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Breathing Walls Concept for Energy Efficient Comfortable Housing Using Natural Local Material

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Abstract: 'Breathing walls' concept is an innovative construction procedure that can help improve thermal comfort in houses utilising local material. The author designed this concept based on teaching civil engineering procedures, observations and understanding of construction practices in building industry through research and practice. One such accommodation was developed in 1992-93, another in 2000 and more in 2005. The practices were progressively improved and proved that a temperature drop of 10-15 degrees Celsius can be achieved by breathing walls concept without cost exceeding 5-10% for the overall project. Breathing walls concept can help develop comfortable eco-friendly low cost housing in the developing as well as in developed countries.

Keywords: Breathing walls, Eco-friendly, Low-cost housing, Developing countries, Low carbon construction, Natural construction material, Carbon footprint.

I. INTRODUCTION

The countries located closer to equator have inherited problem of hotter climates. They also receive comparatively lesser rainfall. Many of them are developing countries. In this paper, the communities are grouped into east and west in the geographical context and rich or poor in the economic prosperity framework.

Changing climate resulting in global warming, arising from extensive and uncontrollable use of fossil fuel has considerably magnified the thermal comfort problem. In winters, it is intensely cold and summers are intense too making newer hottest days records every year passing. Oil producing countries may be able to provide cheaper fuel to their citizens but the countries that must import fuel for energy are facing increasing energy cost thereby a difficulty to provide a comfortable living environment for their inhabitants. It is worth mentioning that extreme climates have resulted in many deaths all over the planet Earth. Many die due to lack of heating and many due to in sufficient cooling added with shortage of water to make problem more complex. Cost of energy and economic activity relationship is adversely affected by increasing fossil fuel prices. This aspect alone is forcing the poor communities to switch to alternate methods of making homes comfortable.

Cost of energy and carbon footprint are increasing in the construction industry in manufacturing construction materials like steel, cement, glass, plastics and numerous supplementary and complementary building materials etc. A quick look in the supply chain will show that before the building materials reach the site, much of fossil fuel energy has been used and consequent carbon has been produced. From the workers who start their day to reach the quarry site, may it be in remote areas of barren mountains or agricultural plains, transporting labour to site has initiated the consumption of fossil fuel and subsequent greenhouse gases (GHG). Transportation of raw material to the manufacturing sites and then the manufacturing processes and associated labour all add to GHGs. Finally, the material is transported to the construction site. During all these process times, the cost is rising due to increasing fossil fuel prices. Although scientific advancements have improved efficiencies in almost all manufacturing processes; for the poor, it is still unaffordable to use industrially produced products for thermal comfort. Hence, they must resort to more basic methods

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of construction for achieving thermal comfort. In the following paragraphs, you will note the impacts of use of fossil fuels and how innovative practises of local natural materials can counterbalance the production of GHGs in the construction industry.

Energy demand and its impacts:

The world energy demand and methods of generation has been estimated by International Energy Administration in their energy outlook report until 2035.

Year	OECD	Non-OECD
2007	245.7	249.5
2015	246	297.4
2020	254.1	336.3
2025	263.2	375.5
2030	271.4	415.2
2035	280.7	458
Total	738.7	2131.9

Table 1: Cumulative effect of demand; Units: Quadrillion Btu; Source: International Energy Administration [2].

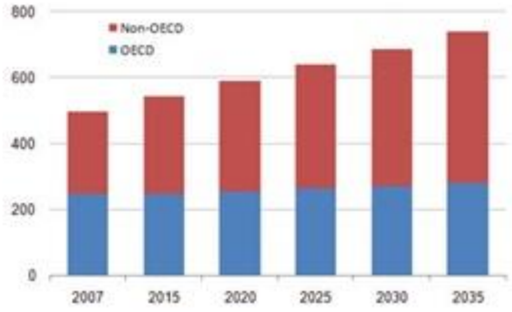

Figure 1: World marketed energy consumption.

Year	Liquids	Coal	Natural gas	Renewables	Nuclear	Total (Trillion kWh)
2007	0.94	7.92	3.86	3.46	2.59	18.77
2015	0.86	8.83	4.17	4.96	3.08	21.9
2020	0.82	9.83	4.97	5.82	3.59	25.03
2025	0.78	11.19	5.76	6.62	3.94	28.29
2030	0.77	12.91	6.43	7.34	4.2	31.65
2035	0.83	15.02	6.85	7.97	4.51	35.18

Table 2: Fuel spread forecast by share.

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Energy demand in OECD countries will increase by 14% whereas in the Non-OECD countries the increase is 84%. It is important to note that an analysis given in 1975 showed projected electricity demand in 2025 to be 31 Terawatts [9] whereas the latest projection by Energy Information Administration in 2010 International Energy Outlook [2] is quite closely in safe limits to the earlier estimate. This gives reasonable confidence in projecting scenarios and the mechanism behind the analyses. However, the overall cumulative effect is much higher as can be noted in Figure 1, Table 1 and 2.

Oil production:

The present global oil production by developed countries is about 33% as compared to twice the consumption, and is reverse for the developing countries. Developing countries consume 2 barrels per capita per annum as compared to 14.2 barrels per capita per annum by the developed countries, and alarmingly high 25 barrels per capita by United States of America. It can be well understood that economics of supply and demand phenomenon is at work however the rest of the world pays more for the same oil as compared to an American citizen. Table 3 below shows world crude-oil production versus demand in 2000 (bn barrels).The oil produced for warming houses and buildings can be saved if the concept of breathing wall construction is implemented globally as a matter of policy.

Investigations in the history of different civilizations on the globe has shown that the inhabitants of the world have long history of using natural materials for housing need. This is no different for the people living in developing countries like Pakistan, India, many Asian, and African countries. The use of local materials as well as various biological waste in one form or the other for housing and energy needs had been in practice since centuries and even today in many parts of the world.

However, using natural materials for building a house has few serious problems that needs to be addressed before incorporating any policies associated with the use of natural materials for domestic or industrial purposes. This paper will focus on developing countries that do not have enough GDP/capita to invest in thermal comforts. Results of this research can be tailored to suit the requirements of the colder regions as well.

Fate of the poor's houses in floods and earthquake:

This is a case study from Pakistan. A country with four seasons and heavy rains in monsoons. Disaster Emergency Committee (DEC) UK [14], report grades Pakistan as 125th in 169 countries in human development index. With unprecedented monsoon rains in the north and the plains of Punjab, Sind and Baluchistan the Indus river gets flooded very often resulting in homeless people due to floods [14]. Statics by DEC show that during the worst floods one fifth of the country was affected with a death tool of about 2000 lives. The main reasons are adverse effects of rain on mud plasters houses that have not been designed by any professional in the construction industry. Clay based mortars are a good plaster and binding material if it stays dry. Any excess moisture in clayey soils suffers shear failure resulting in collapse of wall.

It can be very clearly seen in photo 1 that in floods or earthquake, the load bearing walls collapse resulting in the collapse of roof. When the roof collapses then the occupants gets, trapped and killed. If the pillars are made in Reinforced Cement Concrete (RCC) and the roof rests on beams, then the chances of collapse of wall reduces considerably. It is strongly recommended that all rehabilitation and regular constructions shall always be designed in RCC framework. However, bricks or cement blocks may be bound in local clayey soils. Walls can be filled with any material that serves relevant purpose. This is evident from the same location under same circumstances Photo 2 is from the same location and time as details in photo 1, that show houses built in cement blocks and cement mortar tend to stay as higher moisture content in cement can only cause any hydration process to continue giving more strength.

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Photo 1: Mud plaster adversely affected by rain.

Photo 2: Cement Block construction is unaffected by rain.

Initial Concept Development 1987-92:

In any learning process, observation and experiments are key features for any research. The author has spent much of his time in various locations in Pakistan with extreme climate conditions. In summers, a small town known as Risalpur in the Khyber Pakhtoon Khwa (KPK) normally receives more sun and temperatures in summer exceeds 48°Celcius. Single story houses as well as double storey houses made in cement mortar and bricks tend to be very warm making living spaces unbearably warm. Without air conditioner, it is not possible to maintain thermal comfort. Continuous use of air conditioners is expensive. The author noted that walls and ceiling exposed to direct sunrays were far warmer than those that did not receive direct sunlight. It was also noted that temperatures during night would fall considerably due to dew effect and absence of sunlight. However, the energy absorbed by the concrete structure would keep the houses warm, hence sleeping inside the rooms without an air conditioner was not possible even at night. On the contrary, the outside temperature at night would fall instigating the locals to sleep outside at night under the sky or shade. An experiment was conducted for the single room with no air conditioner. An extractor fan was installed in the one room flat. The windows on the opposite wall to the extractor fan were kept open for air mass to be replaced giving lesser resistance to airflow. All openings on the wall with extractor fan were closed to ensure that complete air cushion is replaced by the cold outside air. The extractor fan would operate from sunset to sunrise, this helped in replacing the

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warm inside air from the cold outside air. This replacement of inside air also cooled off the inner walls and absorption of moisture further lowered the inner temperature. In the morning, all windows were closed with glass painted in black colour and further covered with dark curtains. The idea was to ensure that no direct sunlight enters the room. The extractor fan consumes lesser energy than an air-conditioner. The experiment was repeated on daily basis for three months. It was noted that the thermal comfort of the room increased considerably keeping the temperature in range of 19-22°C during the day. The deduction from this experiment was that direct sunlight on walls and ceiling were conducting thermal energy to inner environment. However, the walls on the shade side where comparatively cooler. This formed the basis of the design of breathing walls concept.

In 1992, in one of the projects for a military community in Pakistan, a 10000sqft club house was designed in a conventional manner. The local climatic conditions demanded an air-conditioned environment. The community was donated with an air conditioning plant. However, the plant's capacity was just half the requirement and funds were not available for an additional plant. This challenge had created an opportunity for improving the design of the club house. 'Necessity is the mother of invention' is a common proverb; an addition of this phrase will complete the proverb 'and innovation is the father'. This shortfall of air conditioning plant presented an opportunity to improve the design midway during construction. The idea of breathing wall was created and applied by addition of a 9 inches' wall on the sun-side of the building and a soil filled roof top. This created an environment of protecting all walls and the roof from direct sunlight. The problem was resolved partially and the structure stands today saving recurring energy cost and the carbon footprint.
A similar concept was adopted in designing a house in the year 2000 using a shade instead of a soil filled roof. This was a well organised practice and yielded better results.

Introduction to Area of Jhal-Magsi (Project location):

Subsequently, a similar opportunity rose in a place called Jhal-Magsi in Pakistan midlands during the construction of M8 motorway project. M8 motorway links the north of Pakistan to the south and further linking the country with Gwadar port in the Arabian Sea. This project is part of China-Pakistan-Economic-Corridor (CPEC). The author was assigned duty of implementing M8 project in the tribal community that had extreme climatic conditions.

Jhal-Magsi is located on the border of two provinces in Pakistan (photo 3). It has very little rain fall and comparatively warmer climate. With little rain fall in the area, the inhabitants rely on cultivation with water from tube wells, and a small river that can be very violent during monsoon (photo 4). Most of the poor people work as farmers toiling the fields of the landowners. The population was about 4000 in the nearby villages of the project area. Official statistics show about 92% of population is associated with agriculture, 53% males, and a population density of 30.4 per sq. km. Average household size is 6.8 with 12.3% literacy ratio. M8 motorway is the main highway under construction. Nearest city is about 70 miles.

The temperature ranged between 45-47 degrees Celsius during summer days and above 36 at night. The author was project director on this project with authority to improve designs of ancillary structures not relating to the motorway. The accommodation for the work force was designed with improved functionality by the author. Local material was used to construct the camp. The camp stands today surviving the terrible floods that washed away the entire village in 2008-09.

This paper is based on simple and common practices in rural areas in developing countries for communities that may be living below poverty line [12].

In author's opinion, the definition of poverty can be rephrased as 'Poverty can be defined as a financial situation when any human chooses to deviate from the ethical and moral values and corresponding actions for acquiring food to maintain the relationship between body and soul'. Men or women in any culture or religion normally violate morality

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due to poverty. This may be because of political, environmental or any other reason. Morality is the first victim of poverty in most cases.

Constructing and living in a comfortable house is everyone's dream. For this reason, this paper will restrict to 'comfortable and affordable dwellings for the poor'. Results from this work may be applied for multi-storey buildings as well where possible. Official statistics show 22% of people live in extreme poverty, they survive on less than $1.25 (US) per day, 23% of people are undernourished and 25th highest infant mortality rate in the world [14] in Jhal-Magsi.

Photo 3: Project location: Jhal-Magsi.

Photo 4: Aerial view of project area. Courtesy: Google maps.

Thermal Comfort:

It is imperative to improve indoor environments to optimise performance depending upon the function (work or leisure). The basic idea is to maximise human resource output. At leisure or home when resting, thermal comfort ensures recuperating energy by a sound sleep in a comfortable room temperature, low noise levels, and quality air circulation; to ensure better oxygen levels for recovering lost body energy from the previous day's work. This will ensure an optimised output at work resulting in improved life style and consequently improved GDP for any country. This is more pronounced for very old and very young and for infants. An investigation carried out by a team of researchers at Rensselaer Polytechnic Institute in the USA has shown a direct and measurable relationship between individual comfort control and efficiency by use of environmentally responsive workstations (ERW). The results had shown an increase in output by 2%. Human body is an energy system that responds to internal energy levels to corresponding outer environmental conditions. Controlling perspiration, temperature and humidity, a human body can function at optimum levels.

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History of Materials in Construction:

The quest of a safe, affordable and comfortable home dates back to 7th century BCE [7]. It actually would have started with first family on planet Earth but those who believe in the Great Floods also accepts that much of manmade houses would have washed away without leaving any evidence. Natural and readily available shelters were a common dwelling to offset adverse climatic conditions [7]. Timber, Clay and subsequently clay-lime mortar using stones is the oldest cementing and construction material. Steel, plastics, glass, Portland cement etc are now a common construction material.

Photo 5: Bamboo purlins and mud plaster.

Material and their uses

Ingredients found in different mortars in the eastern world are timber, clay, sand, lime, cow dung, hay, rice husk. Portland cement and few more variations are a common use items in construction. Materials used in rural areas are either burnt or sunburnt bricks and/or commonly renewable materials including timber; and different types of soils in several combinations with some addition of hay, lime, and cow dung etc. depending upon the cost and convenience of supply. Uses of the above materials are shown in photos 5-8.

Photo 6: Thin bamboo walls and mud floor.

Clay: Clay is used as a binding material in mortar to give a mud like paste for brick laying and plastering in the east and in poor communities. Adhesive quality, workability and strength makes clay the most popular and reliable ingredient in mud house construction.

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Lime: Lime is a well-known construction material used since man realised that it reacts with water to harden when used in combination with clay. Lime is also used in making cement. The quality of giving strength gives lime a priority as a construction material. Lime also uses much less CO_2 than cement based mortar.

Photo 7: Stone walls and mud floor.

Cow dung: Cow dung is used in most of Asia and Africa as an adhesive agent in clay mortars [8] this has also been tried to place in-situ lining in field irrigation channels with ease. Wooden guides are used for lining. It was tried with natural clay and clay mixed with cow dung [6]. Apart from other uses it is also used for burning when dried like a pie knows as 'cow chip' [6].

Photo 8: Timber pillars and beams, bamboo purlins, hay and hemp used as walls.

Hay, hemp and rice husk: Hay, hemp and rice husk etc. are all organic and a crop waste. It has been experienced that these and similar bio waste products are commonly used for enhancing integrity as clay tends to develop cracks on drying. Fibres from similar organic materials are very safe and economically viable for achieving better plastering results. One more advantageous aspect of such organic waste is that it stores thermal energy. In one of the buildings, cavity walls were filled with rice husk as a deviation to the original concept and the occupants complained that in summers the rooms become comparatively warmer than outside temperature during day and is quite warm even during the whole night. This result has encourage using hay, hemp or rice husk to be used in areas that have colder climates and energy is used in warming the household.

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Bricks: Common bricks either burnt or sunburnt are made from calcareous soils. The common practice of producing bricks will not be discussed. In most of the communities in the developing countries in urban areas, only burnt bricks are used for construction. However, in rural areas, depending upon the economic prosperity, communities use either sunburnt bricks or burnt bricks if they can find or afford it. Few also use stones trimmed to requirement in place of bricks.

Sand: Sand is commonly used in filling up foundations for load bearing and filling purpose due to its incompressible nature. Sand is also the main ingredient in the concrete and clay mortar.

Portland cement: Portland Cement Mortar is a commonly used in construction because of its strength as compared to other mortars. Portland cement is a common product having a mixture of 75% of limestone ($CaCO_3$) and 25% clay by weight [8]. On adding water the initial exothermic reaction (200 W/kg) stays for about 30 seconds and later drops to 1W/kg after an hour. However, after achieving initial setting the process is detected even after 30 years. Extra strength is important in large civil engineering projects but is it important at a domestic scale?

Concept of Breathing Walls and Background

This design emerges from author's personal experience of living in the severe higher temperature environment in Pakistan. The design is simple and logical. This design was developed because of understanding effects of temperature on different materials. Several materials have been used in the past to offset thermal conductivity through the construction material or even to store thermal energy. The worst medium for thermal conductivity that responds in the shortest timeframe to temperature is air. This is the basic principle. The design is based on double-wall configuration with 2-3 inches' gap between inner and outer walls. Standard bricks (or cement blocks) are used with mud and hay mortar for brick bonding and plastering. The configuration gives a comfortable living environment without any extra energy requirement for thermal comfort. During day, the outer walls get heated from the direct sun rays. Solar heat absorbed by the outer bricks warms and expands the air in the gap reducing the density of air and the ability to transfer heat to the inner wall. At night, the temperature falls outside thus cooling the air inside the walls as well. This temperature drop contracts the air and creates a partial vacuum in the gap; helping outer cold air to enter the walls through ports on the top layer of the walls. The gap between the walls helps contain the moisture and cold air during the day repeating the cycle. In addition, the wind catchers also help in developing limited cooling effect. Sketch 1 in Figure 4 gives a schematic diagram of how breathing walls work. The direct sunlight is absorbed by the exposed brick wall. The conduction depending upon the density and the material absorbs the energy and conducts it through the medium. The air in the cavity receives this energy and begins to expand. The expansion increases the volume and reduces the density and associated thermal conductivity. This expansion pushes the warm air outside the wall through the openings left at the upper end of the wall. Increase in volume also reduces density of air and proportionately reduces thermal conductivity capability of air. At night, when the temperature falls, the cooling takes place and the inner air also cools resulting in contracting and creating a vacuum in the cavity. This vacuum helps the outside cold air to enter the wall cavity with the moisture content thus cooling the air inside the cavity. In addition, the wind catchers that are common in the southern Pakistan can help regulate the fresh air at night. In the morning, these wind catchers can be closed. Wind catchers can be embodied in the structure by using sunburnt bricks and they work on the reverse phenomenon of fire place exhaust/chimney.

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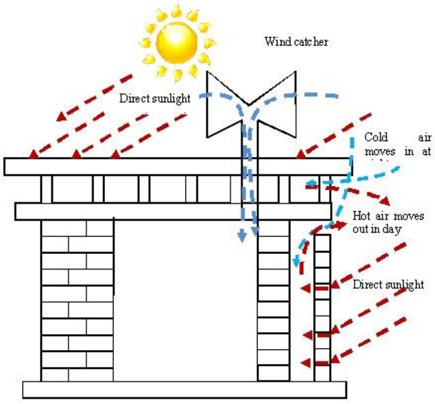

Figure 4: Sketch showing the breathing wall concept.

Analysis of Breathing Wall practices

This concept was based on simple logic and has proved it effectiveness. We can now analyse how it works and if it can be adopted as a standard practice to reduce the carbon foot print in general and to help the poor community. If it becomes part of the building code at international level, then it can be effectively implemented globally cutting down cost and improving thermal comfort. At an EU level, there are some very tentative steps to harmonise building codes like BREAM etc. but this has progressed very slowly. Codes should have some variation for climate and availability of building materials.

It can be seen in table 4 that brick's conductivity is 0.72, oak is still better with 0.17, glass is even better with 0.043 but the best material to create a cavity that resists thermal conductivity is the air with just 0.026. Further, urethane rigid foam is equal in thermal conductivity with air; however, producing foam and using it is still expensive for the poor and problems of disposal at the end of its life. Also, it will have embodied energy and transportation cost involved apart from the addition of pollution to environment.

Material	Thermal Conductivity	Material	Thermal Conductivity	Material	Thermal Conductivity
Diamond	2300	Silver	429	Copper	401
Gold	317	Aluminium	237	Iron	80.2
Mercury	8.4	Glass	1.4	Brick	0.72
Water	0.613	Human Skin	0.37	Wood (Oak)	0.17
Helium	0.152	Soft rubber	0.13	Glass fibre	0.043
Air	0.026	Urethane Rigid foam*	0.026		
Source: *embodied energy, cost of material and transportation					

Table 4: Thermal Conductivities of Some Materials at Room Temperature.

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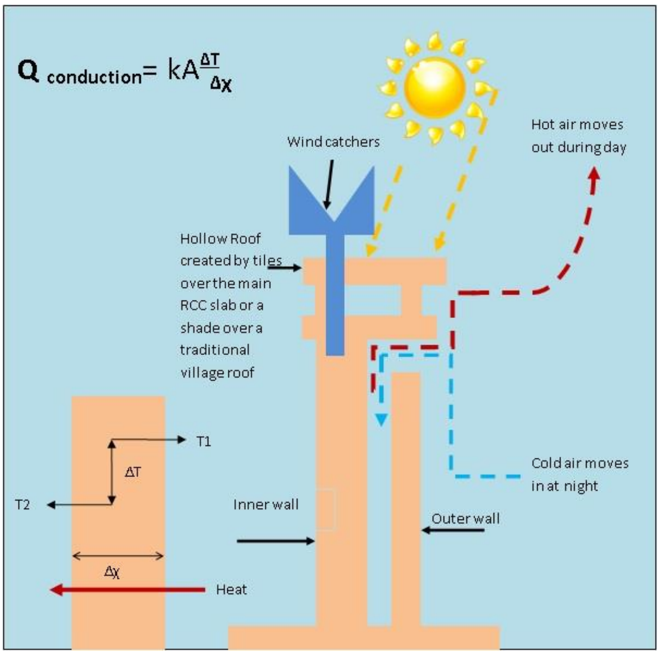

Table 5 gives the emissivity value of the materials. It can be seen that choice of colours can also play a vital role in reducing the temperature of the walls exposed to the direct sunlight. Many vernacular architectural styles from hot countries already do this – southern Spain; Greece Red brick can be improved to have a lighter colour that may absorb lesser thermal energy. Similarly, in concrete walls admixtures can be used to reduce concrete density and further reduce the coefficient of thermal conductivity. It is a matter of choice with respect to location and climatic conditions that engineers and architects may design to get best response from the materials and the colour combinations.

Material	Emissivity	Material	Emissivity	Material	Emissivity
Aluminium foil	0.07	Black paint	0.98	wood	0.82-0.92
Anodised Aluminium	0.82	White paint	0.9	Soil	0.93-0.96
Polished copper	0.03	White paper	0.92-0.97	Water	0.96
Polished gold	0.03	Asphalt pavement	0.85-0.93	Vegetation	0.92-0.96
Polished silver	0.02	Red Brick	0.93-0.96		
Polished stainless steel	0.17	Human skin	0.95		
Source: [13]					

Table 5: Emissivity of Some Materials at 300° K.

Storey Community Housing:

In community housing the same method can be used by making multi-storey houses. The framework can be made in reinforced cement concrete and the walls may be filled in by using cavity method. For maintaining strength from the exposed faces vulnerable to weathering and to maintain the thermal comfort or reducing the air conditioning

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requirement, outer walls may be plastered in cement mortar. Clay-lime mortar may be used for brick laying for the inner walls and may be plastered with cement mortar for finer finish. Lime mortar can also be used for inner plaster.

Application in High Rise Buildings

For high rise buildings in developing countries it is important to use lighter and stronger material for walls. The construction industry now produces many admixtures that can give lightweight concrete. Thin RCC cavity walls can be used in high rise buildings. Cavities shall be used for services like water and electricity supply.

Thermal Comfort in high rise buildings increases by filling the cavities in cold weather locations. The filled material should have capacity to retain temperature, this can be achieved if cavities are filled with rice husk, hay or hemp packed in small bags for easy handling. Almost all hemp and hay type materials have the capacity to stores thermal energy. It is important to note that hemp, hay or rice husks are better off in natural packing as compared to pressed mechanically; as it may increase thermal conductivity with the increase in density. When using natural materials in cavities it is important to be aware of any insect infestations or fungus; hence the cavities must be kept dry. Locations that have comparatively hotter climate shall leave the cavities empty for air. It is important to note that air has the least thermal conductivity that further decreases with increase in temperature. The temperature rise in air increases the volume and forces the air out of the wall resulting in reduced density and decreased ability of thermal conductivity. This leaves the inner walls comparatively cooler because expansion is also a cooling process. However, in cold areas, all the walls and the roof should have cavities for better thermal energy storage.

II. RESULTS

In the structures that were built on this concept by leaving cavities to air rather than any other filler material, a temperature difference of 10-15°C has been noted. This may not be a concluding result because it will depend on many other meteorological factors e.g. wind speed, moisture content in the structure, humidity and rain fall. However, engineers and architects may try other variations as well and choose the one best suited for that environment. Apart from the thermal comfort, the cost was quite less as most of the brick laying was completed with clay mortar.

III. IMPLEMENTATION OF CONCEPT

The world has seen many different concepts in variety of discipline namely politics, economics and engineering to name a few. No concept is bad if it has rational and follows the laws of nature. The success in solving the global energy problem lies in a combination of approaches very similar in the manner that nature follows.

IV. CONCLUSION

Realizing the need of discovering, designing, implementing comfortable and affordable living environment, this paper is being presented as author's original research experience in designing and constructing energy efficient housing for the poor. It is possible to use results from this research to design and construct multi-storey buildings. This procedure can be accepted as a standard practice with the developed and the developing countries due to its inherent advantages of reduced GHGs in construction industry. This alone will reduce the carbon footprint to a considerable extent. In most of the analyses carried out for construction industry, the embodied energy is seldom considered for calculating carbon dioxide. Breathing walls concept has emerged as a logical development from the experience of construction; the suggested method for multi-storey buildings is recommended to the architects and the engineers. Any addition or variation is possible depending on the affordability, ingenuity and aestheticism of the designer or/and the user.

Engineering and precisely civil engineering is to strike a fine balance between strength, aesthetics and the cost; additionally, now I will like to add another aspect of sustainable environment. Switching to breathing wall concept can

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help us reduce the cost of the house and add to the improvement of the environment together with reducing our energy demand in the developing and the developed world if it can be adopted as a standard practice for providing community houses to the needy. Planet earth has transformed into global village because of scientific advancements even then we have failed to provide a respectable and safe shelter to the poor who toil sweat to produce that grain of wheat that becomes the life for us. I will thank you for your patience and will conclude with the quote '*our ignorance is not so vast as our failure to use what we know' [3]*

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