Ferrocement in Eco-Housing System

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Received: 24.12.2013 Accepted: 16.01.2014

Abstract- Urban development is a key consumer of energy, a structural system based on generic services facilities is introduced by Al-Rifaie and prefabricated ferrocement cavity wall and roof panels within the proposed system present a series of possibilities for the solution of building construction at maximum reduction of the electrical energy. The energy required to run the building using the proposed ferrocement construction system and the use of traditional method of construction is determined. It may be concluded that the modern method (ferrocement eco-housing system) is able to produce very energy efficient dwellings.

Keywords- Eco-Housing, ferrocement, renewable energy

1. Introduction

Urban development is a key consumer of energy, in other words, a basic product of environmental pollution and therefore, the relationship between several elements such as building materials of natural and manufactured building materials and renewable energy sources and energy sources depleted should be determined. Since the green building is always based on the concept of the 3R (reduce, reuse, recycle), it doesn't matter which te‡chnology that would be adopted [1]. Actually, it has been reported that it is not difficult to achieve a green building, this is clear through many success accomplishments in this field. As a matter of fact, the golden point of this success is the architect's mind, because merely it needs implementing simple and practical technologies which can be selected through deep understanding of the objective and the local conditions. Fenga [2] clarified that the green buildings' forms and the combined technology will be always changed, because the green buildings must meet the local features, which may refer to the local natural, economic, social resources and to many other conditions. It has been known that green building can be defined in many forms. Using ecologically based principles [3], green building can be defined as the healthy facilities, which is designed and constructed in a resource-efficient manner. It is worth noting that green building has been used as a term interchangeable with sustainable building and high performance building. Robichaud and Anantatmula pointed out that there are four pillars of green buildings ,i.e. minimization of impacts on the environment, enhancing the health conditions of occupants, there turn on investment to developers and local community, and the life cycle consideration during the planning and development process [4]. Common elements of these definitions are: life cycle perspective, environmental sustainability, health issues and impacts on the community [5]. Despite of massive and up to date technologies that have been implemented to produce more effective sustainable buildings, green building is considered to have a major goal which is mainly to minimize the whole effect of the constructed environment on the human health and the natural environment through the following objectives of the sustainable building: (a) Life cycle assessment (LCA), (b) Energy Efficiency and Renewable Energy, (c) Water Efficiency, d) Environmentally Preferable Building Materials and Specifications (e) Waste Reduction, (f)Toxics Reduction (g) Indoor Air Quality, (h) Smart Growth and Sustainable Development, (i) Environmentally Innovative materials and services [6]. The satisfaction of building users is closely related to thermal comfort which is a complex dynamics of temperature and humidity [7–9]. This has attracted extensive attention from researchers to simulating and measuring the thermal comfort level in green building compared to conventional buildings. As a result, the range of room temperature required could be proposed [10,11]. Psycho-logical, physiological, cultural and behavioural factors may play a role as well which attributes to adaptive thermal comfort [12–15], whereas a survey instrument for the identification of problems in respect to energy-efficient design which affecting the occupants' comfort was developed by Huat and Akasah [16]. A complete solution to meet energy demand of an Indian village by renewable energy sources was presented by Singh and Mishra [17], where the optimization (biomass + solar) was done by Hybrid optimization Model for Electric Renewable (HOMER) which provides a better understanding of utilization of renewable resources in an isolated /off grid locations. The upgrades and expansions of primary feeders from normally closed loop to a mesh arrangement have been explored for building a friendly environment for renewable energy resources [18], where the effects of the interconnection of distributed renewable energy resources (DER) on a meshed distribution network under normal and abnormal operation conditions were investigated.

As a matter of fact, the majority of homes in Iraq are built using traditional masonry construction for walls. Now these days in Iraq a large number of homes with their walls are built either by concrete block or by stone block constructions. Sixty years ago clay brick jack arching was the method of construction for slabs and/ or roofs and since then most of homes their slabs or roofs are reinforced concrete constructions. Generally, in the last three decades, ferrocement has been developed and adopted significantly in many applications, and this is obvious through the advanced techniques and design theories that have been used. Production of ferrocement members, like roofs, walls as well as floors have been tested experimentally at the Building and Construction Engineering Department of University of Technology, Iraq. Building system must not only cope with strengths and flexibility requirements, but the insulation value is of high importance. In summer heat must be kept outside as much as possible. The great demands of electric power due to heating and air-conditioning systems require control to make maximum reduction of the electrical energy. The increasing demand to low energy houses has led to the introduction of so called green houses. Improving the thermal performance of any building is considered as one of the major and important goal through adopting green or eco-house principle. This can be achieved through keeping the heating or the cooling energy consumption in low levels during the year. Green or eco-houses may then be built using the proposed ferrocement system with a well-insulated. Simply made of cement–sand mortar of a 10-50mm thickness, and using layers of fine wire meshes as a reinforcement, with or without skeletal reinforcement, a thin reinforced concrete, i.e., ferrocement [17-22] is considered to have a great potential. Ferrocement is an excellent construction material due to its mechanical properties, and low cost, and it is considered to possess high cracking strengths. Cement mortar is a material used in construction of ferrocement which is a cement composite material made up of Portland cement, sand, water and sometimes admixtures [23-31]. It is well known that, in order to save annually hundreds of kilograms of emitted CO_2, it is necessary to adjust the thermostat of the heating or the cooling systems by just 3 degrees, through turning the heat down and the cooling up. A structural system based on generic services facilities is introduced by Al-Rifaie and prefabricated ferrocement cavity walls and hollow roofs within the proposed system [32] which introduce a possible solution of building construction at maximum reduction of the electrical energy and the modern system provide excellent thermal insulation. Reducing the amount of energy required to run a building means reducing the emissions of carbon dioxide. The emissions of carbon dioxide depends on the fuel source for kWh. If it is wind, solar, hydroelectric or nuclear, then zero pounds of carbon dioxide are created. To estimate CO_2 emissions per kWh, the U.S. average in 2005 is adopted in the present work [33]. The average is approximately 1.31 pounds of CO_2 per kWh generated. The energy required to run a building using the proposed ferrocement structural system and the use of traditional methods of construction is determined and the possibility of using the renewable energy production rather than energy depleted is presented.

2. The Proposed Modern Method of Eco-Housing Construction (Ferrocement System)

A structural system [34] for ferrocement construction based on generic services facilities is introduced. The construction concepts as shown in Figure 1 lend themselves readily to rapid delivery and assembly of flexible accommodation where designs can be adapted to meet local requirements for both structural performance and thermal comfort as demonstrated. The structural part of the house consists of three basic components; the base, walls, and roofs. An integral framing concept allows for overall above-ground structural integrity which considerably exceeds that of traditional methods and this minimizes the need for ground works in all. The membrane construction also enables new concepts in passive downdraught cooling to be explored where airways are incorporated within structural features as wall cavities. Potential applications of the system include sustainable solutions for disaster relief and secure accommodation.In comparison with the traditional construction systems, ferrocement has many benefits, which can be summarized according to the following perceived advantages:

1. Controlled manufacture, i.e., very high quality control.
2. Pre-Fabricated products and fast construction.
3. Reduced labor requirements and manpower can be easily trained at site.
4. Cost reduction, 15-50% cheaper than conventional techniques.
5. Less maintenance and improved safety.
6. Reduction in dead weight, 50-75% lighter than conventional techniques.
7. Reduced wastage.

8. Basic raw materials are available.
9. Reduced energy use for heating and cooling.
10. Ferrocement is very adequate to resist the impact, due to its higher ability of absorbing impact energy as compared with the conventional reinforced concrete, and the damage is localized at the impact zone [35].
11. The ferrocement building components can withstand direct fire with a temperature values up to 756 oC for a period of 2½ hours with no segregation in the surface of the elements facing the fire [36].
12. Rehabilitations and strengthening of reinforced concrete elements by using ferrocement technique is very effective in increasing the cracking and ultimate loads and increasing the impact resistance [37].

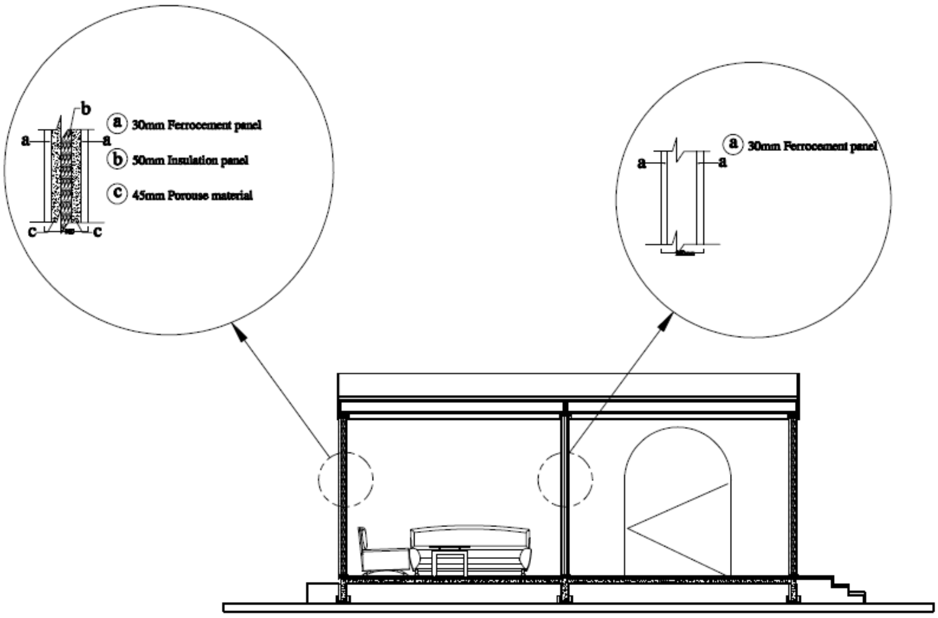


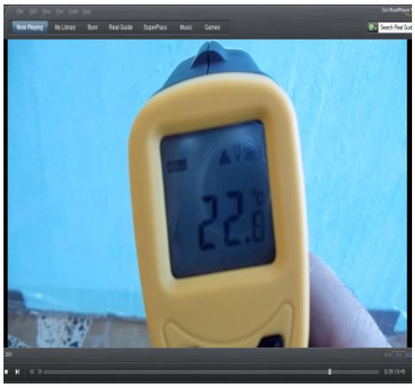
Fig. 1. The proposed ferrocement system for house construction.

Building system must not only cope with strengths and flexibility requirements, but the insulation value is of high importance. In summer heat must be kept outside as much as possible. The structural system for ferrocement construction based on generic services facilities and insulating these structures involves the application of insulation material by means of cavity wall which consists of two leaves (sides) of ferrocement separated by a wide space and ferrocement hollow slab construction. Insulation material is used through a cavity walls and hollow slabs. Test was carried out on panels with insulation elements as shown in Figure 2.

The obtained results as shown in Figure 3 showed that cavity wall construction consists of two leaves (sides) of ferrocement, separated by air space and the insulation elements positioned as shown gives a very good solution for insulation as shown in the figure, air is still the actual insulator, consequently reducing the demand to electrical energy.

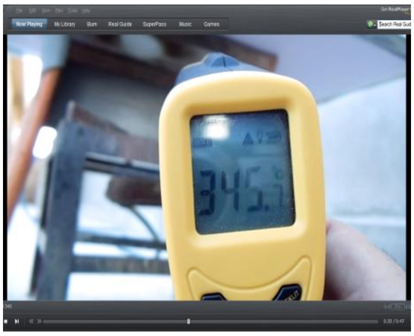
Fig. 2. Ferrocement insulation panels.

Front face 230.1^{o}C



Rear face 22^{o}C 22

Fig. 3a. Heating measurements of cavity ferrocement panel representing walls.



Lower face 345.1^{o}C

Upper face 28^{o}C

Fig. 3b. Heating measurements of horizontal hollow ferrocement panel representing slabs.

As stated earlier that the structural system which consists of two leaves (sides) of ferrocement (30 mm each) separated by a wide space and insulation material is used through a cavity wall. Test was carried out on a ferrocement cavity wall panel with insulation panel placed between the two leaves of the wall panel as shown. The obtained results showed a very good solution for insulation, (air is still the actual insulator), consequently reducing the demand to electrical energy. Cavity wall insulation may also be used to reduce heating/or cooling losses.

3. Energy Assessment

In home construction there are two main areas have to be in focus: energy efficiency and construction efficiency. The present work concern with energy efficiency. In fact energy performance is highly prioritized in the development of building systems and construction productivity. The obtained results are compared with the proposed ferrocement construction method. Five kinds of traditional construction methods are:

- Method 1; concrete block walls and reinforced concrete slab/ roof.
- Method 2; clay brick walls (with cement mortar) and reinforced concrete slab/ roof.
- Method 3; stone walls and reinforced concrete slab/ roof.
- Method 4; clay brick walls (with cement mortar) and clay brick arching slab/ roof.
- Method 5; ferrocement system.

It may be noted that the materials used for outer and inner wall finishing considered through the determination of heating and cooling loads are cement mortar and gypsum plastering respectively. Also, 100 mm concrete lining and 50 mm tiles with cement mortar for ground finishing and 150 mm soil and 40 mm tiles for roofing are considered in the determination of heating and cooling loads.

4. Residential Heating and Cooling Load Calculation Requirements

For assessing the energy efficiency of a residential house, the design temperatures for use in performing load calculations considered in the present work are:

- In winter: Indoor = 25 ^{o}C , Outdoor = 0 ^{o}C
- In summer: Indoor = 23 ^{o}C , Outdoor = 57 ^{o}C

To determine the annual heating and/ or cooling energy consumption of a residential home using various traditional construction methods usually used in Iraq and most of Middle East Countries, the following formulas are used in the present investigation [38, 39].

4.1. Heating Load

$$Q_p = U_p A_p(t_i - t_o) \quad (1)$$

Where:

Q_p = Heat Loss from the panel, Watt
A_p =Net Area (normal to heat flux direction), m^2
t_i = Indoor temperature(desired temp.), ^oC
t_o = Outdoor temperature, ^oC
U_p = Panel overall heat transfer coefficient,
$U_p = 1/\sum R_{th}$, Watt/ $m^2.^oC$.
R_{th} = Thermal resistance(for each layer of panel), $m^2.C^o$/Watt
$R_{th} = L/K.A$
L = Panel layer thickness. m
K = Thermal conductivity (for each layer according to the material used), Watt/m. ^oC
A = Area (normal to the heat flux). m^2

4.2. Cooling Load

$$q=U.A.CLTD \quad (2)$$

Where:

q = Heat gain (from walls and roofs), Watt
U = Wall overall heat transfer coefficient, Watt/ m^2. ^oC
A = Area (normal to the heat flux direction), m^2
CLTD (Cooling load temperature difference), ^oC

4.3. Heat Gains from` Doors And Windows (Glasses)

$$q/A=(SC).(SHG)_{max}.(CLF) \quad (3)$$

Where:

q/A: Heat gain per unit area of glass, Watt/ m^2
SC : shading coefficient.
SHG: solar heat gain.
CLF: cooling load factor.

The values of the overall heat transfer coefficient of each of the structural panel considered in the present investigation are given in Table 1.

The 77 m^2 residential house shown in Figure 4 is chosen for comparison.

Table 1. The determined values of heat transfer coefficient for the structural panels considered in the present investigation

Structural member	Panel system	U_p= Heat transfer coefficient
Wall.	Concrete block	5.485
	Clay brick	4.835
	Stone	3.5
	Ferrocement cavity wall with insulation panel positioned between the two ferrocement leaves.	0.22
Roof	Reinforced concrete	2.31
	Clay brick jack arching	2.1719
	Ferrocement channel like cross-section	0.1337

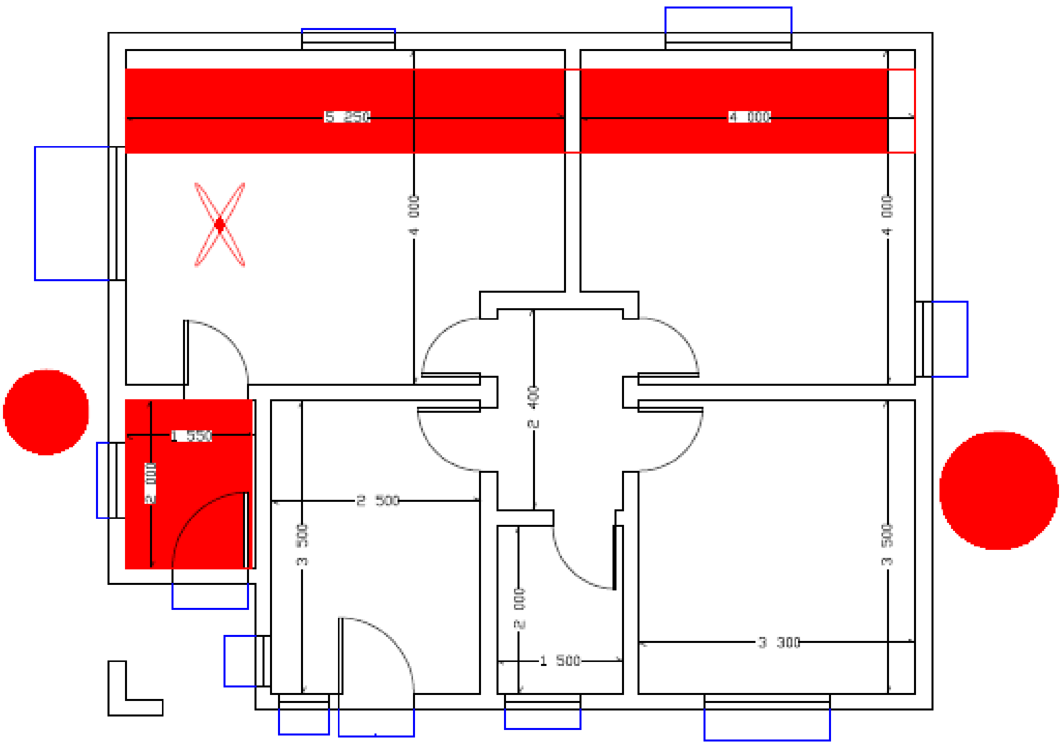


Fig. 4. The 77 m^2 residential house adopted in the present work.

Heating and cooling loads can be determined using a whole house approach. Using expressions 1, 2, and 3, the heating and cooling loads are calculated as given in Tables 2 and 3. It may be noted that 1 Ton of refrigeration = 3.517 kW is used `for calculating the amount of heating or cooling. It is assumed in the present work that a single home need to run 20 hours of electricity per day to cover the need for heating and cooling as given in Tables 2 and 3.

To estimate carbon dioxide (CO_2) emissions, the U.S. average of CO_2 per kWh in 2005 which was approximately 1.31 pounds per kWh is adopted15 to determine the emissions of CO_2 per month as given in Tables 4 and 5.

Table 2. The calculating values of heating loads

Construction system		Heating load	
Wall	Roof	kW	Ton
Concrete block	Reinforced concrete	25.17	7.157
Clay brick	Reinforced concrete	19.345	5.5
Stone	Reinforced concrete	16.45	4.677
Clay brick	Clay brick jack arching	22.75	6.47
Ferrocement cavity wall with insulation panel positioned between the two ferrocement leaves.	Ferrocement Channel like cross section	9.328	2.653

Table 3. The calculated values of cooling loads

Construction system		Cooling load	
Wall	Roof	kW	Ton
Concrete block	Reinforced concrete	23.257	6.613
Clay brick	Reinforced concrete	21.172	6.02
Stone	Reinforced concrete	18.147	5.237
Clay brick	Clay brick jack arching	20.94	5.954
Ferrocement cavity wall with insulation panel positioned between the two ferrocement leaves.	Ferrocement Channel like cross section	8.012	2.278

Table 4. Comparison of heating load and CO_2 emission for construction methods

Method of Construction	Heating load		Emission of CO_2 kg/month
	kW	kWh/ month	
Method 1	25.17	15102.87	7741.1
Method 2	22.98	13787.64	7066.9
Method 3	20.08	12049.19	6175.9
Method 4	22.75	13649.26	6996
Method 5	9.33	5597.29	2868.9

Table 5. Comparison of cooling load and the emission of carbon dioxide between different method of construction

Method of Construction	Cooling load		Emission of CO_2 kg/month
	kW	kWh/ month	
Method 1	23.26	13954.58	7152.55
Method 2	21.17	12703.67	6511.38
Method 3	18.42	11050.24	5663.9
Method 4	20.94	12563.39	6439.4
Method 5	8.01	4807.25	2463.9

It may be noted that there are some sources that generate heat inside the house have been taken into consideration such as cooker, and frozen refrigerator and sources that have been neglected such as house lighting.

The reduction in the amount of energy needed for running heating or cooling of 77 m^2 house shown in Figure 2 when the modern ferrocement system is used, may leads us to the possibility of using renewable energy rather than physical energy depleted. Since wind energy is considered as one of the renewable energy system, since it produce electricity by using the power of the wind to drive an electrical generator [40], so it was proposed of using solar energy or wind energy or both combined, as illustrated in Figure 5.

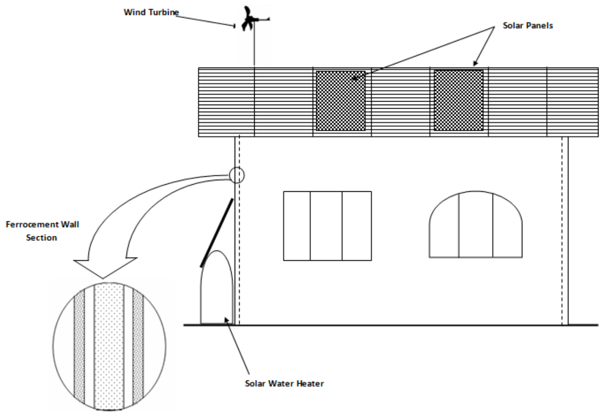


Fig. 5. Proposal for the possibility of using solar energy or wind energy or both combined.

5. Conclusion

1 High standards of energy efficient housing construction have been demonstrated in the present work. It may be seen that the modern method (ferrocement eco-housing system) is able to produce very energy efficient dwellings. It is seen that with thermal insulation installed as part of the construction panels lend to achieving high levels of thermal performance.

2 Using method 5 (ferrocement eco-housing system), the reduction in energy consuming in heating and cooling loads in comparison with traditional methods 1, 2, 3, 4, may be summarized as: 63, 52, 44, 59% for heating and 66, 62, 56, 62% for cooling respectively.

3 Upon to what have been stated in conclusion 2, the reduction in the emission of CO_2 when method 5 is used for house construction may in comparison with the traditional

methods 1, 2, 3, 4 be summarized as: 63, 59, 53, 59% for heating and 65, 75, 65, 72% respectively.

References

[1] Q. Baoxing, Energy Efficiency and green building, 201, Beijing, China Building Industry Press.

[2] P. Fenga, “2011 International Conference on Green Buildings and Sustainable Cities Brief discussion of green buildings”, Procedia Engineering, vol. 21, pp. 939-942, 2011.

[3] C.J. Kibert, Sustainable construction: green building design and delivery, 2008, Hoboken, NJ: John Wiley and Sons, Inc.

[4] L.B. Robichaud, V.S. Anantatmula, “Greening project management practices for sustainable construction”, J Manage Eng, vol. 27, no. 1, pp. 48-57, 2010.

[5] J. Zuo, Z. YuZhao, “Green building research current status and future agenda: A review”, Renewable and Sustainable Energy Reviews, vol. 30, pp. 271-281, 2014.

[6] K.I. Vatalisa, O. Manoliadisb, G. Charalampidesa, S. Platiasa, S. Savvidisa, “Sustainability components affecting decisions for green building Projects”, Procedia Economics and Finance, vol. 5, pp. 747-756, 2013.

[7] Y. Zhang, H. Altan, “A comparison of the occupant comfort in a conventional high-rise office block and a contemporary environmentally-concerned building”, Build Environ, vol. 46, no. 2, pp. 535-45, 2011.

[8] S. Mekhilef, A. Safari, W.E.S. Mustaffa, R. Saidur, R. Omar, Younis. M.A.A, “Solar energy in Malaysia: current state and prospects”, Renew Sustainable Energy Rev, vol. 16, no. 1, pp. 386-96, 2012.

[9] T.S. Bisoniya, A. Kumar, P. Baredar, “Experimental and analytical studies of earth-air heat exchanger (EAHE) systems in India: a review”, Renew Sustainable Energy Rev, vol. 19, pp. 238-46, 2013.

[10] F. Sicurella, G. Evola, E. Wurtz, “A statistical approach for the evaluation of thermal and visual comfort in free-running buildings”, Energy Build, vol. 47, pp. 402-10, 2012.

[11] A.M.R. Aminuddin, S.P. Rao, H.W. Thing, “Thermal comfort field studies in two certified energy efficient office buildings in a tropical climate”, Int J Sustain Building Technol Urban Dev, vol. 3, no. 2, pp. 129-36.

[12] N. Djongyang, R. Tchinda, D. Njomo, “Thermal comfort: a review paper”, Renew Sustain Energy Rev, vol. 14, no. 9, pp. 2626-2640.

[13] M.K. Singh, S. Mahapatra, S.K. Atreya, “Adaptive thermal comfort model for different climatic zones of North-East India”, Appl Energy, vol. 88, no. 7, pp. 2420-8.

[14] S.T. Mors, J.L. Hensen, M.G. Loomans, A.C. Boerstra, “Adaptive thermal comfort in primary school class rooms: creating and validating PMV-based comfort charts”, Build Environ, vol. 46, no. 12, pp. 2454-61, 2011.

[15] M.P. Deuble, R.J. de Dear, “Green occupants for green buildings: the missing link?”, Build Environ, vol. 56, pp. 21-7, 2012.

[16] N.B. Huat, Z.A. Akasah, “Reliability and Validity of a New Energy - Efficient Building Performance Survey Framework in Hot and Humid Climatic Regions: A Review”, International Journal of Renewable Energy Research-IJRER, vol. 2, no. 4, pp. 697-701, 2012.

[17] S. Singh, R. Mishra, “Building a friendly Environment for Renewable Energy Resources by Upgrading Primary Feeders from Normally Closed Loop to Mesh Arrangement”, International Journal of Renewable Energy Research-IJRER, vol. 3, no. 3, pp. 560-570, 2013.

[18] S. Singh, R. Mishra, “Sustainable Energy Plan of a Village in Punjab for Self Energy Generation”, International Journal of Renewable Energy Research-IJRER, vol. 3, no. 3, pp. 627-639, 2013.

[19] IFS Committees 10, “Ferrocement Model Code,” Building Code Recommendations for Ferrocement (IFS 10-01), 2001.

[20] ACI Publication SP.61, “Ferrocement–Materials and Applications”, pp 1-195, 1979.

[21] ACI committee 549, “Guide for the Design, Construction, and Repair of Ferrocement”, ACI Structural Journal, May-June, pp. 325-351, 1980.

[22] ACI Committee 549, 1988, “State-of-the Art Report on Ferrocement”, ACI Manual of Concrete Practice, part 5.

[23] W.N. Al-Rifaie, “Ferrocement Wall: Penetration Testing”, The Eighth International Symposium and Workshop on Ferrocement and Thin Reinforced Cement Composites, 6-8 February, Bangkok, Thailand, 2006.

[24] M. Zaki, W.N. Al-Rifaie, ”Design Of Ferrocement in Flexure”, Journal of Engineering and Technology, vol. 18, no. 4, 1999.

[25] W.N. Al-Rifaie, N.S. Mahmood, “Finite Element Method for Non-Linear Analysis of Ferrocement Slabs and Box-Beams”, Proceedings of the Seventh International Symposium on Ferrocement and Thin Reinforced Cement Composites (FERRO-7), Singapore, 2001.

[26] W.N. Al-Rifaie, N.S Mahmood, “Computational Model for Non-linear Analysis of Ferrocement Shells Using F.E.M”, Journal of Ferrocement, vol. 30, no. 1, 2000.

[27] W.N. Al-Rifaie, A. Majeed, “Structural Behaviour of Thin Ferrocement One-Way Bending Elements”, Journal of Ferrocement, vol. 24, no. 2, 1994.

[28] W.N. Al-Rifaie, A. Abdul-Aziz, “Thin Ferrocement Bearing Walls”, Journal of Ferrocement, vol. 25, no. 3, 1995.

[29] W.N. Al-Rifaie, A. Al-Hmedawi, “Structural Behaviour of Ferrocement Shells Roofs”, Journal of Ferrocement, vol. 30, no. 1, 2000.

[30] W.N. Al-Rifaie, A. Mnasrah, “Connection for Segmental Ferrocement, Semi-Cylindrical Shells as a Roofing System”, Journal of Ferrocement, vol. 31, no. 1, 2001.

[31] W.N. Al-Rifaie, S. Kalaf, “Experimental Investigation of Long-Span Roofing System”, Proceedings of the Seventh International Symposium on Ferrocement and Thin Reinforced Cement Composites (FERRO-7), Singapore, 2001.

[32] W.N. Al-Rifaie, “Modern Housing System Using Ferrocement As Sustainable Construction Materials”, 7th. Municipal Work, Conference & Exhibition, Kingdom of Bahrain, pp. 24-26, April, 2012.

[33] http://www.epa.gov/cleanenergy/energyresources/eg r d/index.htm.

[34] “Ferrocemnet Building system”, Copyright for Nottingham University, Nottingham, UK, 2007.

[35] O.A. Abdul-Ameer, “Ability of Ferrocement to Raise the Resistance of Reinforced Concrete Beams”, M.Sc. Thesis, University of Technology, 2000, Iraq.

[36] A.H. Riyadh, “Structural Behaviour of Ferrocement Under Direct Fire”, M.Sc. Thesis, University of Technology, 2005, Iraq.

[37] N. Salah, “Ferrocement for Structural Rehabilitation”, Ph.D Thesis, University of Technology, 1998, Iraq.

[38] R.C. Jordan and G.B. Priester, “Refrigeration and Air-conditioning”, Prentice Hall, 1956.

[39] J.P. Holman, Heat Transfer, 1986, 6th ed., McGraw Hill.

[40] W.K. Ahmed, “Mechanical Modeling of Wind Turbine Comparative Study”, International Journal of Renewable Energy Research-IJRER, vol. 3, no. 1, pp.9 4-97, 2013.