CHAPTER 2
LITERATURE REVIEW

2.0 INTRODUCTION

The climate change (viz. the rising temperatures, change in the amount of precipitation as well as variation in humidity, wind patterns and number of sunny days per year) significantly affect the energy sector (both consumption and production) of many countries especially the developing nations (Frank, 1998). The energy sector is sensitive to climate change and sub-sectors most likely to be affected are space heating, space cooling, and hydroelectric generation (Frank, 1998).

Several countries and many environmental non-governmental organizations, have agreed that global average temperature increase should be limited to 2°C above pre-industrial levels to avoid such dangerous interference, agreement which is reaffirmed by international negotiation processes in (COP 21, 2015). The predicted effects of climate change present a number of primary challenges for buildings, increased demand for cooling in summer, and increased thermal discomfort in buildings (West and Megan, 2005).

Buildings, worldwide, account for as much as 40% of energy consumption, and similar share of greenhouse gas emissions that makes buildings the biggest single contributors to anthropogenic climate change (Butler 2008). This accounts for the adoption of compelling and cost-effective opportunities to reduce energy consumption in buildings both in International Energy Agency (IEA) member countries and in developing countries. William Ramsay, Deputy Executive Director
of IEA, remarked that, *in order to ensure sustainable development, a policy to minimize energy consumption and greenhouse gas emissions has to include measures to reduce the end use of energy in buildings*, (ECOFYS, 2007). Hence, to promote energy conservation in the residential sector and to estimate the CO₂ emissions, it is important to examine the building energy consumption for different countries and to exchange information about this area, so that policy-makers and energy experts can learn from each other in devising policies related to residential energy standards (Zhang 2004; Filippin *et al.*, 2010).

The energy consumption, in case of buildings is also associated with the maintenance of thermal comfort inside it. The thermal comfort defined by ASHRAE as “the condition of the mind in which satisfaction is expressed with the thermal environment” (Djongyang *et al.*, 2010; Rupp and Ghisi 2014). The Zero Energy and Buildings (ZEB) or Net Zero Energy and Buildings (Net ZEB) (Solar Heating and Cooling Programme; Lenoir *et al.*, 2011; Musall *et al.*, 2010 and Voss *et al.*, 2011) concepts are the outcomes of such concerns. Also, application of climate adaptive building shells, building environmental assessment schemes and green building rating tools have been used by technocrats and researchers for many years for sustainable construction activities (*Chen et al.*, 2015). Compared to conventional, the climate adaptive building shells offer ways for energy saving and improving indoor air quality (Loonen *et al.*, 2013).

The recent advances in the development of natural fibers represent a significant opportunity to produce improved-materials and energy from renewable resources (*Ingrao et al.*, 2015). The improvisation of insulation has resulted in reduced sensible
load although the latent load from internal gains and requirement for ventilation has remained relatively constant. This has increased the need for dehumidification equipment and for accurately predicting the space relative humidity (Rudd and Henderson 2007; Vasilyev et al., 2015). Indoor relative humidity should be controlled to maintain occupant health and comfort, and to limit the likelihood of building decay (Florez et al., 2009). The humidity in a building is primarily affected by five factors: internal moisture gains, ventilation, infiltration, removal with space-conditioning equipment, and moisture sorption into (or desorption out of) the materials. Hence, study of the Hygrothermal performance of building becomes more essential. This is used to estimate the durability and service life of building envelope, as hygrothermal processes can occur in all three states namely vapour, liquid and ice, and each contributes differently to deterioration mechanisms (Karagiozis et al., 1997).

This section reviews the effects of air, temperature and moisture i.e. hygrothermal effect on the building envelope along with exergy based analysis activities, pertaining to buildings. During this study, consideration will be given to how and why hygrothermal behavior affects the thermal comfort with an emphasis, on the behavior of building material and remedies to the problems thus rising. This section also reviews the work undertaken by various researchers where the CFD has been used to simulate the building environment (inside and outside the building).

2.1 EXERGY BASED ANALYSIS

As we know that most of the energy systems used in buildings are designed based on law of energy conservation. But, this does not encompass the important
aspects of building’s energy use, like energy supply and end-use and advantages of using passive and ambient energy in the buildings. Thus, to ascertain the nature of energy flows, one can depend on exergy concept, in addition to energy conservation principle (Schmidt 2003). The exergy of a system in a given environment is the maximum theoretical work that might be extracted from it and thus exergy is a measure of the potential of a given energy flow that can be converted into the high quality energy. It has been very recently that concept of exergy has been applied to both building and community levels. Major amount (nearly half) of energy supplied to the buildings is utilized by HVAC systems installed inside the building for establishing thermal comfort. Since, these low quality energy demands are mainly satisfied with high quality energy sources such as fossil fuels, which are also high exergy sources. On the other hand, use of renewable energy sources (solar energy, biomass etc.) may further decrease CO₂ emissions from the buildings. Hence, a greater margin for exergy and energy saving exists along with the use of renewable energy-based systems in order to maintain thermal comfort within the built environment. Torio et al., (2009) presented a comprehensive view on the most recent studies especially methodological aspects specifically related to renewably operated acclimatization systems. They also conclude the use of exergy method as a significant tool (Calise et al., 2015).

Exergy is stated as “warm” and “cold”. The exergy contained by air at a temperature higher than its environment is an ability of thermal energy contained by air to disperse into the environment. On the other hand, exergy contained at a temperature lower than its environment is an ability of the air, in which there is a
lack of thermal energy compared to the environment, to let the thermal energy in the environment flow into it. We call former “warm” exergy and the latter “cool” exergy.

The energy and exergy consumption in four hotels of Greece were compared (depending on the use of building, the construction type, maintenance, existing heating, cooling and lighting systems and other types of services) as they have high energy consumption rate because of their unique operational characteristics. Energy consumption in hotels is among the highest in non-residential building sector in absolute values. The aim was to have a sustainable development of hotel systems. The data thus fetched was also used to identify the scope for improvement in new or existing hotels (Xydis et al., 2009). Kerdan et al., (2015) did an analysis where similar study was carried out for the Mexican area.

An energy and exergy analysis was employed to assess the performances and compared energy and exergy efficiencies and sustainability index of heating systems based on heat pump; condensing boiler; conventional boiler and solar collector. The energetic and exergetic renewability ratios were utilized along with sustainability index. The results showed that solar collector based heating system gave the highest exergy efficiency followed by heat pump based, condensing boiler and lastly the conventional boiler. Also, sustainability index was highest for solar collector based unit followed by heat pump based, condensing boiler and conventional (Balta et al., 2010). Also, in a separate study exergetic assessment of an educational building heated by a conventional boiler in a heating center was carried (Yucer and Hepbasli 2011).
An office building equipped with low-temperature heating and high temperature cooling systems situated in Netherlands was analyzed by Sakulpipatsin et al., (2010). They analyzed the building for its energy and exergy demands and losses in the HVAC systems. They found that main causes of exergy inefficiencies in HVAC systems are the thermal emission, control system and energy conversion systems.

The applicability of solar cooling in Greece was investigated in a medical Centre in Igoumenitsa. The use of a thermal solar system creates significant environmental benefits in the area of climate change with the reduction of CO₂ emissions. The investment cost of such a solar thermal system (70 kW, AB absorption technology and a collector area of 291m²) reaches the level of 600D /m² of solar collector area. The economic viability of such an innovative cooling method is of great importance; nevertheless technical effort in the implementation of a solar thermal air conditioning system is higher compared to implementation of a conventional system (Koroneos et al., 2010).

Liu et al.,(2010) performed a case study to analyse environmental impact of a building life cycle in Chongqing, China. Various environmental impacts like energy consumption, resource consumption and pollutant discharge; were analyzed with reference to energy-embodied exergy, resource chemical exergy and abatement exergy, respectively. The work evaluated a building’s environmental sustainability through its exergy footprint and environmental impacts. The study concluded that energy consumption constituted 70–80% of total environmental impact during a 50-
year building lifecycle out of which 80% share is of operational phase, 15% share is of building material production phase and 5% for the other phases.

In another study, exergy analysis and life cycle assessment (LCA) for space heating, cooling and hot domestic water production, for an average house using a photovoltaic system (PV) and geothermal energy for electricity production in Northern Greece was carried out by Koroneos and Tsarouhis (2012). After performing the necessary exergy analysis of different elements of system it has found that exergy efficiency of solar systems and geothermal system are relatively low and should be analyzed only at manufacturing stage. Torío and Schmidt (2010) gave a new framework to be used for exergy analysis of direct-solar systems in the context with built structures. They highlighted the physical inconsistencies present in the exergy analysis framework for assessing direct-solar systems. Kilkis (2012) analyzed two case studies (a building in Ankara and city of Stockholm) based on the role of exergy strategies at the building and district level.

A concept of Low exergy (LowEx) building systems for venturing into the newer areas aiding the design of newer high in performance, buildings was analyzed (Meggers et al., 2012). These buildings, instead of possessing thick insulations used low exergy systems. They suggested that implementation of integrated LowEx systems maintains low temperature-lifts, which can drastically increase heat pump performance from typical COP range of 3 to 6 to values ranging from 6 to 13. In another work, by Hepbasli (2012) LowEx relations were used to estimate energy and exergy demand in buildings and key parameters for performance assessment and
comparison purposes were analyzed. Finally, LowEx studies and applications conducted were reviewed.

Goncalves et al., (2012) proposed new energy performance indicator based on case study of a hotel building in Coimbra, Portugal. Not just the primary energy based indicators but primary energy ratio and exergy efficiency were used as indicators. Results depicted that electric equipment were major contributors towards the primary energy consumption of the hotel; however, they were having highest exergetic efficiency when compared to the HVAC systems.

Exergy analysis, as an important assessment tool for a comfortable dwelling, was explored in the context of Spain and a comparison was done for the energy and exergy losses. Total energy supply system was analyzed which included demand side systems, their respective components and energy input from different energy resources like conventional and /or renewable. The study revealed that exergy analysis added to the results also by finding thermodynamic aspects and hence there is a need to develop ways based on the exergy principles (Jansen et al., 2012).

A study, combining the modeling and simulation of building heat dissipation, heat consumption and exergetic efficiency calculation was done by (Cheremnykh et al., 2013). Initially, building was modeled for thermal characteristics to establish the thermal comfort inside the space which further was simulated for a plant acting as source of power to identify the most convenient exergetic pairings.

Shenawy and Zmeureanu (2013) developed a new tool for exergy analysis of buildings to achieve a sustainable building and tested it for 05 different buildings as
a case study. They proposed an exergy based definition of a sustainable building, the calculation method of a new exergy-based index of building sustainability, and rating scale.

The exergy flow rate was calculated, from the power plant to the building envelope with hourly outdoor temperature as well as humidity as reference state also considering the chemical exergy of room air in cooling mode. Results showed that building envelope insulation is necessary in hot summer and cold winter area of China in reducing the building exergy consumption. The total year larger exergy loss rates take place in the primary energy transformation and heating/cooling production, which is about 80% of the system’s total exergy loss. The room air chemical exergy was about 12% of physical exergy. So, chemical exergy cannot be ignored in cooling mode (Zhou and Gong 2013).

The overall energy and exergy performance of 8 space heating options were compared for different outdoor environmental conditions. The methodology started from the demand to supply side, assuming that each heating option is divided into various sub-systems like room emission, heat generator etc. with primary energy ratio (PER) and primary exergy ratio (PExR) as indicators. Furthermore, assessment of irreversibility rate revealed that sources of inefficiencies could be pinpointed and measured for further improvements (Goncalves et al., 2013).

In a distinct work the concepts of exergy analysis and exergetic efficiency were utilized by Vargas-Parra et al., 2013 using a life cycle approach. They evaluated the performance of 08 scenarios in urban rainwater harvesting systems of Metropolitan Area of Barcelona. The results show that the highest exergy input was associated
with the transport of materials to construct the rainwater harvesting systems. Further, exergy requirements could be minimized by material substitution, minimizing weight or distance traveled.

Baldi and Leoncini (2014) carried an exergy analysis to evaluate direct energy impact of a building on the environment. The work was consisting of a description of the model and its application to a building. The aim was to analyze thermodynamic interaction of building and it’s surrounding in order to estimate input exergy loss and its destruction.

This review suggests that exergy based analysis, is a widely excepted tool for analyzing the building and its various components with respect to the interaction within themselves and with surroundings, for energy consumption. Many researchers have individually analyzed different sorts of built structure like the school, hotels and old built structures etc. for their interactions within their heating and cooling components and their surroundings. Some work also concentrates on the life cycle analysis of renewable energy based space heating and cooling systems to be used in buildings existing on the concepts of low exergy buildings, so as to reduce/optimize the energy consumption. However, these studies mostly concentrate on buildings in the European countries and very few researches (except few researches who have done work in the context of China) analyzed the buildings in Asian context. So, this gives us a margin to carry out the required work in the Asian context, especially, India. So the work here will concentrate on the exergy analysis of the built structure at some Indian location.
2.2 HYGROTHERMAL CONCERNS FOR DIFFERENT BUILDING COMPONENTS

Building, as stated shelters the occupants from external influences and for its favourable and efficient working has many components. But all these components, as are made up of different materials and positioned differently, show different hygrothermal characteristics. The wetting and drying cycles play a key role in determining water movement inside construction materials (I’Anson and Hoff 1986; Evins 2013). Water can wet a building through the pores present in the buildings by the capillary suction of ground moisture, rain and condensation of air humidity, leading to a massive decay as it carries soluble salts too (Torres and Freitas 2007; Snethlage and Wendler 1996). Furthermore, the salt crystallization is favored when evaporation rate increases and the water uptake decreases. In the opposite condition, dissolution is favored when evaporation rate decreases and the water uptake increases.

This section reviews the work carried out on various building elements viz., the walls, ventilation system, building materials, etc.

2.2.1 WALLS

Walls form the major portion of a building and are bearing various other features like windows, doors, ventilators etc. thus, present section reviews the various hygrothermal researches carried on the walls.

Budaiwi et al., (1999) analyzed the behavior of multi-layer non-cavity walls for the transient thermal and moisture transfer using an implicit FDM scheme. All
the possible material moisture conditions (moisture transport process and material moisture content) for different layers of the wall were evaluated employing this scheme.

Investigation of frequency analysis of air conditioned buildings using 1D moisture transfer model and vapour pressure as driving potential was done by Chen and Wang (2001). The test revealed the moisture ingress through wall can be neglected and model was not only very simple but also had satisfactory accuracy to evaluate the moisture transfer effect of buildings on indoor air humidity and latent cooling load.

Karoglou et al., (2007) studied the effect of seasonal moisture transfer to and from the walls of a building using an Excel based simulator which accounts various aspects viz. moisture transfer mechanisms (to and from building), wall materials and size, properties of the construction material and weather conditions. All this data was used to calculate the season dependent moisture ingress and its equilibrium, capillary rise, rate of wall drying etc.

A simple model of heat, air and moisture transfer (HAM model) through a wall to save large computational cost was developed (Fanga et al., 2009; Steeman et al., 2010).

Guimaraes et al., (2010), describes moisture transfer process between a moving air flux and a saturated wall, by both advection and diffusion. The ineffectiveness of the traditional techniques and experimental studies validated its effectiveness. A mathematical expression was proposed to accurately describe the numerical dependence
Desta et al., (2011) investigated the HAM transfer through a wall under natural conditions with an objective to obtain informative data to be used for the numerical validation of model. The data was collected for two years to get an insight about the hygrothermal behavior to generate a well-documented data set to be used for model validation.

Liu et al., (2011) investigated numerically, the simultaneous transport of heat and moisture by conjugate natural convection in a partial enclosure with a solid wall. Moist air motions are driven by external temperature and concentration differences imposed across enclosures with different ambient moisture conditions. The fluid, heat and moisture transports through the cavity and solid wall were, analyzed using the stream-lines, heat-lines and mass-lines, and heat and mass transfer potentials were explained by the variations of overall Nusselt and Sherwood numbers. The numerical simulations presented spanned a wide range of the main parameters (heat and mass diffusion coefficient ratios, solid wall thickness and thermal Rayleigh numbers) in the domain of aiding and opposing buoyancy-driven flows. It was shown that heat transfer potential, mass transfer potential, and volume flow rate can be promoted or inhibited, depending strongly on the wall materials and size, thermal and moisture Rayleigh numbers.

The behavior of a multi-composite panel of wood with humid air in between was studied for the heat and mass transport by Traore et al., (2011). Various mechanisms like conduction, convection, radiation, diffusion and condensation were solved. The transient change of temperature, heat flux and humidity with respect to weather conditions were plotted.
HSM model was analyzed for a quasi-steady state airflow in a porous media. The hygrothermal behavior of a building envelope was accessed for the buoyant and external air flow Langmans et al., (2012). The approach was validated with the already existing case studies from literature.

D’Agostino (2013) investigated the effect of moisture ingress in the Cathedral of Lecce and its below ground Crypt (South Italy). He utilized the sharp front (SF) theory to analyze rising dampness. Moisture transfer dynamics (in the walls and columns) were investigated as a steady state between the water absorbed and evaporated. A varying state of non-equilibrium was derived using simplified formulae, to calculate indoor and outdoor evaporation rates, and validation was done using experimentations. The information thus obtained shall aid the understanding of moisture behavior leading to an explanation related to dynamics of deterioration of a built structure and can also help in masonry maintenance.

A new application of HAM model for computational studies of moisture freezing effect on wall material structures, which is important for regions with cold climate was conducted (Kong and Zheng2008; Kong and Zhang 2013).

The characteristics (mechanical degradation) of bricks in humid weather and salt crystallization were analyzed by Foraboschi and Vanin (2014). The reduction in compression strength of brick was reported experimentally in the presence of salts and moisture. However, absence of moisture and presence of salts increase brick’s compression strength as it lead to sub florescence and efflorescence inside the bricks.
Vasilyev et al., (2015) studied the moisture distribution under influence of seasonal variations in atmospheric air temperature and humidity using one dimensional model of heat, steam, and water transfer across a wall consisting of several layers of different materials through finite difference method. They used the system of coupled diffusion equations for wall temperature; vapour pressure, and water concentration in material pores, with account of vapour condensation and water evaporation.

Vasilyev et al., (2015) presented a 1D numerical model of heat, steam, and water diffusion across a wall, consisting of several layers of different material. The model was a coupled diffusion equation for material temperature, vapour pressure, and water concentration in material pores, accounting for vapour condensation and water evaporation. The system of nonlinear partial differential equations is solved numerically using the finite difference method. The primary objective of modeling is the simulation of long-term behavior of building wall moisture distribution under the influence of seasonal variations in atmospheric air temperature and humidity.

2.2.2 BUILDING MATERIALS

Walls and its various other features like the windows, doors, ventilators etc. are made up of different materials and also walls are in link with the ground (soil), hence the characteristics of these materials are important to be investigated. The present section reviews the various hygrothermal researches carried out on different building materials.
Chen and Shi (2005) analyzed the thermal driving forces and fluxes in heat and moisture migration process for unsaturated porous building materials, based on non-equilibrium thermodynamic theory. The mechanisms of HAM transport and equations describing it, in porous materials were discussed using diffusion law and ideal gas equation. The effects of moisture and temperature were also discussed.

Based on the fact that a better knowledge of interaction between an indoor climate and a heavy timber structure is important and can lead to high air exchange rate thus enhancing the thermal comfort of inhabitants, Hameury (2005). A FDM based model was developed as a stand-alone application enabling the indoor climate energy calculations. A numerical simulation was provided to depict the buffering capacity of a massive timber structure as a function of air exchange rate and effective wood wall area.

A model to find the heat and moisture transfer in soil and floor and psychrometrics of indoor air was formed. Santos and Mendes (2006) also carried a lumped transient analysis of a building room to associate it with the soil model. Results were presented in terms of temperature, humidity and heat flux at the interface between room air and floor.

Talukdar et al., (2007) provided experimental data of numerical models of heat and moisture transfer, for two building materials; cellulose insulation and spruce plywood, when subjected to transient 1-D conditions. The material properties, thus documented were presented to be used by other researchers.
Rantala and Leivo (2008) investigated drainage layers under the hot ground slabs as they are moist and warm throughout the year. Due to such conditions the microbe growth is very common. But it was found that high microbe concentration in the fill layer beneath the ground is not a sign of moisture damage. Instead it must be considered as an existing boundary condition for analysis in any new or old ground floor structure.

Leivo and Rantala (2008) analyzed the effect of soil temperature, relative humidity and floor’s vapour resistance; on moisture transport in the ground lay slab in a moist steady-state conditions (excluding the capillary transport). The moisture transport is much affected by water vapour gradient across the structure and resistance to vapour penetration of structural materials. A thermal insulation under the slab can ensure temperature gradient and decreases the vapour gradient and diffusion flow (inwards). The high vapour resistance decreases the relative humidity at slab.

Peuhkuri et al., (2008) experimentally investigated porous building materials for moisture transport due to temperature difference which caused the shift of moisture from warm side to cold side. It was rather surprising to find that almost non-hygroscopic materials like the rock wool and a very hygroscopic material like cellulose insulation gave same characteristic results.

A complex process of determination and prediction of moisture transport (water vapour and liquid water) processes in the presence of salts in building materials was studied by Terheiden (2008). A possibility to find a function depending on the multi-phase (moisture) systems with and without the influence of
salts was explored. It was also established that water vapour and liquid water transport can be analyzed simultaneously. By using salts only as ‘marker’, it was even possible to measure water vapour and ‘pure’ liquid water transport.

Nasraoui et al., (2009) studied that salts (being soluble) are hazardous to building health and hence pose a challenge to the health of buildings and its restoration. There are many qualitative and quantitative techniques to check the same which are complex. However, simpler ways like hygroscopic moisture content (HMC) and electrical conductivity (EC) of extracted salt solutions can be used to carry out preliminary diagnosis. The authors compared salt assessment from all methods to access the damage in buildings and ways of preservation.

A computer program for testing a new methodology for carrying out the hygrothermal test, from several months to a year to study wetting and drying processes for reducing cost and getting affordable testing of buildings was introduced. In one method, indoor conditions were varied while maintaining climatic conditions constant in the other method, weather conditions are varied, while indoor conditions are kept constant. The implementation of methodologies with the developed code was demonstrated using Montreal (Canada) weather data (Fang et al., 2009).

An advanced numerical tool to advance building envelope design towards an engineering approach and reduce occurrence of future failures, in conjunction with an extensive full-scale experiment, was developed and investigation for the hygrothermal performance of various wood-frame wall assemblies, thus providing the building science researchers a flexibility to modify, maintain and share their
modelling work efficiently. Major features of the tool were multi-dimensional and transient coupling of heat and moisture transport; natural air convection integrated in hygrothermal simulation through Darcy-Boussinesq approximation; heat transfer by conduction and convection of sensible and latent heat; moisture transport by vapour diffusion, capillary suction and convection; material database of common building materials in North America; experimental settings or weather data as boundary conditions; and moisture added in the building envelope to simulate the wetting process. The numerical tool achieved a good compliance to the benchmarking cases of HAMSTAD project, and its predictions showed a good agreement with data from the full-scale wall experiment. Li et al., (2009), numerical tool employed a commercial finite-element software to solve governing equations.

Slanina and Silarova (2009) studied 3D cases of low-slope compact roofs with a waterproofing membrane where vapour retarder was perforated using wet cup method. They presented a way of describing the apparatus for measuring vapour resistance of materials. Further, they formulated an equation that described the water vapour diffusion through perforated vapour retarders.

Experimental investigation was done to solve moisture transfer (at early age) and its variation (with age) in concrete based on measurement of humidity of concrete specimens under fully plastic sealing and environmental drying conditions. The model results depicted that moisture diffusion coefficient ($10^{-8}$ to $10^{-10}$ from 3 to 28 days starting from concrete casting) depends on the concrete age. Zhang et al., (2011) also found that high-strength concrete had a lower moisture diffusion coefficient than that of normal strength concrete under the same curing period.
Swirsk – Perkowska (2011) presented the various types of diffusions in capillary-porous media. Firstly, theoretical expressions were talked over which described a dependence between superficial and volumetric moisture diffusion and temperature. Then after, an idea of effective moisture diffusion coefficient taking into account the analyzed mechanisms of water vapour diffusion in volumetric part of material pores and diffusion in moisture films adsorbed on pore walls, were studied. On this basis a relation coupling effective moisture diffusivity with volumetric and superficial diffusion coefficients was derived. Finally, results of own experimental research of effective moisture diffusivity temperature dependence and sorption isotherms for building gypsum samples which allowed estimating the superficial diffusivity of gypsum, were presented.

The manufacturing and using cellulose based materials requires the study of their hydrophilic characteristic (i.e. interactions of water and cellulose) as this has a greater influence on their physical and chemical properties. A large number of well documented reports (Engelund et al., 2013; Samyn 2013) have been published on this topic. Absolutely amorphous cellulose samples do not exist naturally but can be formed using different methods (Ciolacu 2011), including ball milling (Shimura et al., 2014).

Mazeau (2015) studied the relationship between cellulose and water. He began from completely dry cellulose and by substituting the O\textsubscript{6} and O\textsubscript{2} hydroxyl groups of cellulose from diffused water molecules and hydrogen bond. The study benefited by allowing the prediction of various physical parameters of amorphous cellulose and their variations under hydration.
Many practitioners (Anderson 1991; Goh 1995; Rees et al., 2001; Mihalakakou 2003; Dalinaidu and Singh 2004 and Balghouthi et al., 2005) have analyzed soil for significant fluctuation daily and annually; due to the variations in soil temperature and humidity at shallow depths. This variation can be seasonal and irregular and is not only due to the soil properties but also due to ambient temperature, radiations of sun, air velocity, weather conditions and shading etc. hence making it difficult to predict soil behavior. This also impacts thermo-physical properties of soil which are not part of building simulation codes. Recently, due to their strong learning capabilities, there is a growing use of Artificial Neural Networks (ANNs) in the areas of pattern recognition, system identification etc. and hence ANNs have also been proposed for analyzing temperature or moisture profiles by Mihalakakou 2002; Varol et al., 2007 Erzin et al., 2008; Karadag and Akgobek 2008.

2.2.3 VENTILATION SYSTEM

Building ventilation is necessary for supporting life by maintaining acceptable levels of oxygen in the air. This also aids in preventing space odor and other contaminants, rise in CO₂ levels and moisture. Although, CO₂ is not a harmful gas (below 5000 ppm) and above this it may lead to reduced levels of O₂ in air (Awbi 1998).

Pavlovas (2004) investigated a Swedish building for its ventilation system in an aim to apply and evaluate the IDA Indoor Climate and Energy (ICE) simulation software on the application. The simulations showed that it is possible to achieve energy savings using occupancy and/or humidity controlled ventilation while
keeping an acceptable indoor climate and can be used to developed ventilation strategy and implement it in occupied apartments.

A holistic HAM model that integrated the building envelope enclosures, indoor environment, HVAC systems, and indoor heat and moisture generation mechanisms, and solved simultaneously for respective design parameters was developed by Tariku et al., (2010). The model was bench marked with internationally published test cases that require simultaneous prediction of indoor environmental conditions, building envelope moisture performance and energy efficiency of a building.

An improvement in thermal comfort and indoor air quality with the conservation of energy used for heating and cooling using Double-Skin Facade (DSF) was evaluated by Zhou and Chen (2010). Their study described the existing main research methods on thermal performance of DSF and shading devices along with their associated problems and possibilities. They suggested that application of ventilated DSF with controlled shading device system would be a new efficient way for the commercial buildings in hot-summer and cold-winter zone to get a sustainable building design.

Vera et al., (2010a and 2010b) investigated moisture transport through staircases in a full-scale two-story test-hut, experimentally and using CFD on the basis of different ventilation rates and strategies and temperature differences between lower and upper rooms for 20 cases. This study was performed on buoyancy-driven flows, combined buoyancy air-flows with mechanical ventilation and cases with warmer upper room than lower rooms. The results showed that temperature difference strongly influences air and moisture exchanges through
openings and that mechanical ventilation significantly restricts airflows in comparison with cases without mechanical ventilation.

The impact of high initial moisture content in colder areas on indoor condition and energy consumption was studied using coupling transfer of heat and moisture and experimentally, Kong et al., (2011). The moisture content gradient was used as mass transfer driving force while temperature gradient was used as heat transfer driving forces.

Rongpeng et al., (2014) used variable air volume systems to optimize building’s night ventilation and air conditioning using simultaneous collocation method. This was implemented in the general algebraic modelling system and was supported by an Interior Point Optimizer. The energy savings of around 23.19–49.31% in varying weather conditions were achieved.

Fauchoux et al., (2014) in their chapter presents different methods for moderating indoor humidity levels using hygroscopic materials, in the form of hygroscopic building materials, desiccant coated air-to-air energy wheel and a new ceiling panel concept with a vapour permeable surface. The study was simulated for an apartment and two office buildings, in different cities of North America. The simulated indoor relative humidity and percent dissatisfied with perceived air quality depicted benefits of using hygroscopic materials in buildings. Experimental results were presented for the ceiling panel, with results showing the sensible and latent effectiveness as well as heat and mass flux rates obtained from the panel. The results of the simulations and experiments show that these devices and methods have the
potential to improve thermal comfort, indoor air quality besides reducing energy consumption of the buildings.

An investigation for optimizing building’s ventilation system for enhanced air quality in the space and better energy efficiency under influence of weather conditions, was carried out by Liu et al. (2014). They utilized and compared two control strategies viz. proportional-integral (PI) control and multivariate model predictive control (MPC) fixing indoor air temperature and CO\textsubscript{2} concentration. The results indicate that performance of optimized MPC controller is better than that of PI controller. Also, use of optimized MPC controller reduced the energy consumption by 5.22% and CO\textsubscript{2} content by 13.39%.

Hesaraki et al., (2015) investigated a Swedish household for energy utilization based on theoretical and experimental schemes and deduced the impact of varying levels of ventilation (0.10 L/s m\textsuperscript{2}, 0.20 L/s m\textsuperscript{2}, 0.35 L/s m\textsuperscript{2} and 0.70 L/s m\textsuperscript{2}) on indoor air quality. The air flow rate, CO\textsubscript{2}, relative humidity (RH) and temperature were set as the indicators of air quality. Four ventilation levels were taken. Mechanical measurements were used to establish CO\textsubscript{2} concentrations at various ventilation levels. The measurements showed that RH and temperature were within acceptable ranges in all the cases. An energy savings calculation showed that in second case 43% reduced energy requirement than third case.

Heat and moisture transfer was used to simulate and predict airflow temperature, RH and heat loads by Yang et al.,(2015), in a building, using Energy Plus in its conduction model, Combined Heat and Moisture Transfer model and Effective
Moisture Penetration Depth model. The effects of different room infiltration rate on accuracy of different models were analyzed.

Green roofs, in addition to creation of a pleasant environment, green roofs offer several benefits in comparison to conventional roofs. Green roofs increase vegetal and animal biodiversity in cities (Schrader and Boning 2006; Brenneisen 2006). In the urban areas green roofs control urban heat island effect (Takebayashi and Moriyama 2007). Their photosynthesis capability helps in reducing the city’s carbon footprint by converting carbon dioxide to oxygen (Li et al., 2010; Feng et al., 2010). Aiding storm water management (Fioretti et al., 2010) reducing air pollution (Li et al., 2010) and noise (Renterghem and Botteldooren 2011) are their few but major effects. Green roofs also contribute in the longevity of HVAC systems by reducing inlet fluid temperature before it returns to the chiller. Thus improving efficiency of photovoltaic panels (Castleton et al., 2010). Building’s energy efficiency is further improved by improving heat transfer thus limiting the thermal stresses (Teemush and Umander 2009 & 2010; Fioretti et al., 2010; Castleton et al., 2010 and Lin and Lin 2011).

This section discusses research on the moisture transport in various building components. Initial investigation of building walls suggested that many researchers have adopted many numerical methods particularly finite difference methods for analyzing moisture transport through capillary actions. The study of transient heat air and moisture (HAM) model under influence of seasonal variations was carried out. The investigation also draws attention to some work, as to how to evaluate the structure for establishing comfortable dwelling conditions and increasing air
exchange rate for varying building insulations (wood, cellulose and spruce plywood). The hygrothermal transport through soil, floor, slab on ground structure etc. were also analyzed by many researchers for varying temperature conditions. The effects of presence of salts in moisture transport and life cycle study of concrete based on its drying cycles was done. Artificial neural networks were also utilized for deducing a more logical solution for the hygrothermal problem in buildings. The study of different ventilation schemes for finding dominant moisture zones inside the building was done for various controller set points. Discussions on freezing of the moisture in building components thus affecting the building’s energy consumption were carried.

This review again suggests that analysis of various building components (viz. building material, interaction through walls and ventilation schemes) for developing thermal comfort inside building has been carried by many researchers. However, it again lacks studies in Indian context. Also, it has been seen that study of such sorts are full of complex computations and hence much work needs to be done in the direction of finding simpler ways of finding solutions, since by adopting efficient ways of expending energy, its use can be brought down by 30% - 80% (United Nations Environment Programme). The complex strategies can be simplified and help of the present day programming software like MATLAB, Engineering Equation Solver, which can be used to model various aspects of the building. It was also found that options of resorting to using renewable energy based HVAC systems can also be accessed. For this the aid of TRNSYS can be taken. Klein et al., (2011) and Ochs et al., (2013) carried out simulations using MATLAB and TRNSYS respectively, to
renovate a building and found that there is a lot of difference in modelling strategies of two software but results shows a close agreement. Gustafsson et al., (2014) compared energy performance of three HVAC systems for renovation through dynamic simulation using MATLAB and TRNSYS. Capability of TRNSYS was also utilized for analyzing comfort conditions through refined ventilation strategies (Rasouli et al., 2013). Dynamic simulation of different cooling strategies using TRNSYS was done (Salvalai et al., 2013). Again, Chargui et al., (2013) investigated the coupling of heat pump and cooling tower using TRNSYS. Chargui and Sammouda (2014) used TRNSYS to study effect of incidence solar radiation in all directions during winter season in the residential house. Also, as establishing of thermal comfort inside the building is an important aspect to be addressed and also calculations of this sort are very time consuming and complex the aid of computational fluid dynamics (CFD) can be taken so that impact of the existing technologies can be enhanced. This technique is also widely used, as explained in the next section for the computations of such sorts and thus can be utilized here too.

2.3 USE OF COMPUTATIONAL FLUID DYNAMICS FOR MODELLING THE BUILDING INDOORS AND OUTDOORS

Wind tunnel testing is a technique largely utilized to test the effects of wind on a model. Hence, was also largely utilized for testing flow of wind over the buildings, changes in wind pattern due to clustering of varied sized buildings in a locality and to find effective ventilation scheme for building. However, testing requires a wind tunnel apparatus and a carefully crafted prototype of a real life model to be tested. This in turn possesses a disadvantage as these requirements are very
costly and prototype development requires a lot of time and precisions for construction.

Advances in the field of computers have made it possible to integrate them with almost everything and also to utilize their capability as an efficient computing device. In the field of fluidics, Computational Fluid Dynamics (CFD) is also such a derived field which takes its worth from computational power of the computers. This technique is utilized to simulate almost all sorts of environmental conditions at very cheaper costs. Although, time consumed for computations, hardware requirements and level of knowledge required are essential aspects. Zhai and Chen (2005) had emphasized on use of CFD for speculating the building’s interaction with environment, by finding heat transfer (in and out of the structure) and air flow (inside the structure and outside) to compute energy consumption and particle dispersion. Further, evaluation for the best ventilation strategy using CFD was done by Tominaga and Stathopoulos (2007). Hence, it can be stated that various utilizations of CFD in the field of buildings is with respect to its thermal analysis (steady state and transient), ventilation analysis (air flow and contaminant dispersion) and in selecting the best location/orientation of built structure.

Despite being much used, CFD is still not being adopted by engineering masses due to the fact that computations involved are very difficult to understand and soft tools present are very vast and volatile in nature. Enormous regular practice is required to keep up breast with the skill. Also, computational time required is much as it tests patience of user for large real time problems. Despite the efforts of Wang and Malkawi (2014), where they had developed a new algorithm for reducing
computational time in CFD by reusing the earlier deduced results to generate new values.

This review introduced under audits the solution finding ability of CFD for buildings related issues, attempted by the different scientists. The work here is sectioned as the utilization of CFD bundle to recreate indoor and open air condition, for distinctively utilized structures like health centers, research facilities, apartments, monuments and so on.

2.3.1 ANALYSING AND ESTABLISHING BUILDING INDOORS FOR A BETTER THERMAL COMFORT AND DWELLING

The indoor environment quality (IEQ) is a relation between occupant and building’s health in regards to protecting human health, improving quality of life, and reduce stress and potential injuries (http://www.cdc.gov/niosh/topics/indoorenv/default.html). This depends on the illumination of indoors, quality of air entering and moisture ingress in building. Under and over illumination can make the occupant very uncomfortable in the same way as inadequate air exchange and damp indoors can do. There are also studies stating the occupant developing various respiratory disorders due to exposures to microbial growths inside the building. Not only this poor air circulation and improper ventilation scheme can also expose the space dweller to various particles dispersed due to different equipment, outdoor pollutants, fumes from the cleaning products paints and furniture etc. So, a proper understanding about such conditions can help occupant in achieving a better thermal comfort condition inside the room.
Wu et al., (2007) investigated the 3dimensional, displacement ventilation model for speed and temperature for two different cases of heat sources.

Villi et al., (2009) used CFD to investigate a building roof for its effect on cooling load by comparing different ventilation schemes for varying channel height (i.e. 3, 5 and 10 cm) with a non-ventilated structure. They used the “two equation model”, $k$-$\varepsilon$ model for the flow properties. The analysis demonstrated a clashing inconsistency among the lists of execution portraying genuine vitality sparing capability of a ventilated rooftop.

Ravikumar and Prakash (2009) investigated thermal comfort of an office space by varying the window opening values and aspect ratios. The results were utilized to find optimum window opening area and relevance of aspect ratio in establishing thermal comfort in researched space based on the predicted mean vote (PMV) values. The optimum window opening area ($a^*$) is a non – dimensional quantity $[a^* = \frac{(a \times b)}{(W \times H)}]$, where $a$ and $b$ are width and height of the window respectively, and $W$ and $H$ being the width and height of the wall, respectively.

Boukhris et al., (2009) investigated closeness between simulated and experimental values for a Mediterranean locale. The results were found to be contrasted with CFD and literature.

Huang and Tuan (2010) investigated a regional air-conditioning mechanism based on two areas, viz. impact of wind speed at entry, separation between the bottom surface and exit of a wind current flow cell, and to determine the reasonable
changes for making a superior technique for utilizing CFD. The experiments were validated with test results which were in great concurrence.

Hiyama et al., (2010) focused on joining building simulation with spatial distribution for analyzing the 3D wind stream utilizing a 3D CFD investigation. Omri and Galanis (2010) analyzed a numerically recreated ice arena heated by brilliant radiators utilizing the standard k-ε model with wall functions. The outcomes demonstrated CFD as an effective method which gives a nice depiction of air stream, temperature fields and heat fluxes in the ice.

Zhao et al., (2010) analyzed university cafeteria for indoor contaminants. This work used CFD technique to perform various investigations. In light of outcomes, it was reasoned that having an exhaust mechanism, partitioning cooking region with different areas and adding scuttles are of much use in overcoming such situation.

Taro Sasamoto et al., (2010) examined internal climate using CFD based on the individual contributing heat factors. For instance, a strategy for foreseeing real time temperature anytime in a room with few temperature sensors in view of contribution ratio of indoor climate was developed. The exactness of technique is analyzed by contrasting forecast with a simulation.

A comparative performance examination of displacement ventilation, air terminal devices etc. was done by Almesri and Awbi (2011) to anticipate thermal comfort in a building. The thermal comfort was looked at in light of comfort model of Center for the Built Environment, Berkley. It was found that semi-cylindrical
A Combined CFD and Finite Element Method (FEM) based transient simulation was completed for a hospital room. Multi-physics modeling was used to determine the efficiency of the conditioning unit. A dispersion and particle tracing models associated with coughing occasions, was produced to mimic the dispersal of microbes conveying infected droplets. The investigation for transient simulation gave proof of creation of zones (Balocco 2011).

Ravikumar and Prakash (2011) utilized CFD to investigate pressure drop and hence wind flow pattern; which essentially decreased and air temperature; which increased; through an insect proof screen (modeled using porous media approach) in a room. They also included impact of varying dimensions of wall openings and screen perforations in their investigation of thermal comfort.

In an alternate sort of investigation, Chen et al., (2012) used CFD for some other indoor applications differing from the usual. The particle sedimentation in an enclosed space with heat gains was investigated using the random walk model when system is located very close to walls.

Yi and Feng (2013) developed and tested relation between energy consumption monitoring techniques and CFD for buildings. The condition for analysis was the influence of microclimate on the building exterior.

In an another study by Fan and Ito (2014), summer and winter working of upgraded CO$_2$ demand controlled ventilation system combined with energy
convalesce ventilators was examined, using combined TRNSYS and Fluent. They developed a new computational model combining the building energy simulation and CFD. Owing to this merger, the sustained energy utilization of warming, cooling and ventilation were anticipated dynamically and accurately. It was also found that the aggregate energy utilization is lessened by 29.1% in summer and 40.9% in winter.

Zhuang et al., (2014) tried to analyze a very important aspect pertaining to leased/ rented office accommodation, as there is very less flexibility to alter the already placed ventilation arrangement. The team analyzed twelve leased spaces using CFD of which the model was validated by an already published experimental data for various furniture layout designs under various ventilation plans. The concluded that by merely changing furniture layout design in the space, a lot can be achieved as far as air flow, quality of air and temperature distribution inside the space is concerned, without rolling out any improvement in ventilation framework.

In an another examination, capability of CFD was put to test for analyzing air current pattern of an ultra-clean ventilation (UCV) installed for an orthopedic surgery operation theatre, in view of higher danger of contamination from uncovered profound injuries. Investigations were carried for the impacts of fissuring and shutting of entryways for 0Pa and 20Pa related to the adjoining chamber for different inlets and entryway inrush speeds were explored. The UCV framework works successfully in positive pressure (20 Pa) situation however fizzles when there is no pressure distinction between operation theatre and adjoining pockets (Lydon et al., 2014).
Cai and Chow (2014) utilized CFD to analyze heat discharged during the combustion of burning oil and wood inside a room. The results were contrasted with literature from full-scale consuming tests.

Hybrid ventilation framework and their components, reasonable for private applications were analysed using CFD by Turner and Awbi (2015). They modeled a wall-mounted convector unit suitable to control airflow rate (mechanically is needed, otherwise natural) and air temperature, that is a part of a current residential hybrid framework. The optimization of air flow lines and energy transfer were found using CFD model. They could propose some design alterations in the blades of window blinds for the benefit of energy usages.

Park and Battaglia (2015) inspected and validated the impacts of different natural conditions and room designs on air circulation and thermal conditions inside a room using CFD. The model was further added with furniture and additional thermal loads, for inspecting their impacts on air circulation and thermal conditions. They deduced that by and large, the addition of extra thermal loads didn’t alter the room dwelling. An identical analysis, using CONTAM, was carried out by Viegas et al., (2015) for a day care center for children.

A room was investigated for three ventilation situations: constrained convection, blended (regular + constrained) convection and influence of constant temperature and results were validated with the literature for authenticity. The computation was done using the RAST (Rahman - Agarwal - Siikonen - Taghinia) sub-framework scale model and shear stress transport with scale-adaptive simulation, k–ω model (Taghinia et al., 2015).
It is evident from literature that CFD is also an effective tool in carrying out analysis of indoor air quality, inside a built structure. Many different studies in this regards have been carried out by many researchers. These include study of the analysis of a cafeteria, office rooms, hospital facilities etc. with regards to the establishment of thermal comfort, particle deposition and checking the ventilation effectiveness etc. The continuing section further investigates use of CFD for the analysis of building outdoors.

2.3.2 RECREATING AND ANALYSING BUILDING FOR A COMFORTABLE OUTDOORS

Wind tunnel testing (as discussed in the earlier section) is used to analyze air flow over building exteriors. This also includes the estimations for air pressure impact on existing roads/ streets and pedestrians or street users. CFD can be a good answer for finding all these estimations and that too not only with precision and accuracy (can be a concern, sometimes) but also at any place and instant and for many variables only after proper validations. However, there are some costly experimental techniques which can be utilized for such analysis. Murakami 1990a and 1990b, studied and analyzed the impact of large buildings on wind pattern thus affecting the street users utilizing. He found that such analysis can be of great importance as such elevated structures can cause heavy wind flows on the streets.

Souster (1979) in his Ph. D. work initially modeled wind driven rain on built structures, utilizing CFD based simulations. The similar work was also done by Choi (1991; 1993; 1994a; 1994b), but only of building facades. However, many
practitioners have tried to extend the work of Choi to check its transient impact, but the modeling difficulty and computation time have caused a big hurdle.

Many researchers have researched the technique of working of CFD by comparing techniques such as Reynolds Averaged Navier-Stokes (RANS) with the Large Eddy Simulation (LES) (Murakami et al., 1992; Murakami 1993; Mochidai et al., 2002 and Tominaga et al., 2008), for turbulent flows. Tominaga and Stathopoulos (2007a, 2007b and 2008) had also worked substantially on CFD based simulations for isolated buildings. Some contribution has also been made by Kastner-Klein and Plate (1999) in understanding urban street canyon for dispersed pollutants around the built structures.

Apart from these studies many researchers like (Neofytou et al., 2008; Huang et al., 2008 and Lohner et al., 2008) have performed many studies pertaining to different complex urban situations.

Tominaga (2012) examined urban geometry for the direction of wind and its velocity in the light of CFD technique. He concluded that areas with low-ascent structures experienced lesser air exchange, high temperature and low speed whereas, regions around tall structures encounter low air temperature and higher air exchange resulting from the stronger winds due to higher elevations.

The capabilities of CFD have been elaborated for indoor applications in previous section but are not limited to such applications only. CFD, owing to its powerful computational power, has also being used to assess urban physics by predicting the air flow, temperature contours and other thermal conditions,
contaminant transportation and heat transfer around the buildings (Di Sabatino et al., 2013).

Balocco et al., (2014) transiently analyzed coupled heat and dampness exchange model, considering overall movements of population. The strategy was instrumental in assessing air quality, bargained value between working individuals and guests. The works also analyzed the presence of fumes and their permitted levels to preservation and support the artefacts and providing ventilation solutions for plants. They carried all this in compliance with national and international building indicators for conservations of old buildings and their precious heritage.

Wang et al., (2014) numerically examined a 2D radiation model for its impact with differing emissivity for same heat source assuming it to be a consistent temperature heat boundary. They found that radiation impacted the heat flux and ventilation rate. The results were also validated using a scaled model.

Ramponi et al., (2015) examined parallel streets with similar or dissimilar widths using CFD. The streets were analysed for air percentage and wind velocity patterns for slanted and perpendicular wind direction. The results were validated with the earlier published wind tunnel tests and were performed using grid convergence analysis.

Yau and Lian (2015) used temperature, wind velocity and surface temperature surrounding Malaysian Energy Commission, as input for air flow analysis around the building, using CFD. The outcomes demonstrated that wind current around building had the highest air speed of 0.69 m/s with an appreciable
buoyancy effect under no wind condition. They also concluded that buoyance impact was negligible for a wind flow of 3m/s.

Meng et al., (2016) explored built structures (numerically and experimentally) for the impacts of heat gains due to both convection and also combined convection and radiations. It was observed that Grashof number, ventilation rate, temperature and air speed for convective model was more than for combined convection and radiation model.

It is evident from this review that researchers are trying extensively to model effects of building distributions in the city and also trying to analyze the impact of high rise buildings on air dispersion in streets thus affecting the pedestrians. Similar effects have also being analyzed in the crowded low rise buildings. However, complexity in modeling such environments along with complexity of pollutant dispersion is still a challenge. The difficulty in modelling the situations, the computational time and computational capability required are still limiting factors.

2.4 CONCLUSION

Form above discussion we can conclude that building’s hygrothermal behavior has been one of the most discussed and studied topics for long. Many attempts have been made to cover extensively the discussion(s) of past and numerous ways adopted for the analysis of hygrothermal dynamics on various building aspects.

It is indeed important to know that many mathematical solutions are available which take into account, one or more environmental variables for the study of hygrothermal behavior of buildings. But, results thus achieved are more than
theoretical and not applied practically. Many of the researchers have tried to study moisture dynamics with respect to porosity of materials, thus applied on walls and roof of building. Some have tried to discuss the effect of salt content of moisture and consequently its effect on moisture dynamics of a building.

Also, a brief view of how the use of present day techniques like the various simulation tools like the MATLAB and TRNSYS software have enhanced results thus obtained and giving a more clearer picture of as to what exactly happens. Not only this, these packages have also made it a bit easier for user to model problem of their choice and analyze it. But choice of using these packages is still restricted to aim of problem and thus a variety of them are required.

However, it has also been seen that these techniques have not yet taking into consideration effects of heating and cooling systems, and other appliances installed in room/building. Also, use of concept of exergy as applicable for establishing building performance is scarce. It has also not been established that how closeness of buildings effect the moisture dynamics and thus affecting the thermal comfort. So, scope remains for investigation of building performance by exergy approach with the inputs regarding orientation of building and internal loads.

Also, methodology of CFD is discussed as an alternate way to comprehend the building performance. The various issues influencing health of building and occupant comfortable dwelling in building are discussed for spaces internal to building. The issues are establishing warm solace, analyzing ventilation framework for its viability, thermal gains and losses etc.
Constructing a building has a huge impact on environmental conditions exterior to building, which can really create a discomfort for street dwellers. The effects of rain and its direction on building with respect to moisture ingress and defacing of buildings is also discussed.

It has been found that CFD has much to offer than the conventional wind tunnel testing methodology. Much work is required to increase awareness and knowledge of CFD and to widen its scope. Also, issues like enormous time required for real time problem solving and to have more generalized governing equations for modeling and simulation needs to be addressed. The more this technique would be propagated more its scope will become.

So the scope still remains to perform the exergy analysis of built structure. This is primarily important to properly understand the building’s energy demand. Also, there is a lot of potential in renewable energy sources and thus can be used as a space heating alternative in the colder zones. The scope is also to investigate solar based HVAC systems on the basis of their exergy, for a built structure and also for utilization/application of CFD to choose proper HVAC system to be installed in an already constructed building.