ENERGY EFFICIENT HOUSES: A SOLUTION TO LOCAL WARMING IN MAJOR CITIES CAUSED BY AIR CONDITIONERS

CLIMATE CONCERNS, ENERGY SECURITY AND FUTURE AHEAD

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ABSTRACT: The temperature fluctuations associated with extreme weather will require more energy for cooling buildings. It is found that waste heat from air conditioning systems is a crucial variable in the local weather patterns. This paper aims to calculate the heat generated by air conditioners (AC) during days with higher temperature in metropolitan cities around the globe. While there is surplus data of electricity consumption and predictions regarding AC demand, there is scarce data and statistics available for cities and their respective AC demands and residual heat effects of the same. Using thermodynamic functions and varied data sets this study manages to calculate the effect of ACs over metropolitan cities like New Delhi, India, in which 41% of the population uses ACs, causing local warming of about 0.5C during March-October. Humid cities like Bangkok, (Thailand) have a record 80% population using ACs, causing local temperature hikes up to 0.9C. Cooler regions like Hong Kong register a difference of 0.08C which is not insignificant. Coupled with the increase in demand and usage the warming that results from household ACs is much higher than global warming (~0.2C). This is a major cause of concern seeing that the demand will keep on increasing and so will the temperatures, forming an endless cycle. This study proposes a solution to this vicious problem the society has created for itself. To eliminate ACs there is a need to bring a fundamental change in the planning of residences, community structures as well as urban planning. The newer models of architecture are proving to be too expensive and sophisticated for practical implementation. An attempt has been made to study the houses existent before the times of air conditioner. Efforts have been made to integrate the design, and the materials of such houses into the urban lifestyle to take a step forward towards sustainable development.

1. INTRODUCTION

The temperature increase is particularly significant all over the globe at a rate of 0.15-0.20^{0}C per decade since 1975 [1]. A phenomenon where temperatures of urban areas are higher than surrounding is defined as Urban Heat Island (UHI) or as it is addressed here in terms of local warming [2]. The local warming is strongly dependent on anthropogenic heat emitted from automobiles, air conditioner (ACs) and buildings [3]. In this paper one of the causal factors of local warming which is waste heat from air conditioner in urban areas of metropolitan cities during temperature exceeding daily mean average of 25^{0}C is analysed. The heat is absorbed (cooling the indoor air) from households and release into the surrounding environment by air conditioners thereby raising the outdoor temperatures [4]. The size of the air conditioning market shows growth in the number of households and increase market penetration into existing households [5]. Increased temperature in local warming lead to increase use of ACs which in turn causes more waste heat leading to a vicious cycle in urban environment [2]. There are existing studies on energy consumption and caused UHI [3,4] but literature is scarce on effects of ACs and corresponding local warming. Air conditioning industry is generally privatised worldwide and hence the air conditioning demands of cities is difficult to obtain. Here the research has been done on local warming in six metropolitan cities: Delhi (India), New York (USA), Hongkong (China), Bangkok (Thailand), Tokyo (Japan) and Sydney (Australia) due to air conditioners situated in different climatic conditions. Using thermodynamic functions in the present urban scenario it is measured that local warming is generally much higher than global warming like in New York (USA) where local warming is as high as 1.636^{0}C or in Delhi (India) where it is 0.514^{0}C or Bangkok (Thailand) where it is 0.912^{0}C. It can be deduced from current energy demand projections that AC usage will increase significantly in the upcoming decades [5, 6, and 7]. Hence further calculations are performed to estimate the local warming in the same cities with increased air conditioning usage and comparing it to the predicted global warming scenario. Similar to the preceding results, in this framework also the local warming temperatures exceed the global warming effects and are in fact magnified. Like in 2030's New York (USA) local warming reaches 17.286^{0}C, in Delhi (India) it reaches 4.068^{0}C and in Bangkok (Thailand) it reaches as high as 9^{0}C. . Local warming in these cities poses serious threats to public health in terms of night thermal stress (for those without access to ACs), a factor previously identified as highly related to excess mortality during heat waves [9] and ecosystem. [22]. Besides the increase in temperature observed for most of the cities the corresponding increase in energy demand and cooling demand is an evident cause of concern [6]. Understanding climate science and the changing to our climate in present and those projected in the near, mid and long term future is pivotal. Knowing the likely impacts that local warming can cause in urban environment can help in reducing the risks faced over time [8].As demonstrated in this study waste heat from air conditioners during summers is majorly responsible for increase outdoor temperatures and to curb the same a more energy efficient method of cooling households' needs to be understood and implemented. To control the increasing local warming, use of energy efficient houses is one of the probable solutions explored here. The traditional construction styles of rural areas around the world has proved to be sustainable and energy efficient in all aspects. This study outlines the characteristics, designs and materials used in such houses to combat the existing temperature and energy crisis in urban environment.

2. METHODOLOGY

There is considerable research being done towards developing models of different cities and finding out the causal factors of local warming. Most of these models are based on urban planning and development and calculating the heat based on energy consumption [3, 6]. In this study the importance is given to thermodynamics functions and considering cities which are spread across the world, attempt has been made to include all climatic conditions like humid, dry, hot, ambient or cold.

2.1 AIR CONDITIONING SPECIFICATIONS AND DETAILS

Air conditioning usage is prevalent and proliferating at alarming speeds in household and domestic purposes, seeing this, only demand of room air conditioners and domestic air conditioning needs are taken into account here. Due to lack of surveys and data sets highlighting the exact number of air conditioner(s) in one household, it has been assumed that each household has one air conditioner. Further lack of classified data in the area of types of air conditioners used, their BTU values, Seasonal Energy Efficiency Ratings (SEER) and maintenance levels have lead to further assumptions. This study is based on 100% operating installations, i.e., the considered air conditioners are all operational and in use. An average of 3 star efficiency is considered for all the air conditioners. From case studies and surveys, it was found that most the household and domestic facilities use split ACs or room ACs. Generally these are available in 0.75 ton, 1 ton, 1.5 ton or 2 ton weighing range. This study assumes all air conditioners to be split air conditioners weighing 1 ton. The average Energy

Efficiency Rating (EER) is taken to be 3 and all air conditioners are assumed to be at 100% their labelled efficiency [10]. An average split air conditioner or room air conditioner weighing 1 ton with 3 star rating and cooling capacity in the range of 3370-3747watts/hour and a rotary compressor has the power consumption in the range of 1.4-1.5 kilowatthours(kWh). In the following calculations 1.45 kWh has been taken into account for each air conditioner.

The air conditioning demand for each city is different and hence the principle aim of this paper is to highlight the need for such surveys so that more precise and conclusive studies can be performed. The air conditioning demand for hot cities like New Delhi is 41% of the total households in the city [11]. For humid cities like Bangkok it can be as high as 80% of the total households in the city [2]. For cooler cities like Hong Kong and Sydney the demand are 21.2% [13] and 69% of the total households in the city [12] respectively. For cities with extreme temperatures but high population density, like New York has 73% air conditioned households [14].

2.2 STUDY AREAS

2.2.1 Delhi

India's capital Delhi is the major gateway to country. It is located in the area of 1484km^2 with population density of 6000/km^2. Delhi is situated at 28^{0}39ʾ07" N and 77^{0}13ʾ53"E and the elevation above the sea level is 227m.Temperature is hot over 40^{0}C from April to June. Temperature can nearly go down to zero during winters especially during December-January.

2.2.2 New York

New York City and port is situated at 40.7128° N, 74.0060° W. It is the largest and the most influential American metropolis. It is located at area of 789km^2 and has 3,114,811 households. New York has been the largest and the wealthiest American city for last two centuries with population density of 10890/km^2. July is the hottest month of New York with an average temperature of 25^{0}C.The coldest month of New York is January.

2.2.3 Bangkok

The capital of Thailand, Bangkok, at 13.7563° N, 100.5018° E is one of the largest cities (1569km^2) with population density of 5300/km^2 (1,961,600 households). It is located in the centre of the country which is in the Basin of Chao Phraya River and close to Gulf of

Thailand. The hottest months in Bangkok are from March to May. The annual average temperature of Bangkok is about 29^0C.

2.2.4 Hong Kong

Hong Kong is situated at 22.3964° N, 114.1095° E on the South coast of China. The strategic location on the Pearl River Delta and South China Sea has made Hong Kong one of the world's most thriving and cosmopolitan cities. It has total area of 1068 km^2.With 2500000 households, population density is of about 6544/km^2. The climate of Hong Kong is Sub-tropical. In summers, the temperature often crosses 31^0C and in winters, it drops down to 10^0C.

2.2.5 Sydney

The state capital of South Whales located at 33.8688° S, 151.2093° E is most populated city in Australia and Oceania is Sydney. It is located in the East coast of Australia. Sydney is covered by total area of 12,367.7 km^2. With a population density of 400/km^2 and 1719676 households, the climate of Sydney is humid sub-tropical climate. The annual temperature of sea ranges from 18.5^0C in September to 23.7^0C in February.

2.3 VOLUMETRIC MEASUREMENTS AND ASSUMPTIONS

Calculating volume of a city and its respective households is not an easy task. Previous studies have used various mathematically and graphically advanced models to calculate the same [3, 6]. In this study as the focus has been on energy and local warming, we have used multiple approximations for such calculations. Households and domestic facilities like flats, buildings, and such structures are generally three or four storied tall, especially in developing countries like India, China, and Thailand. Hence in these calculations the considered average height of all the cities is taken to be 10 meters. To analyse the local warming in urban setting we have considered the densely populated regions of metropolitan cities only thereby reducing the areas and corresponding volume. In the cities considered, the household size in terms of volume is small due to increased cost of living and high population density. Hence a uniform volume of 300m^3 for each household is assumed in the following calculations. The entire household is considered to be one roomed and hence becomes the effective cooling volume in houses owning air conditioners. Due to diversified building materials in the said cities, heat capacity of structures is not taken into account. Effect on the volume that is not under the influence of air conditioner, (but can or cannot be considered as volume of households) is found and used for further calculations.

2.4 OPERATIONAL TIME MEASUREMENTS AND ASSUMPTIONS

All the cities used for our study belong to different climatic zones. While some require air conditioner usage all throughout the year, some use it only for a few months in a year. The local warming is proportionate to the time duration of air conditioners as well. For this study it has been assumed that air conditioners are used in an urban environment when the daily mean temperatures exceed 25^0C. This also means that the average maximum temperatures during the day are around 29^-31^0C. Usage of air conditioners in winters is considered to be 0%. The hours for which air conditioners are in operation is accounted to be 12 hours per day. The following is the data collected for all five cities in this manner.

2.5 THERMODYNAMIC FUNCTIONS FOR CALCULATIONS

This paper uses simple thermodynamic formulae to evaluate the increase of temperature in urban surroundings due to waste heat produced by air conditioning usage. In classical electro dynamics in physics, it is known that heat produced due to insulation in resistors is directly proportional to the power consumed by the resistor or appliance and the time duration for which it has been running.

$$H = P\ t$$

Where, H= Heat, P= Total power consumption, t= time duration.

Using the average values of power consumed by each air conditioner and the number of air conditioners in each city, the heat released in the outdoor environment was measured. The time duration for each city varied as discussed above and the corresponding values were used.

Using another basic formula from principles of thermodynamics, the relationship between this released heat and the temperature rise was determined. The heat of a thermodynamic system is equal to the product of the mass of the system, the specific heat of the system and the temperature difference.

$$Q = m\ C\ \Delta T$$

Where, Q= heat of the system, m = mass of the system,

C = specific heat of the system, ΔT = change in temperature.

Taking mass as product of volume and density, the temperature difference was obtained. The volume here was taken to be the affected volume with no air conditioners (total volume of the city – volume of air conditioned households). The specific heat of air at 33^0C is taken to be 0.718 kJ/kg*K.

2.6 PROJECTING AIR CONDITIONING DEMAND BY UPCOMING DECADE AND CORRESPONDING CALCULATIONS

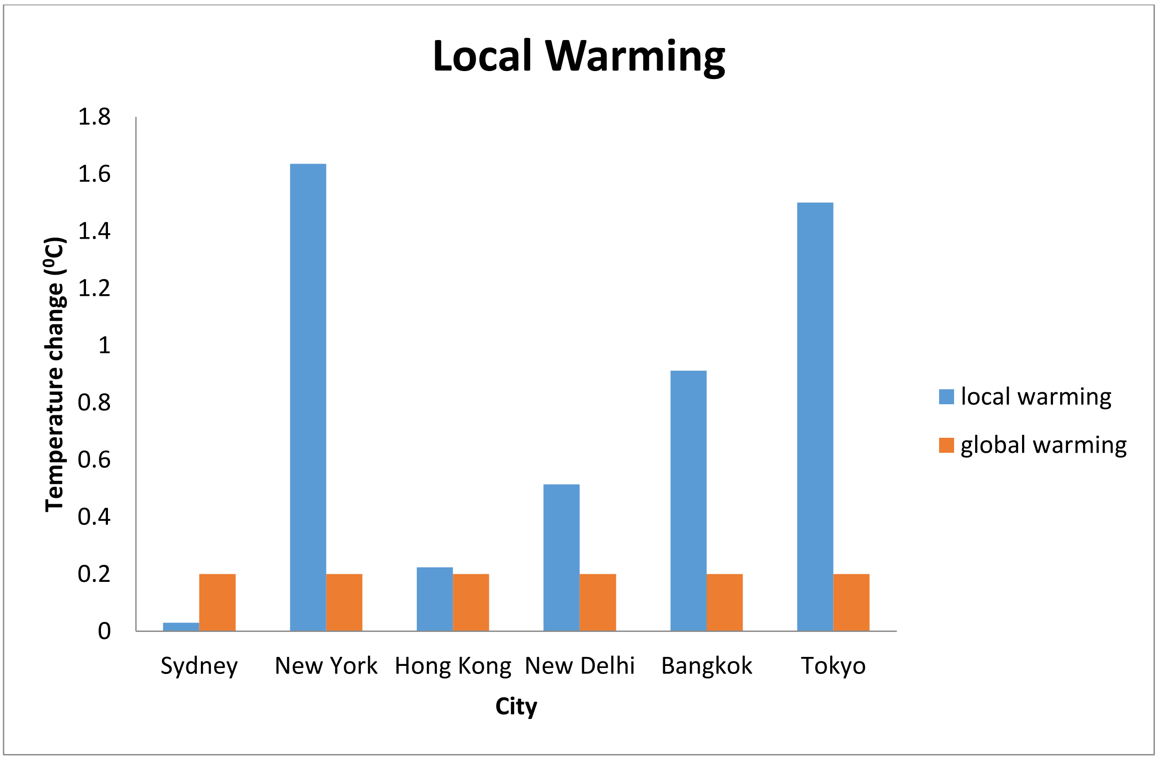
The current local warming is produced due to air conditioners and other factors as well. To exhibit the significance of air conditioning in future climate change scenario. Increased air conditioning demand in not only humid and hot regions but colder regions as well is predicted by a lot of researchers [5]. The average increase in the air conditioning market is projected at 20-25% per annum worldwide [7, 6]. Taking an average of 20% rise every year in the current air conditioning demand in all the cities, calculations for the temperature rise in the same volume of city and households is performed.

Temperature rise due to global warming during the upcoming decade has been carefully examined and envisioned for these cities in multiple papers and reports [8, 17, and 18]. Here this data is used to compare the future global warming and local warming temperatures that we obtained from our calculations.

3. RESULTS AND DISCUSSIONS

The results of the calculations done as described above are shown in Graphs 1 and 2.

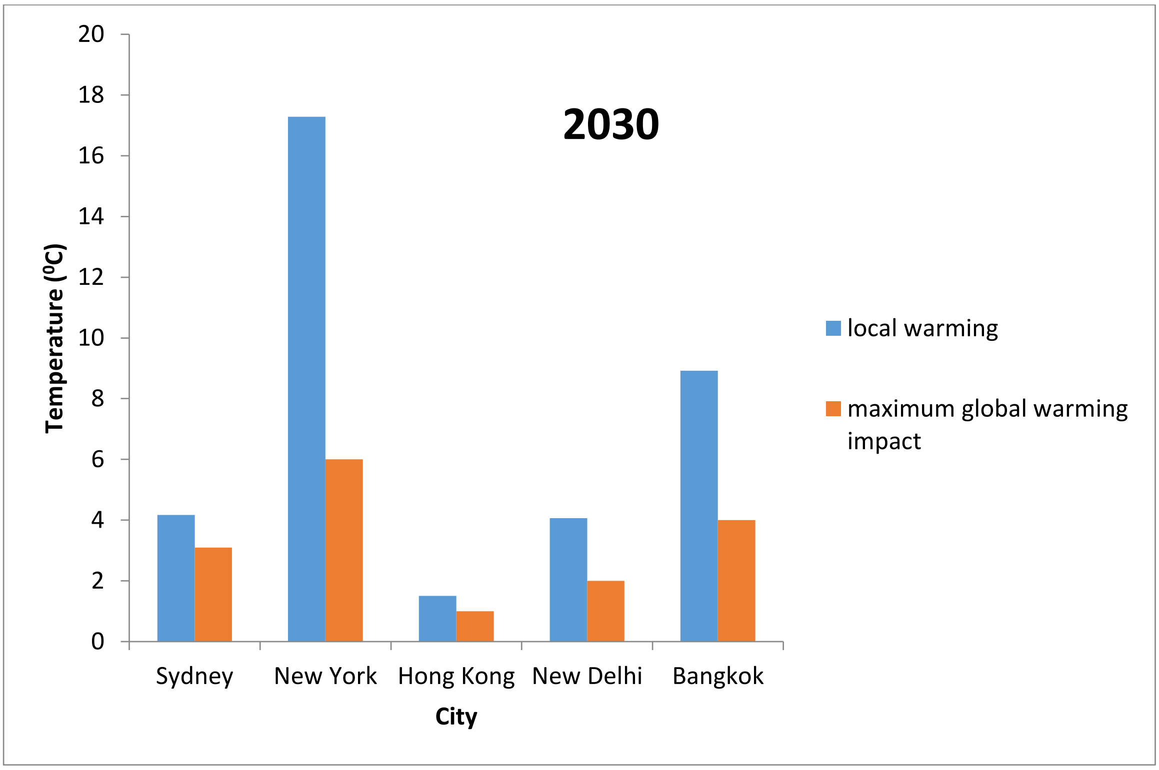
As seen in the graph 1, local warming exceeds global warming in most cities by a large margin. In hot and humid cities like Delhi and Bangkok, the temperature difference is as high as 0.314 and 0.712 respectively. In Delhi, less than half the population uses air conditioners, while in Bangkok, the usage is almost 80%, hence, it can be concluded that the air conditioning demand is responsible for the temperature hike in Bangkok. In addition to this, the time for which air conditioning is used also matters, like in Bangkok the usage is all throughout the year, but in places like Delhi it is for a few months. The extreme increase in New York can be attributed to these factors as well. New York uses air conditioning for a few months but its air conditioning demand is almost 30% more than Delhi, and hence the huge increase. The area taken into consideration for New York is smaller and thus translates to a denser urban environment. Population density is also a driving force for the local warming caused in urban environment especially in metropolitan cities. Hong Kong displays a marginal difference in the measures of global warming and local warming this seems to be because of the small air conditioning demand of only 20%. This shows that local warming can be reduced drastically by refraining from the use of air conditioners. In colder regions the gap between local and global warming is less apparent because of this reason. Another attribute to be considered is the large area of Hong Kong. Lesser urbanisation, lower population density and reduced usage combine to combat the local warming temperature rise. Sydney is the only city studied here that reports a negative difference between the global and local warming. Global warming is almost 80% more in the case of Sydney. As discussed before, there are numerous factors to be considered. Sydney has an air conditioning demand almost equal to that of New York and yet there exists a huge difference in the results. One of the prime factors is reduced time duration.



Graph 1: This graph compares the local warming in each city as per the calculations with the global temperature rise at 0.2^{0}C uniformly across all cities.

As Sydney has ambient temperatures all around the year, air conditioning usage is limited to only 3-4 months. This is the lowest time duration in this data set and hence, conclusively proves that reducing air conditioning usage not only in terms of demand but also in terms of hours used can have an exponential effect in the local warming temperatures in urban environment. Sydney is not as densely populated as the rest of the cities in this study; in fact it has the largest metropolitan area among the cities considered here. This further shows effect of urbanisation in metropolitan cities and how reduced population density can affect the local warming temperatures and help in combating global warming as well.

The second graph (Graph 2) was plotted using future projections in air conditioning demand and expected impact of global warming on the said cities.



Graph 2: This graph compares the expected local warming in the cities with 20% increase in air conditioning every year and the maximum expected temperature rise due to global warming by the year 2030.

Considering an average rise of 20% in the air conditioning demand in all the cities, the calculations were repeated and the temperature increase in each city by the year 2030. The rise in temperature due to global warming in the each city was found from different sources [18, 14, and 15].While the data shows that the difference in temperature increase due to local warming is intensified in New York; the reason is mainly increased air conditioning demand. The density also remains constant for all the cities and hence in cities like New York, the urban environment is stiflingly hot. In Delhi and Bangkok, similar trends are observed. The biggest change is in Hong Kong and Sydney temperatures. The balance seen in the present scenario is disturbed in the very near future. Thus, it can be concluded that the local warming induced temperature rise is extremely sensitive. With the slightest increase in the air conditioning demand or the usage hours the temperatures rise exponentially in the urban context. The demand of air conditioners does not depend as much on population density but the exponential rise does show some amount of dependence.

The growth in air conditioning demand indicates the increased demand of energy consumption. In an urban context, the waste heat from an air conditioner is released into the outdoor environment. This in turn causes a spike in demand of air conditioning leading to further increase in local warming. This vicious cycle of increased energy consumption and local warming does not break easily. In this paper an attempt has been made to address the issue of increased local warming due to air conditioning usage in urban setting. To reduce the use of air conditioning in household and domestic institutions, there needs to be a fundamental change in the planning of our houses and cities. The traditional architecture, design and planning was done in such a way that need for air conditioners was negligible. The materials used in such houses were decided keeping in mind the weather patterns and conditions of the city. In this study we surveyed the case studies of such houses all over the world and found the relevant characteristics of such houses that, if implemented in the urban housing can decrease our dependence on air conditioning. Efforts have been made to include rural and tribal housing designs and structures from regions with hot and humid climate like India, China, and Turkey. To understand the diverse materials used, inclusion of ancient Roman and American houses are also studied.

3.1 CHINA

The households in the mountainous region of western China are unique in design and adaptable in urban context. These houses are stilted s that they can adapt to the local ecology, geography and environment which are characterized by a humid climate, extremely hot summers, severe winters, wood covered topography and steep mountains. It adapts to the topography in the mountain areas by constructing an empty space in the lower level or slope of the hillside, the space is supported by many wooden columns that form the corridors under the huge roof and overhang balcony(refer figure 1 and 2). The stilted buildings have many advantages like keeping people away from the humidity that is close to the ground and preventing humidity related diseases, people can stay away from deadly daily dangers, such as miasma, poisonous vegetation, venomous snakes, and huge wild animals. This design also provides better lighting to the residents as they are above the ground level which is densely vegetated [17].

Figure 1

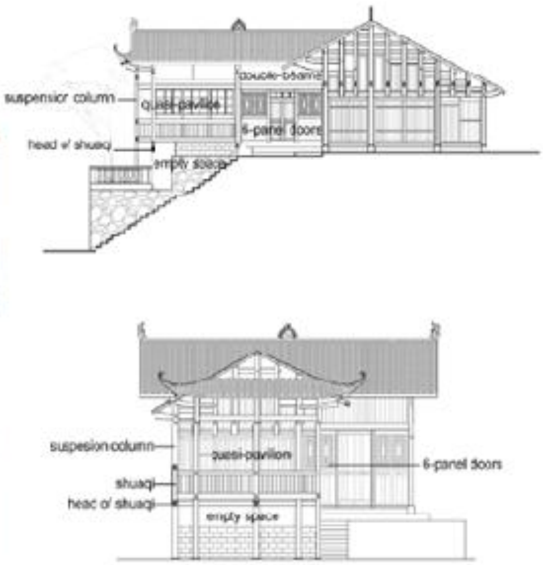


Figure 2

3.2 TURKEY

The most important material that is used in traditional Turkish house in Anatolia is timber. The ground floor of such houses is generally made with stone in the frame of timber. Apart from this, it has been observed that timber construction elements are used in masonry walls and horizontal construction components like beam and lintel have significant functions against the earthquake loads. The houses are located in a courtyard, which is surrounded by higher walls that provides privacy to the house. The surfaces of the walls are covered by lath and plastered by “Kitikli Siva (plaster)” which is usually made of mud and tow (figure 3). The first floor in traditional houses is constructed with timber floor beams that were covered with timber boarding. The outer shell of the house is finished with a timber covered with tiles [18]. The prominent use of timber helps in reducing weight and the plaster of mud and tow helps in keeping the house cool even during high temperatures outside. (Figure 4)

Figure 3

Figure 4

3.3 ANCIENT ROME

Ancient Rome is known for its architectural styles. The houses were designed to allow light and fresh air (Figure 5). Rainwater was channelled into an underground cistern which would help in keeping the floor cool this water was then used for household purposes (Figure 6). Many ancient Mediterranean houses show the same propensity as the roman houses [20].

Figure 5

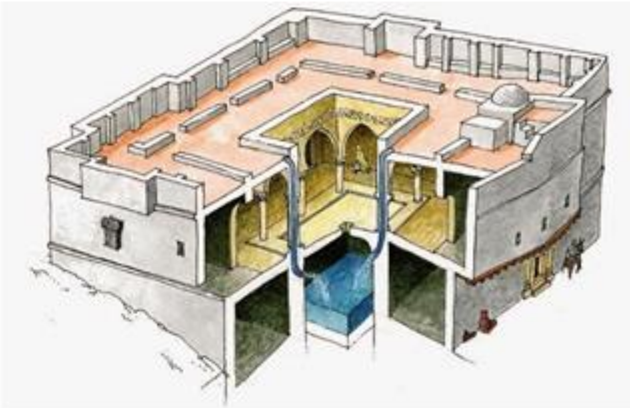


Figure 6

3.4 INDIA

The Indian houses in southern parts have a white urban veranda out front or one that runs around the house this helps in air circulation throughout the house. Large, ornate wooden pillars supported the terracotta roof(Figure 7). A more modest replacement is a thatched roof. The thatched or tile roofs keep the heat at bay and the mud walls or the sun baked brick had antiseptic properties keeping insects away. These traditional houses have floors coated with red oxide that can retain coolness even in warmer seasons. These Indian houses prove to be a passive form of architecture along with maintaining a cool climate within the house [21].

Figure 7

The traditional houses in eastern India are equipped for climates which are humid and cool. These quaint little houses were light and, at the most, a storey high. They are constructed from materials like bamboo and timber with metal sheet or thatched used for the roofing. The traditional house designs feature bamboo walls raised by stilts and typically found in hilly regions; this construction was inspired by the frequent flooding and landslides (Figure 8) [21].

Figure 8

Houses in northern India have to face extreme climatic conditions as summers are relentlessly hot and winters are very cold. These houses have open spaces at both ends and have a single corridor connecting them so that air can enter the house. They usually have a courtyard with small flower beds or small orchards in the centre of it. These houses are composed entirely of baked bricks with timber doors, ideal for the sweltering heat. The bedrooms are set along the opposite side of the courtyard and various sections floors are all connected by curved corridors and winding staircase (Figure 9) [21].

Figure 9

4. CONCLUSION

This study proves that air conditioning usage has a direct impact on the local warming causes in metropolitan cities around the globe. In most of the cases the local warming exceeds the effects of global warming and thus this issue need to be addressed as effectively and as quickly as possible. With reduction in operating hours of air conditioners, demand of air conditioners and the population density of the particular city, local warming can be reduced. If the present conditions in terms of demand and population density continue, the increase in local warming temperatures will be more evident and it will have much bigger repercussions than global warming. To curb air conditioning usage in urban setting a probable solution is suggested which is to make energy efficient houses. These houses are based on architectural styles previously used in rural and traditional housing. The characteristics of tribal, rural and traditional houses from different regions across the globe are discussed and special emphasis is given to energy efficient cooling techniques in the said houses.

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