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SIMULATION TOOLS FOR RESIDENTIAL BUILDINGS-A REVIEW ON CONCEPTS AND TECHNOLOGIES

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ABSTRACT

In hot and humid climates thermal discomfort is a major problem to the occupants of small residential houses especially when they are not equipped with air conditioners or provided with proper natural ventilation systems. Many research works indicate that, the energy consumption in residential sector amounts to a major portion in the total global energy consumption. In recent years, the issue of energy consumption modelling techniques in the building sector has been widely considered by architects and builders. Experimental studies in building energy usage and environmental analysis are very time consuming, expensive and require sophisticated sensors and instrumental techniques. Hence the building energy simulation is being increasingly used as an architectural design research tool, since it allows a detailed comfort and energy consumption evolutions. Powerful and affordable computing has made possible the detailed whole building energy simulations a reality. More number of software and web based tools are available for building energy computer simulation. Some widely used building simulation tools, technologies and their methodologies were reviewed and presented in this paper.Energy efficient buildings should maintain the best environment for human comfort, while minimizing the cost of energy. Many energy modelling approaches were emerging to cater for new design concepts towards energy efficient building and maintaining thermal comfort. Literature review on the concepts applied by many researchers, in different climates and in different places, for designing efficient and comfort residential buildings was done and presented in this paper.

Keywords: building simulation, energy efficient buildings, thermal comfort, energy modelling.

1. INTRODUCTION

In many studies, residential energy consumption has been found to be one of the largest sources of energy demand and GHG emissions. The building energy use accounts for as much as 30-40% of the global energy requirements. Considerable opportunity exists for attaining energy efficiency and applying alternate energy means for residential buildings. Those who own small buildings, lack the expertise to assess the potential energy savings, possibly through building structure or equipments retrofits. Computer simulation of energy use and retrofit can provide valuable input for planning an efficient building. Nowadays the building simulation is commonly used as a tool to evaluate building energy and thermal comfort efficiency. The building simulation is widely applied as an alternate method in energy labelling of commercial buildings and as a powerful tool in building projects, due to the capability of quantification of different techniques and strategies to save energy [1].

It was widely accepted that passive house planning could only be managed with the help of dynamic building simulation programs. Hundreds of such programmes which can take in to account the hourly performance and the different uses of the rooms are available. Simplified calculation methods are sufficient to dimension the conditioning system and predict the energy consumption of passive houses. Building simulation programmes can also perform thermal and energy performance analysis for different alternatives. Prototype buildings can be developed, one designed to comply with the baseline code and one otherwise identical building complying with the revised code. This comparison will be simulated, in the relevant climate zones to estimate the overall energy impact of the new code [2].

There is no global definition for low energy building, but it generally indicates a building that has a better performance than the standard energy efficiency requirements in building codes. Low energy buildings commonly use high levels of insulation, energy efficient windows, low levels of air infiltration and high recovery ventilation to lower heating and cooling loads. They may use passive or active solar building design techniques and also hot water recycling technologies for recovering heat from showers and dishwashers.

Thermal comfort can be defined as that condition of mind, which expresses satisfaction with the thermal environment. In hot and humid climates, acceptable level of thermal comfort in both residential and commercial buildings is essential. Thermal comfort has a great influence on satisfaction of the occupants in a building and productivity. Due to the advancement in technology, building comfort was achieved using mechanical devices like air conditioners and room heating systems. The buildings were constructed alike around the world. Microclimate providing comfort indoor was concerned mainly. As time passed, the disadvantages of this design aspect were observed and energy efficient design becomes important. Also, a balanced climatic design in regard to local climate elements is given importance.

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2. BUILDING SIMULATION TOOLS

Many building simulation tools and software are applied by the designers and architects. Continual research in developing codes for energy modelling and for achieving energy efficient and comfort buildings is going on. Some of the successful building simulation methodologies followed by the researchers and their suggestions were presented in this review paper.

Building Performance Simulation (BPS) in architecture is a best technology for conserving energy. While planning, the energy specific parameters such as building orientation, building mass, glazing type and ratio and shading are to be taken into account [1].

In several energy efficiency labelling programs one of the widely used software is Energy Plus, which was used to develop the QTR-C prescriptive method. The QTR-C method complies with ASHRAE standard 140 and hourly multi zone simulation. It presents two different modelling procedures according to the building conditioning requirement i.e., for buildings with mechanical ventilation system and for naturally ventilated buildings. The researchers suggested, for the first type a comparative analysis must be performed, with the energy consumptions of a proposed model based on the building design and a similar reference model based on the prescriptive method. For the later, the percentage of hours with occupation in thermal comfort must be obtained [4].

A fast computer with large memory is required, if CFD program is applied to calculate simultaneously indoor and outdoor airflow. Hence, it is a common practice to separate indoor airflow simulation from outdoor air flow simulation. If more than one building is involved in the simulation, the approximation may be used [5].

Chi-Ming Lai *et al*.,[6] used a hybrid CFD simulation result to predict thermal comfort indices. Mean values of these indices were then calculated for different window sizes to generate a database used for training and validate Radial Basis Function artificial Neural Network input and output models, which were used to formulate an optimization problem. They also suggest that, eQUEST (Quick Energy simulation tool) is a quick energy simulation tool developed by Doe2.com, which is a sophisticated and easy to use building energy analysis tool that provides professional level results.

A building energy simulation software IES Virtual Environment (VE) was used by Michael Pollock *et al*.,[7] to conduct a series of sensitivity analysis on a set of design parameters which influence the building performance. The parameters include the building orientation, construction, natural ventilation scheme integrated with window type opening area, shading devices and how they are positioned, day lighting and heating strategy. It is possible to do day light calculation, by using the Radiance module implemented in the IESVE. Also to examine the thermal comfort within a building an overheating analysis provision available can be used.

Freefem++ is a high level open source computational language written in C++ aligned to the implementation of finite element methods. Juan M.Rojas*et al*.,[8] developed a code written in Freefem++ to approximate the solution of Navier-Stokes with variable density using the Boussinesq approximation. The numerical code developed had take into account pre-calculated radiations over the walls of the courtyard, which varies in space and time.

For whole building hydrothermal and energy simulation, the building simulation tool Domus recently renamed as Power Domus will be effective. Nathan Mendes *et.al*.,[9] states that, in this tool, enhancements accomplished by improving the features for input and output data applied to multi zone buildings, by adding HVAC systems and plants, by adding attics among other Graphical User Interface (GUI) features were available. Also improvement in the numerical algorithms for calculating sun angles, shading projections and moisture prediction through composite walls using moisture content as driving potential were incorporated. In addition, the interface has been considerably improved so that simulations can be rapidly performed and the sun kinematics and shadows from overhangs and adjacent buildings can be easily visualized using an OpenGL based interface.

Monika Woloszyn*etal*.,[10] also added that, development, use and validation of whole building simulation tools, which are able to represent various physical dealings with moisture, heat and air transfer were greatly encouraged by subtask presented in International Energy Agency Project, ECBCS. The central ambition has been to combine the capabilities of earlier tools in order to make it possible to describe all relevant hygrothermal process in a composite building i.e., to bring a holistic perspective to building physical modelling.

To analyse the performance of the envelope of new buildings and the performance of different passive and active heating and cooling systems, dynamic building simulations are commonly used. Some dynamic building simulations listed by Rimante A.Cox *et al*., [11] are TAS, BSim, IES, IDAICE or Energy Plus. They suggested that, a dynamic building simulation requires detailed model of the building, its heating and cooling elements and also a weather file that represents the typical weather conditions in the location of the building. To investigate the impact of climate change on buildings, a dynamic building simulation must be carried out using a future weather file incorporating climate change projections. Dynamic simulation programmes typically require weather files to have an hourly temporal resolution.

Mark Shaurette[12] suggested some low cost commercial energy analysis simulation tools such as, Design Advisor v1.1,Doe -2.2 v47d, EE4 CBIP v1.7, ENERGY-10 v1.8, Energy plus v3.1, eQUEST v3.63, EZSim v6.0, HEED v3.0, RESEM v1.0, RETScreen v4.1, VisualDOE v4.0. Several other categories of modelling software are also available. They include programs for

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benchmarking or modelling current building performance, financial and environmental analysis tools, programs to examine the use of alternate energy sources, and software that models performance of natural and artificial lighting systems.

Some commonly used building simulation tools and computer application packages for building energy modelling are as listed in the Table-1.

Table-1. Some commonly used building simulation tools for energy modelling.

S.No.	Simulation tool/method	Description	Design parameters
1	BPS	Incorporated Pre design, Schematic Design, Design Development, Construction Documentation, Construction Administration, Post occupancy	Setting energy goals, orientation, massing, interior layout, HAVC, electrical systems, building fenestration, scope of energy consumption
2	QTR – C	Compliance with ASHRAE standard 140 and hourly multi zone simulation, also for naturally ventilated	Temperature, occupancy, wind pressure, internal heat gain
3	CFD	Thermo- fluid processes, external flows, internal flows	Temperature, pressure, air velocity
4	IES Virtual Environment (VE)	Sensitivity analysis, day light calculation, over heating analysis	Building orientation, construction, natural ventilation, window type opening area, shading device and positioning, day lighting, heating strategy
5	e Quest	Predicting thermal comfort indices	Building orientation, roof materials, window glass, sun shielding, electrical systems, and air properties
6	Freefem ++	To study performance in courtyards	Pre calculated radiations varying with space and time
7	Power Domus	Whole building hygrothermal and energy simulation, sun kinematics	Sun angle, shading, moisture through walls,
8	Energy Plus	Performance of envelopes of new buildings and of different passive and active cooling systems. It models heating, cooling, lighting, ventilating and other energy flows as well as water	Building model, building mechanical data, heating and cooling elements, weather files,
9	Design Advisor	Used for comparing early building design concepts	Conditions and technologies used in building constructions
10	ENERGY-10	Cost effective measures of a structure with two thermal zones like cost, energy performance, pay back, energy conservation	Default values in input format
11	EZSim	Simulates a single heating zone in commercial facilities using utility bills	Default values in input format
12	HEED	For small buildings, limited to four HVAC zones	Temperature and air properties along with building data

3. ENERGY EFFICIENCY IN BUILDINGS

The main objective of building simulation should be to achieve energy efficiency. The concepts and the policies followed by the designers to achieve energy efficiency in buildings during various climate conditions in different countries were reviewed and presented in this paper. The ideas will assist in the finalisation of the parameters to be considered for building simulation.

A building showing energy performance better than the standard energy efficiency requirements mentioned in building codes is termed as low energy building. Low energy buildings typically use high levels of insulation, energy efficient windows, low levels of air infiltration, heat recovery and ventilation to lower heating and cooling energy. They may also use passive or active solar building design techniques. The cost of energy efficient building is generally higher due to the extra costs associated with

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improved insulation of all building components, as observed by BertezJ.L[13].

KungligaTekniska[14] form KTH, Department of Urban Planning and Environment, Stockholm 2009 in a report describes building energy efficiency as follows. The building sector is a major user of electricity. Worldwide, 30% to 40% of all primary energy is used in buildings (UNEP, 2007). Buildings also account for a significant amount of carbon dioxide emissions (UNECE, 2008). In low income countries, the residential sector represents 90% of all carbon dioxide emissions from buildings (UNECE, 2008). It is essential to evolve energy efficient building designs that can be used to provide thermal comfort. For improved energy efficiency in residential buildings the focus should be on:

- Reduced energy costs to users
- Security of energy supply
- Cheaper than investing in increased energy capacity
- Improved comfort
- Lower GHG emissions, which mean a major contribution to climate change strategies and helping to achieve the Kyoto Protocol target.

He also reports that, well designed energy efficient buildings maintain the best environment for human habitation, while minimizing the cost of energy. The main aspects for achieving the same have been listed as follows:

a) Planning aspects - Site analysis, Building orientation, Room orientation, Landscaping
b) Building envelope -External wall, Thermal insulation, Building material, Roof, Windows
c) Size
d) Orientation
e) Shading device
f) Natural ventilation
g) Daylight

Several techniques can be applied to new or existing houses to make them more energy efficient, the most effective of which involves changing the exterior colour of the house, employing ventilation control, and installing ceiling as per E.H.Mathews and S.Weggelaar [15]. They also reported that, extensive research has been conducted in this field in order to compare the effect of these measures, and the results obtained from this research were briefly described as follows. The exterior colour of a house or any building plays an extremely important role in its thermal and energy efficiency. Van Wyk and Mathews (1995) have shown that winter heating requirements can be reduced by up to 34% if a dark colour is applied to the exterior of a formal low cost house. Eliminating infiltration by filling the gaps if any between the walls and the roof of the house, winter heating requirements can potentially be lowered by up to 15%. Extensive research has established that, by installing a ceiling in formal low cost houses, both the thermal and energy efficiency of the houses can be greatly improved.

Herald Winkler *et al*.,[16] reported about the urgent need to systematically monitor the impacts of housing and energy efficiency interventions. It is required to understand the social and cultural variables that determine the effectiveness of energy efficient housing interventions while formulating a good policy. This is possible through social as well as technical monitoring of the impacts of large scale housing interventions. Energy efficient technologies have high initial costs and low recurring costs, while less efficient technologies cost less initially but become more expensive due to higher operating costs. The payback period includes the number of years required to repay the capital cost of the intervention with the cost savings generated through the intervention.

Building energy has been well researched, but the focus has been on commercial and industrial domains, which constitute a majority of global energy consumption. Recent research focus is on improving residential energy use. Some research works focus on reducing the single aspect of consumption, while many seek to provide more specific energy information to the builders in order to facilitate convenient design [17]. Also building energy efficiency is strongly linked to the operations and control systems, together with the integrated performance of passive and active systems. In new high quality buildings both the aspects are being considered to reduce whole energy requirement during service life [18].

Levine.M*et al*.,[19] reports that, many technologies are available to reduce GHG emissions in new and existing residential and commercial buildings. Design strategies for energy efficient buildings include reducing loads, selecting systems that make the most effective use of ambient energy, using energy efficient equipment and effective control. They also suggest that an integrated design approach is required to ensure that the architectural elements and the engineering systems work together effectively. HVAC systems include filtration, humidification, and dehumidification, heating and cooling as per the climatic conditions. However, energy efficient houses in climates with seasonal heating are almost airtight, so mechanical ventilation has to be provided. They comments that in developing countries, energy efficient household equipment and low energy building design can contribute to poverty alleviation through minimizing energy expenditure, therefore making more energy services affordable for low income households. Efficient utilization of locally available renewable energy sources reduces or replaces the need for energy and fuel purchases. Therefore, sustainable development strategies aimed at improving social welfare go hand in hand with energy efficiency and renewable development.

Referred to 2013 FP Innovations,[20] the changes in building height, a wider variety of structural systems, and the more stringent requirements for building energy efficiency in recent years have created the need for design

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guidance on energy efficient and durable enclosures. The thermal performance and air tightness of the building enclosure play significant roles in controlling a building's heat loss, heat gain and whole building energy efficiency. Therefore, thermally efficient and airtight wood frame enclosure assemblies are desirable features of an energy efficient building. Well insulated enclosures are a key factor in reducing whole building energy consumption; however, well insulated assemblies do introduce additional considerations with respect to moisture control. For better thermal performance, concrete walls must include good construction practices such as proper concrete mix, control joint waterproofing and crack control. However, when hydrostatic pressure exists, the design must employ better insulated and energy efficient assemblies. Reducing space heating energy use is a primary function of the building enclosure. While heat flow through the building enclosure cannot be prevented, it can be controlled in order to reduce the total energy consumption and improve comfort. The actual benefits of thermal mass within a energy efficient building will vary with solar radiation, building type, internal heat gains, building geometry, orientation, actual amount and location of thermal mass used.

In North and Central Europe half of residential energy use is for home heating. Even prior to the Energy Performance of Building Directive (EFBD), several member states had already legislated towards improving the energy performance of their homes, either through building regulations, or by introducing specific legislation. Significant research towards energy efficient housing for colder climates is progressing. The favoured design strategy has focussed on improving the insulation level of the building envelope and the reduction of infiltration or air leakage [21].

In Ghana, new and renovated buildings are characterised by the use of air conditioners, sliding windows and their orientation. These building design strategies have a direct link to efficiency and energy consumption. For energy efficiency, there is a need to orient the buildings in the direction where less energy is required for maintaining thermal comfort. In passive solar architecture, southward orientation is recommended over east- west, where energy losses up to 30% are expected. For buildings to be energy efficient, simulation must be used in the early stages of design to try out different design parameters. Design parameters such as configuration of spaces, function, shading and passive design methods, are being promoted for an environmentally sound architecture for residential buildings in Ghana [22].

In Finland, all new residential buildings must be "Nearly Zero Energy Buildings" by the year 2020 according to current plans. The target year has been set to 2017, which means a very rapid change within the next few years. More energy efficient building stock would reduce the GHG emissions as such, but it would also support increased renewable energy production [23].

In Germany the building sector is making a significant contribution to save energy and materials, considering the wide range of opportunities. Architects, building designers, building owners are having a social responsibility to plan, build, operate and dispose of buildings in a resource saving and energy efficient manner. The main ecological aspects of energy efficient buildings in Germany are the lowest possible impact to the environment during their life cycle and the minimization of resource and energy consumption as well as land use [24].

In Romania, the implications of building sector to economic, social and environmental issues regarding the energy consumption are very important. Facing high prices for heating the housing sector, the challenging task is to design and promote energy efficient constructions in a cost effective and environmentally responsive way. As almost half of the national energy consumption in Romania is by buildings, the importance of passive design is strongly insisted. Minimizing the energy consumption is possible with strong passive sustainable design, using local materials and specific climate data [25].

4. THERMAL COMFORT IN RESIDENTIAL BUILDINGS

In hot and humid climates, acceptable level of thermal comfort in both residential and commercial buildings is essential. Researchers and builders in various countries had achieved thermal comfort in their buildings and reported the successful strategies. Their reports and the publications supporting building simulation were reviewed and presented.

While designing small residential buildings in developing countries, occupants comfort compromising with the energy efficiency and cost has been the primary policy of the builders and architects. To achieve thermal comfort and energy efficiency in a residential building, many micro and macro parameters are to be taken into account depending on the climatic conditions, occupants type and their activity, indoor and outdoor air conditions, properties of building materials and the existing policies.

To optimize energy consumption in buildings while maintaining thermal comfort as well as healthy environment, energy modelling approaches have to cater for emerging new design concepts towards greener solutions. Instead of conventional approach, attention is given to passive and mixed mode systems in building construction [26].

J.L.Hensen and L.Centnerova[27] defined thermal comfort as that condition of mind, which expresses satisfaction with thermal environment. The most important factor determining human thermal comfort is the general feeling of warmth. They explained that, the main criteria for thermal comfort for human body as a whole are depending on environmental parameters like air temperature, radiant temperature, humidity, air velocity and personal parameters like clothing and activity. In addition there are other environmental parameters that can

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cause local thermal discomfort such as draught, a high vertical temperature difference between head and ankles or too high radiant temperature asymmetry. Current comfort standards such as ISO/EN 7730 and ANSI/ASHRAE 55-92 are based on a more or less static model of human thermal comfort. The physiological and psychological response to the thermal environment is basically the same throughout the year. The one that changes is clothing and this result in different preferred temperatures in winter and in summer. The optimum operative temperature for comfort is a function of metabolic rate and clothing insulation.

Thermal comfort has a great influence on the productivity and satisfaction of occupants in a building. The majority of heating, ventilation and air conditioning (HVAC) systems for thermal comfort are based either on a single temperature control loop or, in some cases, on a multivariable temperature and relative humidity control loop. For thermal comfort optimization, other parameters should be considered in order to provide thermal satisfaction to the occupants. Over the last decades, a large number of thermal comfort indices have been established for indoor climate analysis and HVAC control system design and the quit disseminated one is the PMV (predicted mean value). This index considers environmental variables and individual factors. Closer to zero the PMV value, better the occupant's thermal comfort sensation. Definition and control of indoor conditions for reaching thermal comfort in buildings are hard to be established. As thermal satisfaction depends on several parameters, many research works on thermal comfort have been conducted and some comfort indices have been proposed over the last 50 years [28].

As per YudiNugraha*et al*.,[29] evaluation of thermal comfort involves assessment of at least six factors: human activity levels, thermal resistance of clothing, air temperature, mean radiant temperature, air velocity and vapour pressure in ambient air. Additional information required for thermal simulation includes: building geometry, including the layout and configuration of the space, grouping of rooms in thermally homogeneous zones, building orientation, building construction, including the thermal properties of all construction elements, building usage including functional use, internal loads and schedules for lighting, occupants, and equipments, heating, ventilating, and air conditioning system type and operating characteristics, space conditioning requirements, utility rates, and weather data. It is not easy to measure or to elaborate all of those at a particular location in a building to create thermal comfort. Manual calculation of those values at every point within a building is almost impossible. One way to analyse thermal performance in buildings is by using thermal simulation programs that are capable of calculating all of those values accurately.

In an assessment Haslinda Mohamed Kamar*etal*.,[30] reports that, most residential terrace houses in Malaysia are not equipped with an air conditioning system. They rely mostly on natural ventilation, passive cooling system and mechanical ventilation devices such as ceiling and extractor fans to achieve certain level of thermal comfort. Special attention is given to the design and installation of these devices so as to optimise their effects on the thermal comfort. The quality and energy efficiency of these devices varies widely. It is therefore critical to access several important building characteristics at the design stage. These include the ability to improve energy efficiency, effects of solar radiation, effects of air flow due to wind and the most importantly the occupant's comfort. To access the level of thermal comfort, it is necessary to know the air velocity, temperature distribution, and relative humidity of the ambient air inside the houses. The transfer of heat energy by conduction, convection, radiation and evaporative heat loss affects thermal comfort in buildings. Thermal comfort will be maintained when the heat generated by human metabolism is allowed to dissipate, thus a person will maintain thermal equilibrium with his surroundings. Any heat gain or loss beyond this level will generate a sensation of discomfort. The thermal comfort condition in a ventilated building can be accessed by knowing the air flow pattern and its velocity, the temperature distribution and the indoor air quality. A good indoor climate will not only make its occupants feel comfort but also promote the energy saving and its sustainability. Natural ventilation implies that air is supplied and removed from the indoor space of a building by natural means. The effectiveness of natural ventilation therefore depends very much on the design features of the house. Natural ventilation is usually coupled with the use of mechanical ventilation system such as extractor and ceiling fans to provide better ventilation and thus thermal comfort condition.

In a retrofitting attempt by diagnosis Rafael Suarez *et al*.,[31] detected the deficient indoor comfort conditions affecting the occupants. The concept of thermal comfort is rather subjective and difficult to evaluate. They used a series of calculations to establish the levels of thermal comfort inside the housing units to provide an in depth analysis of thermal comfort upgrades. The calculations followed the free running hypothesis to evaluate the environmental indicators of temperature and thermal oscillations by studying local climate, thermal evolution, and energy characterization. Establishing indoor comfort bands is a guide to thermal comfort. A comfort temperature interval of between 20-22^0 C in winter and 22-27^0 C in summer was established by them.

Pedro Dinis Gaspar *et al*.,[32] feels that, the numerical analysis of building design has raised interest among architects, building service engineers and environmental engineers, due to the growing development of new design standards in indoor air quality, thermal comfort, safety and awareness of the advances in computer aided engineering design, by means of new technological methods in modelling building airflow and related phenomena.

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The study by Richard Holz*etal*.,[33] on clothing level provides strong evidence that clothing is one of the important factor in thermal comfort. The study also supports the notion that a model where clothing levels are constant all year round is far too simplistic and probably incorrect. The sensitivity analysis of the six comfort factors verifies that, the clothing worn by building occupants, the activity level, the air temperature and the mean radiant temperature all have significant effects on thermal comfort. Humidity and air velocity play important roles in comparison, but they do influence the sensitivity of the other four factors. It was also shown that the core zone occupants were experiencing good comfort throughout the day, if they had responded with changes in clothing. First, it is almost impossible to invent some sort of overall comfort index for an entire building for an entire year. Second, there must be flexibility on the parts of both the building occupants and the building HVAC system in order that comfort is achieved for most occupants for most of the year.

As per Tiago Arent Longo *etal*.,[34] the natural ventilation is an important strategy to improve thermal comfort in buildings that are located in hot and humid climates. Also, natural ventilation may improve the indoor air conditions. The air velocity at certain limits can provide the sensation of cooling by decreasing the rate of evaporation from the skin surface. The ventilation strategies were night time only ventilation, day time only ventilation, full day ventilation and no ventilation. The authors suggested an ideal window to wall ratio of 24% to achieve the best thermal comfort conditions in buildings. Horizontal shading devices were recommended for all facades to improve thermal comfort.

MENGQinglin and CHEN Zhuolun[35] in a case study said, the design of climate adapting buildings is based on the bioclimatology. It is a method to reduce building energy consumption in natural conditions while keeping the indoor thermal comfort at the acceptable level. In order to maintain the thermal comfort, it is necessary to dominate thermal environment by controlling the indoor physical parameters, such as wind speed and temperature.

In Beijing, G.Carrilho da Graca*etal*., [36] accessed occupant thermal comfort using Fanger's comfort model. The results show that night cooling is superior to daytime ventilation. Night cooling may replace air conditioning systems for a significant part of the cold season, but with a high condensation risk. Daytime comfort ventilation is the most commonly used passive cooling system. Outdoor air flows through the building during the day, directly removing the heat gains. The system can improve the occupant's thermal comfort by increasing convective and evaporative heat transfer, and by decreasing the indoor air temperature. The study of wind driven passive cooling systems requires accurate modelling of the building thermal response to the outdoor climate conditions and internal heat gains. The thermal response, in conjunction with ventilation models, can determine the indoor air temperature, relative humidity, air velocity, and environmental temperature provided by the ventilation systems. These parameters determine the thermal comfort in the building.

Amjed A. Maghrabi[37] pointed out that, in recent years the use of thermal insulation in buildings has increased significantly and has become mandatory in some countries. This was due to higher demands on human thermal comfort inside residential, commercial, and office buildings, besides the ever increasing costs of energy production and its negative impact on the environment. Reduced energy consumption of the building and the increased human thermal comfort is, therefore, anticipated as a sustainable design feature to be achieved.

In the hotter climates of Cairo and Barcelona, Mohammad Taleghani*etal*.[38]suggest that the sunspace does not show to be efficient building type. They listed several studies which show the environmental advantages of transitional spaces and also commented that, there is still a lack of knowledge on the effect of transitional spaces on the energy consumption and of thermal comfort in residential buildings, since most studies addressed office buildings. The most energy efficient building does not always have the most comfort hours. Future lack of fossil energy and the limited capacity of sustainable energy sources are encouraging the investigation of passive and efficient building types.

5. CONCLUSIONS

This review paper identified and presented some simulation tools successfully used by researchers and architects in support of energy efficient retrofit in residential and small commercial buildings. Improving energy conservation decisions early in building planning and design helps to optimize whole building performance.

This study analysed the thermal comfort of users of a naturally ventilated building located in various countries with varied climatic conditions. Good suggestions on parameters to be considered for maintaining human comfort levels in winter and in summer were presented. Major criteria to consider while designing energy efficient buildings are the environmental parameters like air temperature, radiant temperature, humidity, air velocity and the personal parameters like occupants clothing and activity.

Natural ventilation methods investigated by the researchers to improve indoor air conditions and the strategies in passive house design were presented. Passive house designs include passive solar gain, air tight insulated enclosures, windows positioning, building orientation, ceiling type and proper natural ventilation arrangements.

In an attempt to do simulation on a low cost residential building for energy and thermal comfort analysis, this review was done and the influencing ideas were presented for the benefit of the designers and architects. It is also suggested, the parameters for energy and thermal comfort modelling of a building can be finalised on giving due consideration towards their importance and the purpose.

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