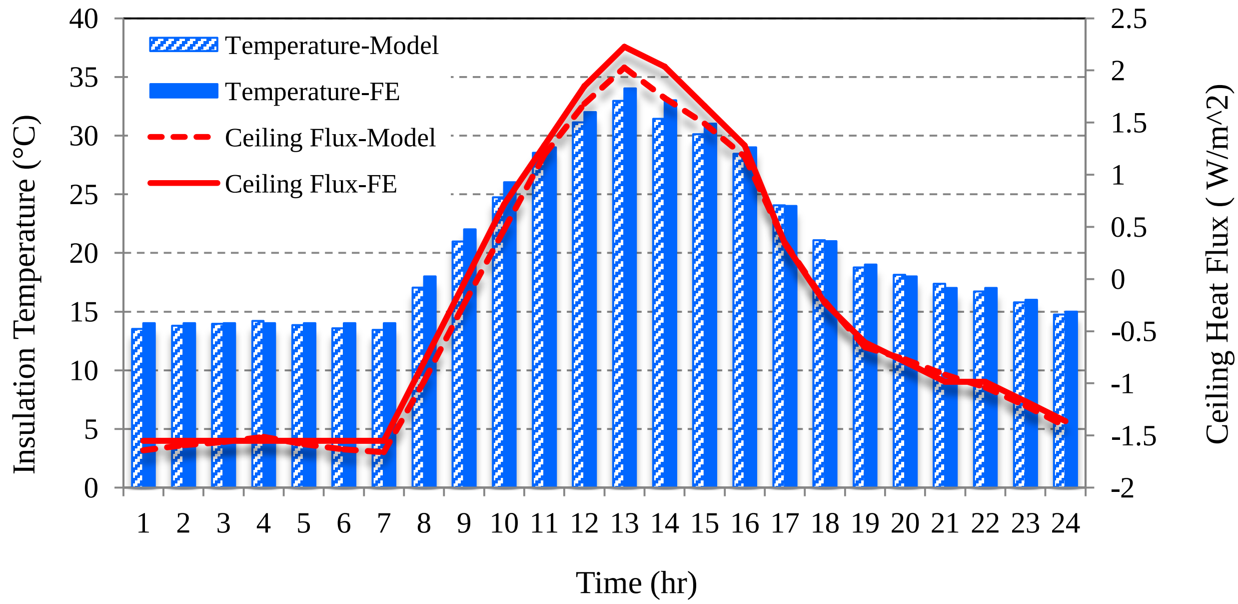


Figure 66: Insulation temperature and heat flux in the house with radiant barrier in Fall-airgap thickness = 0

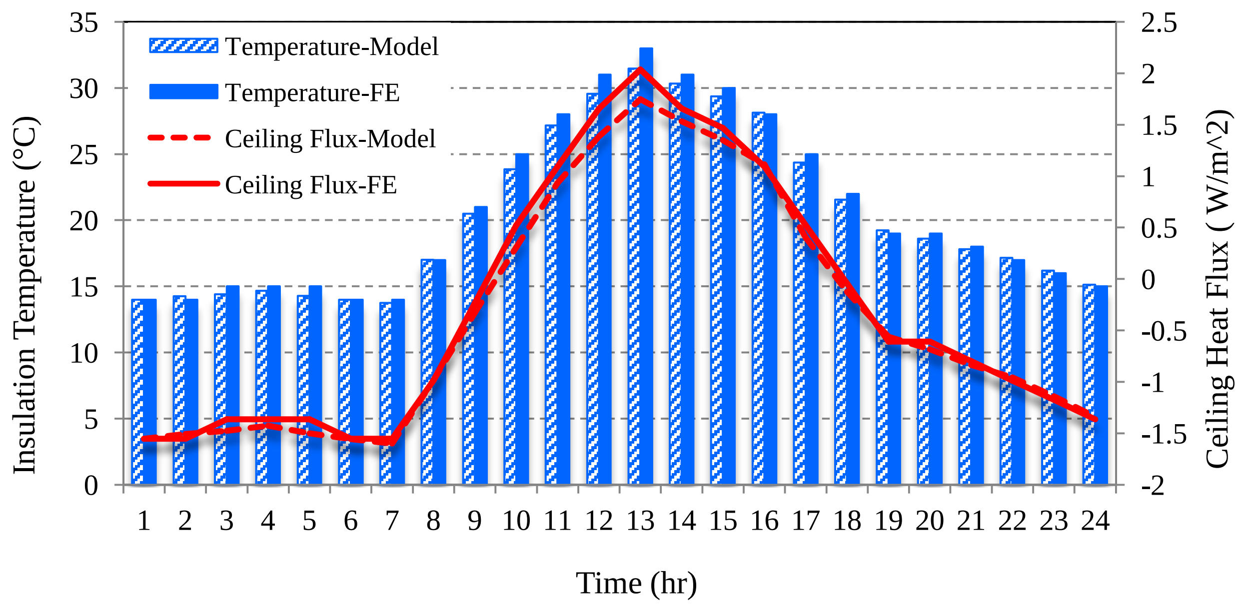


Figure 67: Insulation temperature and heat flux in the house with radiant barrier in Fall-airgap thickness = 0.75

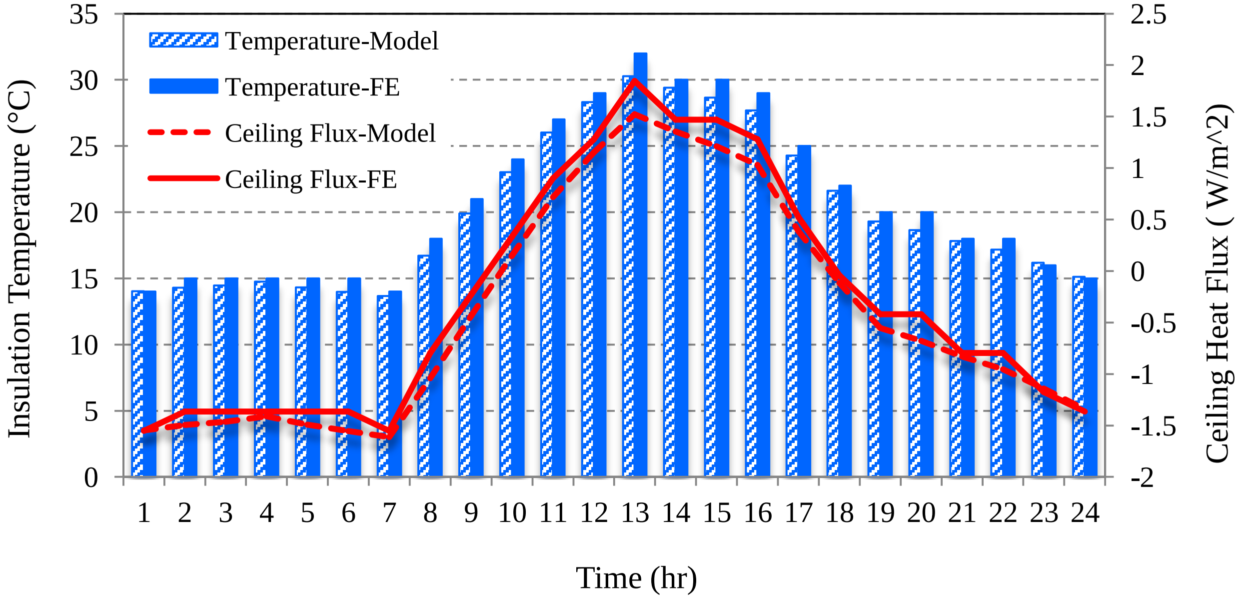


Figure 68: Insulation temperature and heat flux in the house with radiant barrier in Fall-airgap thickness = 5

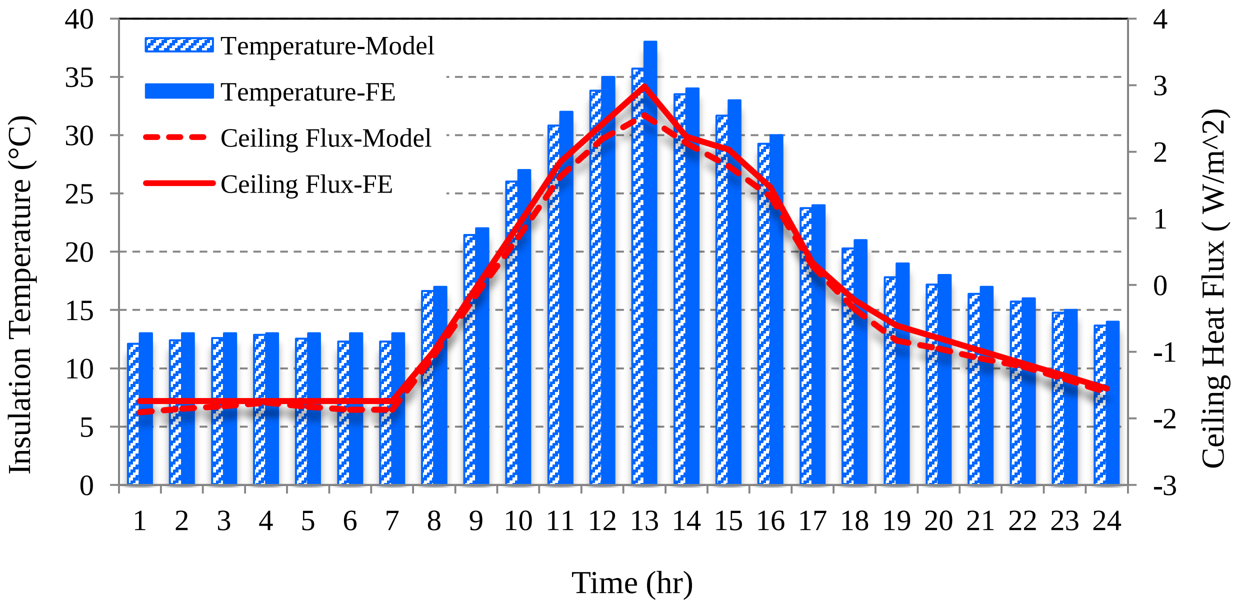


Figure 69: Insulation temperature and heat flux in the house without radiant barrier in Fall

Hot-Arid Region

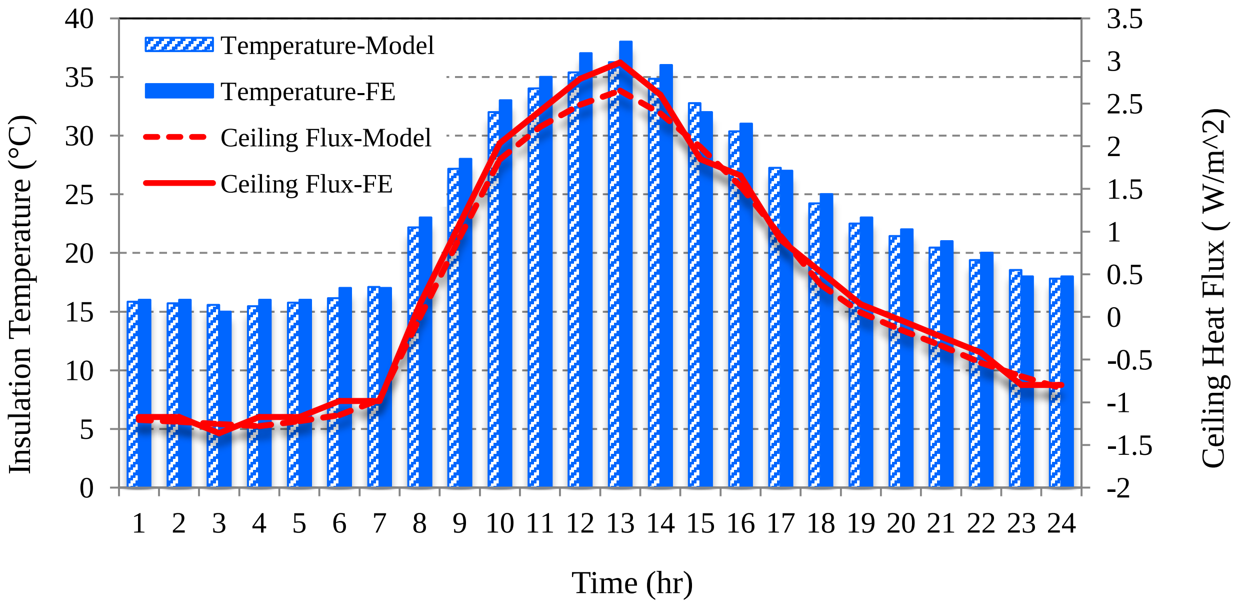


Figure 70: Insulation temperature and heat flux in the house with radiant barrier in Spring-airgap thickness = 0

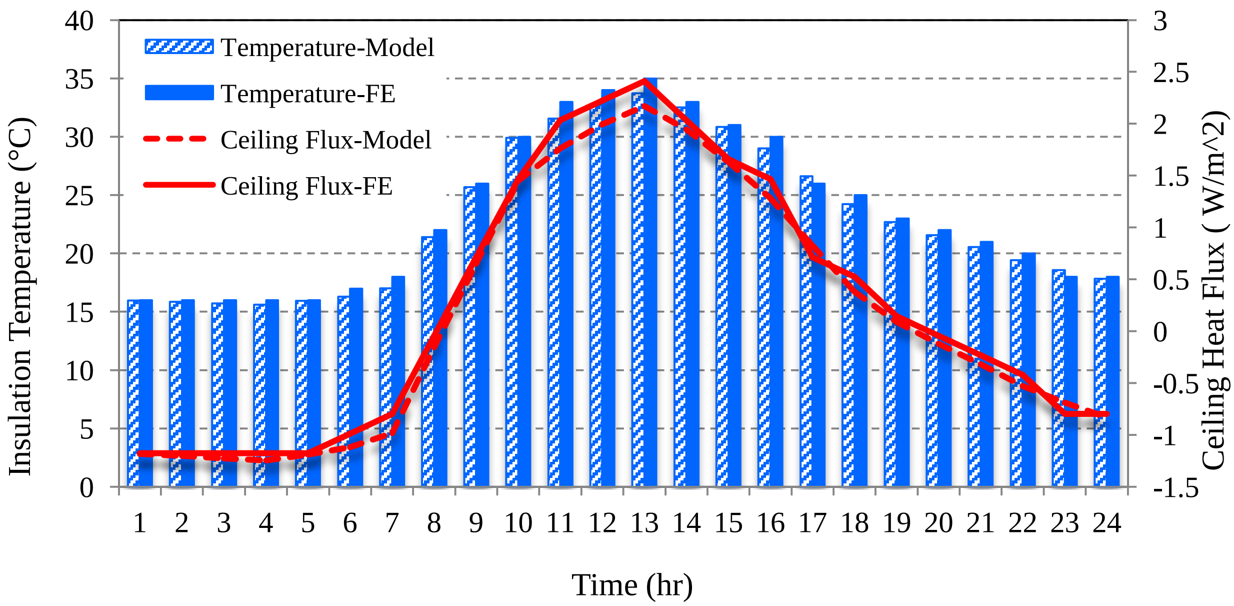


Figure 71: Insulation temperature and heat flux in the house with radiant barrier in Spring-airgap thickness = 0.75

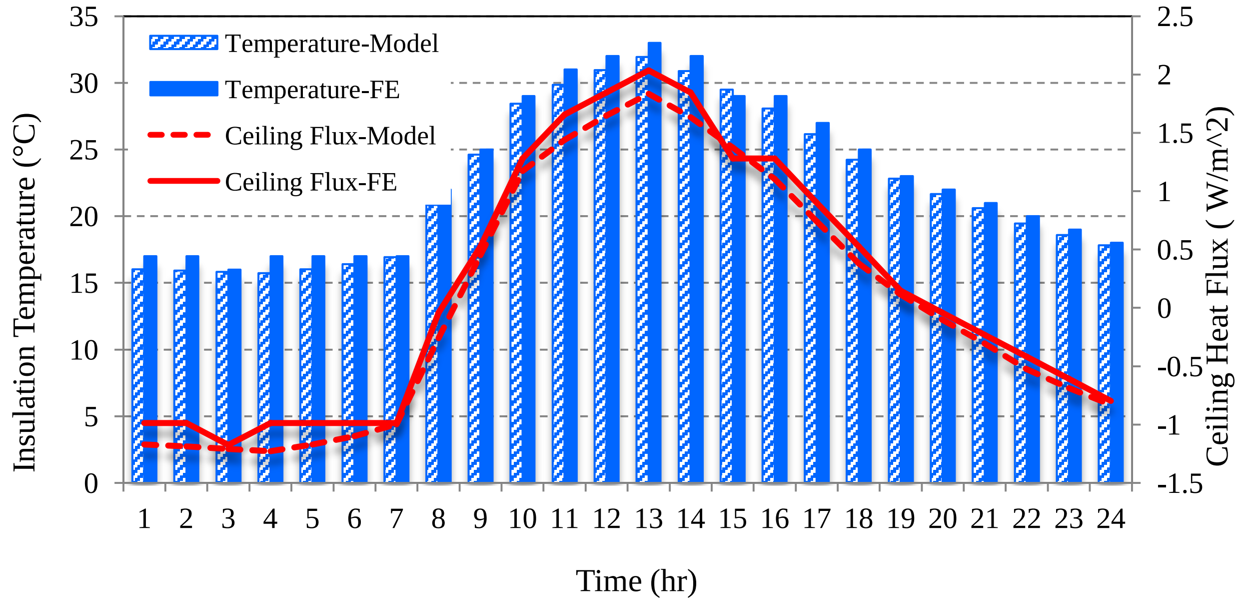


Figure 72: Insulation temperature and heat flux in the house with radiant barrier in Spring-airgap thickness = 5

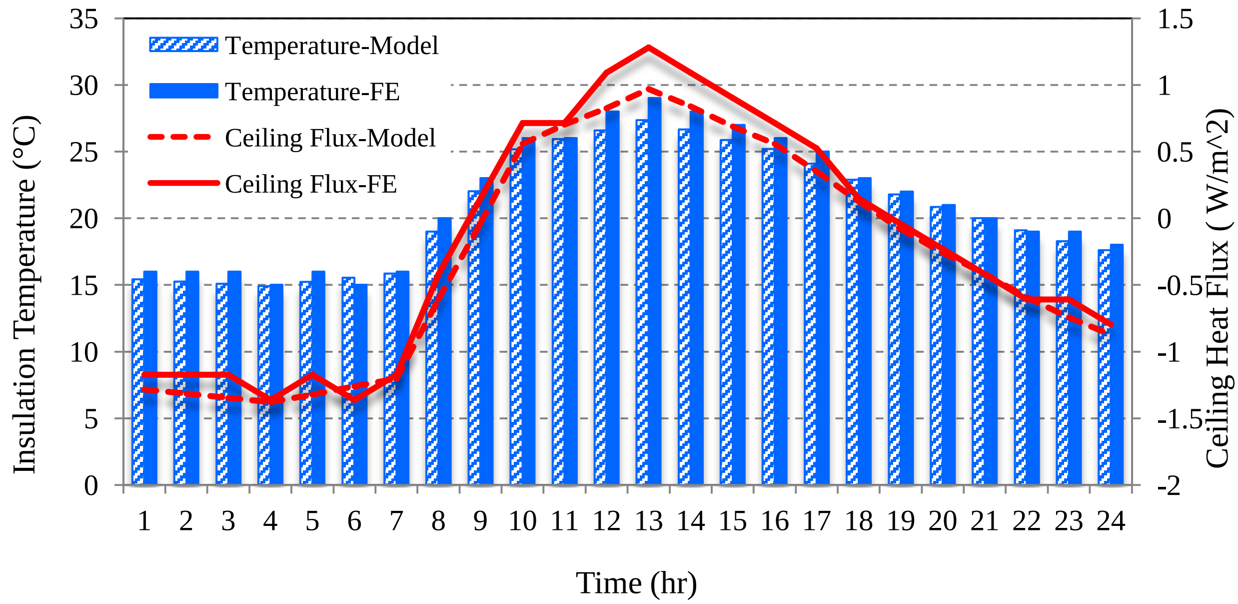


Figure 73: Insulation temperature and heat flux in the house with radiant barrier in Spring-airgap thickness = 5

Cool Region

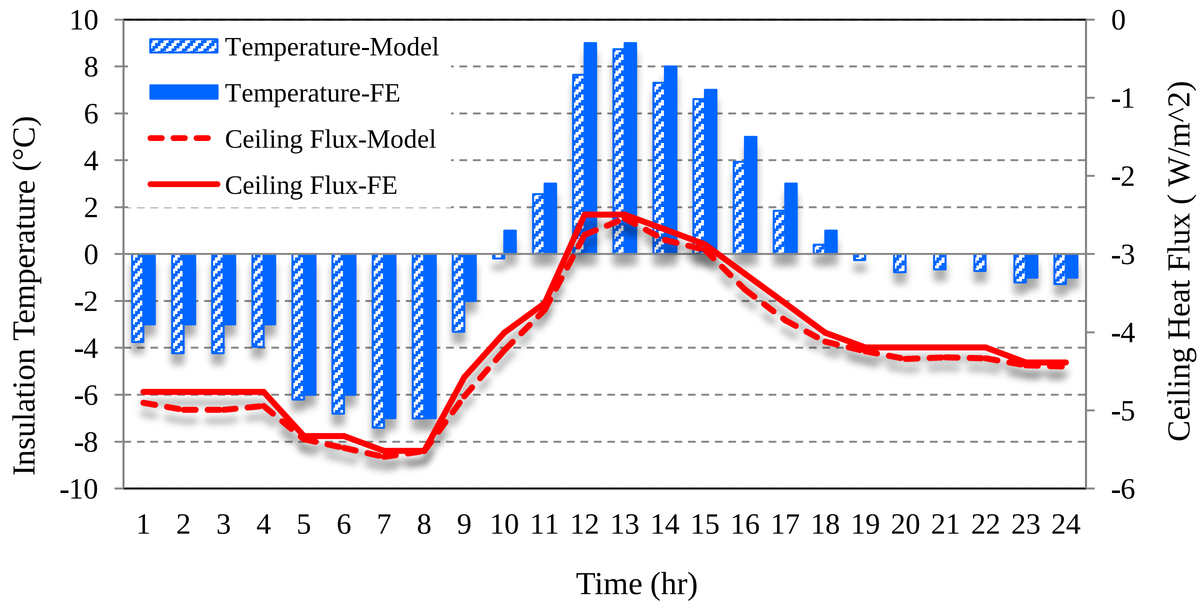


Figure 74: Insulation temperature and heat flux in the house with radiant barrier in Winter-airgap thickness = 0

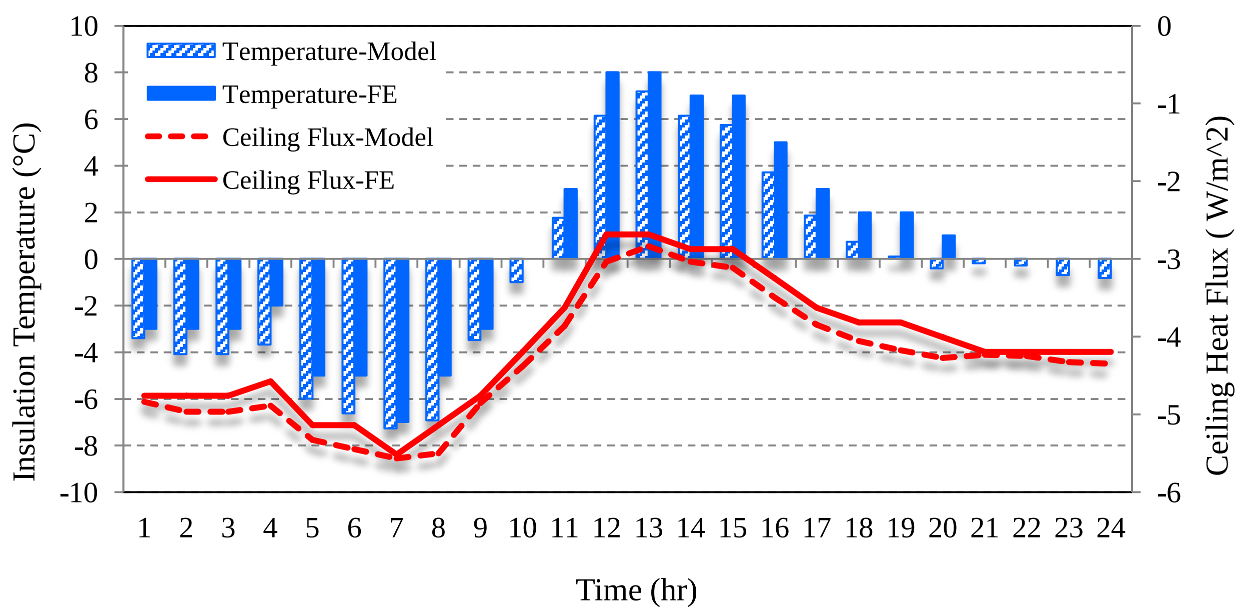


Figure 75: Insulation temperature and heat flux in the house with radiant barrier in Winter-airgap thickness = 0.75

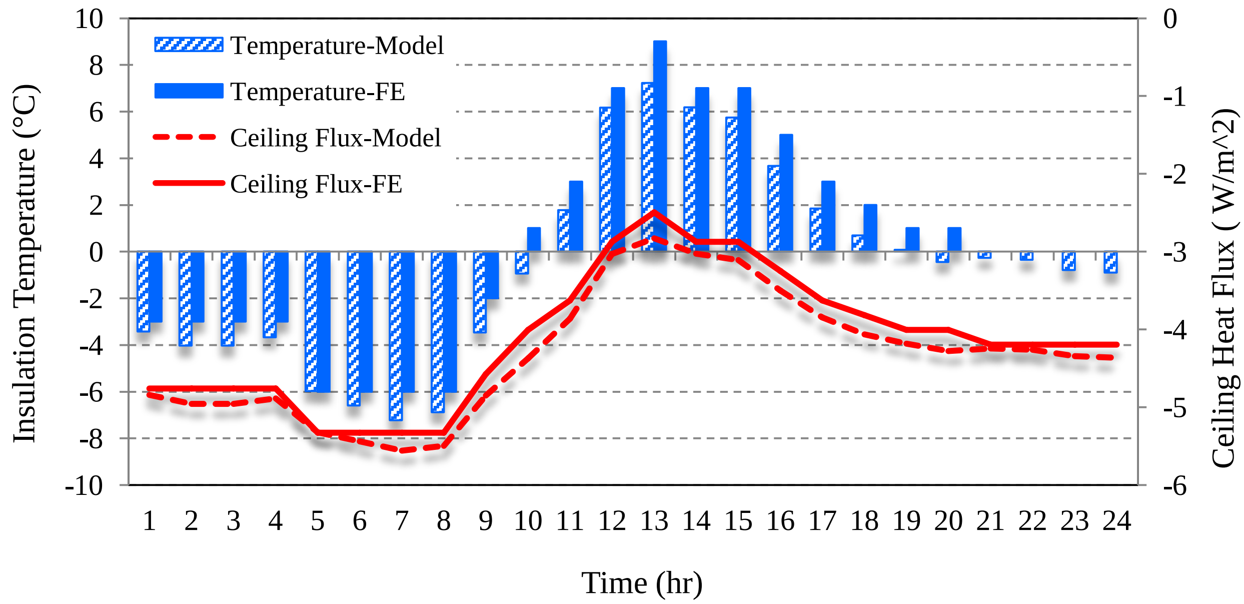


Figure 76: Insulation temperature and heat flux in the house with radiant barrier in Winter-airgap thickness = 5

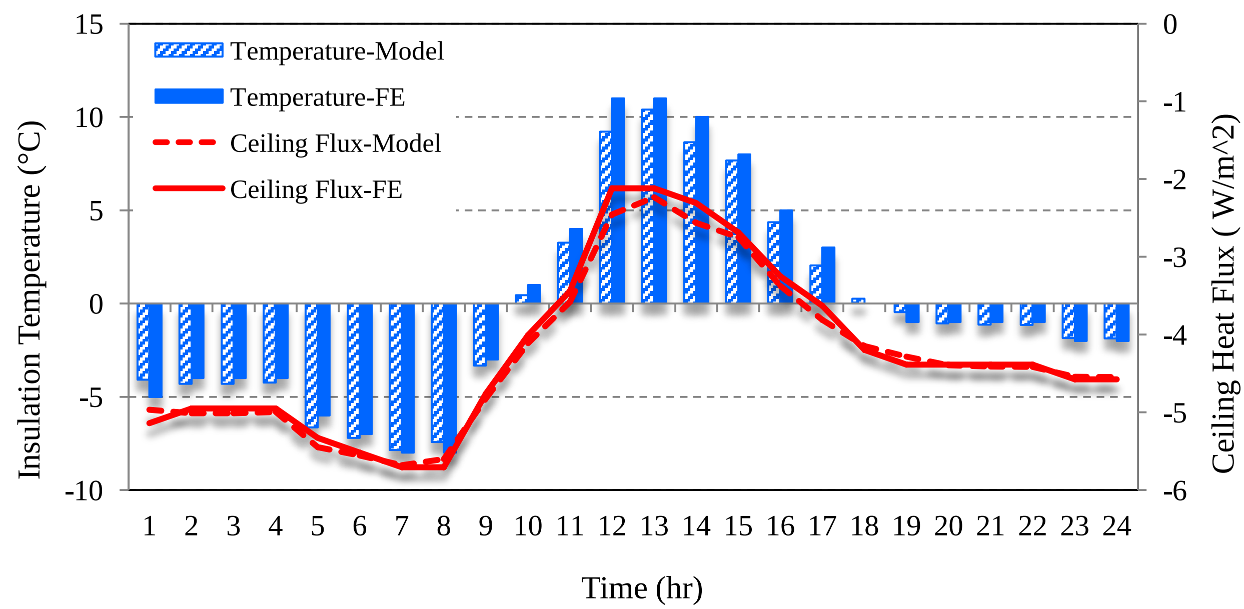


Figure 77: Insulation temperature and heat flux in the house with radiant barrier in Winter-airgap thickness = 5

APPENDIX B

Solar Load Calculation

```
clear
clc
load Radiation.txt;


nDay = 178;
sigma = 33.69*pi/180;%slope
psi =-90*pi/180;   % angeles measured fron south  S=0 & N=180 & W = +90 & E = -90
Latitude =30.5*pi/180;

Rb = zeros(1,24);
Itilt = zeros(1,24);
Ib = zeros(1,24);
Id = zeros(1,24);
isUsingAshraeForIet =1;

for i = 1:24    if(Radiation(i,2)>0)

        delta = abs(23.45*sin(360*(284+nDay)/365*pi/180)*pi/180);

        CT = i;  % hour
        Lstd = 90;
        Llocal= 104;
        B = (360*(nDay-81)/364) * pi/180;
        E =  (0.165 * sin(2*B)-0.126 * cos(B) - 0.025*sin(B));
        Lst = CT  + 1/15*(Lstd - Llocal) + E - 1;

        if(i<=12)
           omega = (Lst-12) * 15 *pi/180;
        else
           omega = (12-Lst) * 15 *pi/180;
        end

        theta_h = acos(sin(delta)*sin(Latitude) + cos(delta)* cos(Latitude)* cos(omega));

        beta = pi/2 - theta_h;

        phi = acos(( cos(delta)* sin(Latitude)* cos(omega) - sin(delta)*cos(Latitude)) / cos(beta));

        if( omega <0 )
           if (phi>0)
              phi = -phi;
           end
```

```
        else
            if (phi<0)
                phi = -phi;
            end
        end

        gamma = abs(phi - psi);

        theta = acos (cos(beta)* sin(sigma)* cos(gamma) + sin(beta)*cos(sigma));

        Iet = 1353 * (1 + 0.033*cos(360*nDay/365*pi/180)) * cos(theta_h)

        myBeta = 360*nDay/365*pi/180;

        if(isUsingAshraeForIet > 0)
            KT = Radiation(i,2)/Iet;
        else
            KT = Radiation(i,2)/Radiation(i,1);
        end
        if(KT<.22)
            Iratio =1-.09*KT;
        end
        if(KT>=0.22 && KT<=0.8)
            Iratio = 0.9511 - 0.1604*KT + 4.388*KT^2 - 16.638 * KT^3 + 12.336 * KT^4;
        end
        if(KT>0.8)
            Iratio =0.165;
        end

        Id(i) = Iratio * Radiation(i,2);
        Ib(i) = Radiation(i,2) - Id(i);

      Rb(i) = cos(theta)/cos(theta_h);
        if(Rb(i)> 0)
            Itilt(i) = Id(i) + Rb(i) * Ib(i);
        else
            Itilt(i) = Ib(i);
        end
    end
end

plot (Itilt, 'DisplayName', 'Itilt', 'YDataSource', 'Itilt'); figure(gcf)
```

APPENDIX C

Convection Coefficients Calculation

```
TS =SURFACE TEMPERATURE, F
! TA = AIR TEMPERATURE, F
! PHI = TILT ANGLE, DEGREES, a FOR HORIZONTAL, 90 FOR VERTICAL
! AL = CHARACTERISTIC LENGTH OF SURFACE
! IFLAG = 1 FOR SURFACE FACING UPWARD
! IFLAG = 2 FOR SURFACE FACING DOWWdARD
! V = AIR SPEED, FEET PER HOUR
! HCF = FORCED CONVECTION COEFFICIENT
! HCN = NATURAL CONVECTION COEFFICIENT
! HC = TOTAL CONVECTION COEFFICIENT
!REAL NUS,K,MU,NU
DT = TS - TA
IF (IFLAG.EQ.2) DT = -DT
CALCULATE FILM TEMPERATURE
TF = (TS+TA)/2.0
TF1 = TF
IF(ABS(PHI).GT.1.E-3.AND.ABS(PHI-90.).GT.1.E-3)&
 TF = TS - 0.25*(TS-TA)
 IF(ABS(PHI).GT.1.E-3.AND.ABS(PHI-90.).GT.1.E-3) &
 TF1 = TA + 0.25*(TS-TA)
TK = (TF+459.67)/1.8
! K = 0.6325E-5*SQRT(TK)/(1.+(245.4*10.**(-12./TK))/TK)*241.77
 MU = (145.8*TK*SQRT(TK)/(TK+110.4))*241.90E-7
PR = 0.7880 - 2.631E-4*TK
```

```
! BETA = 1./(TF1+459.67)
RHO = 22.0493/TK
NU=MU/RHO
CP = (3.4763 + 1.066E-4*TK)*0.068559
RA = (4.16975E8)*BETA*RHO*CP*ABS(DT)*(AL**3)/NU/K
IF(ABS(PHI).LE.1.E-3) GO TO 100
IF(ABS(PHI-90.).LE.1.E-3) GO TO 200
IF(ABS(PHI).GT.1.E-3.AND.ABS(PHI).LT.2.) GO TO 300
IF(ABS(PHI).GT.2.0.AND.ABS(PHI-90.).GT.1.E-3) GO TO 400
! FOR HORIZONTAL SURFACES
100 IF(DT.LT.0.0) GO TO 150
NUS = 0.15*RA**(1./3.)
IF(RA.LT.8.E6)
NUS = 0.54*RA**0.25
GO TO 1000
150 NUS = 0.58*RA**0.2
GO TO 1000
! FOR VERTICAL SURFACES
200 NUS = 0.10*RA**(1./3.)
IF(RA.LT.1.E9) NUS = 0.59*RA**0.25
GO TO 1000
! FOR TILTED SURFACES
400
IF(DT.GT.0.0) GO TO 450
NUS = 0.56*(RA*COS((90.-PHI)*3.14159265/180.))**0.25
GO TO 1000
450 GRC = 10.0**(PHI/(1.1870+0.0870*PHI))
```

```
IF(ABS(PHI).LT.15.) GRC = 1.E6
IF(ABS(PHI).GT.75.) GRC = 5.E9
GR = RA/PR
IF(GR.LE.GRC)
NUS=0.56*(RA*COS((90.-PHI)*3.14159265/180.))**0.25
IF(GR.GT.GRC) NUS = 0.14*(RA**(1./3.) - (GRC*PR)**(1./3.))&
 +0.56*(GRC*PR*COS((90.-PHI)*3.14159265/180.))**0.25
 GO TO 1000
1000 HCN = NUS*K/AL
!CALCULATE FORCED CONVECTION COEFFICIENT
RE = V*AL/NU
IF(RE.LT.5.E5) NUS = 0.664*(PR**(1./3.))*SQRT(RE)
IF(RE.GT.5.E5) NUS = (PR**(1./3.))*(0.037*(RE**0.8)-850.)
HCF = NUS*K/AL
HC = (HCF**3 + HCN**3)**(1./3.)
End
```

APPENDIX D

```
Public Class frmCalculator
    Dim State_City, State, City, Regional, BuildingType As String
    Dim ConditionedFloorArea, NumberOfFloorArea
    Dim HeatingEquipment As String
    Dim ElectricityPrice As Single
    Dim GasPrice As Single
    Dim d As Single = 0, m As Single = 0, y As Single = 0
    Dim HeatingSystemEfficiency, CoolingSystemEfficiency As String
    Dim RoofType As String
    Dim RoofSlope As String
    Dim RadiantBarrier, RadiantBarrierCoverage As String
    Dim RadiantBarrierEmmisivity, RadiantBarrierIndex As Single
    Dim RB_type As String
    Dim Filename As String
    Dim CaseArray(8640, 3), Q(8640, 0), Ta(8640, 0), Wind(8640, 0), Phi(8640,
0), _
    Temp(8640, 0), TempWRB(8640, 0), TempF(8640, 0), TempWRBF(8640, 0)
    Dim QCoolTotal(8640, 0), QHeatTotal(8640, 0), QCoolTotalWRB(8640, 0),
QHeatTotalWRB(8640, 0)
    Dim Qcool_day(365, 0), QHeat_day(365, 0), Qcool_month(12, 0),
QHeat_month(12, 0)
    Dim Qcool_dayWRB(365, 0), QHeat_dayWRB(365, 0), Qcool_monthWRB(12, 0),
QHeat_monthWRB(12, 0)
    Dim QHeat_year, Qcool_year, QHeat_yearWRB, Qcool_yearWRB As Single

    Dim Emissivity_shingle As Single
    Dim AtticInsulation As String
    Dim AtticInsulationEmissivity As Single
    Dim U, SEER, HSPF, AFUE, CoolCost, HeatCost, CoolCostWRB, HeatCostWRB As
Single
    Dim Netcoolcost, Netheatcost, Totalcostsaving As Single
    Dim TempIn As Single = 72
    Dim A1, A2, A3, A4, A5, A6, A7, A8, A9, A10 As Single
    Dim B1, B2, B3, B4, B5, B6, B7, B8, B9, B10 As Single
    Dim max As Single
    Dim discount, NN
    Dim escalation(24, 0), PV(24, 0)



    Private Sub cmdOpenExcel_Click(ByVal State, ByVal City)
        On Error GoTo ErrHandler
        Dim xlsApp As Object
        Dim xlsWB1 As Object

        Filename = "C:\Users\cmieadmin\Documents\Research Radiant
barrier\Calculator\Test\" & State & "\" & City & ".xlsx"
        'Late binding to open an XLS file which is present on my local
harddisk
        xlsApp = CreateObject("Excel.Application")
        xlsApp.Visible = True
        xlsWB1 = xlsApp.Workbooks.Open(Filename)
```

```
        Exit Sub
ErrHandler:
        MsgBox("There is a problem while opening the xls document. " & _
        " Please ensure it is present!", vbCritical, "Error")
    End Sub


    Private Sub cmdParse_Click(ByVal City)
        On Error GoTo ErrHandler
        Dim xlsApp As Object
        Dim xlsWB1 As Object
        Dim xlsWS1 As Object
        'Opening the file to parse now
        xlsApp = CreateObject("Excel.Application")
        xlsApp.Visible = False
        xlsWB1 = xlsApp.Workbooks.Open(Filename)
        xlsWS1 = xlsWB1.Worksheets(City)
        Dim col As Integer
        Dim row As Integer
        Dim str As String
        str = ""
        Dim MaxRow As Integer = 8640
        Dim MaxCol As Integer = 3
        'Declaring an array so that we don't have to depend on the excel file
anymore
        ReDim CaseArray(MaxRow, MaxCol)
        'Reading the Excel file and putting everything in Memory for faster
manipulation
        For row = 1 To MaxRow
            CaseArray(row, 0) = xlsWS1.cells(row + 2, 5).Value
            CaseArray(row, 1) = xlsWS1.cells(row + 2, 32).Value + 273.15
            CaseArray(row, 2) = xlsWS1.cells(row + 2, 38).Value
            CaseArray(row, 3) = xlsWS1.cells(row + 2, 47).Value
            ProgressBar1.Value = row
        Next

        xlsWB1.Close()
        xlsApp.Quit()
        xlsApp = Nothing
        xlsWB1 = Nothing
        xlsWS1 = Nothing
        Exit Sub
ErrHandler:
        MsgBox("An unknown error occurred while Parsing the Excel. Sorry
about that!!", vbCritical, "Error")
    End Sub


    Private Sub CmdCalculate_Click(ByVal sender As Object, ByVal e As
System.EventArgs) Handles CmdCalculate.Click



        State_City = CboState.Text
        State = Mid(State_City, 1, 2)
        City = Mid(State_City, 4, Len(State_City))
        ProgressBar1.Maximum = 8640
```

```
        BuildingType = CboBlgType.Text
        ConditionedFloorArea = Val(TextFloorArea.Text)
        NumberOfFloorArea = Val(TextFloorNumber.Text)
        HeatingEquipment = CboHeatEquip.Text
        ElectricityPrice = Val(TextElectricityPrice.Text)
        GasPrice = Val(TextGasPrice.Text)
        HeatingSystemEfficiency = CboHeatingEfficiency.Text
        CoolingSystemEfficiency = CboCoolingEfficiency.Text
        RoofType = CboRoofType.Text
        'RoofSlope = CboRoofSlope.Text
        RB_type = CboRadiantBarrierType.Text
        AtticInsulation = CboAtticInsulation.Text
        AtticInsulationEmissivity = CboAtticInsulationEmissivity.Text
        RadiantBarrierCoverage = CboRadiantBarrierCoverage.Text
        RadiantBarrierEmmisivity = CboRadiantBarrierEmissivity.Text

        'specifying the region belongs to each state
        If State = "LA" Or State = "AL" Or State = "MS" Or State = "TX" Or
State = "FL" Or _
        State = "GA" Or State = "AR" Or State = "SC" Or State = "AZ" Or State
= "NC" Or State = "TN" Or State = "HI" Then
            Regional = "South"
        ElseIf State = "CA" Or _
        State = "ID" Or State = "UT" Or State = "NV" Or State = "NM" Then
            Regional = "West"
        ElseIf State = "MD" Or State = "WA" Or State = "PA" Or State = "SC"
Or _
        State = "NC" Or State = "VA" Or State = "DE" Or State = "NY" Or State
= "KY" Or State = "WV" Or State = "NE" Or State = "MO" Or State = "IL" Or
State = "IA" Or State = "OH" Or State = "KS" Or State = "NJ" Or _
        State = "RI" Or State = "CT" Or State = "MA" Or State = "OK" Or State
= "ID" Or State = "IN" Or State = "CO" Or State = "OR" Then
            Regional = "East"
        ElseIf State = "MN" Or State = "ND" Or State = "SD" Or State = "NH"
Or State = "MT" Or State = "ME" Or State = "WI" Or State = "WY" Or State =
"VT" Or State = "MI" Or State = "AK" Then
            Regional = "North"
        End If


        ' U for diffrent Insualtion ( BTUh/F/SQFT)
********************************************************

        If AtticInsulation = "R-7" Then
            U = 0.142        'U is finalized BTU/(h °F ft²)
        ElseIf AtticInsulation = "R-11" Then
            U = 0.09        'U is  finalized BTU/(h °F ft²)
        ElseIf AtticInsulation = "R-13" Then
            U = 0.0769        'U is finalized BTU/(h °F ft²)
        ElseIf AtticInsulation = "R-15" Then
            U = 0.06667        'U is finalized BTU/(h °F ft²)
        ElseIf AtticInsulation = "R-19" Then
            U = 0.0526        'U is finalized BTU/(h °F ft²)
        ElseIf AtticInsulation = "R-21" Then
            U = 0.0476        'U is finalized BTU/(h °F ft²)
        ElseIf AtticInsulation = "R-25" Then
            U = 0.04        'U is finalized BTU/(h °F ft²)
```

```
        ElseIf AtticInsulation = "R-28" Then
            U = 0.0357        'U is finalized BTU/(h °F ft²)
        ElseIf AtticInsulation = "R-30" Then
            U = 0.0333        'U is finalized BTU/(h °F ft²)
        ElseIf AtticInsulation = "R-38" Then
            U = 0.0263        'U is finalized BTU/(h °F ft²)
        ElseIf AtticInsulation = "R-44" Then
            U = 0.0227        'U is finalized BTU/(h °F ft²)
        ElseIf AtticInsulation = "R-50" Then
            U = 0.02        'U is finalized BTU/(h °F ft²)
        ElseIf AtticInsulation = "R-56" Then
            U = 0.0178       'U is finalized BTU/(h °F ft²)
        End If
        ' Emissivity for diffrent roof color
********************************************************
        If RoofType = "Dark" Then
            Emissivity_shingle = 0.97
        ElseIf RoofType = "Medium" Then
            Emissivity_shingle = 0.91
        ElseIf RoofType = "Light" Then
            Emissivity_shingle = 0.75
        End If
        ' Value for diffrent Radiant Barrier Coverage
********************************************************
        If RadiantBarrierCoverage = "Full Coverage" Then
            RadiantBarrierIndex = 3
        ElseIf RadiantBarrierCoverage = "East-West Coverage" Then
            RadiantBarrierIndex = 2
        ElseIf RadiantBarrierCoverage = "North-South Coverage" Then
            RadiantBarrierIndex = 1
        End If

        ' Efficiency for Cooling system
********************************************************
        If CoolingSystemEfficiency = "High" Then         ' BTU/Watt-hr
            SEER = 11  'Coefficients are not finalized
        ElseIf CoolingSystemEfficiency = "Mid" Then
            SEER = 9  'Coefficients are not finalized
        ElseIf CoolingSystemEfficiency = "Low" Then
            SEER = 7  'Coefficients are not finalized
        End If
        ' Efficiency for Heating system
********************************************************
        If HeatingSystemEfficiency = "High" Then      ' Btu/watt-hr
            HSPF = 10 'Coefficients are not finalized
        ElseIf HeatingSystemEfficiency = "Mid" Then
            HSPF = 8.5  'Coefficients are not finalized
        ElseIf HeatingSystemEfficiency = "Low" Then
            HSPF = 6.8  'Coefficients are not finalized
        End If

        ' State of
Louisiana********************************************************

        If Regional = "South" Then
```

```
            'Attached to Plywood---------------------------------------------
------------------------------------
            If RB_type = "Attached to Plywood" Then

                'Temp = A1 + A2 * Q + A3 * W + A4 * Ta + A5 * Emissivity

                A1 = 35.23604 : A2 = 0.014472 : A3 = 0.908973 : A4 = 0.242376
: A5 = -0.07663 : A6 = 0 : A7 = 0 : A8 = -3.78313 : A9 = 0 'Coefficients are
finalized
                ' Bubble RB--------------------------------------------------
------------------------------------------
            ElseIf RB_type = "Bubble RB" Then

                A1 = 33.71789 : A2 = 0.010702 : A3 = 0.915071 : A4 = 0.288488
: A5 = -0.07995 : A6 = 0 : A7 = 0 : A8 = -3.74127 : A9 = 0 'Coefficients are
finalized

                ' Installed on Rafters --------------------------------------
-------------------------------------
            ElseIf RB_type = "Installed on Rafters" Then

                A1 = 31.72934 : A2 = 0.008099 : A3 = 0.922654 : A4 = 0.314689
: A5 = -0.08115 : A6 = 0 : A7 = 0 : A8 = -3.99259 : A9 = 0 'Coefficients are
finalized


            End If
            ' No Radiant B-----------------------------------------------------
-----------------------------------
            B1 = -44.524 : B2 = 0.017704 : B3 = 1.182355 : B4 = -0.0979 : B5
= -0.07097 : B6 = 0 : B7 = 0 : B8 = -0.73118 : B9 = 0 'Coefficients are
finalized

            ' State of
Louisiana********************************************************

        ElseIf Regional = "East" Then

            'Attached to Plywood---------------------------------------------
------------------------------------
            If RB_type = "Attached to Plywood" Then

                'Temp = A1 + A2 * Q + A3 * W + A4 * Ta + A5 * Emissivity

                A1 = 45.41772 : A2 = 0.012721 : A3 = 0.872832 : A4 = 0.070998
: A5 = -0.06144 : A6 = 0 : A7 = 0 : A8 = 0 : A9 = 0 'Coefficients are
finalized

                ' Bubble RB--------------------------------------------------
------------------------------------------
            ElseIf RB_type = "Bubble RB" Then

                A1 = 45.56862 : A2 = 0.009053 : A3 = 0.87317 : A4 = 0.099698
: A5 = -0.064 : A6 = 0 : A7 = 0 : A8 = 0 : A9 = 0 'Coefficients are finalized

                ' Installed on Rafters --------------------------------------
-------------------------------------
```

```
            ElseIf RB_type = "Installed on Rafters" Then

                A1 = 45.7913 : A2 = 0.006769 : A3 = 0.872531 : A4 = 0.136683
: A5 = -0.06492 : A6 = 0 : A7 = 0 : A8 = 0 : A9 = 0 'Coefficients are
finalized

            End If
            ' No Radiant B----------------------------------------------------
-----------------------------------

            B1 = 21.71708 : B2 = 0.018951 : B3 = 0.949 : B4 = 0.04154 : B5 =
-0.05331 : B6 = 0 : B7 = 0 : B8 = 0 : B9 = 0 'Coefficients are finalized

            ' State of
Louisiana********************************************************

        ElseIf Regional = "North" Then

            'Attached to Plywood---------------------------------------------
------------------------------------
            If RB_type = "Attached to Plywood" Then

                'Temp = A1 + A2 * Q + A3 * W + A4 * Ta + A5 * Emissivity

                A1 = 36.31017 : A2 = 0.01833 : A3 = 0.883521 : A4 = 0.129559
: A5 = -0.02471 : A6 = -0.37546 : A7 = 20.7827 : A8 = 0.820455 : A9 = 0
'Coefficients are finalized
                ' Bubble RB--------------------------------------------------
------------------------------------------
            ElseIf RB_type = "Bubble RB" Then

                A1 = 37.61691 : A2 = 0.013483 : A3 = 0.879221 : A4 = 0.196569
: A5 = -0.02547 : A6 = -0.37343 : A7 = 20.01347 : A8 = 0 : A9 = 0.042114
'Coefficients are finalized


                ' Installed on Rafters --------------------------------------
-------------------------------------
            ElseIf RB_type = "Installed on Rafters" Then


                A1 = 37.51478 : A2 = 0.013697 : A3 = 0.880076 : A4 = 0.171642
: A5 = -0.02576 : A6 = -0.36419 : A7 = 19.83511 : A8 = 0 : A9 = 0.036603
'Coefficients are finalized

            End If
            ' No Radiant B----------------------------------------------------
-----------------------------------

            B1 = 23.91904 : B2 = 0.022733 : B3 = 0.934127 : B4 = 0.033341 :
B5 = -0.0422 : B6 = 0 : B7 = 0 : B8 = 0.903837 : B9 = 0.033751 'Coefficients
are  finalized


            ' State of
Louisiana********************************************************
```

```
        ElseIf Regional = "West" Then

            'Attached to Plywood---------------------------------------------------
------------------------------------
            If RB_type = "Attached to Plywood" Then

                'Temp = A1 + A2 * Q + A3 * W + A4 * Ta + A5 * Emissivity
                A1 = -26.4892 : A2 = 0.009345 : A3 = 1.101953 : A4 = 0.387712
: A5 = -0.00684 : A6 = 0 : A7 = 0 : A8 = 0 : A9 = 0 'Coefficients are
finalized


                ' Bubble RB----------------------------------------------------------
------------------------------------------
            ElseIf RB_type = "Bubble RB" Then

                A1 = -24.0013 : A2 = 0.005831 : A3 = 1.092776 : A4 = 0.3787 :
A5 = -0.018 : A6 = 0 : A7 = 10.00088 : A8 = 0 : A9 = 0 'Coefficients are
finalized

                ' Installed on Rafters --------------------------------------
-------------------------------------
            ElseIf RB_type = "Installed on Rafters" Then

                A1 = -23.0277 : A2 = 0.003385 : A3 = 1.089251 : A4 =
0.4722015 : A5 = -0.01257 : A6 = 0 : A7 = 13.43894 : A8 = 0 : A9 = 0
'Coefficients are  finalized

            ElseIf RB_type = "No Radiant Barrier" Then

            End If

            ' No Radiant B-----------------------------------------------------
-----------------------------------

            B1 = -28.7302 : B2 = 0.015892 : B3 = 1.108268 : B4 = 0.26468 : B5
= 0 : B6 = 0 : B7 = 0 : B8 = 0 : B9 = 0 'Coefficients are  finalized

        End If


        cmdOpenExcel_Click(State, City)
        cmdParse_Click(City)




        'Hourly heat flux:
        For i = 1 To 8640
            Q(i, 0) = CaseArray(i, 0)
            Ta(i, 0) = CaseArray(i, 1)
            Phi(i, 0) = CaseArray(i, 2)
            Wind(i, 0) = CaseArray(i, 3)

          Temp(i, 0) = A1 + A2 * Q(i, 0) * Emissivity_shingle + A3 * Ta(i, 0)
+ A4 * Wind(i, 0) + _
```

```
            A5 * Phi(i, 0) + A6 * RadiantBarrierIndex + A7 *
RadiantBarrierEmmisivity + A8 * AtticInsulationEmissivity + 0.1 * A9
            TempWRB(i, 0) = B1 + B2 * Q(i, 0) * Emissivity_shingle + B3 *
Ta(i, 0) + B4 * Wind(i, 0) + _
            B5 * Phi(i, 0) + B6 * RadiantBarrierIndex + B7 *
RadiantBarrierEmmisivity + B8 * AtticInsulationEmissivity + 0.1 * B9


            TempF(i, 0) = (Temp(i, 0) - 273.15) * 9 / 5 + 32
            TempWRBF(i, 0) = (TempWRB(i, 0) - 273.15) * 9 / 5 + 32

            QCoolTotal(i, 0) = NumberOfFloorArea * ConditionedFloorArea *
(TempF(i, 0) - TempIn) * U 'U=BTU/h/F/ft^2
            QHeatTotal(i, 0) = NumberOfFloorArea * ConditionedFloorArea *
(TempIn - TempF(i, 0)) * U

            QCoolTotalWRB(i, 0) = NumberOfFloorArea * ConditionedFloorArea *
(TempWRBF(i, 0) - TempIn) * U 'U=BTU/h/F/ft^2
            QHeatTotalWRB(i, 0) = NumberOfFloorArea * ConditionedFloorArea *
(TempIn - TempWRBF(i, 0)) * U



            If QCoolTotal(i, 0) < 0 Then
                QCoolTotal(i, 0) = 0
            End If
            If QHeatTotal(i, 0) < 0 Then
                QHeatTotal(i, 0) = 0
            End If
            If QCoolTotalWRB(i, 0) < 0 Then
                QCoolTotalWRB(i, 0) = 0
            End If
            If QHeatTotalWRB(i, 0) < 0 Then
                QHeatTotalWRB(i, 0) = 0
            End If




        Next

        Form2.Show()

        'Form2.TempF.Text = Temp(1, 0)
        For i = 1 To 9

            Form2.A1.Text = Format(A1, "#####0.0000")
            Form2.A2.Text = Format(A2, "#####0.0000")
            Form2.A3.Text = Format(A3, "#####0.0000")
            Form2.A4.Text = Format(A4, "#####0.0000")
            Form2.A5.Text = Format(A5, "#####0.0000")
            Form2.A6.Text = Format(A6, "#####0.0000")
            Form2.A7.Text = Format(A7, "#####0.0000")
            Form2.A8.Text = Format(A8, "#####0.0000")
            Form2.A9.Text = Format(A9, "#####0.0000")
        Next
```

```
'Summation for days
For i = 1 To 8640
    If (i Mod 24) <> 1 Then
        Qcool_day(d, 0) = Qcool_day(d, 0) + QCoolTotal(i, 0)
        QHeat_day(d, 0) = QHeat_day(d, 0) + QHeatTotal(i, 0)

        Qcool_dayWRB(d, 0) = Qcool_dayWRB(d, 0) + QCoolTotalWRB(i, 0)
        QHeat_dayWRB(d, 0) = QHeat_dayWRB(d, 0) + QHeatTotalWRB(i, 0)
    Else
        d = d + 1
        Qcool_day(d, 0) = QCoolTotal(i, 0)
        QHeat_day(d, 0) = QHeatTotal(i, 0)

        Qcool_dayWRB(d, 0) = QCoolTotalWRB(i, 0)
        QHeat_dayWRB(d, 0) = QHeatTotalWRB(i, 0)

    End If
Next
'Summation for month
For j = 1 To 360
    If (j Mod 30) <> 1 Then
        Qcool_month(m, 0) = Qcool_month(m, 0) + Qcool_day(j, 0)
        QHeat_month(m, 0) = QHeat_month(m, 0) + QHeat_day(j, 0)

     Qcool_monthWRB(m, 0) = Qcool_monthWRB(m, 0) + Qcool_dayWRB(j, 0)
     QHeat_monthWRB(m, 0) = QHeat_monthWRB(m, 0) + QHeat_dayWRB(j, 0)
    Else
        m = m + 1
        Qcool_month(m, 0) = Qcool_day(j, 0)
        QHeat_month(m, 0) = QHeat_day(j, 0)

        Qcool_monthWRB(m, 0) = Qcool_dayWRB(j, 0)
        QHeat_monthWRB(m, 0) = QHeat_dayWRB(j, 0)

    End If
Next

For i = 1 To 12
    If Qcool_month(i, 0) < 0.05 * maximumarray(Qcool_month, 12) Then
        Qcool_month(i, 0) = 0
    End If
    If QHeat_month(i, 0) < 0.05 * maximumarray(QHeat_month, 12) Then
        QHeat_month(i, 0) = 0
    End If
Next
For i = 1 To 12
    If Qcool_monthWRB(i, 0) < 0.05 * maximumarray(Qcool_monthWRB, 12)
Then
        Qcool_monthWRB(i, 0) = 0
    End If
    If QHeat_monthWRB(i, 0) < 0.05 * maximumarray(QHeat_monthWRB, 12)
Then
        QHeat_monthWRB(i, 0) = 0
    End If
Next
```

```
'MsgBox(Qcool_day(1, 1), Qcool_day(2, 1), Qcool_day(3, 1))

Form2.TextBox12.Text = Format(Qcool_month(1, 0), "#####0.00")
Form2.TextBox22.Text = Format(Qcool_month(2, 0), "#####0.00")
Form2.TextBox32.Text = Format(Qcool_month(3, 0), "#####0.00")
Form2.TextBox42.Text = Format(Qcool_month(4, 0), "#####0.00")
Form2.TextBox52.Text = Format(Qcool_month(5, 0), "#####0.00")
Form2.TextBox62.Text = Format(Qcool_month(6, 0), "#####0.00")
Form2.TextBox72.Text = Format(Qcool_month(7, 0), "#####0.00")
Form2.TextBox82.Text = Format(Qcool_month(8, 0), "#####0.00")
Form2.TextBox92.Text = Format(Qcool_month(9, 0), "#####0.00")
Form2.TextBox102.Text = Format(Qcool_month(10, 0), "#####0.00")
Form2.TextBox112.Text = Format(Qcool_month(11, 0), "#####0.00")
Form2.TextBox122.Text = Format(Qcool_month(12, 0), "#####0.00")


Form2.TextBox13.Text = Format(QHeat_month(1, 0), "#####0.00")
Form2.TextBox23.Text = Format(QHeat_month(2, 0), "#####0.00")
Form2.TextBox33.Text = Format(QHeat_month(3, 0), "#####0.00")
Form2.TextBox43.Text = Format(QHeat_month(4, 0), "#####0.00")
Form2.TextBox53.Text = Format(QHeat_month(5, 0), "#####0.00")
Form2.TextBox63.Text = Format(QHeat_month(6, 0), "#####0.00")
Form2.TextBox73.Text = Format(QHeat_month(7, 0), "#####0.00")
Form2.TextBox83.Text = Format(QHeat_month(8, 0), "#####0.00")
Form2.TextBox93.Text = Format(QHeat_month(9, 0), "#####0.00")
Form2.TextBox103.Text = Format(QHeat_month(10, 0), "#####0.00")
Form2.TextBox113.Text = Format(QHeat_month(11, 0), "#####0.00")
Form2.TextBox123.Text = Format(QHeat_month(12, 0), "#####0.00")

Form2.TextBox14.Text = Format(Qcool_monthWRB(1, 0), "#####0.00")
Form2.TextBox24.Text = Format(Qcool_monthWRB(2, 0), "#####0.00")
Form2.TextBox34.Text = Format(Qcool_monthWRB(3, 0), "#####0.00")
Form2.TextBox44.Text = Format(Qcool_monthWRB(4, 0), "#####0.00")
Form2.TextBox54.Text = Format(Qcool_monthWRB(5, 0), "#####0.00")
Form2.TextBox64.Text = Format(Qcool_monthWRB(6, 0), "#####0.00")
Form2.TextBox74.Text = Format(Qcool_monthWRB(7, 0), "#####0.00")
Form2.TextBox84.Text = Format(Qcool_monthWRB(8, 0), "#####0.00")
Form2.TextBox94.Text = Format(Qcool_monthWRB(9, 0), "#####0.00")
Form2.TextBox104.Text = Format(Qcool_monthWRB(10, 0), "#####0.00")
Form2.TextBox114.Text = Format(Qcool_monthWRB(11, 0), "#####0.00")
Form2.TextBox124.Text = Format(Qcool_monthWRB(12, 0), "#####0.00")


Form2.TextBox15.Text = Format(QHeat_monthWRB(1, 0), "#####0.00")
Form2.TextBox25.Text = Format(QHeat_monthWRB(2, 0), "#####0.00")
Form2.TextBox35.Text = Format(QHeat_monthWRB(3, 0), "#####0.00")
Form2.TextBox45.Text = Format(QHeat_monthWRB(4, 0), "#####0.00")
Form2.TextBox55.Text = Format(QHeat_monthWRB(5, 0), "#####0.00")
Form2.TextBox65.Text = Format(QHeat_monthWRB(6, 0), "#####0.00")
Form2.TextBox75.Text = Format(QHeat_monthWRB(7, 0), "#####0.00")
```

```
        Form2.TextBox85.Text = Format(QHeat_monthWRB(8, 0), "#####0.00")
        Form2.TextBox95.Text = Format(QHeat_monthWRB(9, 0), "#####0.00")
        Form2.TextBox105.Text = Format(QHeat_monthWRB(10, 0), "#####0.00")
        Form2.TextBox115.Text = Format(QHeat_monthWRB(11, 0), "#####0.00")
        Form2.TextBox125.Text = Format(QHeat_monthWRB(12, 0), "#####0.00")


        For i = 1 To 12
            Qcool_year = Qcool_month(i, 0) + Qcool_year
            QHeat_year = QHeat_month(i, 0) + QHeat_year
            Qcool_yearWRB = Qcool_monthWRB(i, 0) + Qcool_yearWRB
            QHeat_yearWRB = QHeat_monthWRB(i, 0) + QHeat_yearWRB
        Next

        Form2.TextBox1.Text = Format(Qcool_year, "#####0.00")
        Form2.TextBox2.Text = Format(QHeat_year, "#####0.00")
        Form2.TextBox3.Text = Format(Qcool_yearWRB, "#####0.00")
        Form2.TextBox4.Text = Format(QHeat_yearWRB, "#####0.00")


        CoolCost = ((ElectricityPrice / 1000) * Qcool_year / SEER) / 100 'in
dollars
        HeatCost = ((ElectricityPrice / 1000) * QHeat_year / HSPF) / 100
        CoolCostWRB = ((ElectricityPrice / 1000) * Qcool_yearWRB / SEER) /
100
        HeatCostWRB = ((ElectricityPrice / 1000) * QHeat_yearWRB / HSPF) /
100


        Netcoolcost = CoolCostWRB - CoolCost
        Netheatcost = HeatCostWRB - HeatCost

        Totalcostsaving = Netcoolcost + Netheatcost

        Form2.TextBoxCoolCost.Text = Format(Netcoolcost, "#####0.00")
        Form2.TextBoxHeatCost.Text = Format(Netheatcost, "#####0.00")
        Form2.TextBoxTotalcostsaving.Text = Format(Totalcostsaving,
"#####0.00")
        discount = 0.03
        escalation(1, 0) = 0.033506045
        escalation(2, 0) = 0.006016043
        escalation(3, 0) = -0.017607973
        escalation(4, 0) = -0.012174501
        escalation(5, 0) = -0.007531667
        escalation(6, 0) = -0.009313556
        escalation(7, 0) = -0.00591922
        escalation(8, 0) = -0.000700525
        escalation(9, 0) = 0.001752541
        escalation(10, 0) = -0.00209937
        escalation(11, 0) = 0.004207574
        escalation(12, 0) = -0.001047486
        escalation(13, 0) = -0.001398113
        escalation(14, 0) = 0.002100105
        escalation(15, 0) = 0.000698568
        escalation(16, 0) = -0.00034904
        escalation(17, 0) = 0.001047486
        escalation(18, 0) = 0.001743983
```

```
        escalation(19, 0) = 0
        escalation(20, 0) = 0.001733102
        escalation(21, 0) = 0.001038062
        escalation(22, 0) = 0.001382648
        escalation(23, 0) = 0.001380739
        escalation(24, 0) = 0.001034126

        NN = 24
        For i = 1 To 24
            PV(i, 0) = Totalcostsaving * ((1 + escalation(i, 0)) / (discount
- escalation(i, 0))) * (1 - (1 + escalation(i, 0)) / (1 + discount) ^ i)
        Next




    End Sub
    Private Sub CmdClear_Click(ByVal sender As Object, ByVal e As
System.EventArgs) Handles CmdClear.Click
        'Blank out the text boxes
        TextFloorArea.Text = ""
        TextFloorNumber.Text = ""
        TextElectricityPrice.Text = ""
        TextGasPrice.Text = ""
    End Sub


    Private Sub Label1_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs)

    End Sub

    Private Sub LinkLabel1_LinkClicked(ByVal sender As System.Object, ByVal e
As System.Windows.Forms.LinkLabelLinkClickedEventArgs) Handles
LinkLabel1.LinkClicked

Process.Start("http://www.census.gov/const/C25Ann/sftotalmedavgsqft.pdf")
    End Sub

    Private Sub LinkLabel2_LinkClicked(ByVal sender As System.Object, ByVal e
As System.Windows.Forms.LinkLabelLinkClickedEventArgs) Handles
LinkLabel2.LinkClicked
        Process.Start("http://www.eia.gov/electricity/monthly/")
    End Sub

    Private Sub LinkLabel3_LinkClicked(ByVal sender As System.Object, ByVal e
As System.Windows.Forms.LinkLabelLinkClickedEventArgs) Handles
LinkLabel3.LinkClicked

Process.Start("http://www.eia.gov/dnav/ng/ng_pri_sum_a_EPG0_PRS_DMcf_m.htm")
    End Sub

    Private Sub LinkLabel4_LinkClicked(ByVal sender As System.Object, ByVal e
As System.Windows.Forms.LinkLabelLinkClickedEventArgs) Handles
LinkLabel4.LinkClicked
```

```
Process.Start("http://www.energystar.gov/index.cfm?c=airsrc_heat.pr_crit_as_h
eat_pumps")
    End Sub

    Private Sub LinkLabel5_LinkClicked(ByVal sender As System.Object, ByVal e
As System.Windows.Forms.LinkLabelLinkClickedEventArgs) Handles
LinkLabel5.LinkClicked

Process.Start("http://www.energystar.gov/index.cfm?c=airsrc_heat.pr_crit_as_h
eat_pumps")
    End Sub

    Private Sub CboRadiantBarrier_SelectedIndexChanged(ByVal sender As
System.Object, ByVal e As System.EventArgs)

    End Sub

    Private Sub LinkLabel6_LinkClicked(ByVal sender As System.Object, ByVal e
As System.Windows.Forms.LinkLabelLinkClickedEventArgs)

Process.Start("http://www.energysavers.gov/your_home/insulation_airsealing/in
dex.cfm/mytopic=11680")
    End Sub

    Private Sub LinkLabel7_LinkClicked(ByVal sender As System.Object, ByVal e
As System.Windows.Forms.LinkLabelLinkClickedEventArgs) Handles
LinkLabel7.LinkClicked

Process.Start("http://www.ornl.gov/sci/ees/etsd/btric/RadiantBarrier/rb4a.sht
ml")
    End Sub

    Public Function maximumarray(ByVal A As Array, ByVal size As Integer) As
Single
        'Dim max As Double
        'Dim maximum As Single
        maximumarray = A(0, 0)
        For i = 1 To size '- 1
            If A(i, 0) > maximumarray Then
                maximumarray = A(i, 0)
            End If
        Next
    End Function



    Private Sub TextGasPrice_TextChanged(ByVal sender As System.Object, ByVal
e As System.EventArgs) Handles TextGasPrice.TextChanged
        If CboHeatEquip.Text = "Electric Heat Pump" Then
            TextGasPrice.Enabled = False
            TextElectricityPrice.Enabled = True
        End If
    End Sub
```

```
    Private Sub TextElectricityPrice_TextChanged(ByVal sender As
System.Object, ByVal e As System.EventArgs) Handles
TextElectricityPrice.TextChanged
        If CboHeatEquip.Text = "Natural Gas Furnace" Then
            TextGasPrice.Enabled = True
            TextElectricityPrice.Enabled = False
        End If
    End Sub

    Private Sub GroupBox1_Enter(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles GroupBox1.Enter

    End Sub

    Private Sub ProgressBar1_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles ProgressBar1.Click

    End Sub

    Private Sub CboState_SelectedIndexChanged(ByVal sender As System.Object,
ByVal e As System.EventArgs) Handles CboState.SelectedIndexChanged

    End Sub
End Class
```

VITA

Somayeh Asadi was born in 1981 in Tehran, Iran. She joined Louisiana State University (LSU) in Baton Rouge, Louisiana in August 2009 to pursue a Ph.D. of Science in Engineering Science degree. Her interests include sustainable engineering. Her graduate studies have been in the interdisciplinary program of engineering science with concentration in construction management and sustainability. She obtained a Master of Science in Engineering Science degree with concentration in construction management and sustainability in 2011. She is a candidate for the Doctor of Philosophy degree in engineering science with concentration in construction management and sustainability. The degree will be conferred at the summer commencement 2012.