Military Technical College

Kobry El-Kobbah,

Cairo, Egypt

12th International Conference on Civil and Architecture Engineering

ICCAE-12-2018

Application of biogas to reduce energy consumption and CO_2 of passive country housing under climate change scenarios near Cairo,Egypt

Mohammad Fahmy
Head of Architecture Engineering Department, Military Technical Collage, Cairo, Egypt
Email: md.fahmy@mtc.edu.eg
Mohamed M. Mahdy
Architecture Engineering Department, Military Technical Collage, Cairo, Egypt
Email: mmahdy@mtc.edu.eg

Abstract:

In this research, the application of biogas for passive country housing in Egypt has been simulated dynamically to calculate the annual energy savings as well as CO_2 emissions' reduction. The country house prototype applies vernacular design elements as part of a new urban development project southern Cairo. Various envelope materials and thicknesses have been applied prior to simulating this housing typology with 2m^3 biogas unit operated through the supply of farm animal and agriculture residuals. Climate change scenarios simulations in 2020, 2050 and 2080 using Design Builder showed remarkable energy savings, cost and CO_2 emissions reductions in preference to using biogas with high resistant building envelope.

Keywords:

Passive house, biogas, energy efficiency, climate change.

1. Introduction:

About 42% of energy in Egypt is consumed in buildings which increases built environment energy bill regardless the extra energy supplies added to the national network recently. Practicingsustainable urban and architecture design enhance energy efficiency, and reduces the contribution of buildingsto GHG emissions.From these standing points,adapting built environment to climate change has its importance(1-5). More evidences and symptoms of climate change have been recently acknowledged on an international and scientificresearchbasis (6-8). In the arid zones of Mediterranean areas, fourth assessment report presents that air temperature has already increased between 1-2˚C (9). GHG emissions of the Egyptian environment have increased from 0.4% in 2000 to 0.6% in 2016. Therefore, "adaptation is not a welfare mode of sustainability or a prosperous idea of architecture design" (10), it is one half ofpassively designed buildings, (11, 12) to save energy cost.The other half is to apply renewable energy sources, and minimize the contribution to GHG emissions in turn. One of those promising and cheap renewables is the biogas, (13, 14) even developed countries use it, (15, 16).Biogas is a combination of CH_4 (65%), CO_2 (35%), along with

Hydrogen sulfide and traces of other gases. The domestic biogas unit (Fig.1) is a construction fed with different types of wastes, and by means of several kinds of bacteria the waste decomposes to generate the biogas and slurry which is used as liquid fertilizer in agriculture(17).

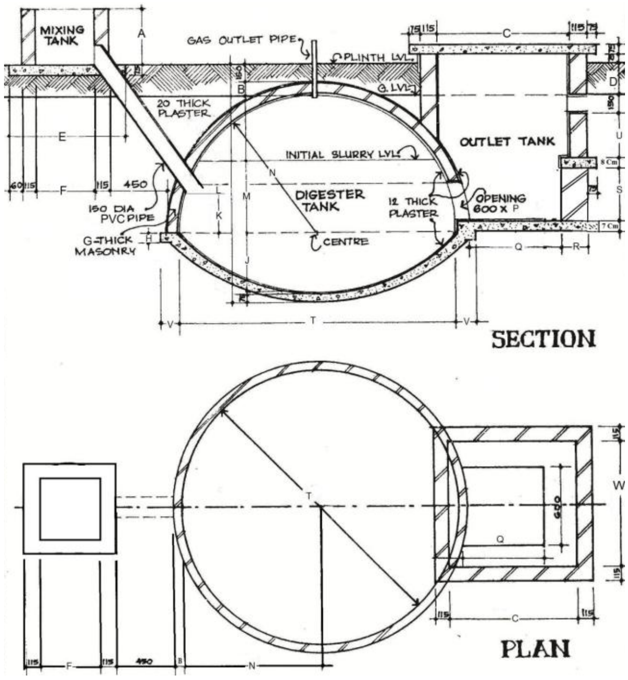


Figure 1: A schematic drawing for a residential Biogas reactor unit.

In Asyut governorate of Egypt, the agriculture waste is already producing biogas in some single family country housing which saves electricity cost of catering, water heating and the organic fertilizer as a side product of the domestic biogas reactor applied, (18). The co-operation of the Egyptian Environmental Affairs Agency, EEAA, with Global Environmental Facility, GEF, and the United Nations Development Program, UNDP, revealed the construction of about 1000 domestic biogas units and about 14 companies specialized in constructing those units along with the establishment of the Egyptian Association of Bio-Energy for Sustainable Development, (18). From this standing point, mega development projects such as the cultivation of 1.5 million Feddan (Feddan is an Egyptian agricultural area unit = 4200m^2) and the regional development project at Atfeh of Giza governorate that include a residential sector is considered a promising case studies. The housingshare of land use budget in those projects depend on passive design, expandable bedrooms' zone and farm animals and agricultural seeds production zone in addition to agricultural industry as an economic support for the urban development. However, in this paper, the production of biogas is utilized in one of the passive country housing projects to estimate energy saving and reduction of CO_2 emissionsin present and future under climate change scenarios for the whole housing neighborhood.

2. Methodology:

24DesignBuilder dynamic simulations took placefor a new design ofcountry house prototype in Egypt, to calculate the effect of applyingpassive architecture strategies and biogas. Calculations were forthemonthly energy consumption (kWh), its correspondingCO_2 emission, the annual cost of energy consumption in Egyptian pound (EGP). Indoor thermal comfort was maintained as a condition through Natural Ventilation (*NV*) in some simulations and mechanical Air Conditioning (*A/C*) in others.

Tested run scenarios were three; first,grid electricity for the natural ventilation mode. Second,grid electricity for A/C mode, and third,grid electricity for A/C mode but with biogas to cover A/Csconsumption, domestic hot water (DHW) and catering.

The three tested scenarios were under present climate conditions (2002), and three periods of climate change scenarios: 2020, 2050 and 2080.The morphing methodology published by CIBSE (Chartered Institution of Building Services Engineers) and its own tool (Climate Change World Weather File Generator) was the tool used to predict those scenarios of Typical Meteorological Year (TMY2) and compile them in (EPW) weather files (19). This methodology has been discussed in the work of Belcher et al. (20) and Jensch et al. (8). The 30 years period (2020, 50 and 80) to determine the climate baseline for morphing is a World Meteorological Organization (WMO) recommendation(20).

Modeling and simulations were carried outusing the dynamic thermal simulations tool, DesignBuilder (DB) in its fourth version (V.4.7.0.027)(21).In order to assure the most reliable data and accuracy, a validated software (DB) has been used(22). Moreover, the simulations were used to compare the predicted performance of the design alternatives instead of predicting a single case performance in absolute sense (22). Additionally, the model has been calibrated against a recent energy survey conducted in Cairo (23, 24)in order to obtain more accurate results and more conformity to the reality in a reasonable ratio.

2.1. The Model Definition:

Country house case is located near Atfeh town, Giza governorate (Fig.2/a). It is supported by the government as a regional development hub. The house will apply a biogas reactor. Fig.2/b, c describes the reactor that generates 2m^{3}of biogas.

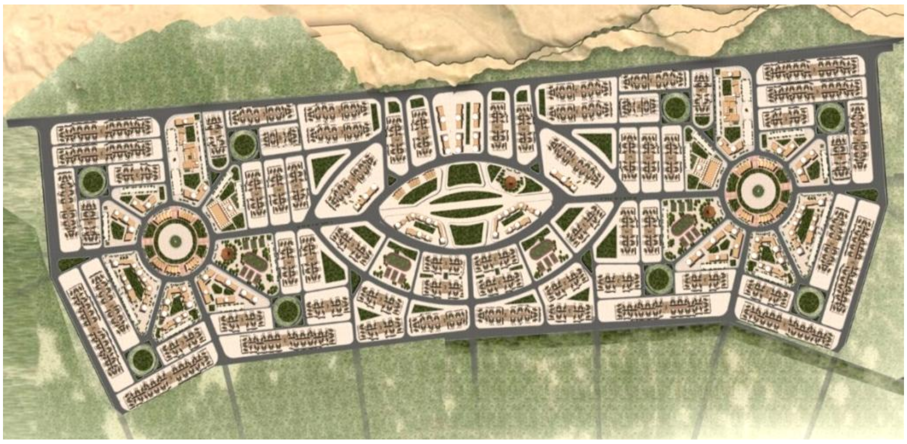


Figure 2/a: Project's layout

Figure 2/b, c: the 2m^3 biogas reactor while construction (left), and after construction (right).

The house is a one floor for one family, with a plotarea of 272 m^2 and built up area of 118m^2. The average housenumber of occupants is five; Fig.3 shows a 3D presentation of the house model.Egypt's conditions for thermal comfort is applied (20°C-29°C) (25), which is an alteration after the Egyptian Code for Improving the Efficiency of Energy Use in Buildings (EREC) (26).

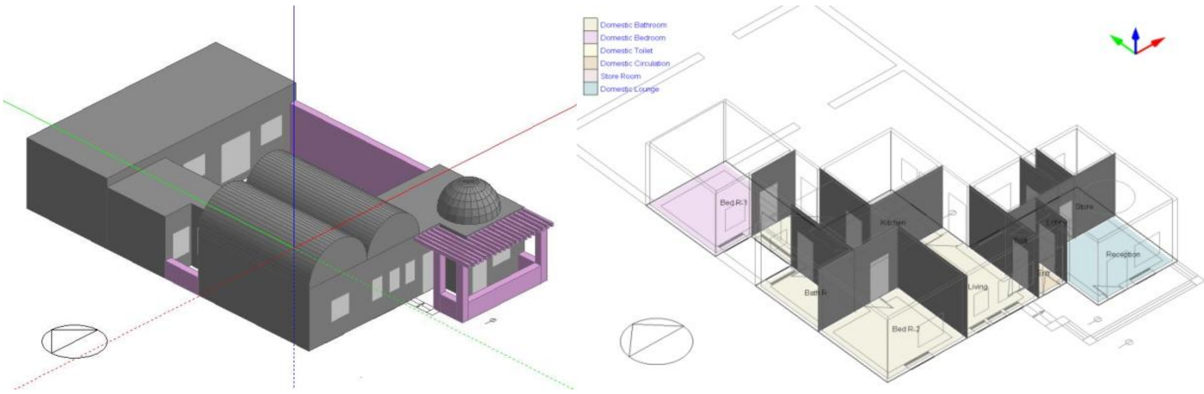


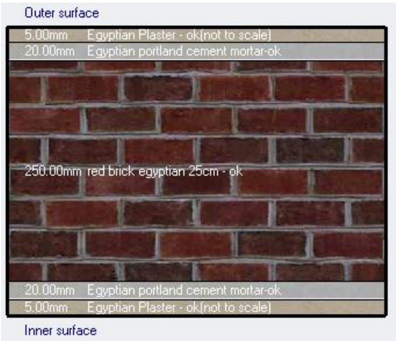
Figure 3: The model 3D presentation and plan

2.2. Specifications of building materials

Table 1 presents the specifications ofwalls. Materials thermal properties were derived from EREC (26), and from the Egyptian Specifications for Thermal Insulation Work Items (27).Figure 4 indicates the construction materials. The Clear 6.4mm single glass was used, as shown in Table 2,EREC(26).

Table 1: External Walls main characteristics.

External Walls	ABBRV.	Thick. (mm)	U-Value (W/m^{2}K)
Full red-brick wall	*RB*	30	1.898
GRC wall (2cm GRC + 11cm thermal insulation + 2cm GRC)	*GRC*	15	0.257



(RB)

(GRC)

Figure 4: Wall envelopes used.

Table 2: Used glass specifications.

Name	Category	SHGC*	LT**	U-Value (W/m^{2}K)
Clear 6.4mm	Single	0.71	0.65	5.76

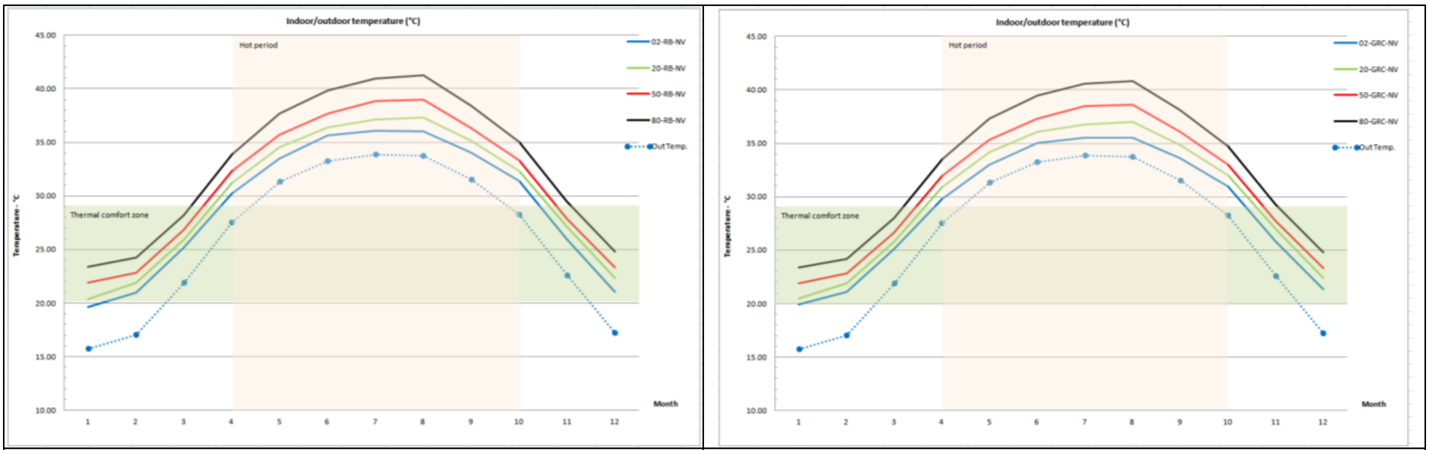
*SHGC: Solar Heat Gain Coefficient. **LT: Light Transmission.

2.3. Weather and activity

Giza governorate climate type is "BSh" (Köppen classification) or Climate type "2B" (ASHRAE Standards 90.1-2004 and 90.2-2004 Climate Zone),with 2004 annual cooling degree-days (18°C baseline), and 321 annual heating degree-days (18°C baseline).Current WDF (2002) was obtained from the official site of the U.S Department of Energy (28), whereasfuture weather data files for 2020, 2050 and 2080 were generated using the Climate Change World Weather File Generator (CCWorldWeatherGen) (29) to cover the period from 2010 to 2099 (30).In all simulations, a fixed schedule,and activity template for energy consumption is applied, based on the common lifestyle for the residents of Egypt (holidays, work hours, etc.). The *HVAC* systems were used as according to previous study (31) natural ventilation was not sufficient to achieve thermal comfort in the summer period; under the same experiment conditions in Cairo with different external wall specifications. The *A/C* equipmentwas kept fixed in all the simulations, as the objective is to evaluate using biogas in replacing and reducing the electricity daily consumption.

3. Results and discussion:

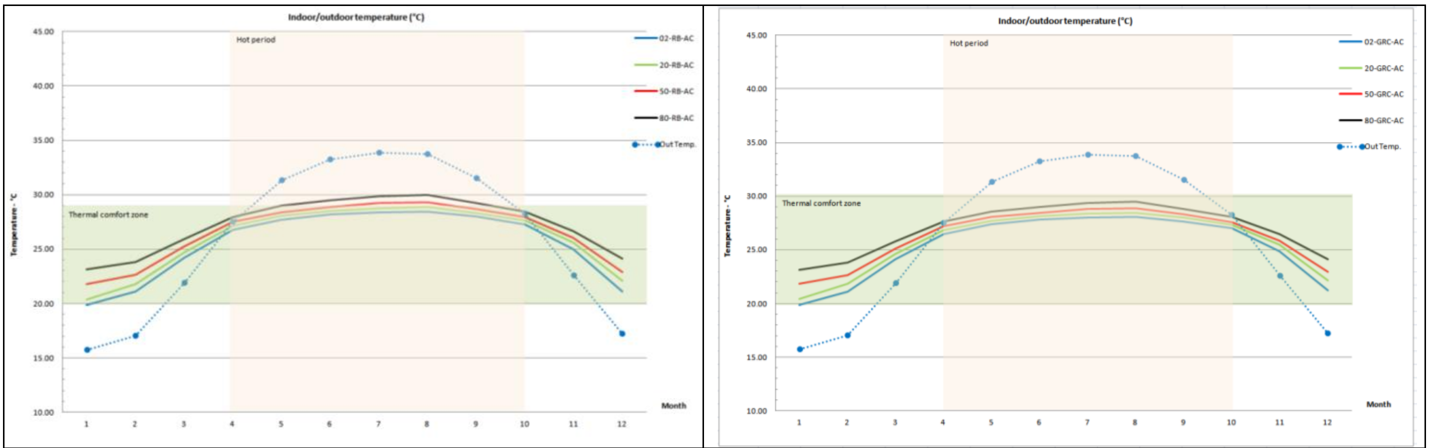
Investigating the benefits of using biogas in preference to fossil fuelsfor the sake ofminimizing energy consumption and GHGemissions is the objective of this work.This is done firstly through assessing the capability of each envelope type to provide indoor thermal comfort while running in *NV* mode. Fig.5 shows that both (*RB* / *GRC*) fails to provide the indoor thermal comfort in *NV* mode during the hot summer period. The indoor air temperatures in both cases exceeded 40ºC in June, July and August, and the inability repeated in all the climatic periods (02, 20, 50 and 80) that have been tested but withvery small improvement in indoor air temperatures when using*GRC*envelope in all the climatic periods.



RB	GRC

Figure 5: Buildings' thermal behaviour- NV mode

Secondly, *A/C* machines were used to provide indoor thermal comfort; the results of using (*A/C*) mode are shown in Fig.6.It shows a remarkable difference and good enhancement for the Indoor air quality (IAQ). The *RB*envelopeshowed comfortable conditions in (2002-2020), while it exceeds comfort zone in 2050-2080 reaching31ºC. Contrary, the *GRC*envelope showed adequate indoor thermal limits in present and future even in the hot summer period because of its low thermal conductance (0.257 W/m^{2}K) compared to *RB* envelope (1.898 W/m^{2}K).



RB	GRC

Figure 6: Buildings' thermal behaviour- A/C mode

Figure 7 shows energy consumption while figure 8 shows energy breakdown after using the *A/C* mode.
As achieving the required internal thermal comfort was a main objective, the increase in annual energy consumption is expected. An increase is recorded in summer months with about 30-82% in electricity consumption between the *NV* mode and the *A/C* mode, and about 44-94% in the annual energy cost.

	Monthly energy consumption (kWh)	Annual energy cost (EGP)

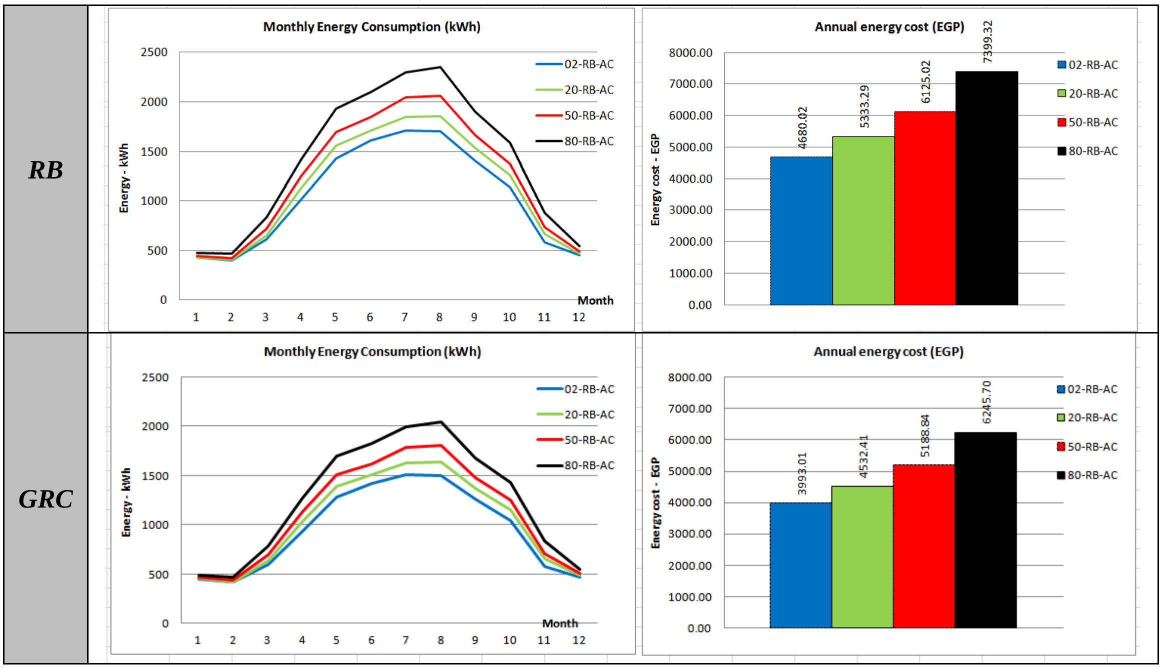
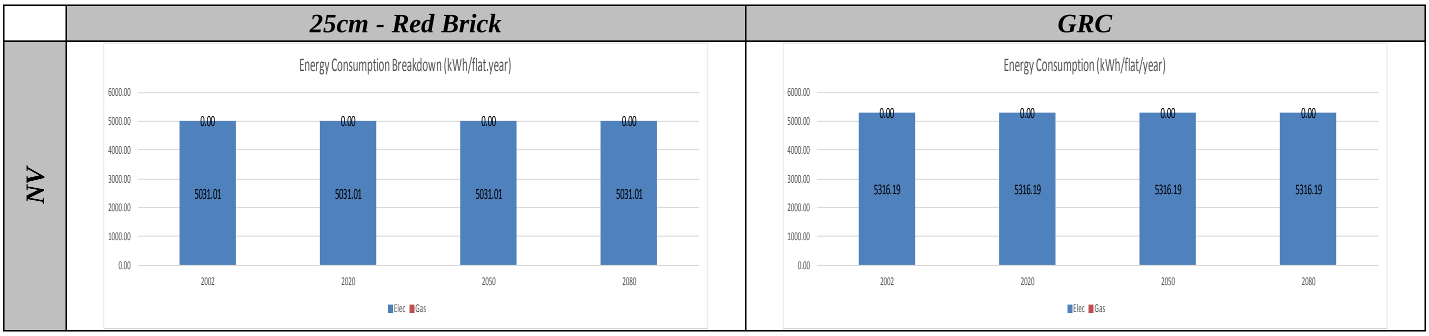


Figure 7: Monthly energy consumption & Annual energy cost in A/C mode

For to minimize the increase in consumption (that resulted because of the desire to provide thermal comfort and the appropriate environment within the architectural spaces),a biogasreactor with 2m^3 capacity was examined. The thermal behavior results which came out of the simulations were similar to the previous A/C results, as both attempts were benefited of the same air conditioning machines with the same capacity and coefficient of performance. However, the reduction in electrical energy consumption was noticeable as shown in Fig.8 for all the different climatic periods. The energy breakdown shows a reduction of 83-87% for *RB*, and a reduction between 80-85% when using the *GRC*, in theelectrical consumption (that was used for the operation ofA/Cs, catering and DHW).

With reference to the CO_2 emission for the same simulation modes, the biogas alternativereduced CO_2 emissions, Fig.9.While using electricity from gird(fossil energy), emissions exceeded 60 kg/month with RB envelope and 70 kg/month with GRC envelope especially during summer. On the other hand, the biogas alternative reduced emissions to barely exceed 20 and 30 kg/month respectively.



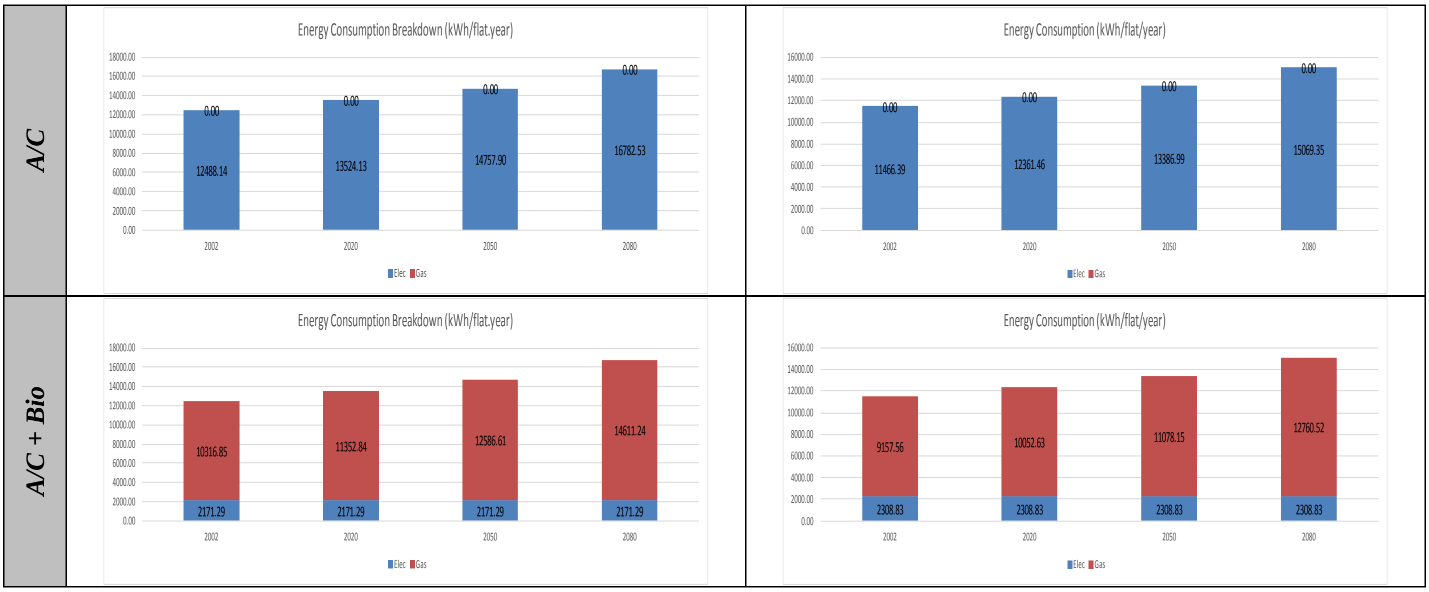


Figure 8: Annual Energy Consumption Breakdown (kWh/flat)

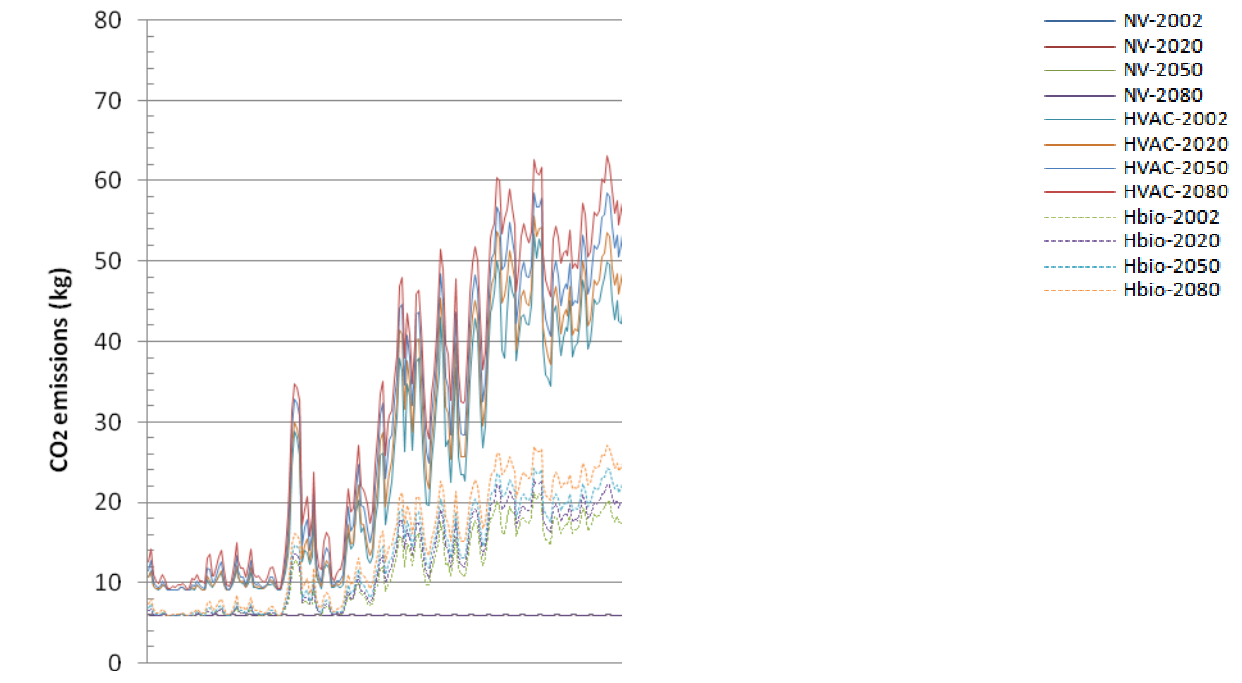
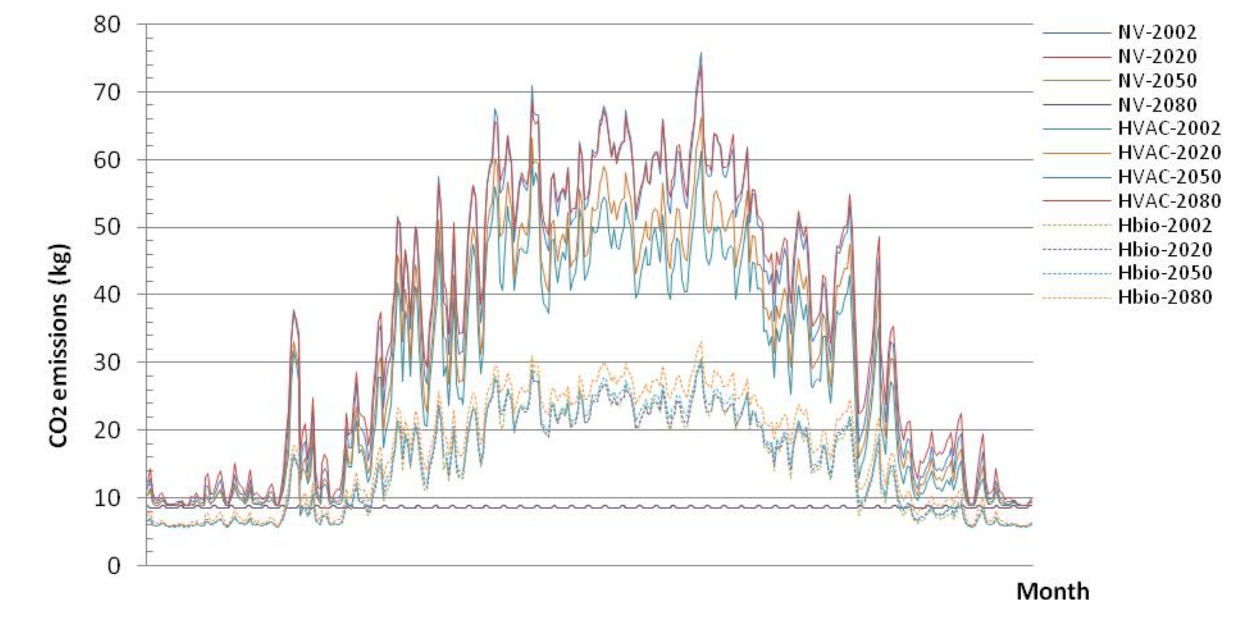
25cm - Red Brick	
GRC	

Figure 9: Annual CO_2 emissions over the different climatic periods.

4. Conclusion:

This research investigated applying the biogas in a country passive house, to achieve thermal comfort, reduce energy consumption and cost in Atfeh town in Giza governorate ofEgypt under present and future climate scenarios. DESIGN Builder dynamic simulations have been applied to do so whereas the CCWorldWeatherGen tool is used to generate future conditions under climate change scenarios 2020, 2050 and 2080. Two envelope types (Red Bricks - GRC) have been usedwith in two different running modes; NVand A/C. Both of (*RB* / *GRC*) failed to provide the indoor thermal comfort in *NV* mode during the hot summer period in all climate scenarios of present and future. The later results repeated in (02, 20, 50 and

80).Applying *A/C* mode is to provide thermal comfort;the *RB* building reachedcomfortable conditions in only two climatic periods (2002-2020), while it exceeds the thermal comfort limits in (2050-2080). The *GRC*envelope achieved indoor comfortin different climatic periods under climate change scenarios.

By the implementation of renewable energy supplied through the $2m^3$ domestic biogas reactors, areduction in annual consumption and cost is recorded, and a reduction in the annual CO_2 emissions is recorded as well. Results with biogas energy showed a breakdown reduction of 83-87% for *RB*, and a reduction between 80-85% when using the *GRC.*This gives an implication about the importance of such renewable source in forming a sustainable desert developmentconcept in Egypt with the country passive and low energy consumption housing design.

References:

1. Akbari H. Shade trees reduce building energy use and CO2 emissions from power plants. Environmental Pollution. 2002;116(1):S119-S26
2. EPA. Reducing Urban Heat Islands: Compendium of Strategies; Green roofs. Available [Online] at; http://www.epa.gov/heatisland/resources/compendium.htm. Accessed 14/9/2009. 2009c.
3. EPA. Reducing Urban Heat Islands: Compendium of Strategies; Trees and Vegetation. Available [Online] at; http://www.epa.gov/heatisland/resources/compendium.htm. Accessed 14/9/2009. 2009d.
4. IPCC. Climate Change 2007: Synthesis Report, fourth assessment report of climate change. Online at: http://www.ipcc.ch/publications_and_data/publications_and_data_reports.shtml. Valencia, Spain: 2011.
5. McEVOY D. Climate Change and Cities. Built Environment. 2007;33(1):5-9.
6. Holmes MJ, Hacker JN. Climate change, thermal comfort and energy: Meeting the design challenges of the 21st century. Energy and Buildings. 2007;39(7):802-14.
7. Hulme M, Lu X, Turnpenny J. Climate change scenarios for the United Kingdom; The UKCIP02 scientific report. 2002.
8. Jentsch MF, Bahaj AS, James PAB. Climate change future proofing of buildings--Generation and assessment of building simulation weather files. Energy and Buildings. 2008;40(12):2148-68.
9. IPCC. Special Report on Emissions Scenarios, Special Report for Working Group III of the Intergovernmental Panel on Climate Change. 2000.
10. Fahmy M, Mahdy M, Nikolopoulou M. Prediction of future energy consumption reduction using GRCenvelope optimization for residential buildings in Egypt. 2014;70:186–93.
11. Olgyay V. Design with climate; bioclimatic approach and architectural regionalism. Book, Princeton University Press, Princeton, NJ. 1963.
12. Olgyay V. Bioclimatic orientation method for buildings. International Journal of Biometeorology. 1967;11(2):163-74.
13. Katuwal H, Bohara AK. Biogas: A promising renewable technology and its impact on rural households in Nepal. Renewable and Sustainable Energy Reviews. 2009;13(9):2668-74.
14. Karellas S, Boukis I, Kontopoulos G. Development of an investment decision tool for biogas production from agricultural waste. Renewable and Sustainable Energy Reviews. 2010;14(4):1273-82.
15. Hoefnagels R, Smeets E, Faaij A. Greenhouse gas footprints of different biofuel production systems. Renewable and Sustainable Energy Reviews. 2010;14(7):1661-94.
16. Akgul O, Shah N, Papageorgiou LG. Economic optimisation of a UK advanced biofuel supply chain. Biomass and Bioenergy. 2012;41(0):57-72.
17. SKG-Sangha. Biogas Plant Construction Manual. Egypt: SKG-Sangha environmental organization, 2014.
18. BSRD. Biogas Plant Construction Manual. Bioenergy for sustainable rural development, 2014.
19. Fahmy M. Climate Change Adaptation for Mid-latitude Urban Developments. PLEA2012 - 28th Conference, Opportunities, Limits & Needs Towards an environmentally responsible architecture 7-9 November 2012; Lima, Perú 7-9 November 20122012.

20. Belcher SE, Hacker JN, Powell DS. Constructing design weather data for future climates. Building Service Engineering. 2005;26(1):49-61.
21. DB DSL-. DesignBuilder software. Retrieved from: http://www.designbuilder.co.uk/". Stroud, UK2016.
22. Hensen JLM. Towards more effective use of building performance simulation in design. the 7th International Conference on Design & Desicion Support Systems in Architecture and Urban Planning; Eindhoven2004. p. 2-5 July.
23. Attia S. A Tool for Design Decision Making: Zero Energy Residential Buildings in Hot Humid Climates Université catholique de louvain 2012.
24. Attia S, Evrard A, Gratia E. Development of benchmark models for the Egyptian residential buildings sector. Applied Energy. 2012;94(0):270-84.
25. Mahdy MM, Nikolopoulou M. Evaluation of fenestration specifications in Egypt in terms of energy consumption and long term cost-effectiveness. Energy and Buildings. 2014;69:329-43.
26. Egyptian Code for Improving the Efficiency of Energy Use in Buildings, Part 1: Residential Buildings (306/1). (2008).
27. The Egyptian Specifications for Thermal Insulation Work Items, (2007).
28. USDoE USDoE-. Weather data 2012. Available from: http://apps1.eere.energy.gov/buildings/energyplus/weatherdata_about.cfm.
29. SERG SERG-. Climate Change World Weather File Generator Southampton - UK: University of Southampton; 2012. Available from: http://www.serg.soton.ac.uk/ccworldweathergen/.
30. Du H, Underwood C, Edge J. Generating design reference years from the UKCP09 projections and their application to future air-conditioning loads. Building Services Engineering Research and Technology. 2012;33(1):63-79.
31. Mahdy MM, Nikolopoulou M. From construction to operation: Achieving indoor thermal comfort via altering external walls specifications in Egypt International Conference on Green Buildings Technologies and Materials (GBTM); China2012.