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Experimental Analysis of Effect of R-Factor on Cooling Load for Room AC's

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ABSTRACT

Air conditioning system is essential for maintaining thermal comfort in indoor environments, especially for hot and humid climates. Today, air conditioning, comprising cooling and dehumidification, has become a necessity in commercial and residential buildings and many of the industrial processes. It accounts for a major share of the electric energy consumption. Therefore, there is tremendous potential to improve the overall efficiency of the air-conditioning systems in buildings to reduce the uses of energy. In this present research work, begins with a review of the type of losses especially conduction loss, recent novel devices that enhances the energy efficiency. Lastly, the research presents efficient cooling strategies and R-factor of building material with minimization of conduction losses that reduce the primary energy utilization for cooling.

Introduction

To the average person, air conditioning simply means "the cooling of air". For research purposes, "Air conditioning is the process of treating air in an internal environment to establish and maintain required standards of temperature, humidity, cleanliness and motion. Air conditionings are necessary to achieve human thermal comfort. Now a day, one of the main goals of the commercial, residential, industrial and pharmaceuticals building and Architecture is to use the solar source for the air-conditioning of buildings. Over the recent years many activities have started to develop new buildings and plant technologies oriented to energy saving by improving indoor comfort air conditioning and reducing environmental pollution emission. Further the main aim is to reduce the cooling load of air conditioning system through the better design of building either from the application of building material or building architecture.

Electricity demand for room ACs is growing very rapidly in emerging economies such as India. It has been estimated that the electricity demand from room ACs in 2030 in India considering factors such as weather and income growth uses market data on penetration of ACs in different income classes and climatic regions. This will be discussed the status of the current standards, labels, and incentive programs to improve the efficiency of room ACs by reducing the conduction losses and improving the wall R Factors.

Cooling Load in Air-Conditioning System

For cooling load calculation, for each methods there are several benefits/limitations. Simplicity and accuracy are two contradicting objectives to be optimized in the refrigeration field. If a method could be considered to be simple, its accuracy would be a matter of question and vice versa. While modern methods emphasize on improving the procedure of calculating solar and conduction heat gains, there are also other main sources coming from internal heat gains (people, lighting and electric equipments). Internal heat gain shows that, when thinking about accuracy, it is not only the method which is effective, but uncertainties in the input data are also important.

Heat transfer is the physical act of thermal energy being exchanged between two systems by dissipating heat. Temperature and the flow of heat are the basic principles of heat transfer. The amount of thermal energy available is determined by the temperature, and the heat flow represents movement of thermal energy. Regions that contain higher kinetic energy transfer the energy to regions with lower kinetic energy. Simply put, heat transfer can be grouped into three broad categories: conduction, convection, and radiation.

Efficiency of AC'S

Since 2006, the Bureau of Energy Efficiency (BEE), a nodal agency for implementing energy efficiency policies in India, has initiated a standards and labeling (S&L) program for different electrical appliances. The energy efficiency labels in India are given in the form a star rating - from one-star to five-star; five-star being the most efficient. The labeling program has been made mandatory for all room ACs sold in India since 2012. This implies that any room AC must earn at least one-star label before it could be marketed in the Indian market. Therefore, the efficiency level for one-star label serves as the de facto Minimum Energy Performance Standard (MEPS).

Research Objectives

There is only one earth, so there is the responsibility of researchers to make energy efficient system which will save energy and make it safe. To protect the earth and to protect the environment is the most vital issue of the mankind. The traditional electric chiller or vapor compression air conditioning system which takes more energy that cannot survive long due to scarcity of energy in the coming days. The far sighted personnel in the field of refrigeration and air conditioning system are seeking the more energy efficient system.

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Following are the key research objectives set from the study of literature and problem statement.

1. Analysis of room air-conditioning system under normal condition.
2. Finding the losses especially due to conduction losses.
3. To minimize the conduction losses and improving the cooling load.

Literature review

In the last few decades, research works have been directed towards energy saving from air conditioning system. Several attempts have been made for minimizing cooling load, aiming at saving energy, optimizing efficiency of air conditioning system and hence having energy efficient system. The common issue is to save energy, to protect the earth and to protect the environment which is of great importance to the mankind. Researchers from all around the world have greatly contributed to the knowledge of the air conditioning heat loss and the way to decrease the cooling load of air conditioning system. In the past, most research available in vapor compression cooling system, not in vapor absorption cooling system. But in the recent years considering the energy crisis, the efficient and economical building design consideration absorption and cogeneration service system is becoming more and more important. Marriott [2006] in his study found that many building owners are choosing sustainable design because the economics make more sense now. Rising energy costs are reducing the payback period for capital improvement that improve energy performance. However, in contrast to the wealth of promotional information for why sustainable building practices should be used, surprising little application information is available on sustainability. Umesh (2014) a new bridgeless rectifier with coupled inductors is used for single phase Power Factor Correction (PFC) circuit. The proposed converter is needed as an AC-DC converter to improve the efficiency by reducing the number of components and conduction losses. Moreover, the number of component conducted is less compared to the other PFC converters. Since the converter is used for low power application around 100W, the converter is operated in Discontinuous Conduction Modes (DCM). The output voltage successfully regulated at 50Vdc and the converter is able to reshape the input current. Amol Phadke (2014), Electricity demand for room ACs is growing very rapidly in emerging economies such as India. We estimate the electricity demand from room ACs in 2030 in India considering factors such as weather and income growth using market data on penetration of ACs in different income classes and climatic regions. Peter palensky *(2011)*, Energy management means to optimize one of the most complex and important technical creations that we know: the energy system. While there is plenty of experience in optimizing energy generation and distribution, it is the demand side that receives increasing attention by research and industry. Robert (2010) Author takes a broad look at how information technology-enabled monitoring and control systems could assist in mitigating energy use in residences by more efficiently allocating the delivery of services by time and location. Kabeel (2017) the effects of the indirect evaporative cooler with internal baffle on the performance of the hybrid air conditioning system are numerically investigated. The hybrid air conditioning system contains two indirect evaporative coolers with internal baffle, one is utilized to pre-cool the air inlet to the desiccant wheel and the other is utilized to pre-cool the supply air inlet to the room. The effects of the inlet conditions of the process and reactivation air and working air ratio on the thermal performance of the hybrid air conditioning system have been analyzed. Siddharth (2015), has presented experimental evaluation of two occupancy-based control strategies for HVAC (heating, ventilation, and air-conditioning) systems in commercial buildings. Prashant et. al. (2016), Rapid growth in the global population requires expansion of building stock, which in turn calls for increased energy demand. This demand varies in time and also between different buildings, yet, conventional methods are only able to provide mean energy levels per zone and are unable to capture this in homogeneity, which is important to conserve energy.

Experimental setup

Each AC was tested in a temperature-controlled test chamber. The test chamber consisted of a small, well insulated room of 20 X 22 Ft^2 with R-17.5 walls, an R-5 floor and an R-25 ceiling. The test chamber was divided by an R-23.6 wall with an opening for the AC or sleeve being tested. Once in place, gaps around the AC unit were filled in with R-23.6 material. On the cold side of the chamber, a refrigeration unit cooled the space to model the outside air temperature. Two space heaters cycled on and off to maintain the test temperature, generally set to 25°C.

On the warm side of the chamber, a 200-watt light bulb cycled on and off to keep the “indoor space” at precisely 70^oF. The on-time of the light bulb represented the amount of energy required to balance the energy losses due to the air conditioner.

Various AC units were installed in the dividing wall, and the warm space heat loss was measured by calculating the energy used by the light bulb to maintain the warm side of the chamber at a constant 70^oF. A correction was made to account for losses to the ambient temperature outside the chamber, using a baseline test in which no AC was installed.

Each AC was tested in a number of configurations and under a range of cold side, or “outdoor” temperatures.

Electrical and Thermal loads

Estimating the power consumption and heat dissipation from the selected room, electrical equipment is very important because the site’s heating and cooling load depends on accurately accounting for the heat put off by the large electrical machines. Some machines have dedicated heat exchangers and fans for cooling. Others have liquid coolant.

Table 1. Roof construction thermal properties

Material	Thickness [m]	Thermal Conductivity [W/m-K]	Density [kg/m3]	Specific Heat [J/kg-K]
Roof Gravel	0.0127	0.38	881	1,674
Inter-piles	0.0095	0.162	1,121	1,464
Membrane	0.0095	0.2	800	1,000
Insulation	0.15	0.039	265	8,368
Decking	0.0015	45	7,680	418.4

Since there are so many different machines of different sizes and functionalities, the plug load for the manufacturing rooms was determined during calibration. It was determined that 35 W/m2 is a reasonable plug load for these rooms.

The air compressor in the large manufacturing room is treated as a separate plug load. The average office has a plug load of roughly 10 W/m2. Since the office is actually two stories lumped into one zone, it is given a plug load of 20 W/m2. The storage and assembly rooms have a plug load of 12 W/m2. The equipment radiant fraction is 0.3 for all equipment.

Non Homogenous Wall

In general the building walls may consist of non-homogeneous materials such as hollow bricks. Heat transfer through non-homogeneous materials such as hollow bricks is quite complicated as it involves simultaneous heat transfer by convection, conduction and radiation. The heat transfer network consists of series as well as parallel paths due to the simultaneous modes of heat transfer. In practice, all these effects are lumped into a single parameter called thermal conductance, C, and the heat flux through the hollow brick is given by:

q = C(Tw,o -Tw,i) W / m^2

The conductance values of common building materials have been measured and are available in tabular form in ASHRAE and other handbooks.

Multi-layered, composite walls

In general, a building wall may consist of several layers comprising of layers of homogeneous and non-homogeneous wall materials made up of structural and insulating materials and air spaces. For such a multi-layered wall, one can write the heat transfer rate per unit area as:

$q_{in} = U(T_0 - T_i) = \frac{(T_0 - T_i)}{R_{tot}}$ W/m² where the overall heat transfer coefficient U is given as:

$$\frac{1}{U} = R_{tot} = \left(\frac{1}{h_i}\right) \sum_{i=1}^{N} \left(\frac{\Delta x_i}{k_{w,i}}\right) + \sum_{j=1}^{M} \left(\frac{1}{C_j}\right) + \frac{1}{h_o}$$

Thus from the structure of the wall, various material properties and conductance values of non-homogeneous materials and air spaces and inner and outer surface temperatures and conductance, one can calculate the heat transfer rate under steady state conditions. It should be kept in mind that the equations given above are limited to plane walls. For non-planar walls (e.g. circular walls), the contour of the walls must be taken into account while calculating heat transfer rates.

Cooling load calculation

For the calculation of cooling load, Hand calculations were done for a small portion of the building. In the building there are total 19 rooms of four floors where air conditioning is required including auditorium, lecture rooms, meeting rooms, library etc. Each one of them is treated as separate system. Then, all the equations were inserted in a particular program MS Excel, to get the results.

The general step by step procedures for calculating the total heat load are as follows

i. Select inside design condition (Temperature, relative humidity).
ii. Select outside design condition (Temperature, relative humidity).
iii. Determine the overall heat transfer coefficient Uo for wall, ceiling, floor, door, windows, below grade.
iv. Calculate area of wall, ceiling, floor, door, windows.
v. Calculate heat gain from transmission.
vi. Calculate solar heat gain
vii. Calculate sensible and latent heat gain from ventilation, infiltration and occupants.
viii. Calculate lighting heat gain
ix. Calculate total heat gain and
x. Calculate TR

Commonly the building walls may consist of non-homogeneous materials for example hollow bricks, air gap and plaster. Heat transfer through these types of wall is quite complicated as it involves simultaneous heat transfer by conduction, convection and radiation. All material has different kinds of thermo-physical properties; the thermo-physical properties of common building materials have been measured and presented in ASHRAE and other handbooks.

Table 2. Thermodynamics properties of building material and calculate the value of U

S.N	Material	Thick	Thermal Conductivity W/m. C	U w/m² °c
1	Wall			
	Outer Plaster Cement	20mm	8.65	2.36
	Inner Plaster Cement	12mm		
	Bricks	200mm	0.77	
2	Roof			
	Outer Plaster	6mm		3.82
	Inner Plaster	4mm		
	Concrete	150mm	1.73	
3	Flooring			3.65
	Granite	25mm	1.73	
	Concrete	20mm		
4	Doors Wooden	25mm	0.1	2.43
5	Window Glass	6mm		4.2

Heat Gain through Lights

Lighting adds sensible heat to the conditioned space. Since the heat transferred from the lighting system consists of both radiation and convection. Cooling Load Factor is used to account for the time lag. Thus the cooling load due to lighting system is given

$Q_{lighting}$= Installed wattage x Usage factor x Ballast factor x CLF

Table 3.Summery of cooling load.

Heat Component	ROOM
Solar glass	634
Walls	3431
roofs	7488
Floor	771
Doors	179
Lights	340
Appliances'	5233
People	3085
Infiltration	21401
Total in watt	21401
TR	6.11

Overall heat transfer coefficient for inner and partition walls

$$U_{exposed\ wall} = \frac{1}{\frac{1}{23} + \frac{0.013}{8.65} + \frac{0.23}{0.77} + \frac{1}{5.8} + \frac{0.23}{0.77} + \frac{0.013}{8.65} + \frac{1}{8.5}} = 1.07$$

W/m²-K

The interior walls of building are consist of 230 mm common bricks with 26 (13 mm both side) inch sand cement plaster.

$$U_{Partition} = \frac{1}{\frac{1}{8.5} + \frac{0.013}{8.65} + \frac{0.23}{0.77} + \frac{0.013}{8.65} + \frac{1}{8.5}} = 1.86 \text{ W/m}^2\text{-K}$$

Overall heat transfer coefficient of roof

The roofs consist of 152 mm concrete poured in metal sheet with 13 mm plaster

Overall heat transfer coefficient of ceiling

$$U_{ceiling} = \frac{1}{\frac{1}{9.4} + \frac{0.154}{1.73} + \frac{0.013}{8.65} + \frac{1}{6.3}} = 2.82 \text{ W/m}^2\text{-K}$$

Overall heat transfer coefficient of floor

$$U_{floor} = \frac{1}{\frac{1}{9.4} + \frac{0.2}{1.73}} = 4.5 \text{ W/m}^2\text{-K}$$

Overall heat transfer coefficient of window glass

$$U_{window\ glass} = \frac{1}{\frac{1}{23} + \frac{0.0127}{0.78} + \frac{1}{8.5}} = 5.6\ W/m^2\text{-}$$

Variation OF 'Q' of Various Section of Room with respect to time, Initial Resistance of wall, glass etc.

Variation of heat transfer for first 15 days of May 2018

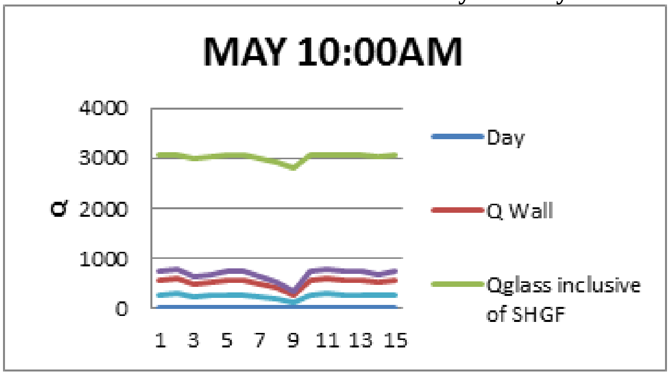

Figure 1. Comparative variation for different section of an individual room at 10:00am of MAY 2018

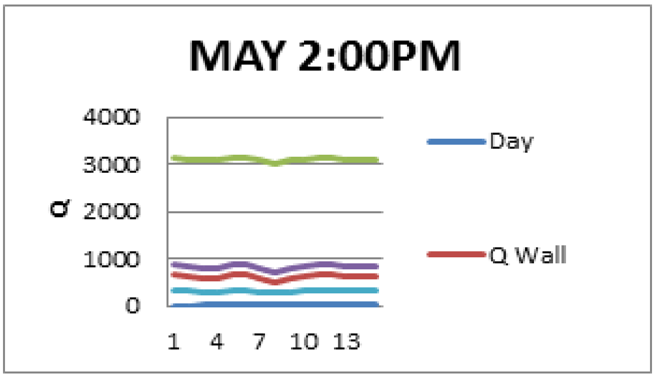

Figure 2. Comaparative variation for different section of an individual room at 02:00PM of MAY 2018

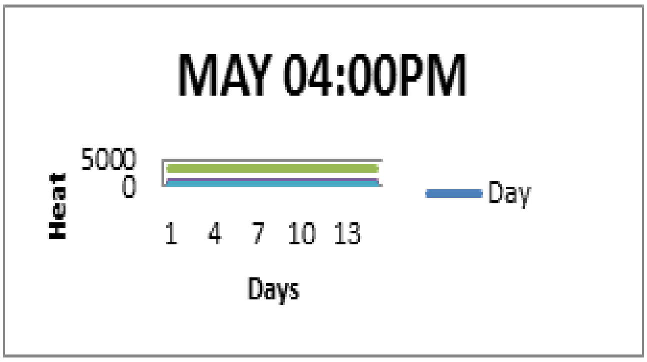

Figure 3. Comparative variation for different section of an individual room at 04:00PM of MAY 2018

Conclusion

From the study of literature the important observation which has been found is that the research in the field of heat transfer through the wall using R factor of material is lacking. Also the conduction losses are rarely considered in the calculation of cooling load. The cooling load calculation is done for a selected room using CLTD Cooling load temperature difference method. Right-sizing the AC system begins with an accurate understanding of cooling loads on a space. The values determined by the cooling load calculation process dictate the material selection for wall along with sun facing and windows etc. Cooling load temperature difference (CLTD) method was used to find the cooling load for summer (month of May and July). Cooling load items such as, people, light, infiltration, electronic equipment and ventilation can easily be putted to the MS-Excel program. The program has also been used to calculate cooling load due to walls and roofs. The results show that the total cooling load for the AC required rooms is 2.00 tons for summer (month of May) before the reduction of condition losses. Thereafter total cooling load is less than 1.5 tons when the conduction losses reduced and the R factors of walls changed. The average sensible heat ratio of the room is 0.76. It shows that the cooling load calculation is properly done with well accounted of latent heat came from the people and infiltration, especially in humid weather. It is also seen that in this research the cooling load requirement of summer is still decreasing after the change of R factor of wall material

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