AN INVESTIGATION OF OPTIONS TO IMPROVE THERMAL PERFORMANCE OF ROOF

MS. PATTAVADEE CHAIVOOT
ID: 54910423

A THESIS SUBMITTED AS A PART OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ENGINEERING IN ENERGY TECHNOLOGY AND MANAGEMENT

THE JOINT GRADUATE SCHOOL OF ENERGY AND ENVIRONMENT AT KING MONGKUT'S UNIVERSITY OF TECHNOLOGY THONBURI

2ND SEMESTER 2013

An Investigation of Options to Improve Thermal Performance of Roof

Ms.Pattavadee Chaivoot
ID: 54910423

A Thesis Submitted as a Part of the Requirements
for the Degree of Master of Engineering
in Energy Technology and Management

The Joint Graduate School of Energy and Environment
at King Mongkut's University of Technology Thonburi

2nd Semester 2013

Thesis Committee

Surapong C
…………………………………………
(Prof. Dr. Surapong Chirarattananon) Advisor

…………………………………………
(Dr. Pattana Rakkwamsuk) Member

Pipat C.
…………………………………………
(Dr. Pipat Chaiwiwatworakul) Member

…………………………………………
(Dr. Vu Duc Hien) Member

…………………………………………
(Asst. Prof. Dr. Atch Sreshthaputra) External Examiner

Thesis Title: An Investigation of Options to Improve Thermal Performance of Roof

Student's name, organization and telephone/fax numbers/email

Ms.Pattavadee Chaivoot

The Joint Graduate School of Energy and Environment (JGSEE)

King Mongkut's University of Technology Thonburi (KMUTT)

126 Pracha Uthit Rd., Bangmod, Tungkru, Bangkok 10140 Thailand

Telephone: 0-8975-91066

Email: tan_girl356@hotmail.com

Supervisor's name, organization and telephone/fax numbers/email

Prof. Dr. Surapong Chirarattananon

The Joint Graduate School of Energy and Environment (JGSEE)

King Mongkut's University of Technology Thonburi (KMUTT)

Telephone: 0-8979-84204 or 02-8729014-5 ext 4128

Email: surapong@jgsee.kmutt.ac.th

Topic: An Investigation of Options to Improve Thermal Performance of Roof

Name of student: Ms. Pattavadee Chaivoot **Student ID:** 54910423

Name of Supervisor: Prof. Dr. Surapong Chirarattananon

ABSTRACT

Thailand is located in a hot humid tropical zone, where the main position of electricity in residential buildings and commercial buildings is consumed by air conditioning loads. A reduction of the electricity consumption by the air conditioning systems, by means of suitable design on the thermal mass of building envelopes should be of interest. The theoretical study on heat transfer through roof when it is insulated and un-insulated, ventilated and un-ventilated, when the exterior roof surface is coated with low-emissivity material and un-coated, and when the room under roof is used as bedroom and as office are experimental results. The simulation program will be use to verify results of theoretical study for the configurations. All result will be help to investigate options to improve thermal performance of roofs of typical configurations when the spaces belows are used under common functions. This study consists of experiments and calculations conducted at the experimental site in Bangkhunthien Campus of the Joint Graduate School of Energy and Environment, King Mongkut's University of Technology Thonburi. The simulation program used to determine the annual results was BESim.

Keywords: Heat transfer, Roof, Thermal performance

ACKNOWLEDGEMENTS

The author would like to express the deepest gratitude to his advisor, Prof. Dr. Surapong Chirarattananon, for providing valuable me encouragement, guidance and suggestions. The author is also grateful to Dr. Pattana Rakkwamsuk, Dr. Pipat Chaiwiwatworakul, Dr. Vu Duc Hien, number of committee and also Asst. Prof. Dr. Atch Sreshthaputra, the external examiner of many valuable comments and suggestions.

The author also would like to express her appreciation to the Joint Graduate School of Energy and Environment for granting the scholarship and research funds. The author wishes to thank all of her colleagues and the staff of the Joint Graduate School of Energy and Environment, King Mongkut's University of Technology Thonburi for their collaboration and assistance in the experimental equipment installation. The special thanks to Mr. Preecha Tummu and Mr. Chalermsak Dulyakup for many valuable encouragement and suggestions. Finally, the author would like to express the deepest gratitude and appreciation to her parents and family members for their continuous encouragement throughout her studies.

CONTENTS

CONTENTS(Cont')

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES(Cont')

LIST OF FIGURES(Cont')

LIST OF FIGURES(Cont’)

NOMENCLATURES

SYMBOL	DESCRIPTION	UNIT
q	Heat flux	(W/m^2)
h	Heat transfer coefficient	(W/m^2K)
E_b	Emissive power	(W)
R	Thermal resistance	(m^2K/W)
E	Solar radiation flux	(W/m^2)
T	Temperature each node around center of mass's air cells	(°C)
$\dot{m}$	Mass flow rate	(kg/h)
C_p	Specific heat	(kJK/kg)
m_{si}	Airflow source in sub-zone I	(kg/s)
h_{ik}	The convection heat transfer coefficient between surface k in zone I	(W/m^2K)
ϕ_{condi}	Wall conductive heat flux to inside surface i	(m)
ϕ_{neti}	Radiant net exchange heat flux among the inside room surfaces	(W/m^2)
A_{si}	The area of inside surface I	(m^2)
σ	The Stefan-Boltzmann constant	$(W/m^2\ K^4)$
α	The solar absorbtance	
Nu_f	Solar thermal gain from the solar collectors	
Pr	The prandtl number	
Gr	The grashof number	
K_i	Factor the radiation interchange	
Re_f	The Reynolds number	
k	A constant value of various flow configurations	

CHAPTER 1
INTRODUCTION

1.1 Background / Problem statement

As a result of the looming shortage of fossil fuel reserves in the earth and the disastrous climate change caused by global warming, many countries are striving to enhance energy efficiency, and to promote renewable energies in the building sector. Existing buildings are responsible for over 40% of the world's total primary energy consumption, and account for 24% of world CO2 emissions (IEA, 2006). Energy consumption in building is allocated for satisfying the building' energy needs for heating, cooling, lighting and the other electrical appliances and equipment. A number of countries in the world have adopted mandatory requirements on energy conservation for building (K.B. Janda et al, 1994). Any strategic plans to promote energy efficiency and energy conservation in buildings would exert a significant impact on the reduction of the energy use in the country as a whole.

The maintenance of indoor comfort in modern buildings is usually ensured by air conditioners, particularly in a hot climate. 70.9% of all the electricity used in urban households in Thailand is consumed by air conditioners (Chirarattananon, 2005). The impact of the use of air conditioners on electricity demand is a serious problem. Peak electricity loads force utilities to build additional power plants, in order to satisfy the demand, thus increasing the average cost of electricity. In order to reduce the cooling load of air conditioners, we need to prevent occurring heat gains in building.

The amount of heat accumulated in a building depends on many factors. The prominent factors are the heat capacity of the structure, the schedule of use of space (and air-conditioning), and ambient conditions (Saman et al, 1991). The design and construction of the envelope of building, can have a significant effect on building's comfort and energy consumption. A breakdown of the cooling load of a typical office building in Thailand, shows the heat gain through the building envelope is dominant, at almost 60% of total Electric lighting is the second largest user, at around 20% of the total (Chirarattananon, 2005). The envelope and the air conditioning system are closely interrelated, and the proper management of the thermal capacity can influence very drastically the power requirements for heating and air conditioning (Fernandez et al, 2005).

A crucial factor that influences the heat capacity of the building envelope is thermal mass, which is a function of material density (ρ), and specific heat (C_p), which is a measure of the heat storage capacity of the material (Gregory et al, 2007). When exposed to external heating, the thermal mass absorbs and stores the solar heat gain during the day, and then slowly releases it into the inside environment later on. For centuries, the vast majority of European and Middle Eastern residential buildings have been built using massive walls (Kosny et al, 2000). Effective use of structural mass of thermal storage has been shown in several studies. It reduces building energy consumption, reduces and delays peak heating and cooling loads, and, in some case, improves comfort (Balaras, 1995, Kosny et al, 2000 and Kalogirou et al, 2001).

Solar radiation is the main driving force promoting heat gain through the building envelope (Chirarattananon, 2005). The amount of total solar radiation on the building surface is related to the location, time and orientation of that building. Thus, the cooling load is related to the quantities of thermal mass and building operating time. Moreover, solar heat can enter into buildings, by being conducted through building materials and entering through transparent opening (Balaras, 1997), and thermal mass can also absorb heat from inside building.

In summer, the minimization of solar loads through a building envelope is primordial. Sixty percent of the thermal transfer occurs in the roof. Thermal insulation of this component is of the utmost importance (Abdessalam et al, 1998; Garde, 1997). Materials frequently used for building insulation are chosen for their low thermal conductivity and their ability to block the conductive heat flux (Hasan et al, 1998; Ulgen, 2002). Materials having high reflectance are also used. They are made of aluminium foil combined with different layers of thin materials and are called Radiant Barriers. They cannot be characterized by a thermal resistance (Fairey, 1982). Radiant Barriers have received increased attention during the past years because of their ability to reflect the infrared radiation (Moujaes, 1996; Al Asmar et al, 1999). They are commonly used in attics to reduce the radiant heat transfer that occurs between the roof deck and attic floor of a residence or commercial buildings (Winiarski et al, 1996). In an attic, the radiant barriers can be located on top of ceiling insulation or underneath rafters. These products, placed in an attic, are a well documented means to reduce heat transfer through the ceiling (Hall, 1988;Medina,2000).

Roofing for residential buildings and high building with large roof area compared to the wall receive solar radiation directly, so it has high heat gain.

Thailand is located in a hot humid tropical zone, where the main electricity in residential buildings and commercial buildings is consumed by air conditioning loads. A reduction of electricity consumption by the air conditioning systems, by means of suitable design on the thermal mass of building envelopes, should be of interest.

This study presents the results of several simulations that investigate the ceiling insulation, air flow under roof, and roof coating under different functions of function room using, roof insulation, and mass of ceiling.

1.2 Objectives

To conduct experiments to verify the theoretical implications on heat transfer through roofs and to investigate options to improve their thermal performance.

To achieve the main objectives above, there are several specific objectives as follows.

1) to conduct a theoretical study on heat transfer through the roof when it is insulated and when un-insulated, ventilated and un-ventilated, when the exterior roof surface is coated with high thermal emissivity and high solar reflectance material and un-coated, and when the room under the roof is used as an office and as a bedroom.
2) to conduct experiments to verify the results of the theoretical study for the configuration in 1).
3) to investigate options to improve the thermal performance of roofs of typical configurations when the spaces below are used under common functions.

1.3 Scope of the Research

This study consists of experiments and calculations conducted at the experimental site in Bangkhunthien Campus of the Joint Graduate School of Energy and Environment. The simulation program used to determine annual result was BESim. The scope of this study includes the following items.

a) Solar radiation, air temperature and relative humidity, and wind measurements were taken from the measurement record from the station in the Bangkhunthien campus. Additional solar radiation, temperature, and heat flux at experimental room were measured by additional sensors and data loggers.

b) Experiments were conducted for certain crucial configurations. The simulation program BESim was used as the main calculation tool.

1.4 Literature Review

Soubdhan, T., Feuillard, T. and Bade, F. (2005) determined the influence of radiant barriers on conductive and radiative heat transfers when they are integrated into a building envelope, and compared their efficiency to traditional insulation material (mineral wools, polystyrene). It is also about determining which insulation material and process can lead to a better heat flux reduction through a building roof. For this study four identical small-scale test cells were used. Their respective roof was equipped with the insulation material to be tested: One with polystyrene, the second with a radiant barrier the third one with fiber glass and the last one with no insulation material was considered as the reference cell. Different test were performed with a view to evaluate the influence of parameters such as roof absorptivity and roof air layer ventilation on the heat flux reduction through the roof. With the measured temperature, the conductive and radiative heat fluxes were calculated. With a white corrugated iron roof top the heat flux reduction provided by the radiant barrier is 37%. With a black one this material allows a reduction of 33%. It is shown that whatever the roof absorptivity value, the radiative heat flux is predominant over the conductive one. With no ventilation, the radiant barrier is comparable to polystyrene and fiber glass; when the airspace is ventilated the radiant barrier provides a better insulation.

Caren Michels, Roberto Lamberts, Saulo Gu¨ths (2007) found that in tropical countries, the greatest thermal gain occurs through the roof of a house. In Brazil, the use of an asbestos-cement roof without a ceiling is very common. Thus, there is intense heat transfer to the internal environment, which may cause thermal discomfort to the inhabitants. There is currently no Brazilian normalization regarding the effective reductions in heat due to the use of these sheets. This study presents a compact apparatus for the determination of the efficiency of insulation sheets based on the use of heat flux transducers. Also, two models using thermal resistances which give simple correlations of great usefulness are presented. The sensitivity of the efficiency in relation to the several variables involved can be verified by exploring these correlations algebraically. Test results for different types of insulation sheets were compiled and compared with the theoretical models. This study demonstrates the great potential for the use of a heat flux transducer, which allows the measurement of the energy exchange in thermal systems in a fast and simple way and also shows it to be a useful tool for the determination of the emissivity of surfaces.

Hamida Ben Cheikh, Ammar Bouchair (2003) developed a dynamic mathematical model for an evapo-reflective roof to improve space cooling in buildings for hot arid climates has been developed. The proposed roof design is composed of a concrete ceiling over which lies a bed of rocks in a water pool. Over this bed is an air gap separated from the external environment by an aluminium plate. The upper surface of this plate is painted with a white titanium-based pigment to increase reflection of a radiation to a maximum during the day. At night, the temperature of the aluminium sheet falls below the temperature of the rock bed mixed with water. Water vapour inside the roof condenses and falls by gravity. This heat pipe effect carries heat outwards and cold inwards. Heat exchange is improved by radiation between two humid internal surfaces. The efficiency of this cooling system is studied using finite difference method. Numerical calculations performed for different external temperatures and solar radiation show that the cooling produced by such a system is significant. As a result of this, the mean air temperature in the room may be kept a few degrees above the minimum nocturnal outdoor temperature throughout the day. However, the maximum indoor air temperature was observed at sunset. This could further be lowered by allowing ventilation of the building in the evening. The work is continuing.

A dynamic mathematical model for an evapo-reflective roof used to improve space cooling in buildings in hot arid climates has been developed. The analysis theoretically examined the effectiveness of such a roof cooling system in comparison to a bare roof. The results showed that cooling inside buildings can be improved by the application of such a cooling design. It was also seen that combining evapo-reflective roofs with night ventilation increased such cooling significantly.

Mario A. Medina, Bryan Young (2005) offered a perspective on how climate and local environmental variables affected the performance of attic radiant barriers across the United States. Transient heat and mass transfer simulations were performed on a vented triangular attic with insulation level of 3:5m2K=W (R-19) and the results were based on integrated hourly ceiling heat fluxes over 3-month periods during the cooling season. The ceiling heat transfer percent reductions ranged from 36.8% in the Tropical Savanna climate to 2.3% in the Mediterranean climate. Peak-hour percent reductions in ceiling heat flux ranged from almost 100% in the Marine West Coast climate to 23% in the Desert climate. The results suggested that local ambient air temperature, humidity, cloud cover index, and altitude had first-order effects. The amount of local solar radiation had no effect on the performance of the systems.

Chirarattananon, S., Hien, V.D. (2006) found that in tropical region, heat gain through the roof during daytime contributed significantly to cooling loads and cooling costs for an air-conditioned space, and caused thermal discomfort when air-conditioning was not used. Radiant barrier, roof tiles of low solar absorptance, and various types of insulation are increasing introduced to ameliorate the problems. Studies on heat gain through roof for specific configurations and under specific weather conditions as have been reported do not seem to offer conclusive results on comparative costs and benefits in each case.

This paper reports an approach used to compute heat gain through roof through separating the mechanism of heat gain to the interior surfaces in the roof from thermal radiation heat transfer between surfaces in the roof. A method is used to compute form factors between surfaces that are then used in the radiosity computation. The results from a series of experiments conducted based on applications of radiance barrier and different types of insulation were then used to compare with calculation results in order to validate the approach of this paper. The method was then applied to calculate comparative energy consumption and space temperature under roof for a number of configurations of application of radiant barrier and roof insulation when the space under roof is used to serve as office, bedroom, and other functions. This same method of life-cycle economic evaluation has been used in the development of building energy code.

This paper has demonstrated that the model for heat transfer through roof is accurate and appropriate for a tropical climate. It also exhibits the usefulness of the model by applying it to evaluate the comparative benefits and costs of different construction materials used on buildings when it is used to serve different functions.

Chirarattananon, S., Hien, V.D.(2006) found that pitched roofs are used in houses and in small buildings around the world because of their ability to drain rain water well. In tropical regions, heat gain through roofs contributed high loads to air-conditioning systems for air-conditioned spaces and caused thermal discomfort for people in un-conditioned spaces. Radiant barrier, roof tiles and roof coating of high solar reflectance, and insulation are increasingly introduced to ameliorate the problems. This paper presents an analysis of heat transfer through roof that treats thermal radiation transfer separately from conduction and convection transfers. Accurate values of form factors are used in the radiosity equations to obtain value of net thermal radiation from a surface. The method also accounts for ventilation air flow that carries heat from the roof attic. Experiments with six types of insulation currently sold in the market were conducted to illustrate the validity and the accuracy of the method. Computer simulations were taken to assess the comparative cost effectiveness of ten configurations of insulation used under roof. The room below the roof was assumed to serve each of five functions in each roof configuration in each computer simulation run that utilizes hour-by-hour data of a full year. It is shown that the insulation products used in all configurations are cost effective to varying degree.

David W. Winiarski, Dennis L. O'Neal (1996) found that during the cooling season, heat transfer from the attic into the conditioned space of a residence represented a significant portion of the total envelope heat transfer. Radiant barriers are one method used to reduce this heat transfer. A quasi-steady-state model was developed for predicting attic heat transfer in residences with radiant barrier systems. The model was used to estimate the reduction in cooling load that would occur with a radiant barrier and to identify important construction and environmental parameters that influence this cooling load reduction. The model's output consisted of hourly ceiling heat fluxes inside the house based on hourly weather data inputs. Model results were compared with detailed experimental results from two small test houses. The model predicted typical summer heat flux reductions of between 35 and 43% with different radiant barrier configurations and levels of insulation. These compared to measured heat flux reductions of between 29 and 37% in attics under the same conditions. Sensitivity studies were also conducted to show the effect of uncertainty in several of the important physical attic parameters on the final heat flow predictions of the model.

Frédéric Miranville, Harry Boyer, Thierry Mara, François Garde (2003) dealt with the empirical validation of a building thermal model that includes a roof-mounted radiant barrier. We first present the thermal model, developed with a building simulation code prototype, the objective being to increase understanding of the thermal phenomena that govern the behavior of the whole building. We then describe the experimental test cell, with emphasis on the details of the roof. A sensitivity analysis technique is applied to the model which shows that convective heat transfer is of great importance for the dry-air temperature of the roof air layer. The origin of the disagreement between measurements and model predictions is then identified as being due to one of the convective heat transfer coefficients. Once this is modified, the agreement is found to be acceptable.

CHAPTER 2
THEORIES

Solar radiation contributes a significant percentage of the total heat flux entering the building envelope. Heat transfer due to radiation is more prevalent on the roof since it is the most exposed to the sky for both direct solar and diffuse sky radiation during daytime periods, and cold sky during nighttime periods. Heat transfer from the roof down to the ceiling is dominated by radiation. The reason is that the air space between the roof and the ceiling has a low thermal conductivity and thermal convection coefficient. So, the reduction heat gain through the roof will help to give less energy consumption. The air-conditioning has penetrated significantly in warm urban household, and has reached saturation level in commercial building in tropical Thailand. Heat gain through a roof contributes substantially to the cooling load of an air-conditioned building and to raising the interior temperature of a naturally ventilated building.

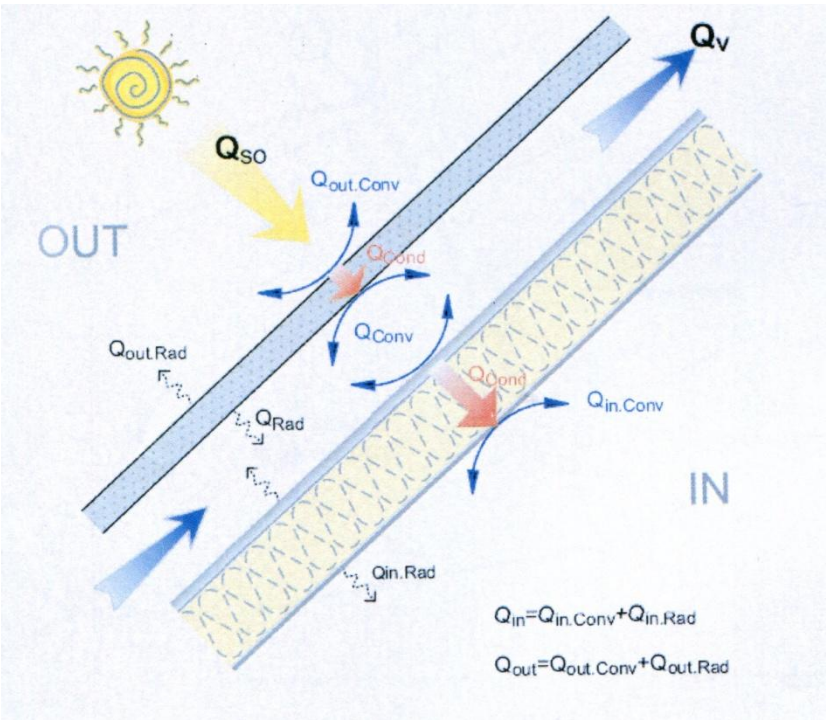


Figure 2.1 Mechanism of heat transfer in a ventilated roof

From Figure 2.1 shows the heat transfer through the roof tilt. It was for consists of radiation, convection, and conduction by divided into heat flux in (cavity roof in a ventilated roof) and heat flux out. (external of roof pitch)

2.1 One-dimensional Heat Transfer in Roof Attic

There are two parts for the solution of heat transfer through roofs: network part and radiation exchange part in combination. In the method, we break the network into two parts in accordance with physical and computation procedures. The radiation exchange in the attic will be dealt with by the use of radiosity, while the other part will be analyzed using network equations. Figure 2.2 illustrates an electrical network used to represent the mechanism of thermal heat transfer on the roof and in the roof attic for this method. One part is the network part for which a set of equation is written. The other part involves thermal radiation exchange for which there is another set of energy balance equations.

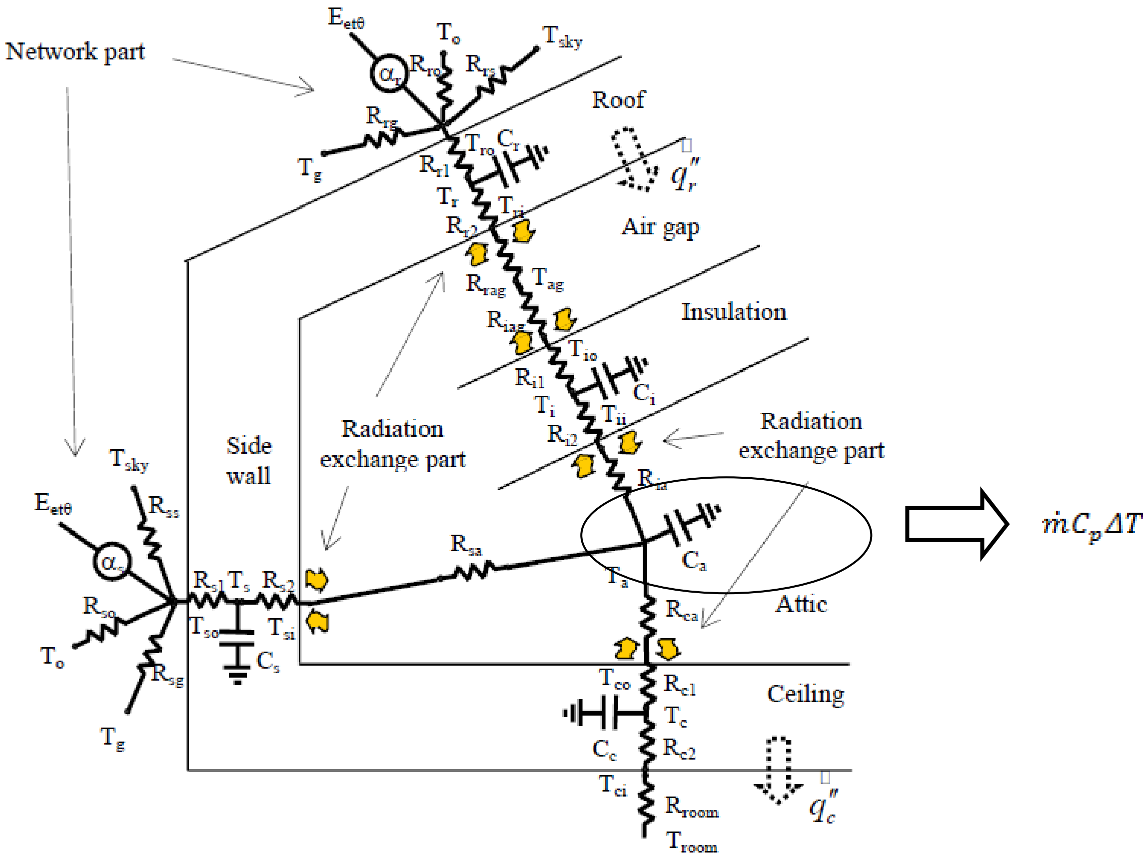


Figure 2.2 Configuration of radiation exchange and networks in combination

Network equation are written around nodes, such as T_{ro}, T_r, T_{ri}, T_{so}, T_s, T_{si}, T_{co}, T_c, T_{ci}, T_{io}, T_i, T_{ii}, etc. A network node is assigned to air signify that air can participate in the heat exchange when there is air movement. The air node is assigned a temperature $T_{a.}$ The node is connected to other nodes through thermal resistance representing air-film resistance of convection heat transfer.

Network part

The exterior surfaces of a roof area at temperature T_{ro} absorbed and α_r fraction of solar radiation $E_{et\theta}$ on its surface. The roof also converts heat to the ambient air that has a temperature T_o. The thermal resistance of convection heat transfer accounts for the velocity and temperature of air and the temperature of the surface involves in the heat transfer. The roof exchange thermal radiation with sky and ground, each at temperature T_{sky} and T_g respectively. Thermal resistance of radiation heat transfer

account for the temperatures involved, surface emittances, and view factors between the surface. Energy balance consideration on the exterior surface of the roof, or around temperature node T_{ro}, gives.

$$\alpha_r E_{et\theta} + \frac{T_r - T_{ro}}{R_{ro}} + \frac{T_{sky} - T_{ro}}{R_{rs}} + \frac{T_g - T_{ro}}{R_{rg}} = \frac{T_{ro} - T_r}{R_{rl}} \qquad (1)$$

The net heat flux is conducted into the roof material. Here, we use finite differences to approximate partial derivatives of the heat conduction equation. Such approximation leads to the use of an analogous resistor-capacitor circuit to represent, in term of heat conduction behavior, a section each of roof material. In the figure, the pitched roof is represented by one section; while for the thicker flat concrete roof more than one section would be used. The equation around temperature node T_r is given as.

$$\frac{T_{ro} - T_r}{R_{r1}} - C_r \frac{dT_r}{dt} = \frac{T_r - T_{ri}}{R_{r2}} \qquad (2)$$

Where $C_r = \rho c_{p\Delta x}$ and ρ, c_p, Δx are density, specific heat, and thickness of the roof section respectively. Heat transfer from the lower surface of the roof through the air to the upper surface of the radiant barrier (RB) or insulation is comprised of conduction, convection, and thermal radiation transfer through the air.

$$\frac{T_r - T_{ri}}{R_{r2}} = \frac{T_{ri} - T_{io}}{R_{ri}} + \frac{T_{ri} - T_{ag}}{R_{rag}} + \frac{\varepsilon_{ri}(\sigma T_{ri}^4 - J_r)}{\rho_{ri}} \qquad (3)$$

Where R_{ri} is thermal conduction resistance through the sir-gap between the lower surface of roof and the upper surface of the RB or insulation, J_r is radiosity of surface r. Equations on the nodes.

Network equation are written around nodes, such as T_{ro}, T_r, T_{ri}, T_{so}, T_s, T_{si}, T_{co}, T_c, T_{ci}, T_{io}, T_i, T_{ii}, etc., similarly to Equations 1 to 3.

Convection heat transfer from all interior surfaces in the attic to the air, and heat removed by ventilation are represented by Equation 4, given as (the equation at air nodes T_a).

$$\sum \frac{T_j - T_a}{R_j} A_j + m_a c_{pa}(T_o - T_a) = M_a c_{pa} \frac{dT_a}{dt} \qquad (4)$$

where $\sum \frac{T_j - T_a}{R_j} A_j = \frac{T_{ii} - T_a}{R_{ia}} A_i + \frac{T_{si} - T_a}{R_{sa}} A_s + \frac{T_{co} - T_a}{R_{ca}} A_c + \cdots =$ sum of convection heat from all interior surfaces of the attic to the air in the attic. A_j, T_j, and R_j are surface area, surface temperature and thermal resisitance of convection heat transfer from each relevant surface, T_a is the temperature of air in the attic, m_a is the rate of ventilation air flow through the attic, M_a is the mass of air in the attic, and c_{pa} is the specific heat of air. Equations 1 to 4 and all other related heat conduction and convection equations form a set of network equations.

Radiation exchange part

The total thermal radiation flux, or radiosity J_j, from a surface j with surface temperature T_j is related to the radiosity of other surfaces in the attic as

$$J_i = \sigma \varepsilon_j T_i^4 + \rho_j \sum F_{jk} J_k \qquad (5)$$

$$q_{rj} = J_i - S_j \qquad (6)$$

$$S_j = \sum_{k=1}^{n} F_{jk} J_k \qquad (7)$$

$$J_j = \frac{\varepsilon_j}{\rho_j} \left(\sigma T_j^4 - J_j\right) + \sum_{k=1}^{n} F_{jk} J_k \qquad (8)$$

$$q_{rj} = \varepsilon_j \sigma T_j^4 - \frac{\varepsilon_j}{\rho_j} \left(J_j - \varepsilon_j \sigma T_j^4\right) = \frac{\varepsilon_j}{\rho_j} \left(\sigma T_j^4 - T_j\right) \qquad (9)$$

where σ is the Stefan-Boltzmann constant, ε_j and ρ_j are emittance and reflectance of surface j, and F_{jk} is the view factor from surface j to surface k.

Equation 9 forms a set of radiation exchange equations. When the values of the environmental variables (such as T_o, T_{sky}, amd $E_{et\theta}$) are known, the two sets of equations above are solved by first assuming initial values of temperature variables for the evaluation of thermal resistances. With assumed values of surface temperatures, the set of radiation exchange equations is then solved to give values of radiosities. These are then used in the the solution of network equations. With the resultant values of temperature variables, the steps of computation are repeated until successive iterations give negligible changes.

2.2 Mechanisms of air flow in roof attic

2.2.1 Convection and Radiation heat transfer coefficient

When a wall or roof within a zone is poorly insulated or a wall surface is exposed to solar radiation, the surface temperature is different from the surroundings, and there is free convection between the wall surface and the surrounding air. In case of driving forces are jet or having forces convection with fluid moving at higher velocity than surrounding fluid. Therefore, it can be shown as source in jet system.

2.2.2 In a part of Natural convection

Natural (or buoyancy-driven) convection occurs when a fluid comes into contact with a heat surface. Heat transfer takes place by conduction and fluid temperature variations are established which give rise to density variations. Buoyancy forces then establish fluid motion to carry away the conducted heat.

Dimensional analysis gives the grouping of the variables for natural convection from:

$$N_u = kf\,(Pr, Gr) \qquad (10)$$

Where Nu_n is the Nusselt number for natural convection, Pr is the Prandlt number, Gr is the Grashof number, k is a constant and f is a function.
Heat ceiling ($9\times10^8 < Gr < 1\times10^{11}$)

$$h_{cn} = \frac{0.704}{D^{0.601}}\,(\Delta T)^{0.133} \qquad (11)$$

$$Nu_n = 1.78\,(Gr)^{0.133} \qquad (12)$$

Many methods exist for natural convection, but none is universal. Some of them were rejected because their applicability is too restricted, or they are of limited appeal in building modeling. For example, the method of Min et al. is only suitable for floor-heated and ceiling-heated rooms [Min et al., 1956]. Some other methods are of questionable accuracy or applicability in the building context.

Table 2.1 Classifying the principle convection regimes [Zhengen Ren,John Stewart, 2003]

Convection regime	**Driving force**	**Cause of driving force**
Natural	Natural	Surface-to-air temperature difference, caused by one of the following • heaters (e.g. radiator, stove) located within room • heat transfer through the external envelope • solar insulation • heated walls • in-floor heating • chilled ceiling panels
Forces	Mechanical	Air supplying system (fans and jets), wind and mechanical air exhaust system
Mixed	Mechanical and buoyant	Mechanical and buoyant forces (as described above)

2.2.3 In a part of forced convection portion

Forced convection is concerned with the transfer of heat between a moving fluid and a solid surface where the fluid motion is caused by external means. When fluid motion is caused by some external forces, such as a fan, jet or wind power, convection is created

$$Nu_f = kf(Pr, Gr_f) \qquad (13)$$

Where Re_f is the Reynolds number, k is the constant of various flow configurations and f is function whose values are found from experiments. Nusselt number correlations usually scale the Nusselt number to a power n of the Reynolds number in the form:

$$Nu_f \approx (Re)^n f(Pr) \qquad (14)$$

For air, this expression reduces to:

$$Nu_f = b(Re)^m \qquad (15)$$

Eventually, the defined area represents a portion of a partition. Convective exchange takes place, which can be modeled by heat coefficient h_{cv}, the heat flow then reads.

$$q_{cv} = h_{cv}A(T - T_0) \qquad (16)$$

Where T_o is the temperature of outside air.

2.2.4 In a part of mixed convection

There are a few methods for mixed convection within a ventilated room or an enclosure. Beausoleil-Morrision (2001) presented a new algorithm for calculating convection coefficient for internal building surfaces for mixed flow in rooms. Awbi and Hatton (2000) performed a series of experiments to describe mixed convection at the heated internal surfaces within an office-sized room, In their study, six configuration tests were carried out with a wall jet covering part of the heated surface to simulate air-conditioning/mechanical ventilation processes.

2.3 Building Simulation Program (BEsim)

Hien and Chiraratttananon (2005) developed a computer program was described earlier, as a part of research on heat transfer through a roof. The program requires setting up of a main rectangular coordinate that is referenced to the cardinal directions. The position of each flat interior surface in a room, such as the panes of glazing and interspersing opaque wall sections, is defined with respect to the main coordinate. The program first calculates the values of view factors between all surfaces in each enclosed zone created by a user. It utilizes the method of Hien and Chiraratttananon, 2005, [11], in the calculation of view factors. The Development of the BESim program was presented in a dissertation for Doctorate of Engineering of Mr. Vu Duc Hien at the Energy Field of Study, School of Environment Resources and Development, Asian Institute of Technology, 2007.

For the program first calculates the direction of solar vector using given information on solar radiation and time. It then calculates part of solar radiation that is not shaded by the shading devices that enters the glazing pane into the room and traced its reflections until the reflected radiation is negligible. For the sky radiation, it calculates contribution of diffuse radiation from a sky patch on to a small subsection of each given surface as direct diffuse component. It uses flux transfer method to calculate the reflected components. In the present version, BESim uses the ASRC-CIE sky luminance and sky irradiance models that utilizes CIE clear and turbid clear sky model, CIE partly cloudy and cloudy sky models.

BESim uses the finite difference method for the calculation of dynamic conduction heat transfer through a wall. Both convective and radiative heat transfer from a wall surface are calculated using the principle of energy balance. The room can be cooled or naturally ventilated.

The main functions of the program are (i) simulation of daylight and electric light in buildings; and (ii) simulation of energy consumption in buildings. Outputs of the BESim program are: (i) heat fluxes through ceiling, roofs, gables, walls, etc.; (ii) temperatures on surfaces of ceiling, roofs, gables, walls, etc.; and temperatures of air in room, attic, etc.; (iii) cooling coil load of air-conditioning system, electricity cost, etc.

This program was developed over ten years to simulate energy use in buildings, and can be applied to many kinds of building. BESim is now a copyrights of the Joint Graduate School of Energy and Environmental (JGSEE). The Thai Ministry of Energy will use this simulation program to simulate a part function of the new Thai building code, such as TD_{eq}, ESR and ΔT and this code will be used for new construction buildings areas that exceed 2,000 square meters

The algorithm of BESim was will be developed using the energy balance principle and takes into account the effect of thermal storage, so that this program is accurate and precise for predicting or simulating energy use in buildings.

This program has been tested for a long time and many papers on to have been published in national and international journals that use BESim in energy simulations, such as “Balancing Benefits and Costs of the Use of High Performance Glazing on High-Rise Buildings” by S.Jiraratananon, P. Rugkwamsuk, and D. Matuampunwong, Energy Program, Joint Graduate School of Energy and Environment (JGSEE) or “Cost Effectiveness of Insulation Used on Building Walls” by S.Jiraratananon,V.D. Hien, and P. Chaiwiwatworakul Energy Program, Joint Graduate School of Energy and Environment (JGSEE). For this BESim was used in this study.

CHAPTER 3
METHODOLOGY

To fulfill the objectives of this study several parameters were used to determine the appropriateness and effectiveness. These parameters are the functions of room using, the ceiling insulation, the air flow on roof attic, and the roof coating. In order to achieve the parameters, several steps according to the particular methods will be conducted, i.e., experimental and simulation study. These methods mainly adopted from Chirarattananon (2010).

For the experimental study, a full-scale physical experiment was made for the measurement and evaluation of heat gain and thermal performances of the roof. A series of experiments will be carried out and the measurement results will be conducted to validate the results from the computer simulation program, BESim.

For the simulation study, the validated BESim program was employed to calculate the heat flux through the roof. This simulation will also determine the heat gain from the window system. From these simulation results, the energy consumption and the air conditioning systems will be obtained.

3.1 Physical Experiments

This study will mainly consists of two steps, such as physical experiments and computer simulations using BESim. The methods of this study are presented in the following flowcharts.

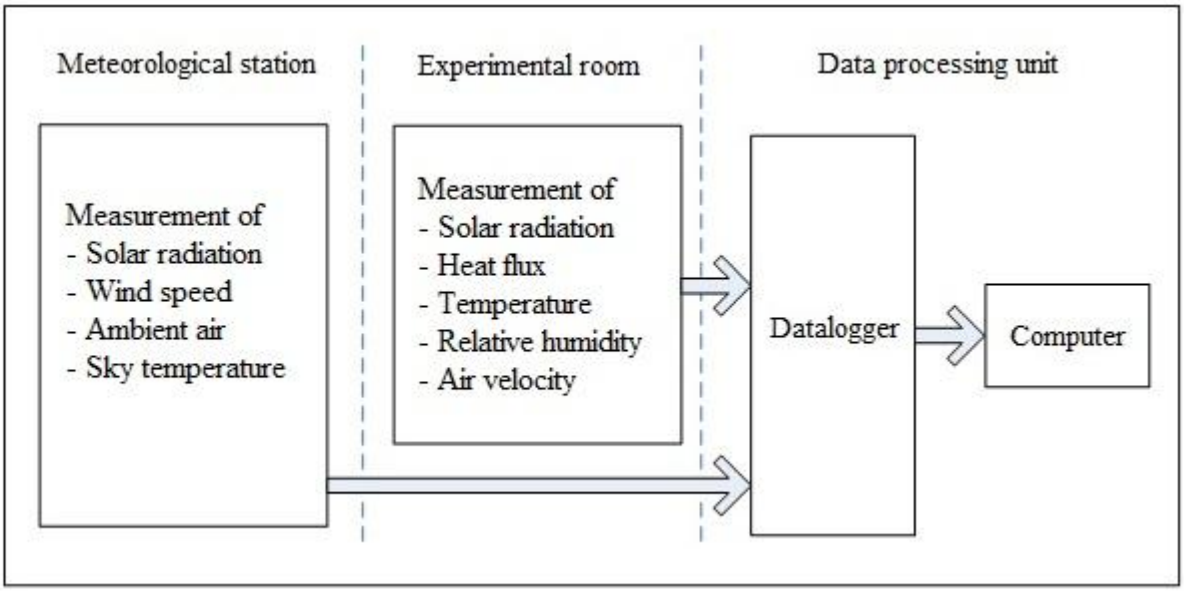


Figure 3.1 The steps of the physical experiments

3.1.1 Experimental Sites

Two main facilities were employed for this study:

- Meteorological Station
- Experimental House

a. Meteorological Station

The station at the Bangkhunthien campus, classified as a research station, was used as the meteorological station.

b. Experimental House

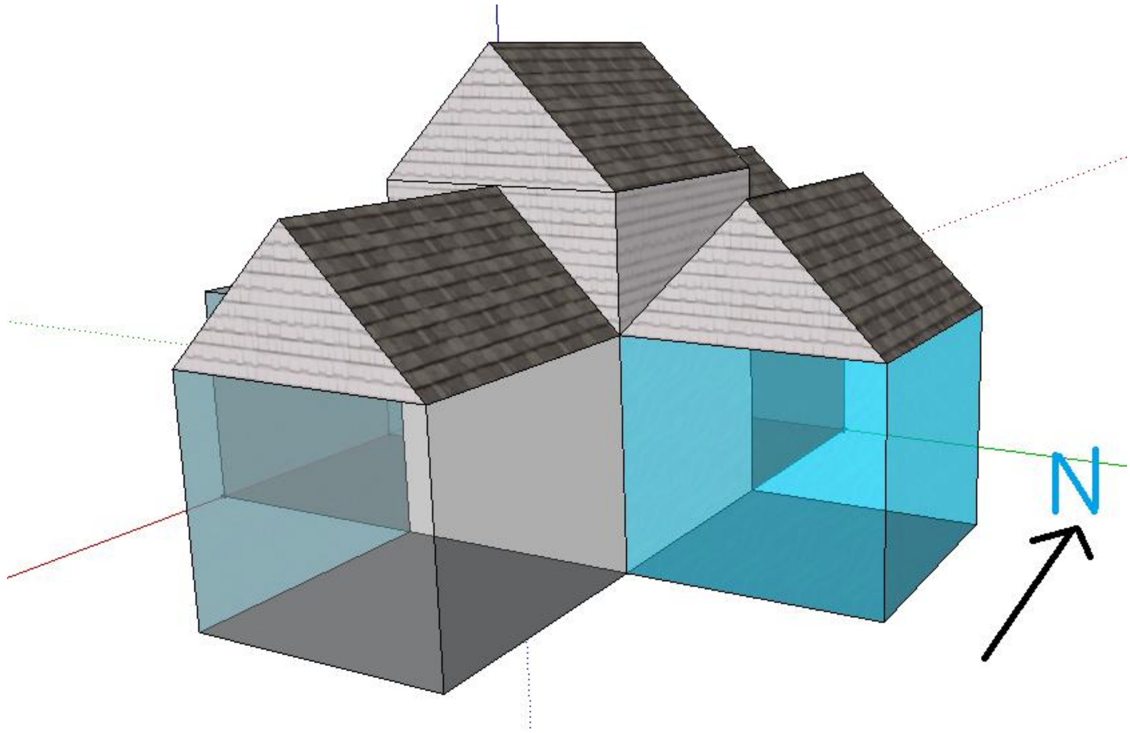


Figure 3.2 Experiment house model

An experiment was conducted at a full-scale laboratory building to study the performance of ceiling insulation and air flow on a roof attic when it was used for heat gain. A room was constructed in Bang Khun Thien Campus of KMUTT for the experiments. A small experimental building comprising five square rooms of identical dimensions, with the five rooms forming a cross, was constructed on the ground near the building where the solar radiation and daylight measurement station is located. The width and length of the room are each 3 meters and its height is 2.65 meters. It was constructed with a 45° pitched roof with the roof ridge aligned along north-south direction. Smart boards were used to cover the gables. The attic under the roof has 1.5 meters height. Electrical fans will be installed on the parts of the gable. In experimental cases the room is cooled by an air-conditioner with the room temperature kept to 26°C. Surface heat flux sensor and type T thermocouples will be placed at various points in the attic and on surfaces with data logged at every 30 minutes in 24 hours.

Measurements of direct and diffuse solar radiation, wind speed, ambient air conditions and sky temperature were routinely taken and recorded at 5-minute interval in the solar radiation and daylight measurement station at Bang Khun Thien Campus. Data corresponding on the days that the experiments were conducted were processed and merged with the heat flux and temperature data from the experiments for the analysis to be described.

3.1.2 Experimentations, Equipments and Measurements

Several thermocouples were placed on the roof and ceiling in the experimental room. Heat flux sensors were placed at 4 placed on the roof, under the roof, on the ceiling, and under the ceiling. Infrared thermometers measured the temperature of the air. Pyranometers measured the solar radiation which placed on roof. Hot wire anemometer measured the air flow through the roof attic. Humidity meters measured the relative humidity of the room attic.

Figure 3.3 Experiment house at Bangkhuntien campus

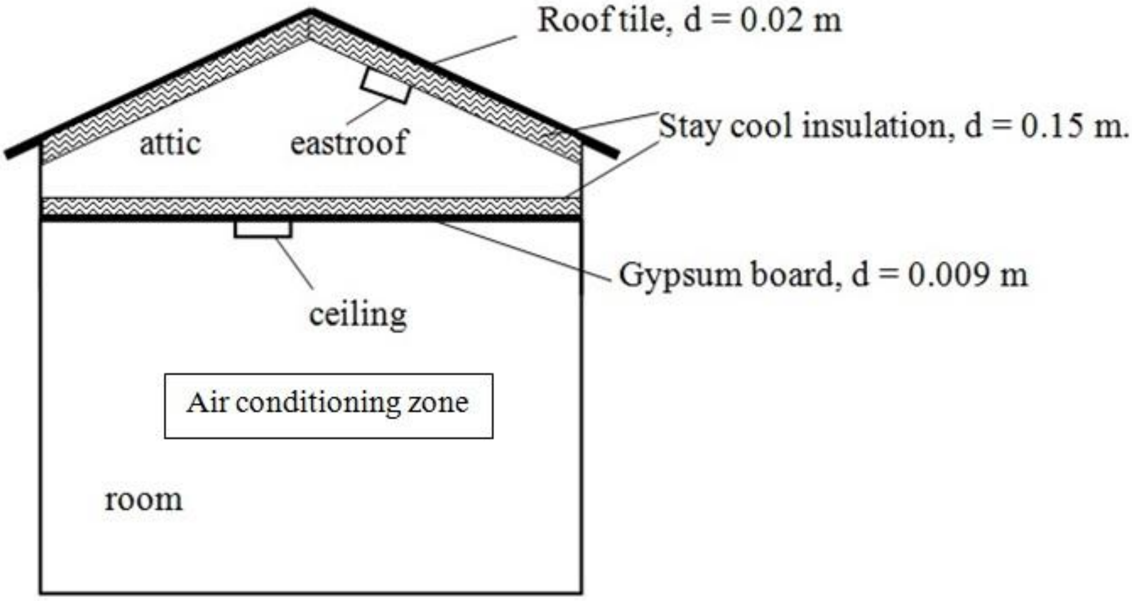


Figure 3.4 Zones of experiment house

Table 3.1 Thermal properties of room materials.

Material	Thickness (m)	Conductivity (w/mK)	Density (kg/m3)	Specific capacity (J/kgK)	Emissivity	Solar absorptivity
Concrete	0.25	1.442	2400	0.92	0.93	0.65
Roof tile	0.02	0.836	1890	1	0.92	0.6
Gypsum board ceiling	0.009	0.191	880	1.09	0.91	0.3
Premium stay cool, 150mm	0.15	0.042	12	0.96	0.05	0.15
Brick wall	0.1	1.154	1600	790	0.9	0.6

The premium stay cool insulation with 150 mm thickness which installed under the roof and above the ceiling of the room.

Figure 3.5 Premium stay cool insulation

Figure 3.6 Premium stay cool on ceiling and under roof

Figure 3.7 Air conditioning systems in room used under roof attic

Figure 3.8 Coating colour

Figure3.9 Roof with coating (right roof) and without coating (left roof)

Table 3.2 Function of use in the experiment

Function of use	Time of use
Office	08.00-17.00
Bedroom	21.00-06.00
24hours	00.00-24.00

Table3.3 Required equipment for this research

Sensor	Quantity	Objectives
Data logger with at least 36 input ports	1	To log experimental data for the experimental room
Pyranometer	2	To measure solar radiation
Infrared thermometer	1	To measure surface temperature without contact
Thermocouple probes type T	6	To measure temperature of air and of room surfaces
Heat flux sensors	6	To measure heat flux from opaque surfaces
Hot wire anemometer	1	To measure air velocity flow through area
Humidity meter	1	To measure humidity of room area

A series of experiments were carried out throughout the day and covered all sky conditions from clear sky to overcast sky. The experiments were carried out for eight cases:

a. insulated and un-insulated on ceiling,
b. ventilated and un-ventilated on ceiling,
c. exterior roof surface was coated with high thermal emissivity and high solar reflectance material and un-coated,
d. the room under the roof was used as an office and as a bedroom

The heat flow measured from the sensors were recorded every 5 minutes by the data logger and transferred to the computer's hard drive. A program was developed using the Labview language onsite in order to deal with this task. The measurement data was analyzed for each experimental day. For the validation process, the measurement results from the experiments were finally compared to those computed from the BESim.

3.2 Simulation Study

The BESim required defining the coordinates of each interior surface in a room and will utilize the method calculating the view factors between all surfaces in each enclosed zone created by a user. The room model was the same with the physical room. This was used to validate BESim.

3.2.1 To verify results of theoretical study for the configurations

In this study, computer simulation software was used to calculate the heat transfer in the room. It was used to simulate a same size of the room model and same position of sensors in order to compare results between computer simulation and model measurement.

The calculation of the heat flux was taken account by the simulation program. Several schemes were conduct:

- insulated and un-insulated on ceiling
- ventilated and un-ventilated of roof attic
- coated and un-coated with high thermal emissivity and high solar reflectance material on exterior roof surface
- the function of room under roof is used as office, bedroom, 24 hrs room, department store, living room, and studio room
- materials use of ceiling
- materials use of roof
- insulated and un-insulated roofs

3.2.2 Functions of room under roof

Table3.4 Usage schedule of each function

Functional use of rooms		**Weekday**	**Weekend**
Commercial functions	24 hrs (such as hotel)	0.00–24.00	0.00–24.00
	Day time (office)	08.00–18.00	No A/C
	Department store	10.00–22.00	10.00–22.00
Residential functions	Living room	18.00–21.00	09.00–21.00
	Bedroom	21.00–06.00	21.00–08.00
	Studio room	18.00–06.00	09.00–08.00

CHAPTER 4
RESULTS AND DISCUSSION

This chapter discusses in two parts the results on the comparison validation between the experiments and the simulation results of the two functional of the room as an office and a bedroom. The experimental results are divided into 2 parts, which are residential function and commercial function.

A series of experiments were carried out throughout the day and covered all sky conditions from clear sky to overcast sky.

The experiments were carried out with five cases:

Case (I): Base case (without insulation)

Case (II): Base case with force ventilation

Case (III): Insulation installed under roof

Case (IV): Insulation installed over ceiling

Case (V): Solar reflective coating

4.1 Residential function : The room use as office function

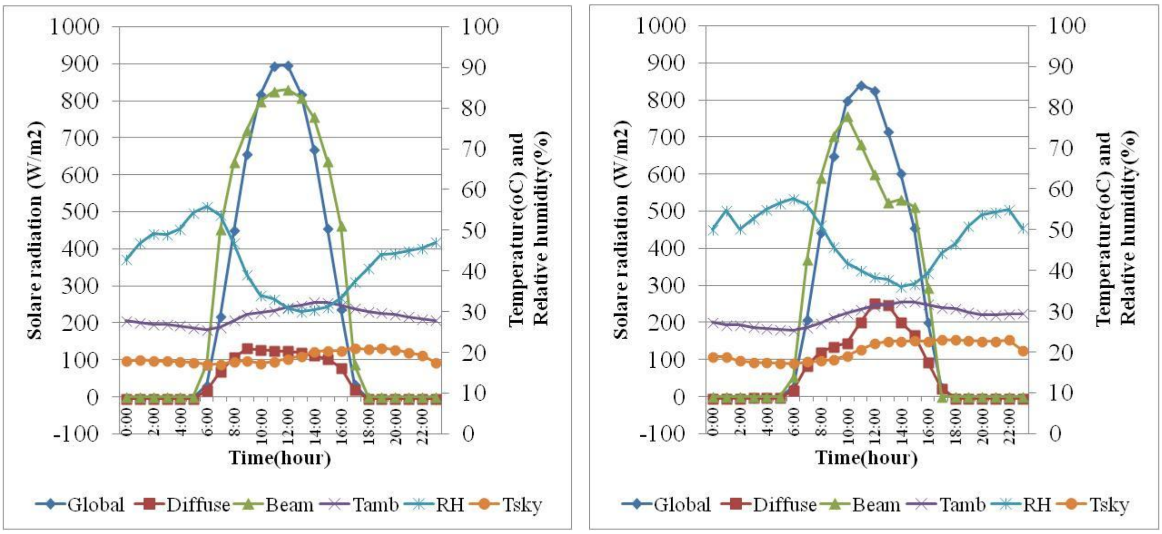
4. 1.1. Forced ventilation case of office function

Base case: without insulation and forced ventilation

Office function: air condition period 8 am-5 pm

Figure4.1 Roof attic with forced ventilation (Installed electric fan)

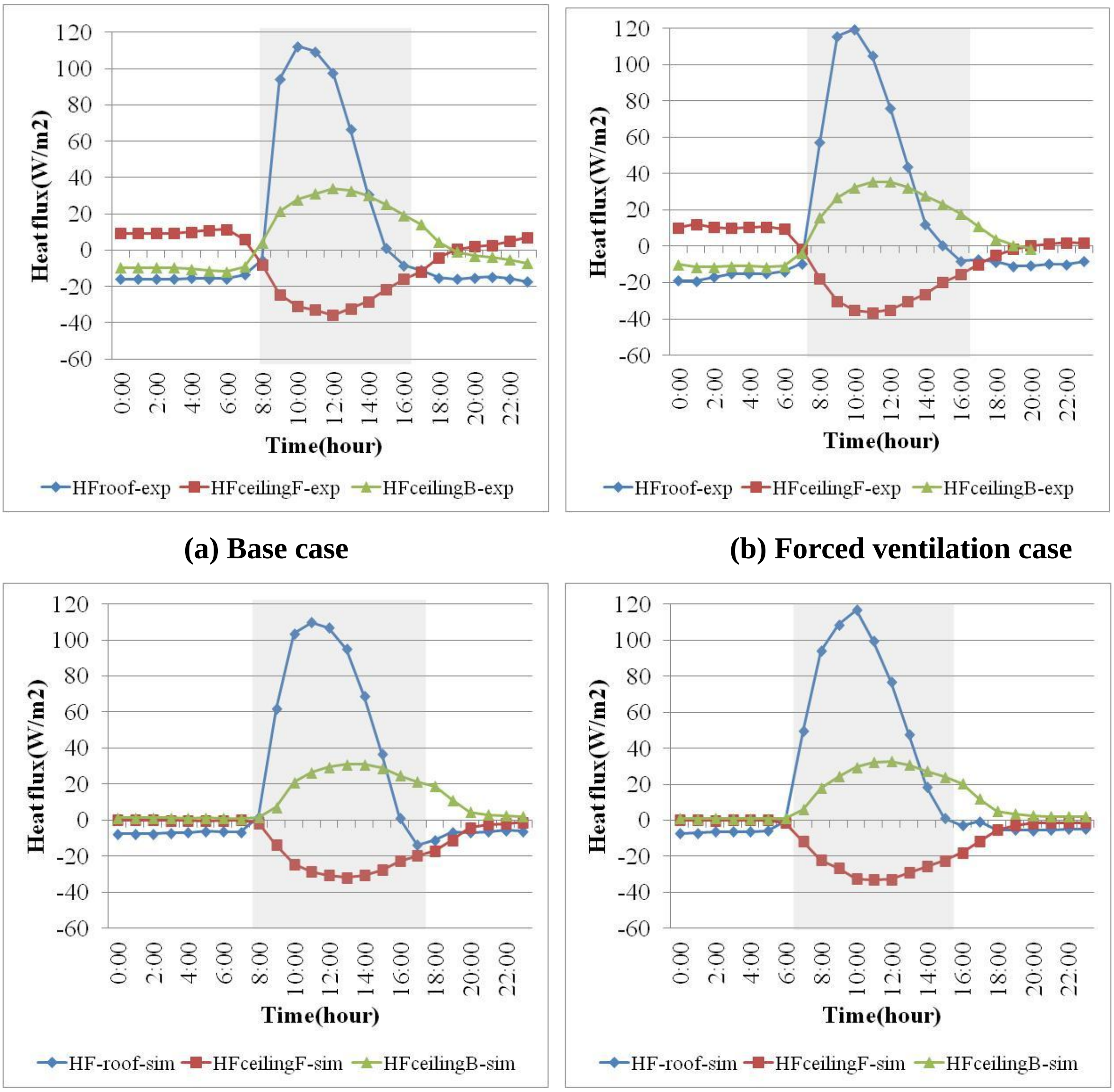
Weather data on 4th November 2013 **Weather data on 5th November 2013**



(a) Base case **(b) Forced ventilation**

Figure 4.2 Graph of solar radiation, ambient temperature, relative humidity, and sky temperatures on 4thand 5th November 2013: (a) Base case (b) Forced ventilation

This study is to prove that heat transfer under the roof will help to reduce the heat transfer into the room. Figure 4.2 shows the weather data between base case and forced ventilation case which gave the similar weather data that both days global radiation show the closely global radiation and the highest ambient temperature only few difference which the global radiation 900 W/m^2 and the highest ambient temperature approximately 33° C of both days. Both days are near clear sky conditions.

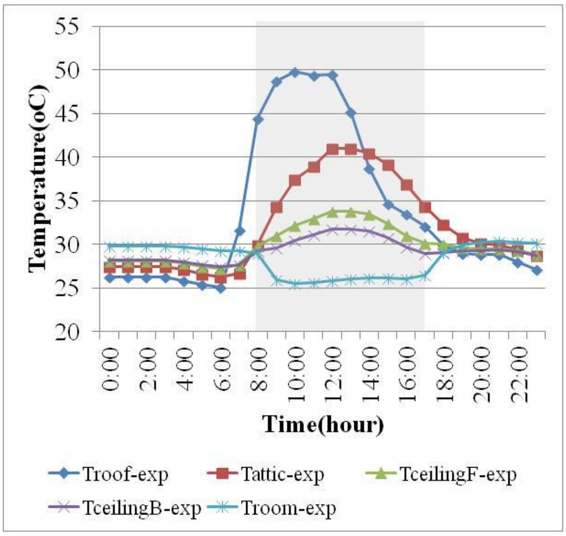


(a) Base case **(b) Forced ventilation case**

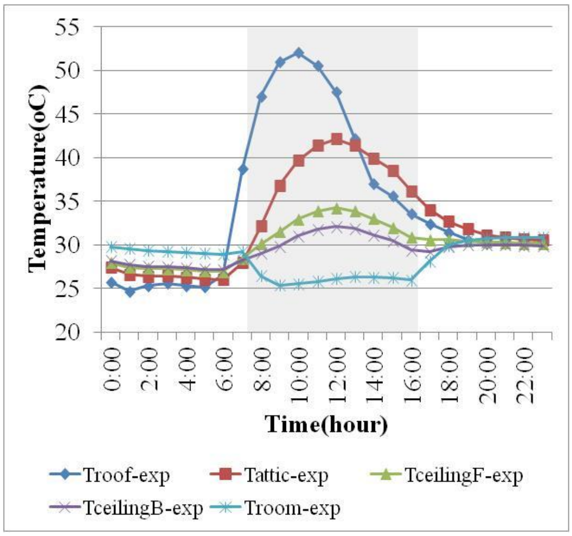
(c) Base case **(d) Forced ventilation case**

Figure 4.3 Graphs of base case and forced ventilation case of heat flux at roof section, front of ceiling section, and back of ceiling section from experiment and from calculation for the office function: (a),(b) experiment and (c),(d) calculation

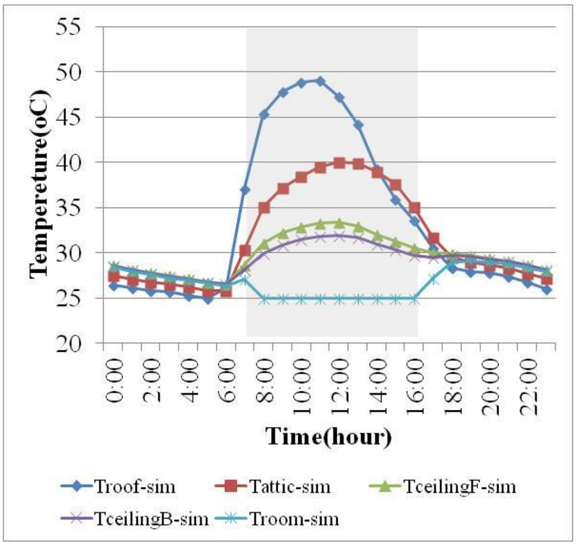
In addition to investigate the heat transfer through the roof, the measurement at the ceiling section of the experimental room is shown in Figure 4.3. Figure4.3 compares the heat transfer through the ceiling in the base case and forced ventilation case. The result shows heat flux through ceiling which the highest value about 35 W/m^2. Forced ventilation by electric fan didn't help to release heat in attic and little effect to reduce heat transfer into the room. Related to the previous research (Chirarattananon. S., Vu Duc Hien., (2006) which explains that the almost mechanism of heat transfer under roof attic are thermal radiation and few effects of conduction. The uses of forced ventilation in the attic do not help to reduce heat flux through the roof. The experimental and calculation results show the same results.



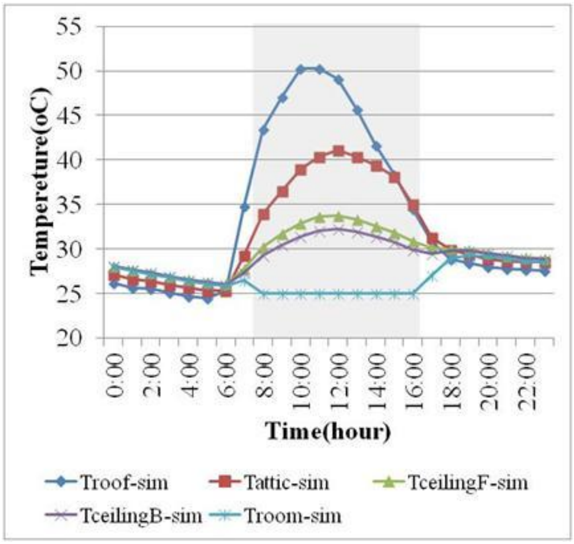
(a) Base case



(b) Forced ventilation case



(c) Base case



(d) Forced ventilation case

Figure 4.4 Graphs of base case and forced ventilation case temperature on roof section, front of ceiling section, and back of ceiling section, attic temperature, and room temperature from experiment and from calculation for the office function: (a),(b) experiment and (c),(d) calculation

Figure 4.4 shows graphs of base case and forced ventilation case temperature on roof section, front of ceiling section, and back of ceiling section, attic temperature, and room temperature from experiment and from calculation for the office function. The result shows temperature of the ceiling section with a value of about 30 W/m^2. The uses of force ventilation in attic do not help to reduce temperature of roof, attic and ceiling. The results are consistent with the hest flux results. The experimental and calculation results are consistent.

4.1.2. Insulation installed under roof case of office function

Position of insulation: insulation under roof section

Office function: air condition period 8 am-5 pm

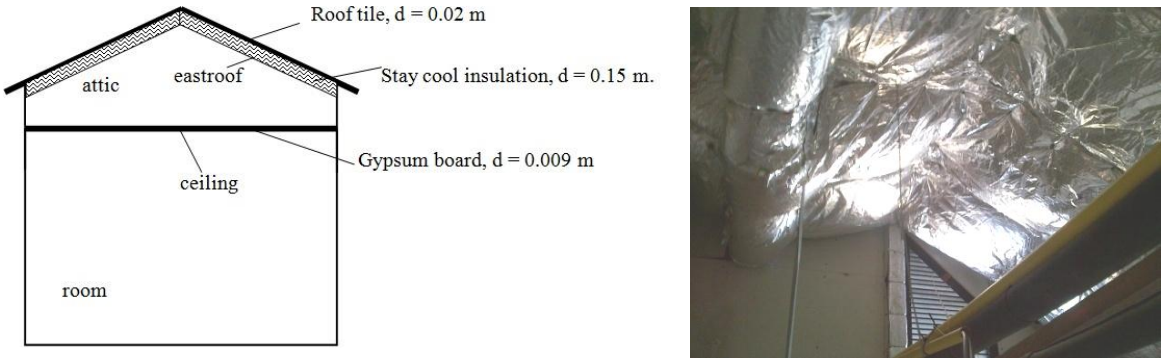
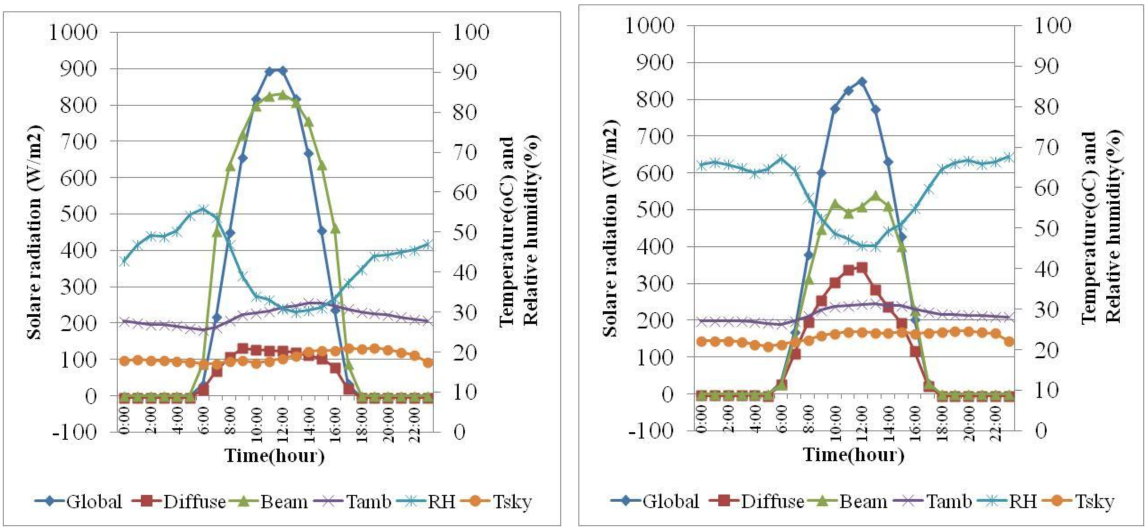


Figure4.5 Position of insulation under roof section

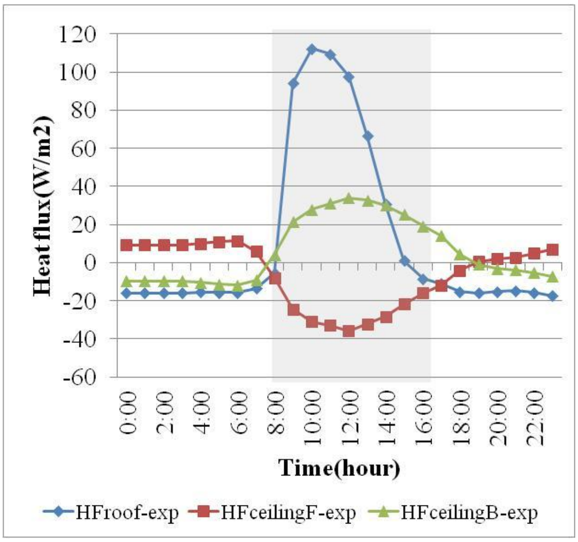
Weather data on 4th November 2013 **Weather data on 12th November 2013**

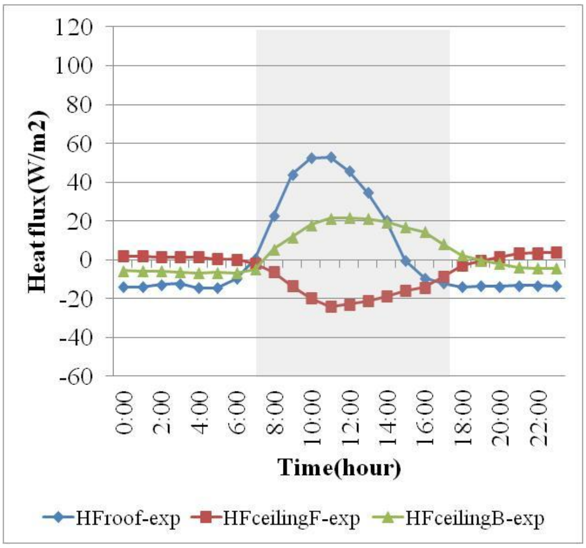


(a) Base case **(b) Insulation installed under roof**

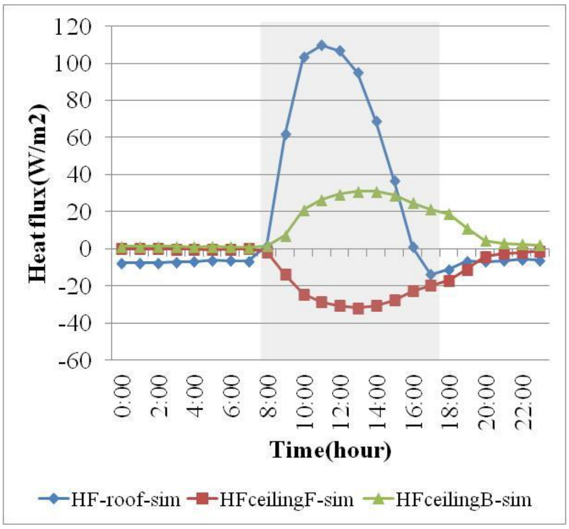
Figure 4.6 Graph of solar radiation, ambient temperature, relative humidity, and sky temperature on 4thand 12th November 2013: (a) Base case (b) Insulation installed under roof

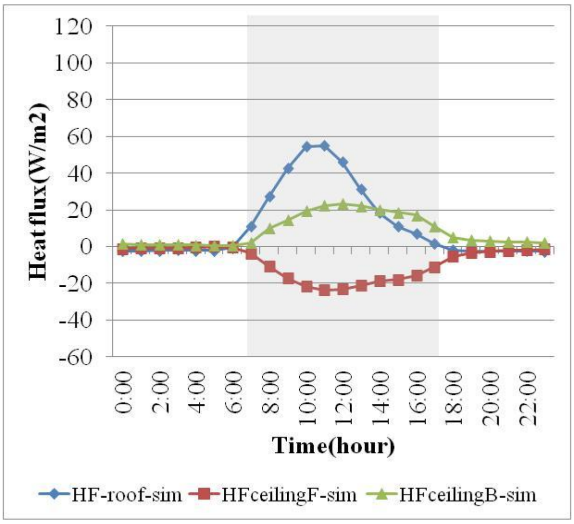
This study shows the result involving the use of insulation at different positions under the roof. The results compare between base case (no insulation) and roof insulation. Figure 4.6 shows weather data between base case and roof insulation case which weather is not different of two experimental days. Maximum solar radiation of both days is 800-900 W/m^2 and maximum ambient temperature around 32-33°C. An experiment of insulation installed under the roof was conducted on 12th November 2013. The ambient temperature of both the base case and insulation under the roof experiment day were similar while the beam solar radiation was smaller for insulation under roof.





(a) Base case **(b) Insulation installed under roof**

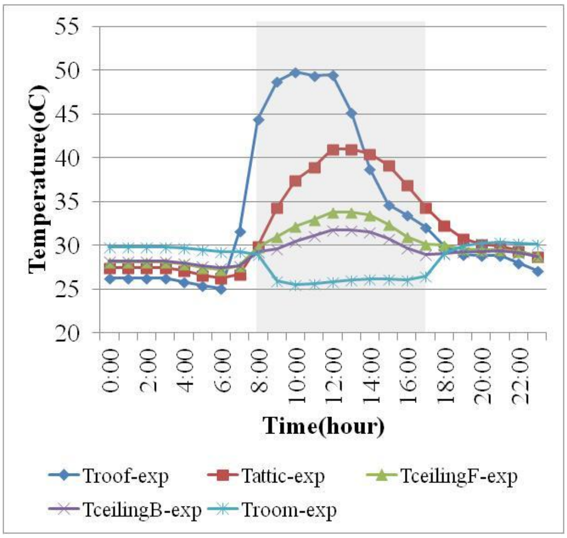


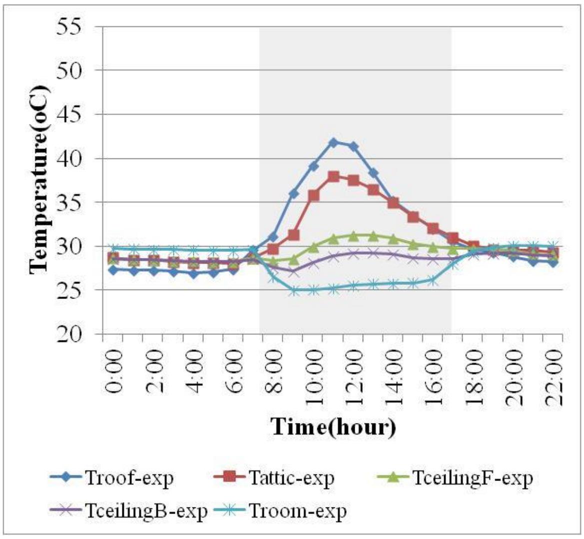


(c) Base case **(d) Insulation installed under roof**

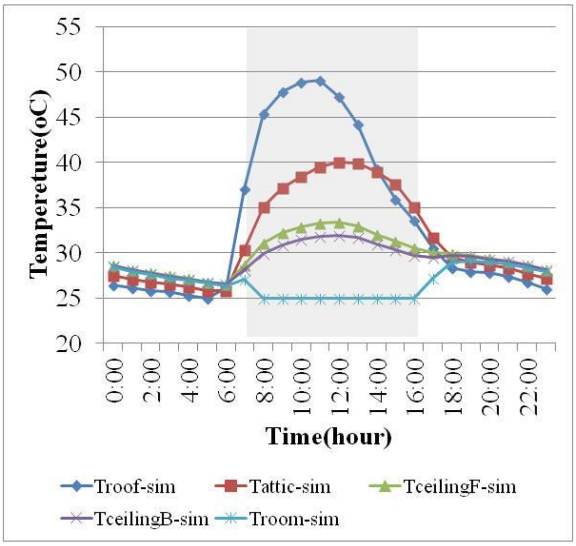
Figure 4.7 Graphs of base case and insulation installed under the roof case of heat flux at the roof section, front of ceiling section, and back of ceiling section from the experiment and from the calculation for the office function: (a),(b) experiment and (c),(d) calculation

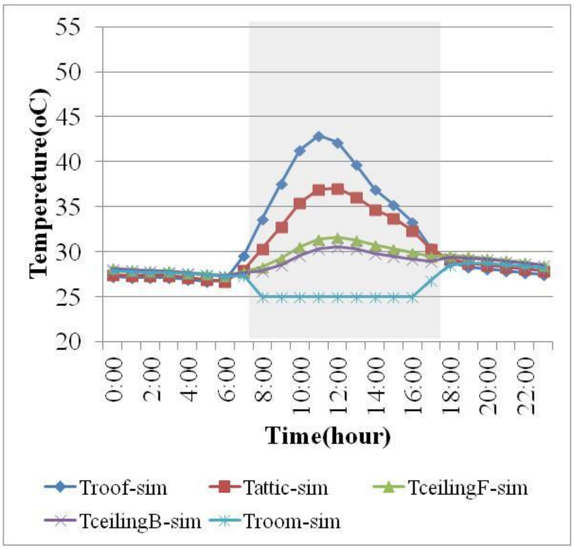
Figure 4.7 shows the graphs of the base case and insulation installed under the roof case of heat flux at the roof section, front of ceiling section, and back of ceiling section from the experiment and from the calculation for the office found that ceiling insulation case gave the heat flux decreasing from 110 W/m^2 to 50 W/m^2 causes of the higher roof temperature, ceiling temperature and attic temperature, which are decreasing after using roof insulation and ceiling insulation case. The insulation helped to reduce the temperature in the roof section and reduced heat transfer through the roof and the room under the roof. The uses of insulation under roof help to reduce heat flux through roof and over ceiling around 40-50%. The experiments and calculation results show the same results.





(a) Base case **(b) Insulation installed under roof**





(c) Base case **(d) Insulation installed under roof**

Figure 4.8 Graphs of base case and insulation installed under roof case temperature on roof section, front of ceiling section, and back of ceiling section, attic temperature, and room temperature from experiment and from calculation for the office function: (a),(b) experiment and (c),(d) calculation

Figure 4.8 shows the graphs of the base case and the forced ventilation case temperature on roof section, front of ceiling section, and back of ceiling section, attic temperature, and room temperature from experiment and from calculation for the office function. The result shows temperature of ceiling section which the value about 33 W/m^2. The uses of insulation under roof help to reduce temperature of roof, attic and ceiling. The results are consistent with the HF results. The experimental and calculation results are consistent.

4.1.3. Insulation installed over ceiling case of office function

Position of insulation: insulation on ceiling section

Office function: air condition period 8 am-5 pm

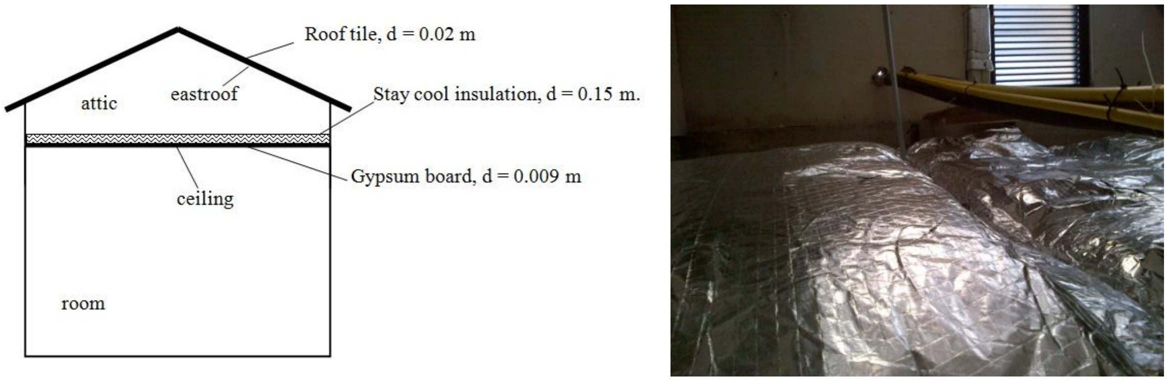
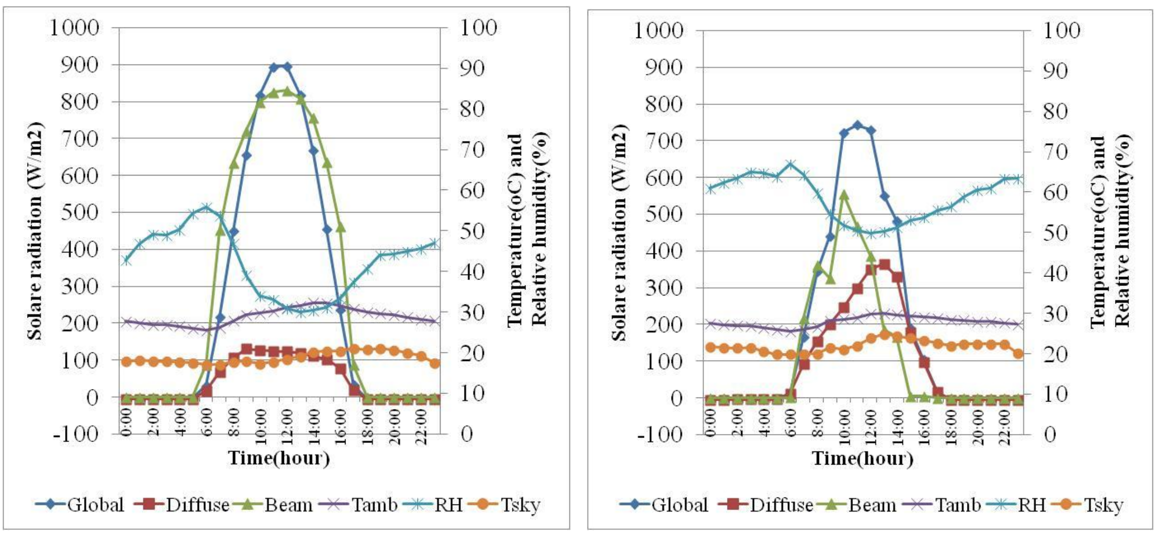


Figure 4.9 Position of insulation above ceiling section

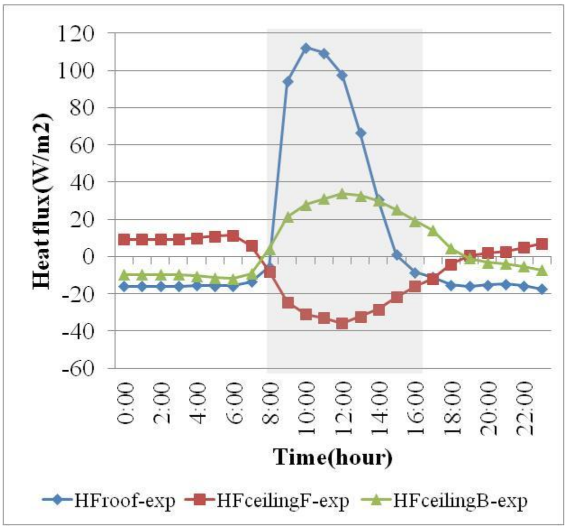
Weather data on 4th November 2013 **Weather data on 19th November 2013**



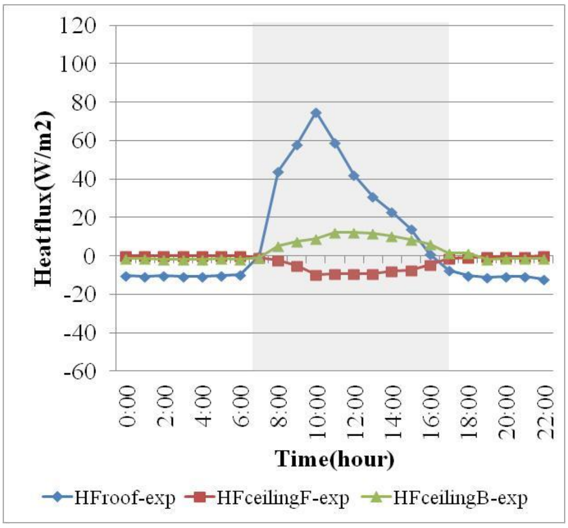
(a) Base case **(b) Insulation installed over ceiling**

Figure 4.10 Graph of solar radiation, ambient temperature, relative humidity, and sky temperature on 4thand 19th November 2013: (a) Base case (b) Insulation installed under roof

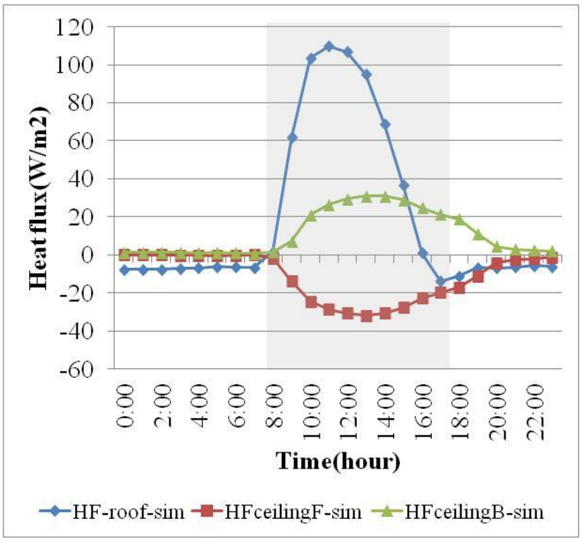
This study shows the result involving the use of insulation at different positions under the roof. The results are compared between the base case (no insulation) and the ceiling insulation. Figure 4.10 shows weather data between base case and ceiling insulation case which weather is not different of two experimental days. Maximum solar radiation of both days is 800-900 W/m^2 and maximum ambient temperature around 32-33°C. An experiment of insulation installed over ceiling was conducted on 19th November 2013. The ambient temperature of both the base case and insulation above the ceiling section experimental days are similar while beam solar radiation is smaller for insulation above the ceiling. Solar radiation and ambient temperature of the insulation over ceiling experimental day are slightly smaller than the base case.



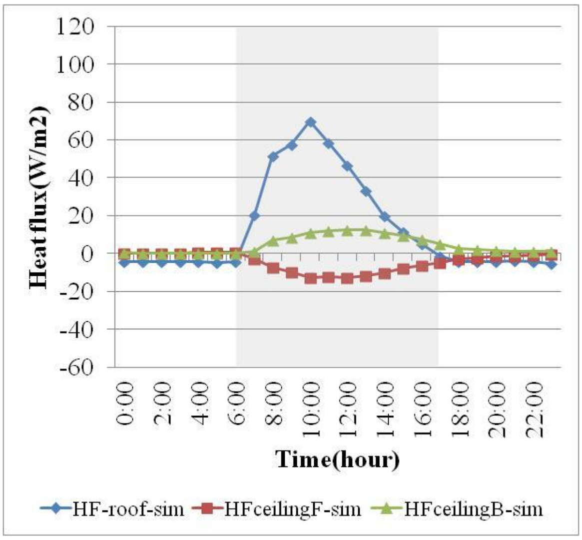
(a) Base case



(b) Insulation installed over ceiling



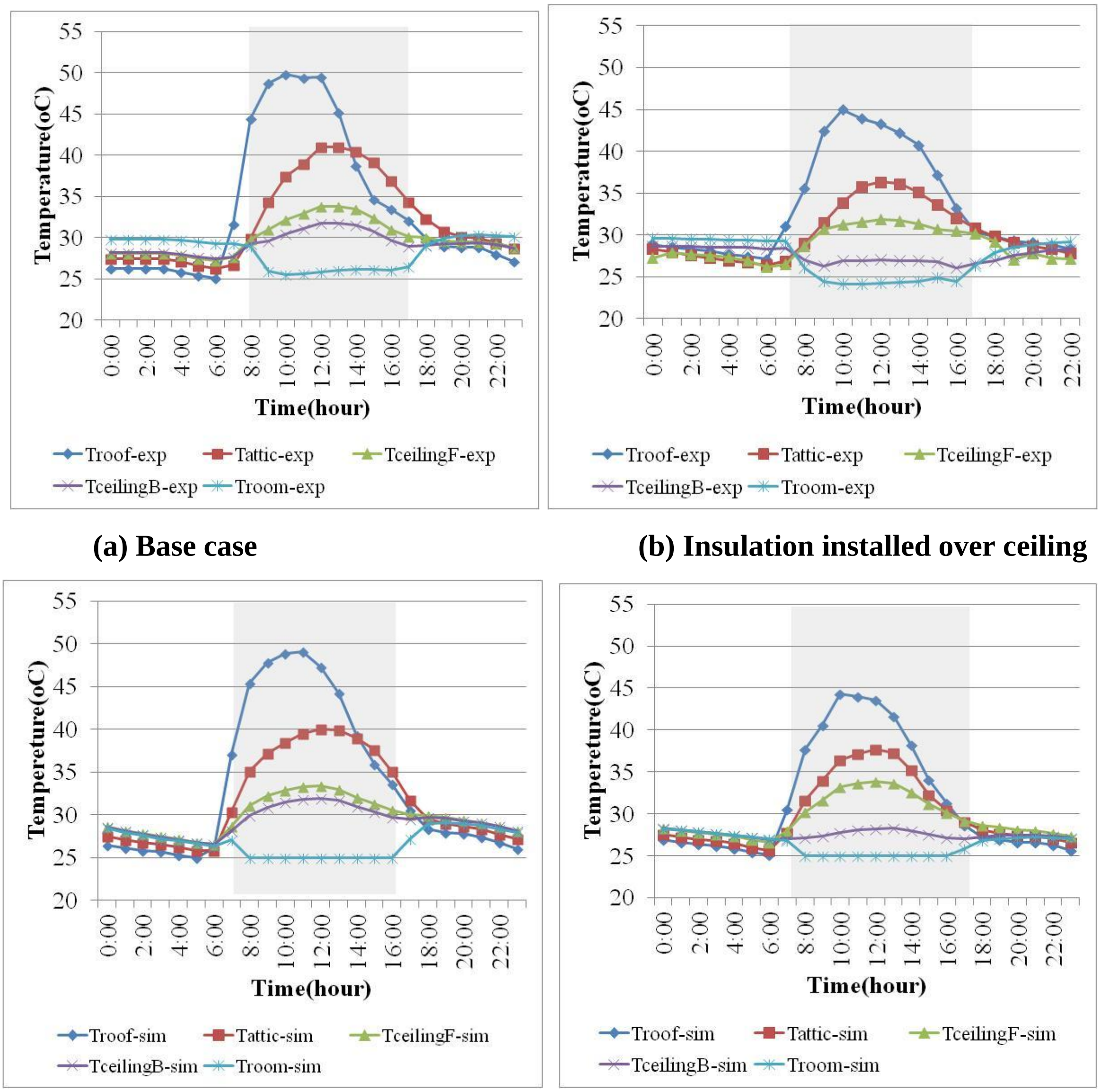
(c) Base case



(d) Insulation installed over ceiling

Figure 4.11 Graphs of base case and insulation installed over ceiling case of heat flux at roof section, front of ceiling section, and back of ceiling section from experiment and from calculation for the office function: (a),(b) experiment and (c),(d) calculation

Figure 4.11 shows the graphs of the base case and the insulation installed over the ceiling case of the heat flux at roof section, front of ceiling section, and back of ceiling section from experiment and from calculation for the office found that the ceiling insulation case gave the heat flux decreasing from 110 W/m^2 to 80 W/m^2 causes of the higher roof temperature, ceiling temperature and attic temperature which are decreasing after use roof insulation and ceiling insulation case. The experiments and calculation results show the same results. The uses of insulation over ceiling help to reduce HF fall on ceiling around 40-60%. The experiments and calculation results show the same results



(a) Base case **(b) Insulation installed over ceiling**

(c) Base case **(d) Insulation installed over ceiling**

Figure 4.12 Graphs of base case and insulation installed over ceiling case temperature on roof section, front of ceiling section, and back of ceiling section, attic temperature, and room temperature from experiment and from calculation for the office function: (a),(b) experiment and (c),(d) calculation

Figure 4.12 shows the graphs of the base case and over the ceiling case temperature on roof section, front of ceiling section, and back of ceiling section, attic temperature, and room temperature from experiment and from calculation for the office function. The result shows temperature of ceiling section which the value about 33 W/m^2. The uses of insulation over ceiling help to reduce temperature of attic and ceiling. The results are consistent with the heat flux results. The experimental and calculation results are consistent.

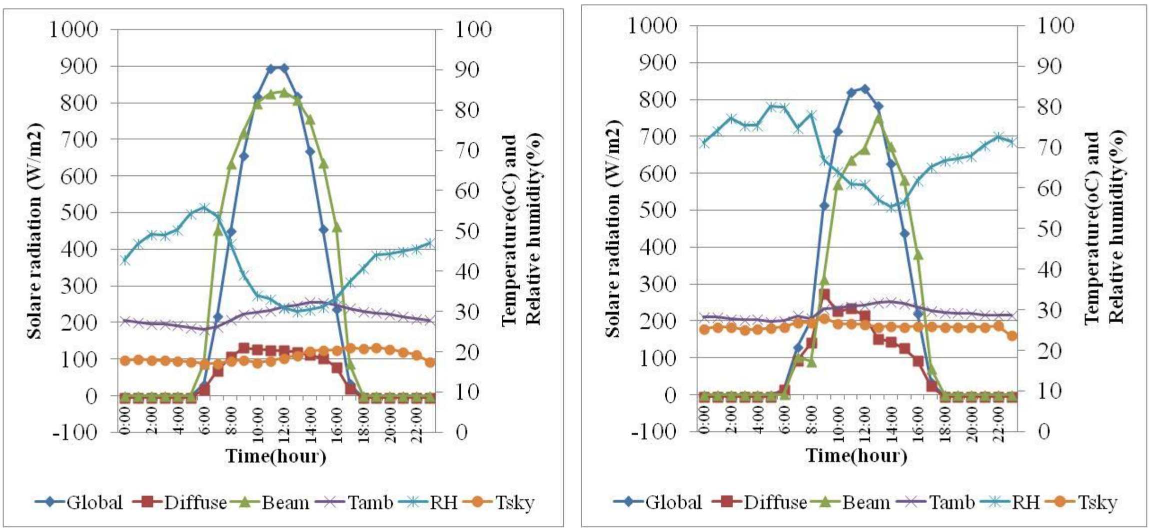
4.1.4. Solar reflective coating case of office function

Position of insulation: coating on roof area

Office function: air condition period 8 am-5 pm

Figure 4.13 Roof coating with high reflective coating colour

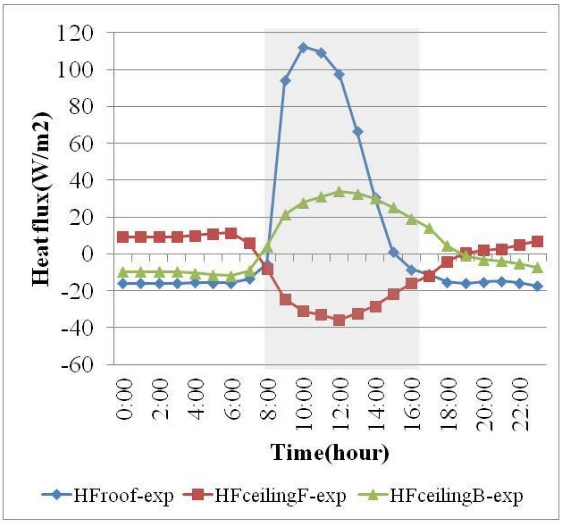
Weather data on 4th November 2013 **Weather data on 28th November 2013**



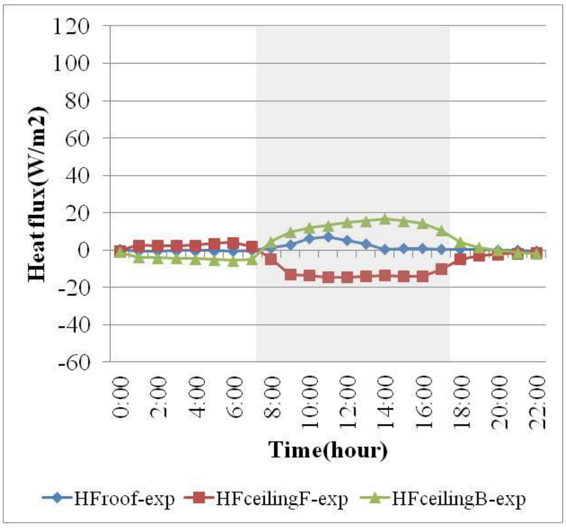
(a) Base case **(b) Insulation installed over ceiling**

Figure 4.14 Graph of solar radiation, ambient temperature, relative humidity, and sky temperature on 4th and 28th November 2013: (a) Base case (b) Insulation installed under roof

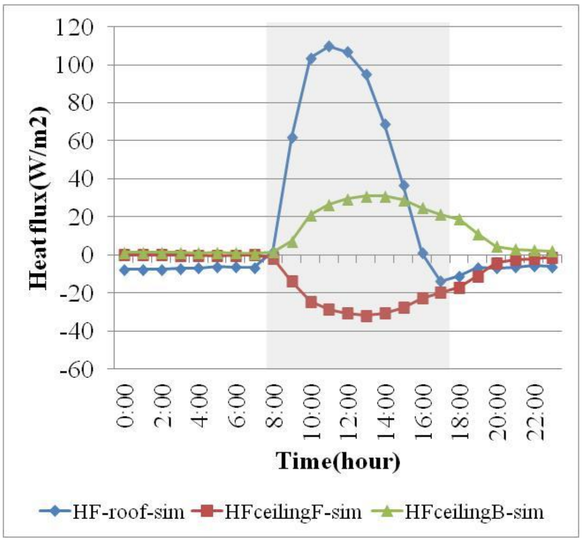
This topic is about the colour used or high reflectant coating, in the experimental use high reflectant coating up to 95% reflectant. From the Figure 4.14 shows the weather data between the base case and the roof coating case, which gave the similar weather data that both days global radiation show the closely global radiation and the highest ambient temperature only few difference. An experiment of solar reflective coating case was conducted on 28th November 2013. Solar radiation profile and ambient temperature are similar for the base case and with solar reflective coating experimental days.



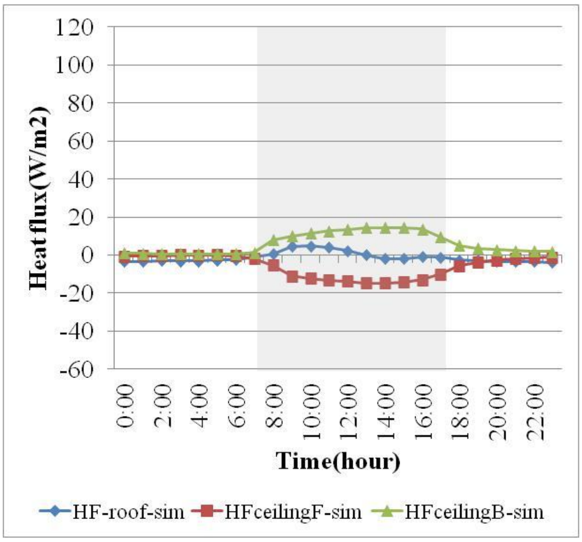
(a) Base case



(b) Solar reflective coating



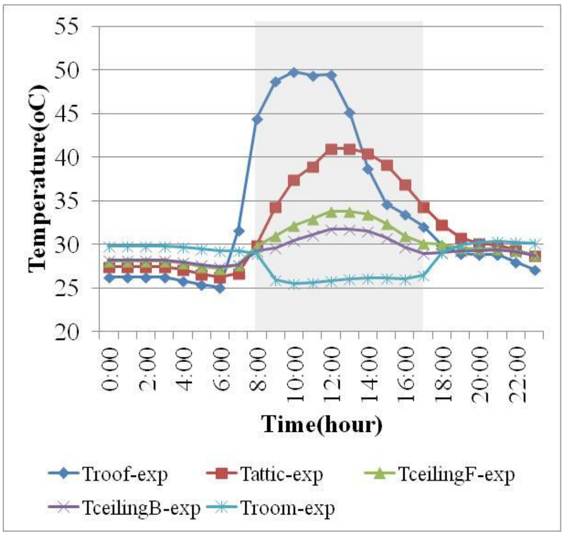
(c) Base case



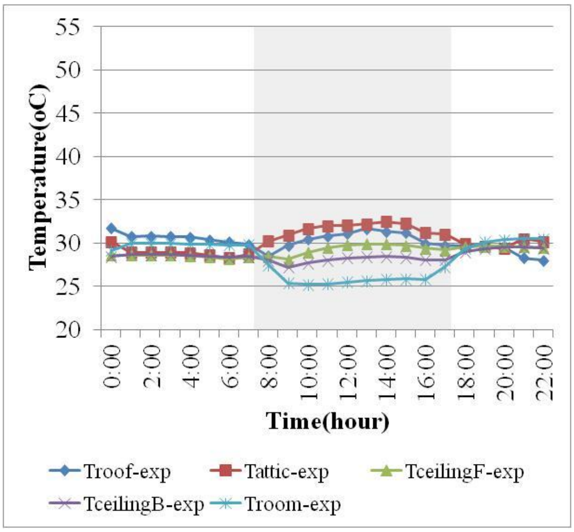
(d) Solar reflective coating

Figure 4.15 Graphs of base case and Solar reflective coating case of heat flux at roof section, front of ceiling section, and back of ceiling section from experiment and from calculation for the office function: (a),(b) experiment and (c),(d) calculation

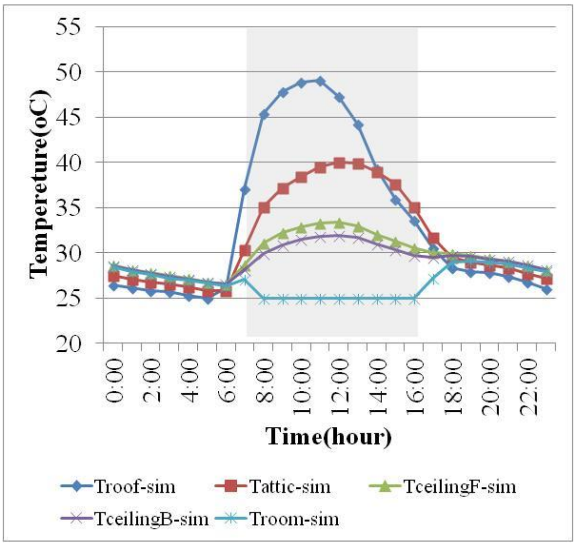
Figure 4.15 shows the graphs of the base case and the solar reflective coating case of the heat flux at roof section, front of ceiling section, and back of ceiling section from the experiment and from calculation for the office function found that roof coating with high reflectance coating case gave the heat flux decreasing from 110 W/m^2 to 10 W/m^2 causes of the higher roof temperature, ceiling temperature and attic temperature which are decreasing after coating case. The result of high reflectance coating helped to reduced temperature in the roof section that reduce heat transfer through the roof. The uses of solar reflective coating help to reduce heat flux through roof and fall on ceiling up to 50-90%. The experiments and calculation results show the same results.



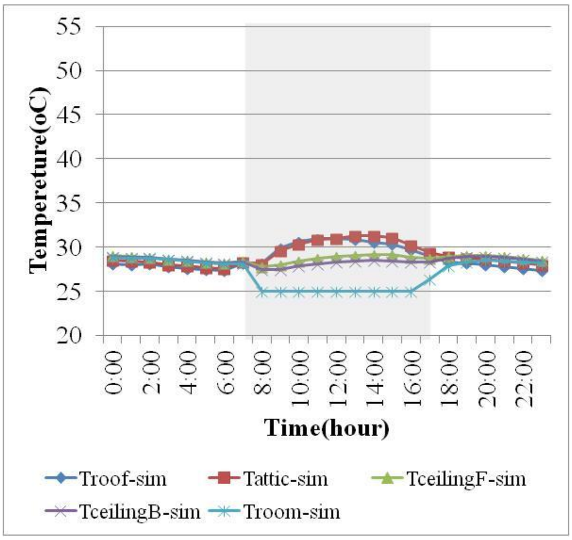
(a) Base case



(b) Solar reflective coating



(c) Base case

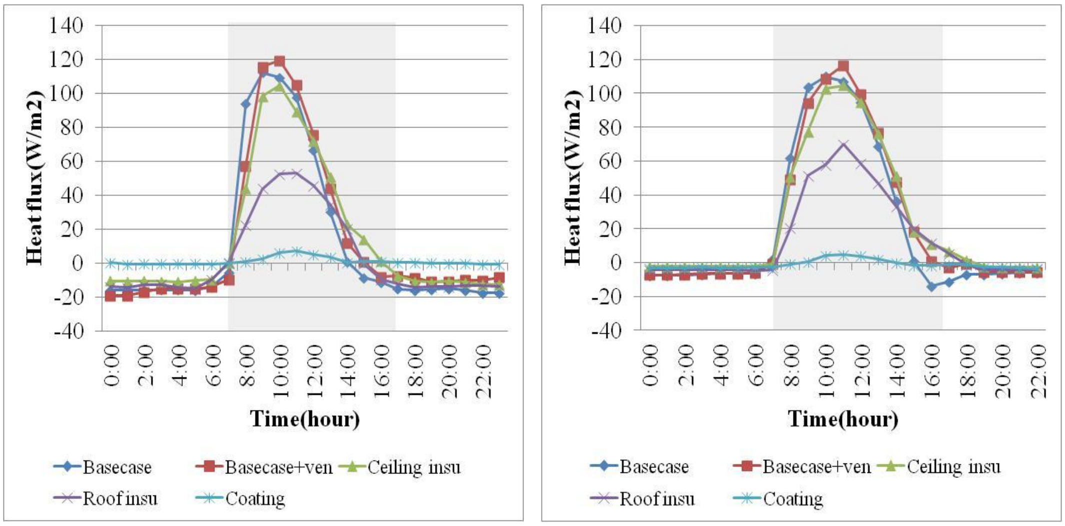


(d) Solar reflective coating

(a) **(b)**

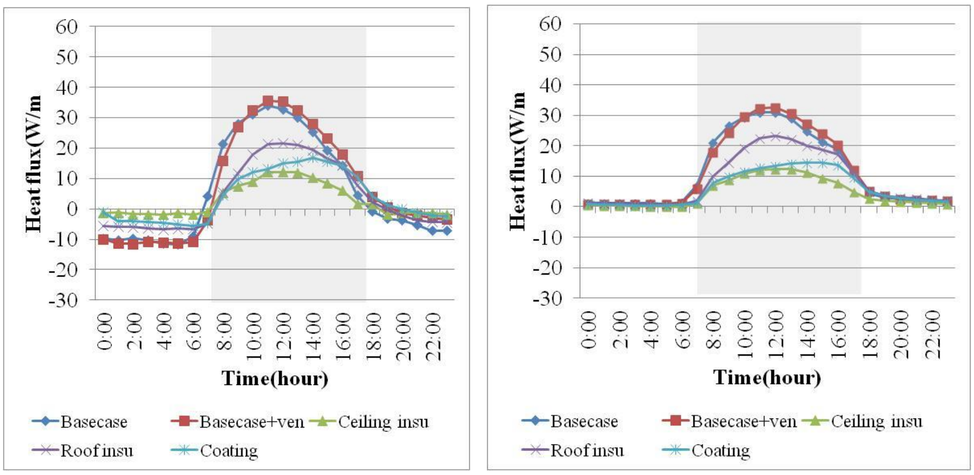
Figure 4.16 Graphs of base case and solar reflective case temperature on roof section, front of ceiling section, and back of ceiling section, attic temperature, and room temperature from experiment and from calculation for the office function: (a),(b) experiment and (c),(d) calculation

Figure 4.16 shows the graphs of the base case and the solar reflective case temperature on roof section, front of ceiling section, and back of ceiling section, attic temperature, and room temperature from experiment and from calculation for the office found that the roof coating with high reflectance coating case gave the heat flux decreasing from 35 W/m^2 to 20 W/m^2 causes of the decreasing of heat flux through roof into ceiling and decreasing of ceiling temperature. This reasons results to the air-conditioning load. The result of high reflectance coating helped to reduce heat transfer through ceiling into the room. The uses of solar reflective coating help to reduce temperature of roof, attic and ceiling. The results are consistent with the HF results. The experimental and calculation results are consistent.



(a) **(b)**

Figure 4.17 Graphs of heat flux at roof section for the office function of five cases: (a) experiment and (b) calculation



(a) **(b)**

Figure 4.18 Graphs of heat flux at back of ceiling section from experiment and from calculation for the office function of five cases: (a) experiment and (b) calculation

Figure 4.17 shows the graphs of the heat flux at the roof section for the office function of five cases and Figure 4.18 shows graphs of heat flux at back of ceiling section from experiment and from calculation for the office function of five cases which are explained for office function of use, the uses of insulation under roof and over ceiling help to reduce heat gain around 40-60%. The solar reflective coating can help to reduce heat gain around 80-90%. The use of force ventilation in attic is not effective for daytime function of use.

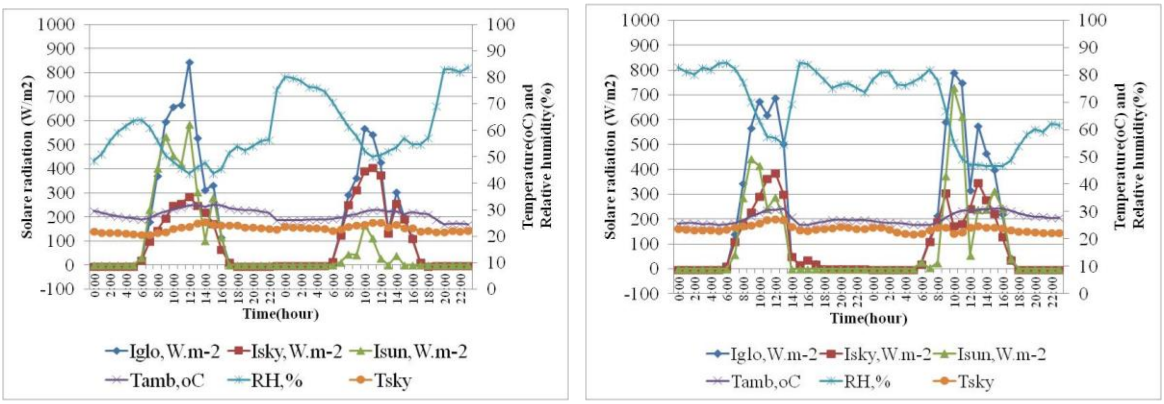
4.2 Residential function: The room use as bedroom function

4.2.1. Forced ventilation case of office function

Base case: without insulation and force ventilation

Bedroom function: air condition period 8 am-5 pm

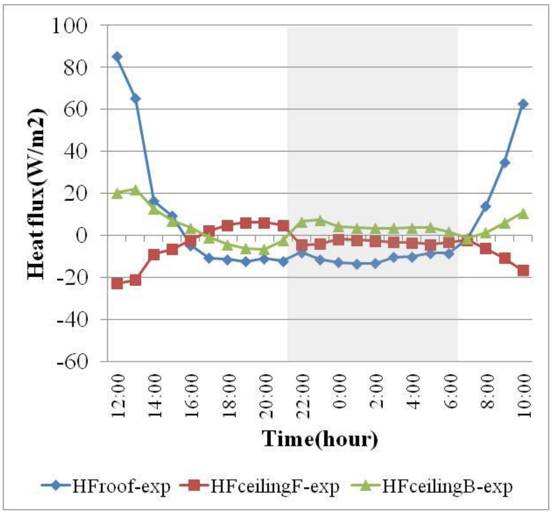
Weather data on 7th November 2013 **Weather data on 10th November 2013**



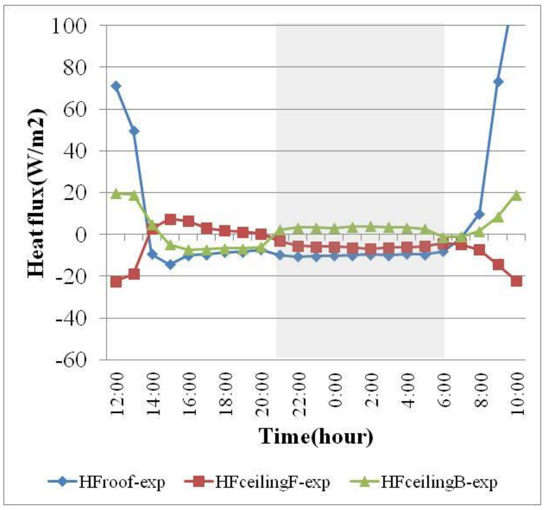
(a) Base case **(b) Forced ventilation case**

Figure4.19 Graph of solar radiation, ambient temperature, relative humidity, and sky temperature on 7thand 10th November 2013: (a) Base case (b) Insulation installed under roof

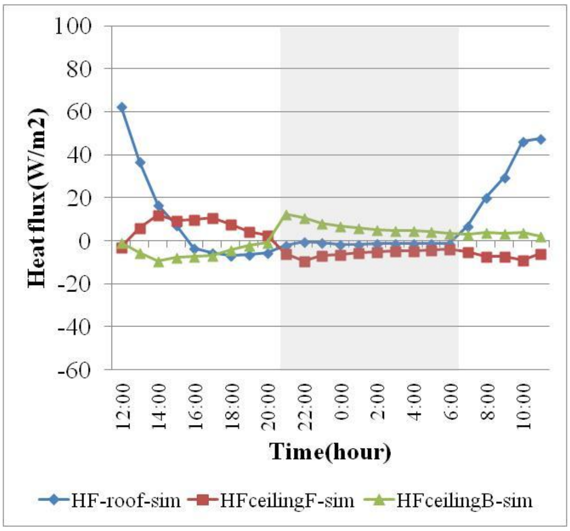
This study is to prove that heat transfer under the roof helps to reduce heat transfer into the room. Figure 4.19 shows the weather data between the base case and the forced ventilation case which gave the similar weather data that both days global radiation show the closely global radiation and the highest ambient temperature only few difference which the global radiation 800 W/m^2 and the highest ambient temperature approximately 33° C of both days. Both days are near clear sky conditions. An experiment of forced ventilation was conducted on 10th November 2013. Ambient temperature, %RH and sky temperature are slightly different.



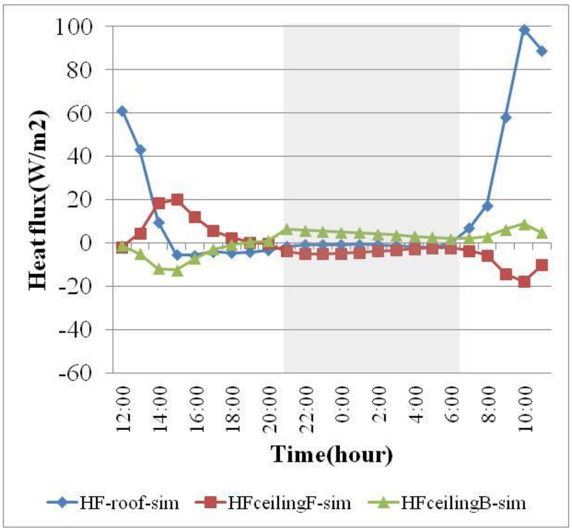
(a) Base case



(b) Forced ventilation case



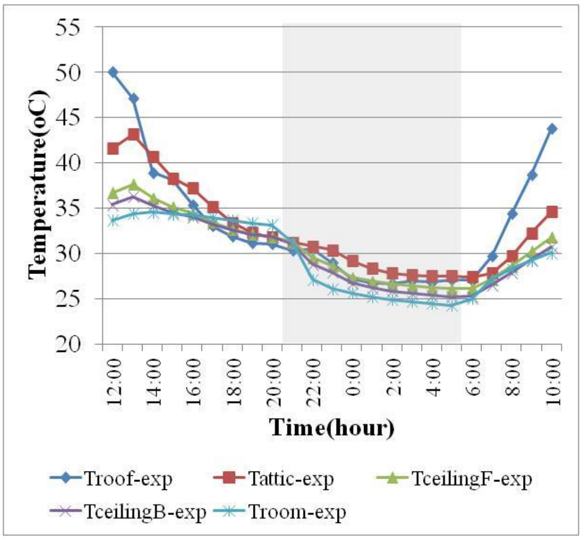
(c) Base case



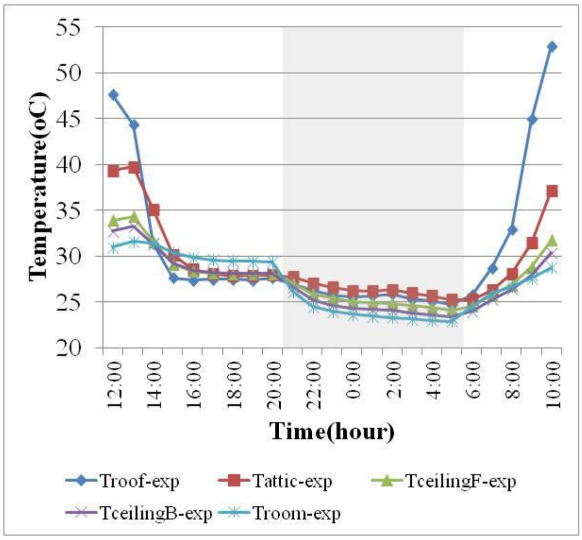
(d) Forced ventilation case

Figure 4.20 Graphs of base case and forced ventilation case of heat flux at roof section, front of ceiling section, and back of ceiling section from experiment and from calculation for the bedroom function: (a),(b) experiment and (c),(d) calculation

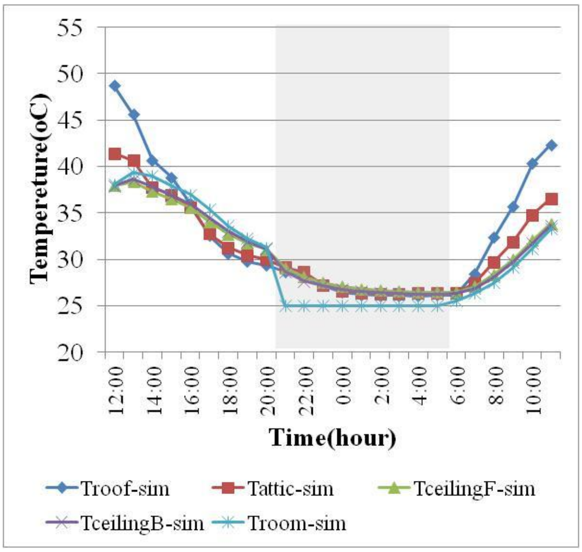
Figure 4.20 shows the graphs of the base case and the insulation installed under the roof case of the heat flux at roof section, front of ceiling section, and back of ceiling section from experiment and from calculation for the bedroom found that force ventilation from the experiments and calculation results show the same results. During night time, solar radiation is absent. Heat gain through roof become negative (heat loss). The uses of forced ventilation help to reduce HF fall on the ceiling. The experiments and calculation results show the same results.



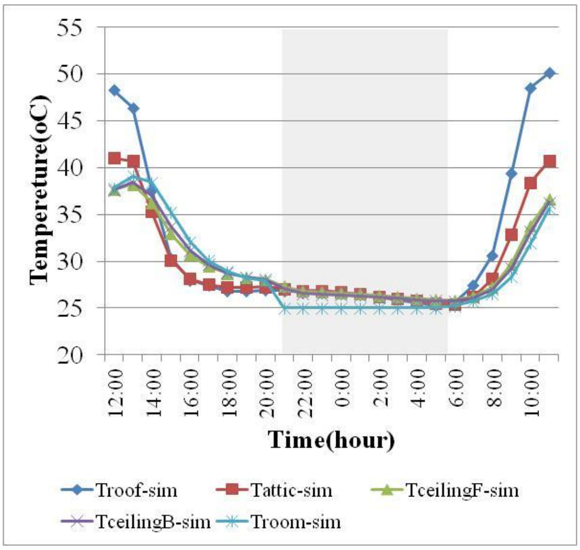
(a) Base case



(b) Forced ventilation case



(c) Base case



(d) Forced ventilation case

Figure 4.21 Graphs of base case and forced ventilation case temperature on roof section, front of ceiling section, and back of ceiling section, attic temperature, and room temperature from experiment and from calculation for the bedroom function: (a),(b) experiment and (c),(d) calculation

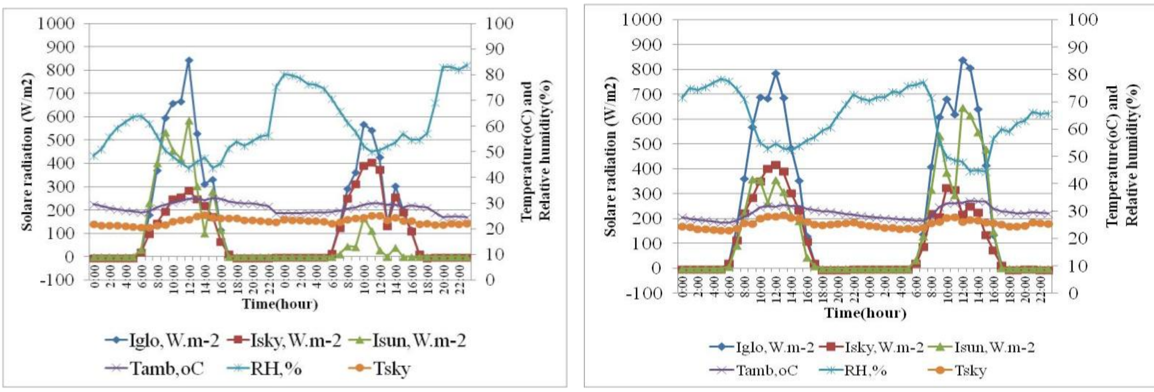
Figure 4.21 shows the graphs of the base case and the forced ventilation case temperature on roof section, front of ceiling section, and back of ceiling section, attic temperature, and room temperature from experiment and from calculation for the bedroom function. The uses of force ventilation help to reduce temperature in attic and ceiling. The results are consistent with the heat flux results. The experimental and calculation results are consistent.

4.2.2. Insulation installed under roof case of bedroom function

Position of insulation: insulation under roof section

Bedroom function: air condition period 8 am-5 pm

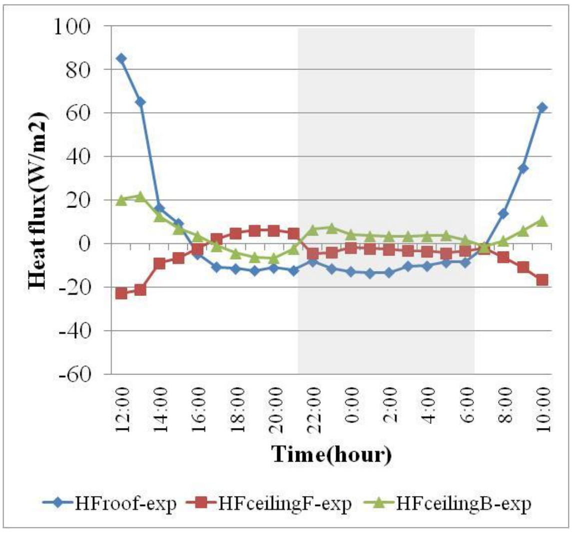
Weather data on 7th November 2013 **Weather data on 30th November 2013**

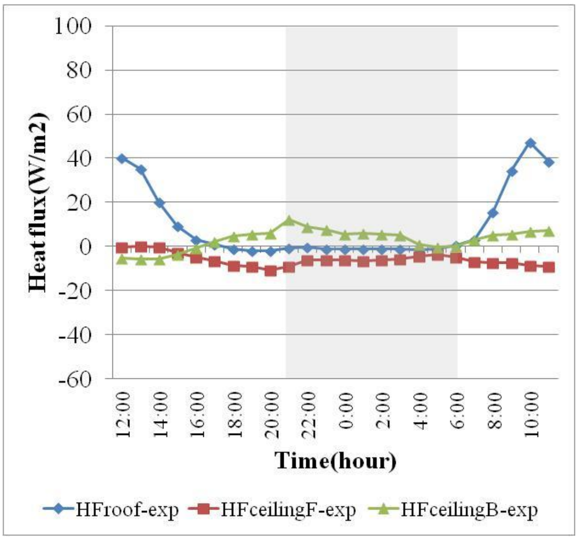


(a) Base case **(b) Insulation installed under roof case**

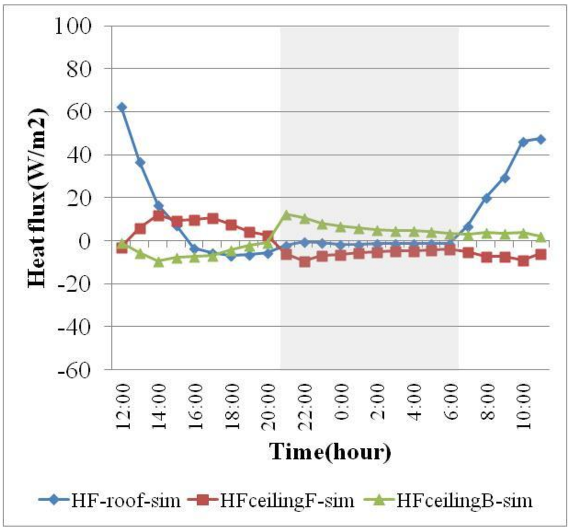
Figure 4.22 Graph of solar radiation, ambient temperature, relative humidity, and sky temperature on 7th and 30th November 2013: (a) Base case (b) Insulation installed under roof

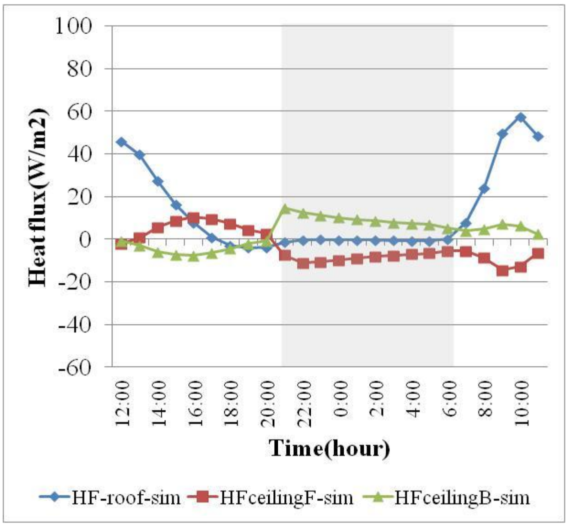
This study shows the result involving the using of insulation at different positions under the roof. The results compare between base case (no insulation) and roof insulation. Figure 4.22 shows weather data between base case and roof insulation case which weather is not different of two experimental days. Maximum solar radiation of both days is 800-900 W/m^2 and maximum ambient temperature around 32-33°C. An experiment of insulation installed under roof was conducted on 30th November 2013. Ambient temperature, %RH and sky temperature are slightly different.





(a) Base case **(b) Insulation installed under roof case**

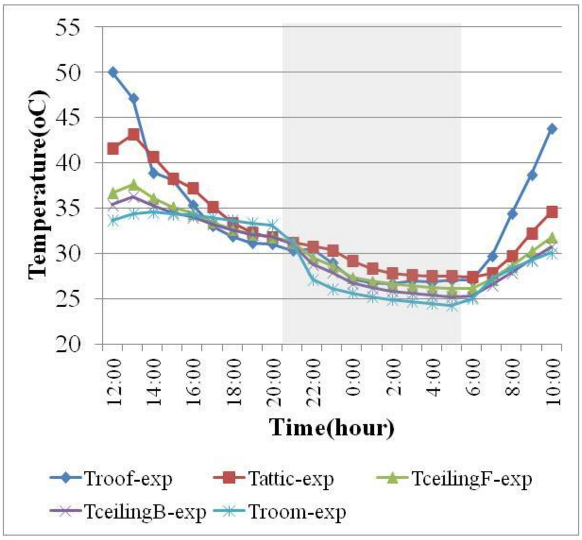




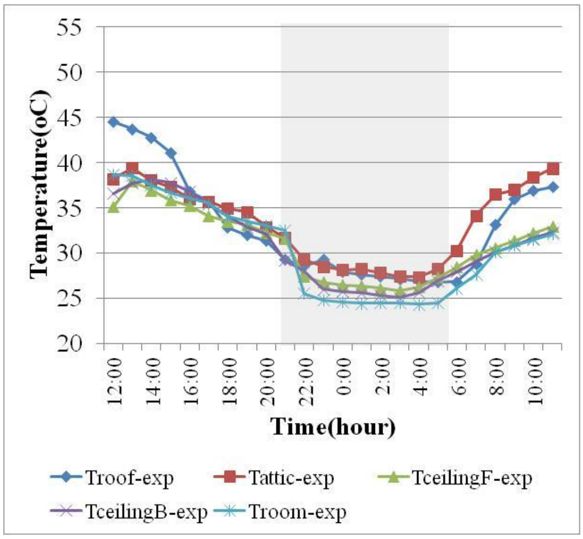
(c) Base case **(d) Insulation installed under roof case**

Figure 4.23 Graphs of base case and insulation installed under roof case of heat flux at roof section, front of ceiling section, and back of ceiling section from experiment and from calculation for the bedroom function: (a),(b) experiment and (c),(d) calculation

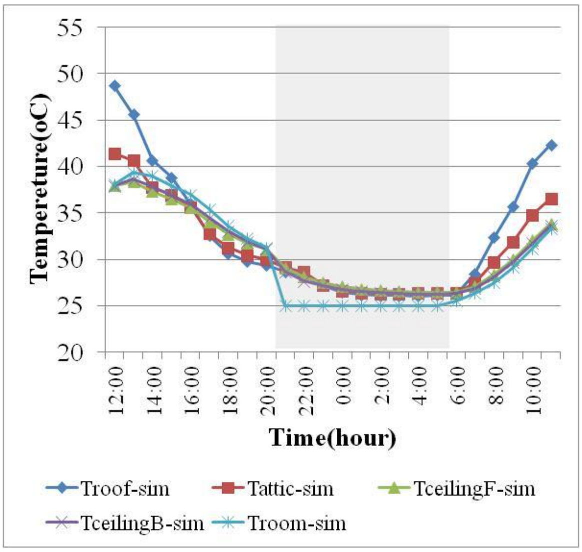
Figure 4.23 shows the graphs of the base case and the insulation installed under the roof case of the heat flux at the roof section, front of ceiling section, and back of ceiling section from experiment and from calculation for the bedroom found that the use of insulation under roof leads to reduce heat loss through roof during night time and slightly increase heat flux through ceiling. The experiments and calculation results show the same results.



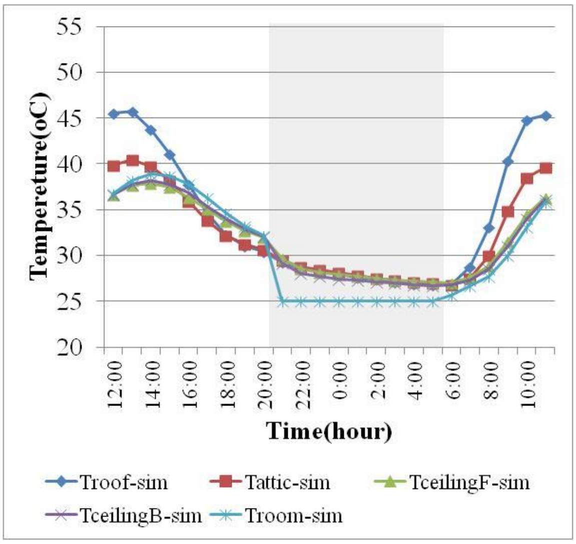
(a) Base case



(b) Insulation installed under roof case



(c)Base case



(d) Insulation installed under roof case

Figure 4.24 Graphs of base case and insulation installed under roof case temperature on roof section, front of ceiling section, and back of ceiling section, attic temperature, and room temperature from experiment and from calculation for the bedroom function: (a),(b) experiment and (c),(d) calculation

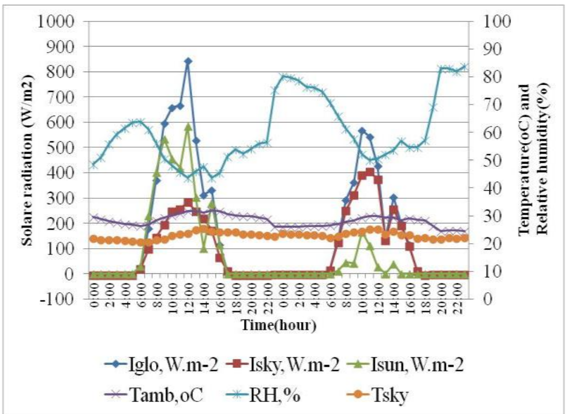
Figure 4.24 shows the graphs of the base case and insulation installed under the roof case temperature on roof section, front of ceiling section, and back of ceiling section, attic temperature, and room temperature from experiment and from calculation for the bedroom function. The uses of insulation under roof lead to increase temperature in attic and over ceiling before air conditioning period because heat loss is reduced. The results are consistent with the hest flux results. The experimental and calculation results are consistent.

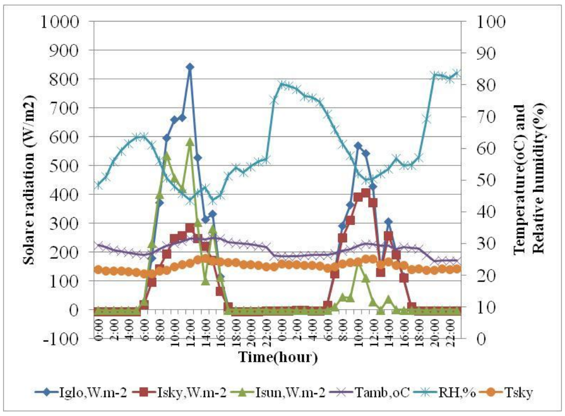
4.2.3. Insulation installed over ceiling case of bedroom function

Position of insulation: insulation on ceiling section

Bedroom function: air condition period 8 am-5 pm

Weather data on 7th November 2013 **Weather data on 22th November 2013**

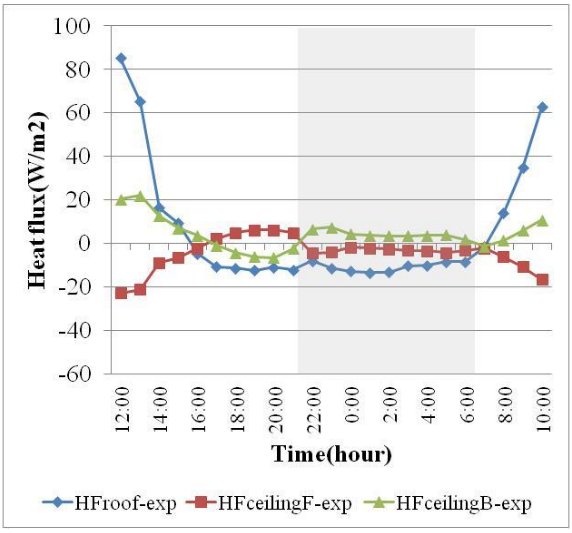


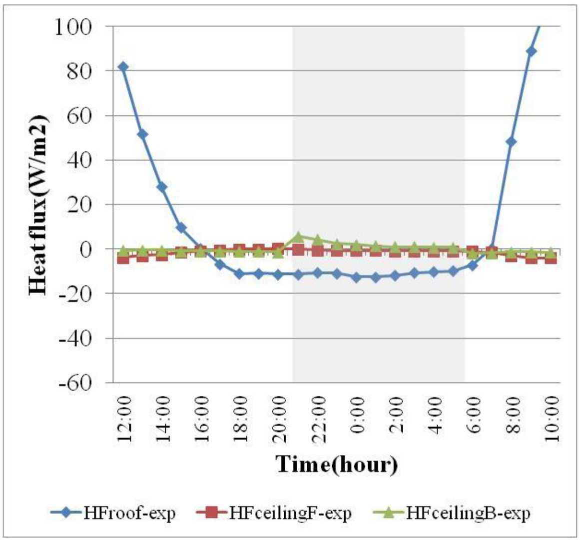


(a) Base case **(b) Insulation installed over ceiling case**

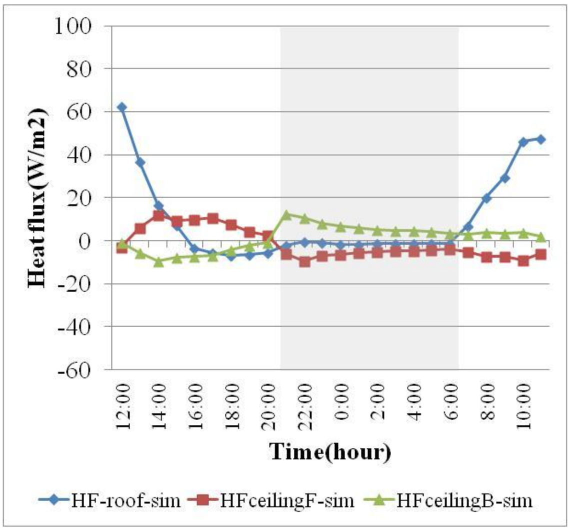
Figure 4.25 Graph of solar radiation, ambient temperature, relative humidity, and sky temperature on 7thand 22th November 2013: (a) Base case (b) Insulation installed under roof

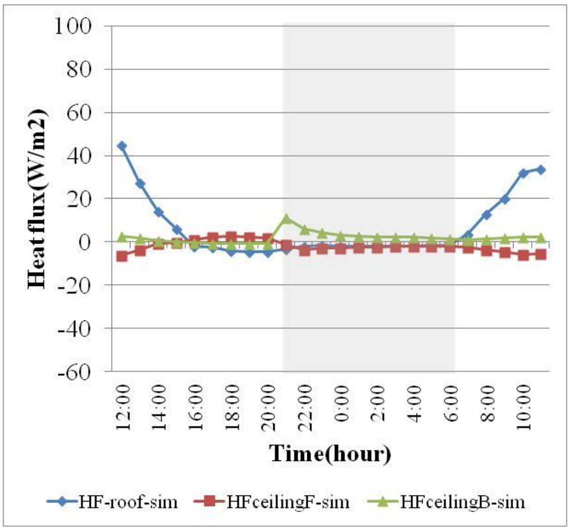
This study gives results the involving the use of insulation at different positions under the roof. The results compare between base case (no insulation) and roof insulation. Figure 4.25 shows weather data between base case and roof insulation case which weather is not different of two experimental days. Maximum solar radiation of both days is 800-900 W/m^2 and maximum ambient temperature around 32-33°C. An experiment of insulation installed under roof was conducted on 22th November 2013. Ambient temperature, %RH and sky temperature are slightly different.





(a) Base case **(b) Insulation installed over ceiling case**

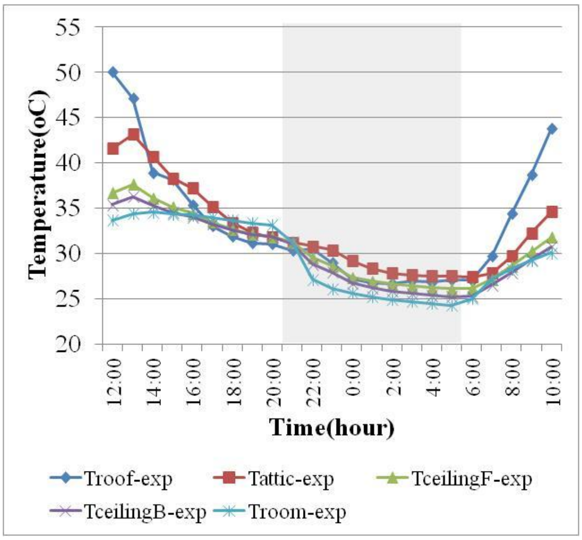


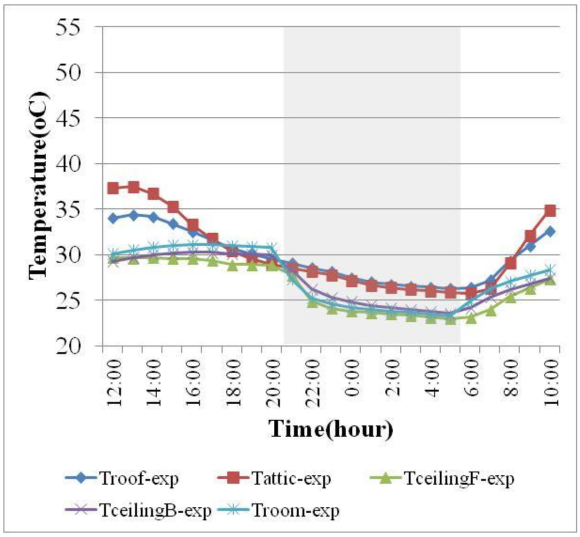


(c) Base case **(d) Insulation installed over ceiling case**

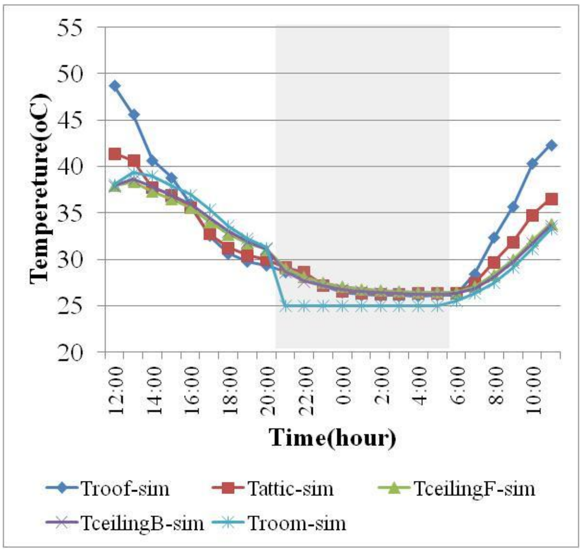
Figure 4.26 Graphs of base case and insulation installed over ceiling case of heat flux at roof section, front of ceiling section, and back of ceiling section from experiment and from calculation for the bedroom function: (a),(b) experiment and (c),(d) calculation

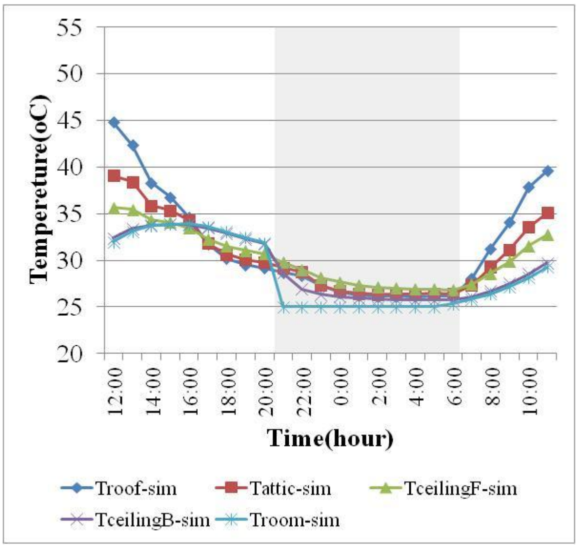
Figure 4.26 shows the graphs of the base case and the insulation installed over the ceiling case of the heat flux at the roof section, front of ceiling section, and back of ceiling section from experiment and from calculation for the bedroom found that the use of insulation over ceiling helps to reduce hest flux fall on ceiling around 50%. The experiments and calculation results show the same results.





(a) Base case **(b) Insulation installed over ceiling case**





(c) Base case **(d) Insulation installed over ceiling case**

Figure 4.27 Graphs of base case and insulation installed over ceiling case temperature on roof section, front of ceiling section, and back of ceiling section, attic temperature, and room temperature from experiment and from calculation for the bedroom function: (a),(b) experiment and (c),(d) calculation

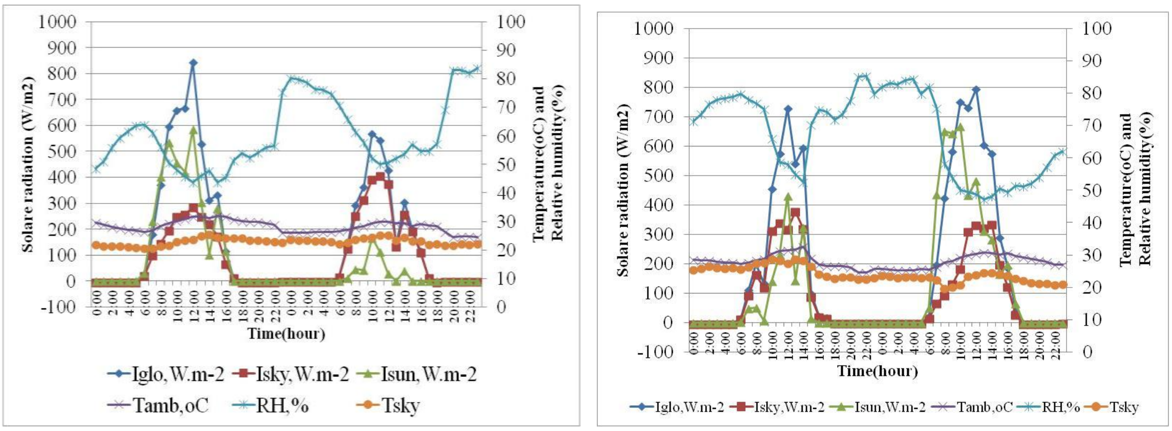
Figure 4.27 shows the graphs of the base case and the insulation installed under the roof case temperature on roof section, front of ceiling section, and back of ceiling section, attic temperature, and room temperature from experiment and from calculation for the bedroom function. The uses of insulation over ceiling help to reduce ceiling temperature. The results are consistent with the HF results. The experimental and calculation results are consistent.

4.2.4. Solar reflective coating case of bedroom function

Position of insulation: coating on roof area

Bedroom function: air condition period 8 am-5 pm

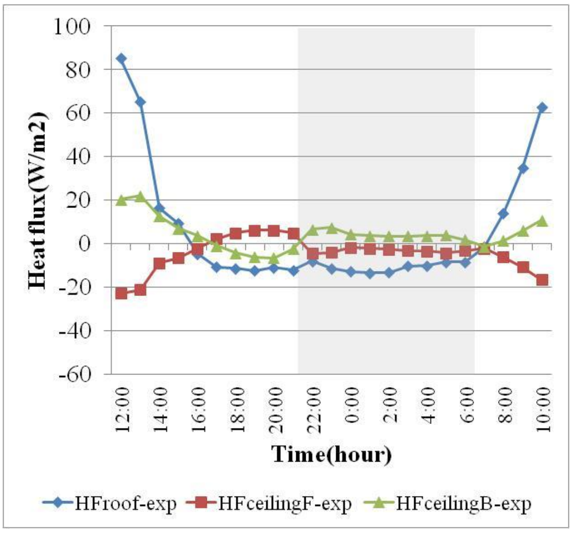
Weather data on 7th November 2013 **Weather data on 15th November 2013**



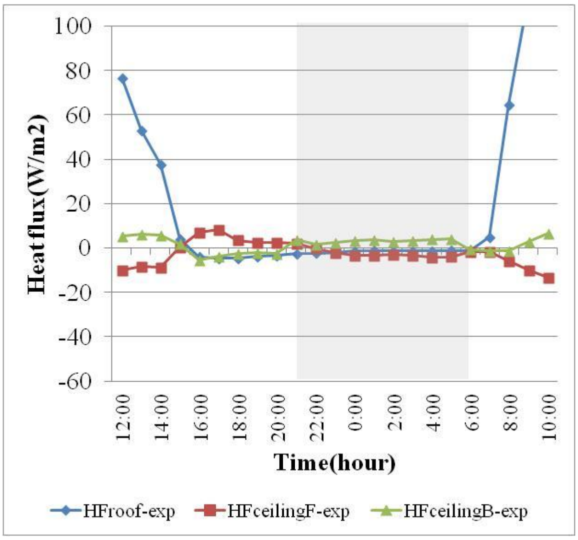
(a) Base case **(b) Solar reflective coating case**

Figure 4.28 Graph of solar radiation, ambient temperature, relative humidity, and sky temperature on 7thand 15th November 2013: (a) Base case (b) Insulation installed under roof

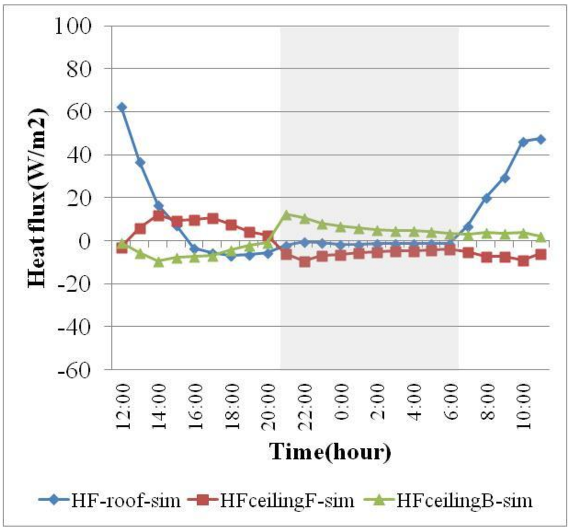
This topic studies the colour used or high reflectant coating, in the experimental use high reflectant coating up to 95% reflectant. From the Figure4.28 show the weather data between base case and roof coating case which gave the similar weather data that both days global radiation show the closely global radiation and the highest ambient temperature only few difference. An experiment of solar reflective coating case was conducted on 15th November 2013. Solar radiation profile and ambient temperature are similar for base case and with solar reflective coating experimental days. Ambient temperature, %RH and sky temperature are slightly different.



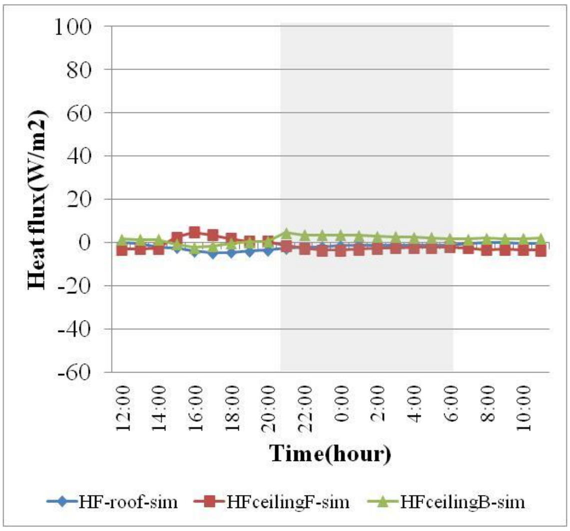
(a) Base case



(b) Solar reflective coating case



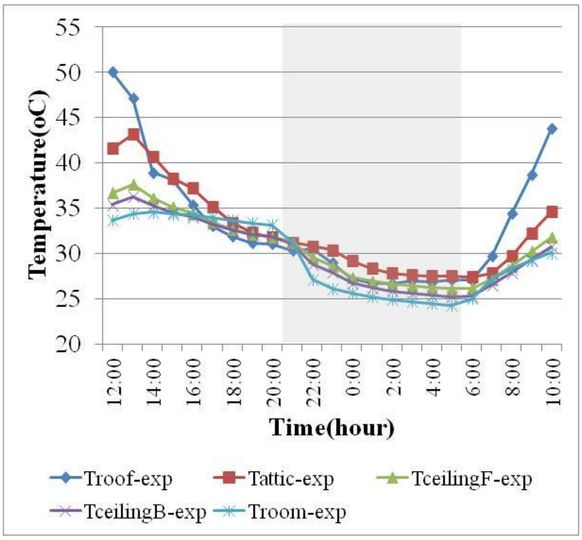
(c) Base case



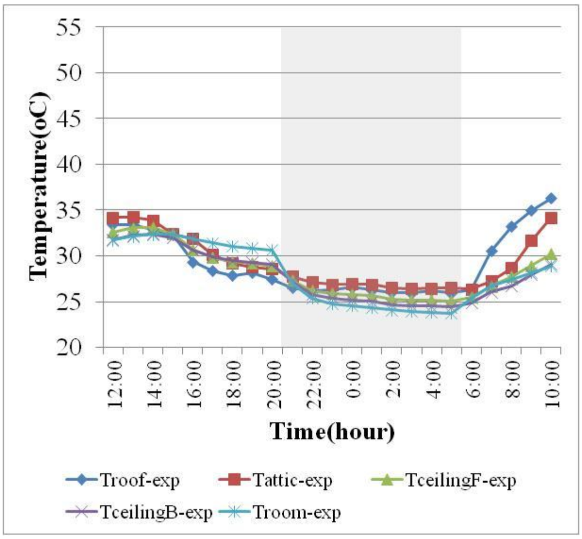
(d) Solar reflective coating case

Figure 4.29 Graphs of base case and solar reflective coating case of heat flux at roof section, front of ceiling section, and back of ceiling section from experiment and from calculation for the bedroom function: (a),(b) experiment and (c),(d) calculation

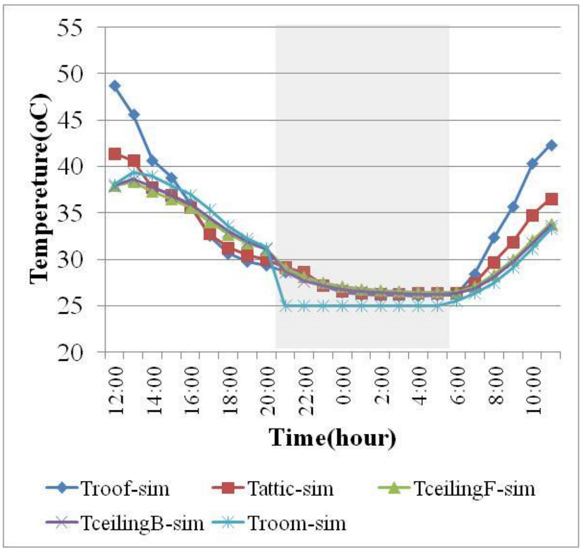
Figure 4.29 shows the graphs of the base case and solar reflective coating case of heat flux at the roof section, front of ceiling section, and back of ceiling section from experiment and from calculation for the office function found that roof coating with high reflectance coating case gave the heat flux decreasing from 110 W/m^2 to 10 W/m^2 causes of the higher roof temperature, ceiling temperature and attic temperature which are decreasing after coating case. The result high reflectance coating help to reduce temperature in the roof section that reduce heat transfer through roof. The use of solar reflective coating leads to reduce heat loss from roof but help to reduce HF fall on ceiling around 50%. The experiments and calculation results show the same results.



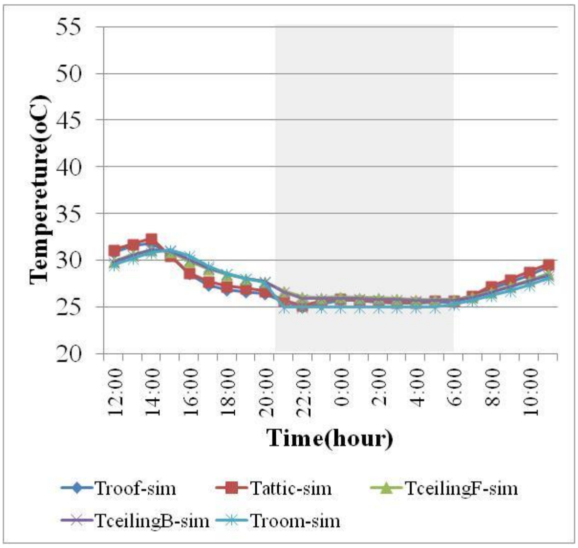
(a) Base case



(b) Solar reflective coating case



(c) Base case



(d) Solar reflective coating case

Figure 4.30 Graphs of base case and solar reflective coating case temperature on roof section, front of ceiling section, and back of ceiling section, attic temperature, and room temperature from experiment and from calculation for the bedroom function: (a),(b) experiment and (c),(d) calculation

Figure 4.30 shows the graphs of the base case and the solar reflective case temperature on roof section, front of ceiling section, and back of ceiling section, attic temperature, and room temperature from experiment and from calculation for the office found that roof coating with high reflectance coating case decreased the heat flux decreasing from 35 W/m^2 to 20 W/m^2 causes of the decreasing of heat flux through the roof into the ceiling and the decreasing of ceiling temperature. This reasons results to the air-conditioning load. The result of high reflectance coating helped to reduce heat transfer through ceiling into the room. The uses of solar reflective coating help to reduce temperature of roof, attic and ceiling before and during air-conditioning period. The results are consistent with the heat flux results. The experimental and calculation results are consistent.

The use of forced ventilation in the attic for night time function is effective because of the absent of solar radiation and absence of thermal radiation emitted from the roof. The use of insulation over ceiling help to reduce heat gain around 50% while insulation under roof leads to reduce heat loss from roof to ambient and slightly increase HF through ceiling. The use of solar reflective coating is still effectively the same as the daytime function.

4.3 Simulation-Base Analysis (whole year : Year2000)

Case (I): Base case

Case (II): Base case with force ventilation

Case (III): Roof insulation

Case (IV): Ceiling insulation

Case (V): Roof coating

4.3.1 Function of room use

4.3.1.1. Commercial function

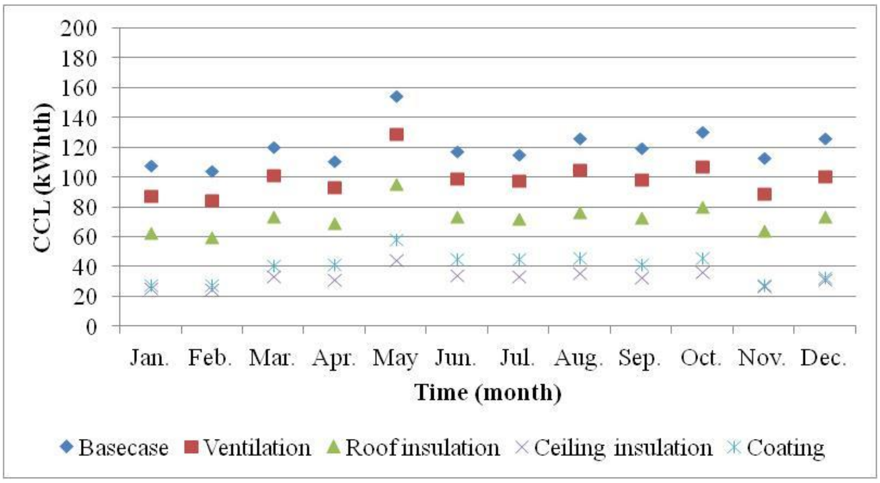


Figure 4.31 CCLs for each case of office function for each case of office function

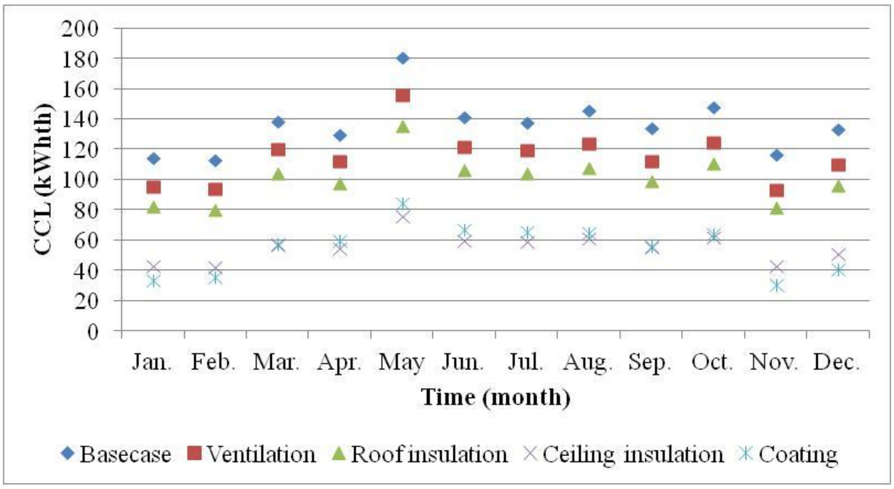


Figure 4.32 CCLs for each case of 24 hrs function

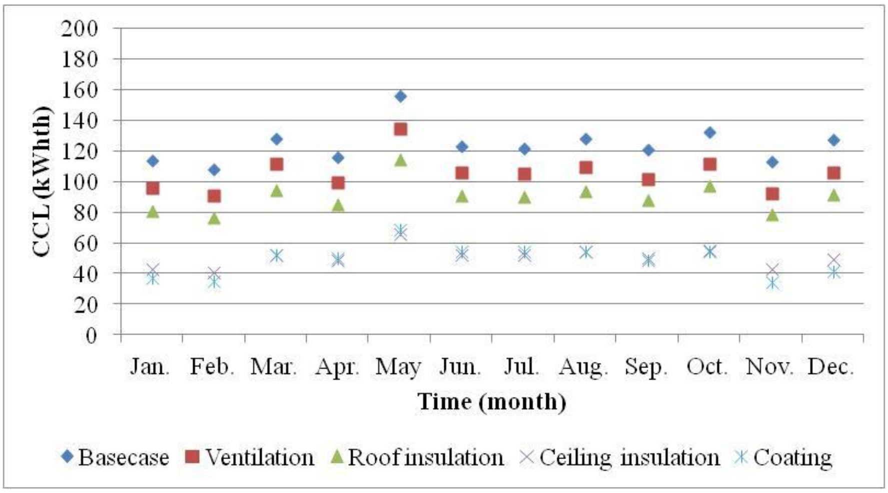


Figure 4.33 CCLs for each case of department store function

4.3.1.2. Residential function

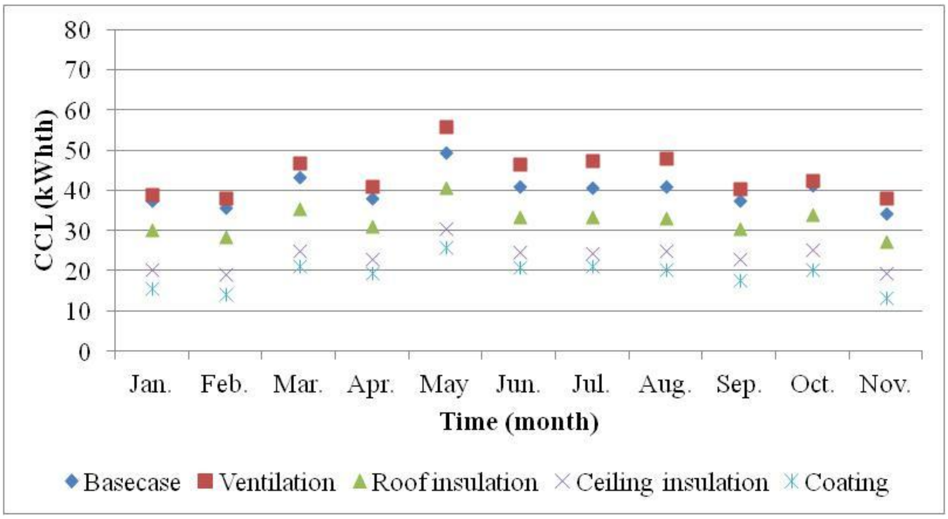


Figure 4.34 CCLs for each case of bedroom function

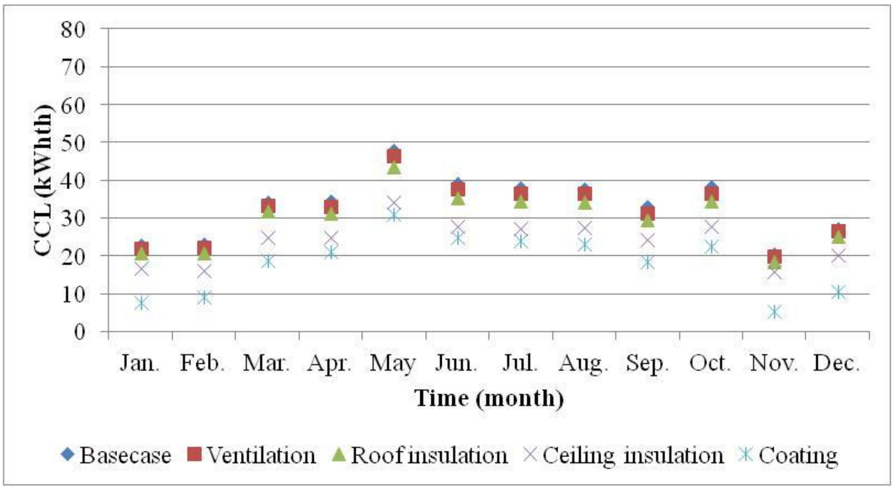


Figure 4.35 CCLs for each case of living room function

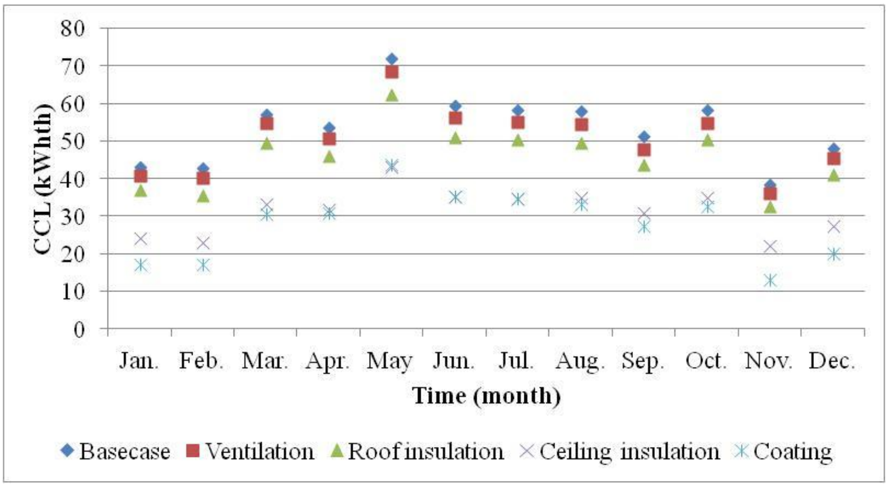


Figure 4.36 CCLs for each case of studio room function

4.3.2 Cooling coil load

Table4.1 Annual cooling coil load of each case

Case	Office	24hrs	Department store	Living room	Bedroom	Studio room
Base case	1446.839	1635.835	1489.311	395.4942	581.3531	641.1663
Ventilation	1193.915	1384.657	1265.352	381.3853	526.1717	606.0319
Roof insulation	873.8482	1209.13	1083.05	358.7139	391.4429	550.0909
Ceiling insulation	391.587	663.8186	609.2955	286.9019	283.5191	376.3167
Coating	479.9483	659.8389	587.0861	215.9222	227.8803	336.7441

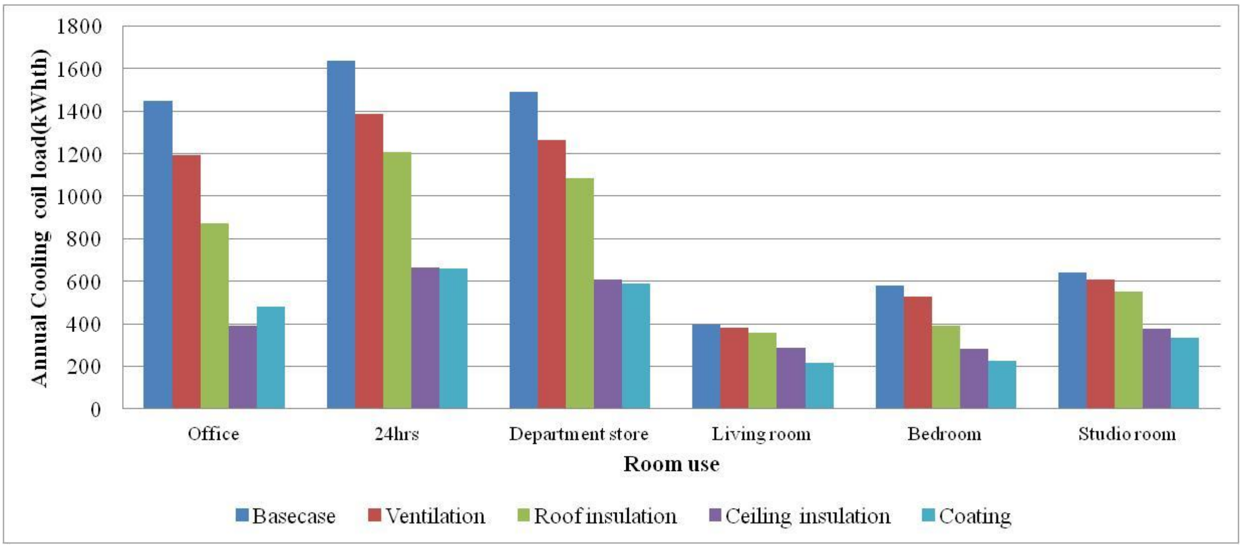


Figure 4.37 Annual Cooling coil load for each case of room function

Figure 4.37 shows the graph of the annual cooling coil load for each case of the room function, which is concluded in whole year CCL and for all function of use indicates that the use of force ventilation is effective for all function of use. Roof coating with solar reflective materials is the best case to reduce heat gain through roof and into spaces for all function of use except for the office function cause of the thermal radiation mechanism of room attic. The use of insulation on ceiling is more effective than insulation under roof for all function of use.

CHAPTER 5
CONCLUSION AND FUTURE WORKS

5.1 Conclusions

This research thesis has investigated the options to improve the thermal performance of roofs from different positions of insulation, ventilation and roof coating, using a simulation method and verifying the simulation program with an actual field experiment.

A simulation program, The Building Simulation Program (BESim) was used. The verification of the simulation program showed that it corresponded closely with predicted heat flux on the surface of ceiling and roof section.

Thailand is has a hot and humid climate. The use of forced ventilation in attic is not effective for daytime function of use due to heat transfer mechanism is almost thermal radiation. But for night time function the use of force ventilation is effective to reduce heat gain into spaces. The use of insulation under roof is also effective for daytime function only. For night time function, the use of insulation under roof leads to reduce heat loss and increase heat gain into spaces. The uses of insulation over ceiling and reflective coating are effective for both daytime and night time function of use and can reduce heat gain into spaces.

5.2 Future Work

- Determine the life cycle cost to reduction of cost from energy consumption.
- Investigate the optimal thermal mass in terms of economy.
- Investigate the balance of the heat resistance and heat capacitance of the building envelope in order to determine the energy effectiveness.

RFFERENCES

Abdessalam, M., Casari, R., Marchio, D., Mace, D., Maley, V., Climatiser dans les DOM, vol. 7, pp. 23–34.

Argiriou, A. (1992), A study of thermal mass in Hellenic building. Institute for Technological Applications, Hellenic Productivity Center, Athens.

Balaras, C. (1996), Thermal comfort / Cooling load of building / Heat attenuation. In: Santamouris,M.and Asimakopoulos,D. 1996. Passive cooling of buildings. James & James (Science Publishers) Ltd, UK.

Caren Michels, Roberto Lamberts, Saulo Guths (2008) Theoretical/experimental comparison of heat flux reduction in roofs achieved through the use of reflective thermal insulators, *Energy and Buildings*, 40, pp. 438–444.

Chirarattananon. S.(2005), Building for energy efficiency. AIT, School of environment Resources and development, Thailand.

Chirarattananon. S., Vu Duc Hien.(2006), Cost-Effectiveness of Insulations Used under Pitched Roofs in Thailand,Thailand

David W. Winiarski a, Dennis L. O'Neal (1996) A quasi-steady-state model of attic heat transfer with radiant barriers, *Energy and Buildings*, 24, pp. 183-194.

Fairey, P.W., 1982. Effect of infrared radiation barriers on the effective thermal resistance of building envelopes. ASHRAE/DOE Conference of thermal performance of the exterior envelopes of buildings II, Las Vegas, USA, pp.859–875.

Fernandez, J.L., Porta-Gandara, M.A. and Chargoy, N. (2005), Rapid on-site evaluation of thermal comfort through heat capacity in buildings, Ener y and Building, 37, pp.1205-1211.

Frédéric Miranville, Harry Boyer, Thierry Mara, François Garde (2003) On the thermal behaviour of roof-mounted radiant barriers under tropical and humid climatic conditions: modelling and empirical validation, *Energy and Buildings*, 35, pp. 997–1008.

Givoni, B.(1998), Effectiveness of mass and night ventilation in lowering the indoor daytime temperatures : Part I, Energy and Building, 28, pp.25-32.

Gregory, K., Moghtaderi, B., Sugo, H. and Page, A., (2007), Effect of thermal mass on thermal performance of various Australisn residential constructions system, Energy and Building, Available online : http://www.sciencedirect.com

Hall, J.A., 1988. Performance testing of radiant barriers (RB) with R11, R19 and R30 cellulose and rock wool insulation.ASHRAE Transaction 73, 174–185.

Hasan, H., Sancaktar, Y., 1998. Effects of wall_s thermophysical properties on time lag and decrement factor. Energy and Buildings 28, 159–166.

IEA (2006), Energy Technology Perspective : Scenarios and Strategies to 2050, OECD/IEA, Paris.

Janda, K.B. and Busch, J.F. (1994), Worldwide status of energy standards for buildings, Energy-The International Journal, 19, 1, pp. 27-44.

Kalogirou, Soteris.A., Florides, G. and Tassou, S.(2002) Energy analysis of buildings employing thermal mass in Cyprus, Renewable Energy, 27, pp.353-368.

Kosny,J.,Patric, T., Gawin, D., Childs, P., Desjarlais, A. and Christian, J.2000. Thermal mass-Energy savings poteneial in residential building. ORNL, Building Technology Center, USA.

Mario A. Medina, Bryan Young (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, pp. 1767–1778.

Moujaes, S., 1996. Use of passive radiation barriers in ventilated attics. ASHRAE Transaction 102 (3963), 307–314.

Ogoli, D.M. (2003), Predicting indoor temperatures in closed buildings with high thermal mass, Energy and Building, 35, pp.851-862.

Saman, N. and Fazzolari, R. (1991), Prediction of preconditioning and storage loads after system shutdown using DOE-2, ASHRAE Transactions, 97, 1, pp.320-324.

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

Winiarski, D., O_Neal, D., 1996. A quasi-steady state model of attic heat transfer with radiant barriers. Energy and Building 24, 183–194.

Wurtz Etienne, Michel Nataf-Jean, Winkelmann Frederick, Two and three-dimensional natural and mixed convection simulation using modular zonal models in buildings, Heat and Mass TRANSFER 1999, 42, pp.923-940.

Zhengen Ren, John Stewart, Simulating air flow and temperature distribution inside buildings using a modified version of COMIS with sub-zonal divisions, Energy and Buildings (2003), 35, pp.257-271.