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An assessment of sustainability of a green residential building in an urban setting: focus in Pueblo de Oro, Cagayan de Oro City

[1]Rey D. Galua, [2]Ermelinda G. Tobias

[1] College of Engineering and Architecture, Mindanao University of Science and Technology, Cagayan de Oro City, Philippines; [2] Department of Biological Sciences, College of Science and Mathematics, MSU-Iligan Institute of Technology, Iligan City, Philippines. Corresponding author: R. D. Galua, rgaluasds@gmail.com

Abstract. A study of the technical, economic, environmental and architectural aspects of green residential building situated in an urban location has been performed. The results of the study revealed the following: the building has been observed to be properly oriented with minimum levels of lighting consumption and sufficient lighting designs, and that with the implementation of the green rooftop, restoration and plantation of different species of plants a considerable amount of carbon has been offset for the growing of the plant at approximately 470 tons of carbon for the 20-year time horizon. As to the elements of sustainable energy use, the energy usage of the green building has been compared with that of the traditional building. The results have indicated that green building has reduced its energy consumption of approximately 40% per unit of floor area when compared with that of the traditional building design. In terms of energy savings, it has been projected that due to the use of the foregoing strategies, the green building can save up to 1,800 kilowatt-hours of energy annually, and the increased construction cost due to the application of these strategies may be recovered at approximately eleven years of operation of the building. In the selection and conservation of resources associated to the construction of the green building, the study revealed that when compared to the traditional building, it has the potential to reduce approximately 40% associated carbon dioxide emissions and 40% primary energy for the construction of the green building. The calculated estimates reveal that with this strategy, it can mitigate approximately 21,000 kg of carbon dioxide emitted to the environment and approximately 2,100 gigajoule of primary energy is avoided; as to building's indoor environmental quality, the results of the study indicates that the resulting design have achieved the maximum natural ventilation possible. As to acceptability of the green building, the survey results as per statistical analyses revealed high level of acceptance of respondents in terms of the overall satisfaction features, the general and the specific features and the given psychological indicators of the design.

Key Words: Energy consumption, green building, carbon, LEED, architecture.

Introduction. There is a global consensus that anthropogenic emission of greenhouse gases in the atmosphere causes the increase of temperatures on the surface of the earth and that this has facilitated climate changes faster than normal (Stern 2007). These emissions caused by anthropogenic enormous growth and development heavily rely on carbon-based fossil fuels to supply these developments. At present, the effects of climate change due to global warming has been recognized and that there have been actions at all levels, i.e. government, private enterprises and professional to mitigate the impacts of these man-made climatic changes or even to adapt with the current climactic changes.

Emissions of carbon dioxide from fuel combustion, in conjunction with that emitted from cement factory are responsible for more than 75% of the increase in atmospheric carbon dioxide since the pre-industrial 18th century (Solomon et al 2007). The construction and occupation of buildings is a substantial contributor of carbon dioxide emissions, with almost a quarter or 25% of the total carbon dioxide emissions attributable to energy use in buildings (Metz et al 2007). A further 5% can be attributed to the manufacture of cement which is a principal component of building construction material. Thus, there is really a great interest in this area to reduce the energy demand

and the consequential carbon emissions attributed to buildings construction and operation.

The aim of this study is to compare the standard or traditionally-designed residential building with that of a proposed set-up which is designed as a modern green residential building situated in the local setting. This study focused on the present research gap, which is to answer whether indeed there is an environmental benefit in the design and construction of green buildings. Problems associated with each key element of sustainable developments shall be addressed in details, such as site selection and development, energy use, water conservation, environmental quality and social or community acceptability. In site development and selection it is expected that issues related to proper building orientation and indoor air quality shall be addressed; in energy use, key problems related to increase in energy demand as the building size increased shall be discussed, and key issues related to improved indoor air quality shall be investigated and ecological parameters were measured and monitored for three months. Foremost to the study is to determine whether the expected green building shall pass social and community acceptability.

Material and Method. The global consensus that the present trends in the construction of building which of a considerable portion are residential units cannot be sustained without inflicting damage to the environment. Residential units, be it in the construction stage or in the operation stage, contribute significantly to the overwhelming demand of energy and thus demand for fossil fuels. In the field of architecture, the culprit of this dilemma is the omission or perhaps failure in the field of looking for another element in any architectural design which consider the “fragility of the Earth”. As of now, the gap in the design of standard or traditionally-designed units is clear that previous trends does not account the environmental impacts of building constructions and/or operations for a variety of reasons, the most obvious is the costs associated when such element is totally addressed.

In line with the overall objective of quantifying the advantage of sustainable housing unit compared with traditionally designed residential unit, the conceptual framework emphasizes the need to subject the standard architectural design into five major sustainable test standards namely: (a) sustainable site and development, (b) water use, (c) energy use, (d) material and resource use and (e) indoor environmental quality. In the evaluation whether what constitutes sustainable designs, the work combined the standard features of sustainable architecture and globally accepted standards for determining sustainable designs such as Leadership in Energy and Environment Designs (LEED).

The design concept as shown in Figure 1 shall be subjected to technical, economic, environmental and architectural assessment to determine whether it is within the scope of the standard scheme of constructing residential buildings. As an added feature, the research methodology incorporate social acceptability measure so as to ensure that the implemented design shall be socially acceptable to the public. Survey questionnaires shall be given to random participants and their comment shall be made basis for revising the design plan during the implementation process and if necessary, as an adjustment after the construction stage.

Results and Discussion

Site selection and development. In the construction of the green building the research has chosen the following practical design and research strategies: (1) proper orientation of the residential unit, (2) site selection that improves the existing site, (3) site development which incorporates carbon abatement strategies, i.e. green rooftop and site tree planting as part of the residential design. An analysis, evaluation and calculation as to how much carbon is abated by using these strategies was made; the calculation was done by estimating the amount of carbon in each individual strategy has abated during the construction up to the whole lifespan of the green residential building. For comparative purposes, the same strategy is applied to a traditionally-designed building in the same subdivision, i.e. carbon footprint comparison, others.

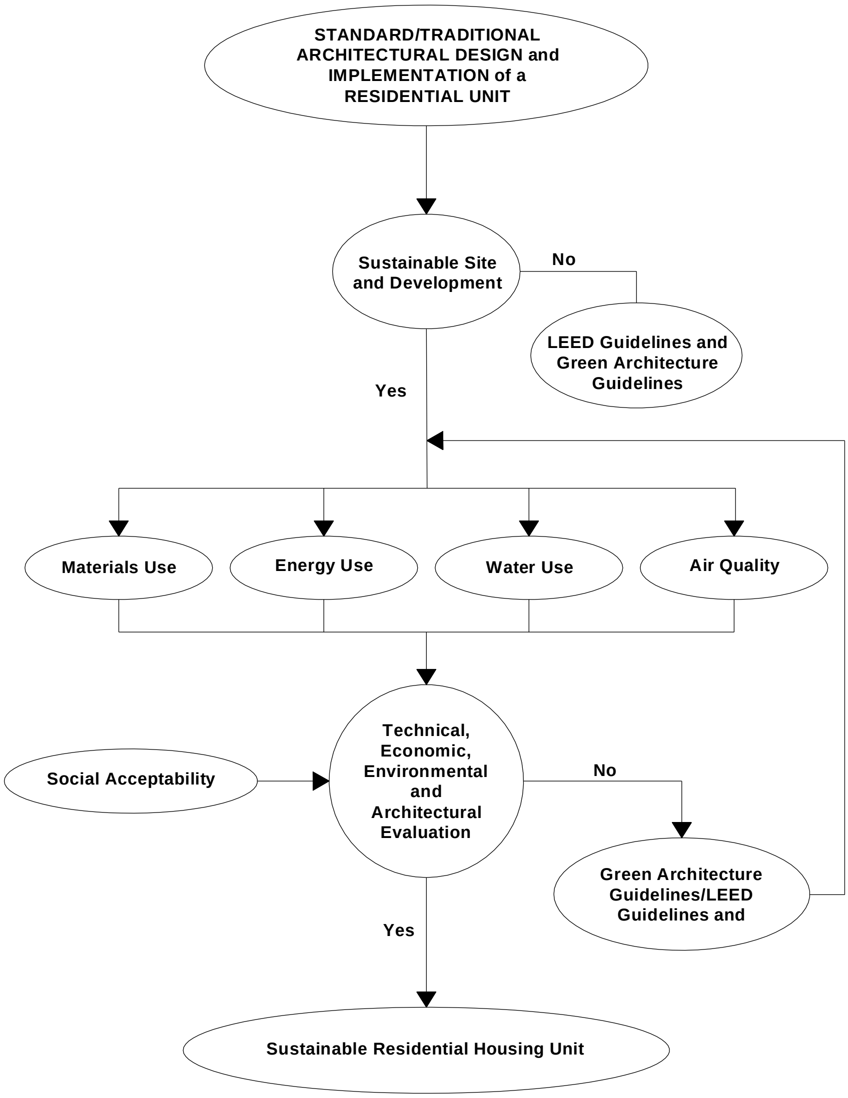

Figure 1. The research conceptual framework.

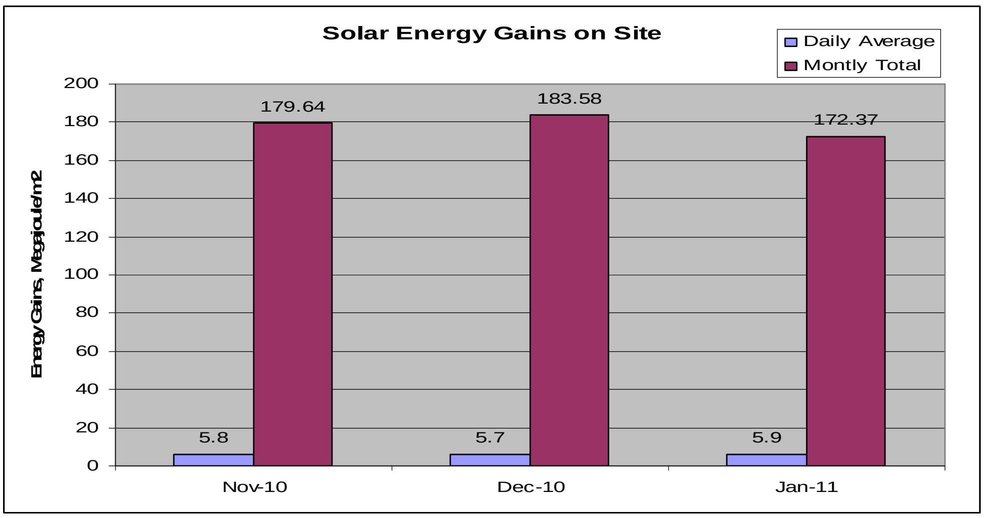

Figure 2. Measured energy gains on the site.

Figure 2 shows the calculated energy gains for a three month period, while Table 1 shows the amount of equivalent carbon derived in incorporating the green rooftop and the plantation of plants on the site.

Table 1

Equivalent carbon emission derived from employing the research strategies

Calculation of equivalent carbon dioxide		
Solar energy gain	5.82 kw-hr x 3.6 MJ/kw-hr	20.95
Biomass energy converted	20.952 MJ/m^2 x 250 m^2 x 0.067	350.95
Mass of biomass	350.94 MJ/8 MJ/kg biomass	43.87
Mass of carbon	43.87kg x 40%	17.55
Mass of carbon dioxide	17.55 x 3.667 kg CO_2/kg C	64.34
Yearly mass of carbon dioxide in kg	64.34 x 365 days	23,484
Equivalent carbon dioxide for 20-year time horizon in tons	23,484 kg CO_2/year x 20 years	470

The calculation of equivalent carbon dioxide taken from the atmosphere for the consumption of biomass may reach approximately 23,000 kg of carbon dioxide yearly or a total of 470 tons for a 20-year time horizon. From a global point of view, the amount of carbon dioxide reduced may be insignificant and obviously the economics of the increased cost associated with the employment of site selection and development strategy may not be quantifiably justified. However, it may be safely argued that there is a true test of sustainability in these site selection and development strategies as it is apparent from the calculation that the impact of construction of buildings in terms of carbon dioxide and in terms of primary energy has been mitigated and reduced respectively.

Energy use. Daylighting and the use of efficient energy consuming lighting and air conditioning features were employed for the green building to reduce the energy consumption of the building.There is a growing body of literature on embodied energy and carbon in the construction of houses. Studies typically use a process based Life Cycle Analysis (LCA) methodology (bottom up) rather than an input–output (top-down) methodology. Individual process based studies have used different parameters, factors, datasets and boundaries. In addition, values of embodied energy, and consequential emissions of carbon, vary by country due to: the energy mix; transformation processes; the efficiency of the industrial and economic system of that country; and how these factors vary over time (Sartori & Hestnes 2007).

As shown in the Table 2, there is a substantial difference at approximately 40% in energy usage for the green building design based on energy usage per size of floor area, i.e. in watts electricity used per square meter of floor area. This means that the building is approximately 40% more efficient than that of the traditionally designed building in terms of operation of the building. Nässén et al (2007) summarized the results of 20 process-based (predominantly Scandinavian) studies published prior to 2001. The studies showed similar results with a range of 1.3–7.3 GJ/m^2 primary energy for residential buildings.

Table 2

Comparison of energy use between the green building and the traditional building design

Parameter	*Traditional design*	*Green residential design*
Total electric load	11,550 kW	11, 393 kW
Total floor area	247 m^2	404 m^2
Electric load/floor area	46.7 W/m^2	28.02 W/m^2
% of electrical reduction	-	39.69%

There is a growing concern about energy use and its implications for the environment. Recent reports by the Inter-governmental Panel on Climate Change (IPCC) have raised public awareness of energy use and the environmental implications, and generated a lot of interest in having a better understanding of the energy use characteristics in buildings, especially their correlations with the prevailing weather conditions (IPCC 2007; Levine et al 2007). It was estimated that in 2002 buildings worldwide accounted for about 33% of the global greenhouse gas emissions (Levermore 2008). In their work on climate change and comfort standards (Kwok & Rajkovich 2010), reported that the building sector accounted for 38.9% of the total primary energy requirements (PER) in the United States, of which 34.8% was used for heating, ventilation and air-conditioning (HVAC). In China, building stocks accounted for about 24.1% in 1996 of total national energy use, rising to 27.5% in 2001, and were projected to increase to about 35% in 2020 (Yao et al 2005). Although carbon emissions per capita in China are low, its total emissions are only second to the US. When the life cycle energy use and emissions footprint are considered, buildings account for a significant proportion of the energy-related emissions (Jiang & Toveyl 2010).

In order to quantify the environmental benefits derived by employing strategies that reduced energy consumption, an evaluation of the amount of carbon dioxide equivalent due to the reduction in energy usage has been computed. Table 3 shows the results of the computation, as shown in the table, the total energy saving for the selected 20-year time horizon approximately reached 36,000 kilowatt hours. Using internationally accepted standard conversion factors this energy savings is translated into approximately almost 12,000 kg of coal or approximately 12 metric tons of coal is avoided to be combusted in coal-fired power plants. On average, a kilogram of coal is 70% carbon thus for every kilogram of coal combusted there is approximately an equivalent emission of 2.6 of carbon dioxide equivalent that is emitted into the atmosphere. Thus, as shown in Table 3, the resulting energy savings due to the application of daylighting designs and efficient lighting features has avoided approximately 30,000 kg of carbon dioxide equivalent for the 20-year lifetime horizon.

Table 3

Amount of carbon dioxide avoided

Environmental analysis	
Annual energy savings	1,800 kWh
Total energy savings (20 years)	36,000 kWh
Amount of coal avoided (in kg per kWh of energy)	0.333*
Total amount of coal avoided	11,988 kg
Total amount of carbon dioxide avoided (kg CO_2)	30769.2

* - Standard conversion factor (IPCC Report 2007).

Material selection and conservation of resources. In evaluating sustainability the carbon impact and primary energy input for the construction of the buildings were evaluated.

As shown in Table 4, the results of the detailed calculation for both the traditionally-designed building and the green residential building indicated a significant difference when the size of occupancy in terms of floor area of the building is considered. As presented, total kg carbon associated with the traditional design is approximately 33,500 kg of carbon dioxide, almost similar in quantity with that of the green building at approximately 33,300 kg of carbon dioxide. However when the results are made in the same dimensional index, i.e. amount of carbon dioxide per unit area, the green building design is almost 40% less compared with that of the traditionally-designed residential building. Total overall primary energy for both building designs are obtained using the calculated material weights, the accepted emission factors and the total energy consumption of the building for an assumed 20-year time horizon. A recent report estimated the waste reduction through substitution of traditional methods with prefabrication systems to be between 20 and 40%, the greater the pre-fabrication the greater the savings (WRAP 2008).

Table 4

Carbon impact for both designs

Parameter	*Traditionally-designed building*	*Green building*
Total kg carbon dioxide (kg CO_2)	33,499.95	33,297.35
Total floor area, in square meters	247.63	404.34
Amount of CO_2 per unit floor area, kg CO_2/m^2	135.38	82.35
% reduction relative to traditionally-designed building	-	39.13%

Figure 3 shows the total primary energy input for both designs in terms of megajoule per unit of floor area (MJ/m^2). The total primary energy is the sum of the primary energy input used to produce the material needed in the construction plus the energy expended or consumed by the building over the specified lifespan of the building.

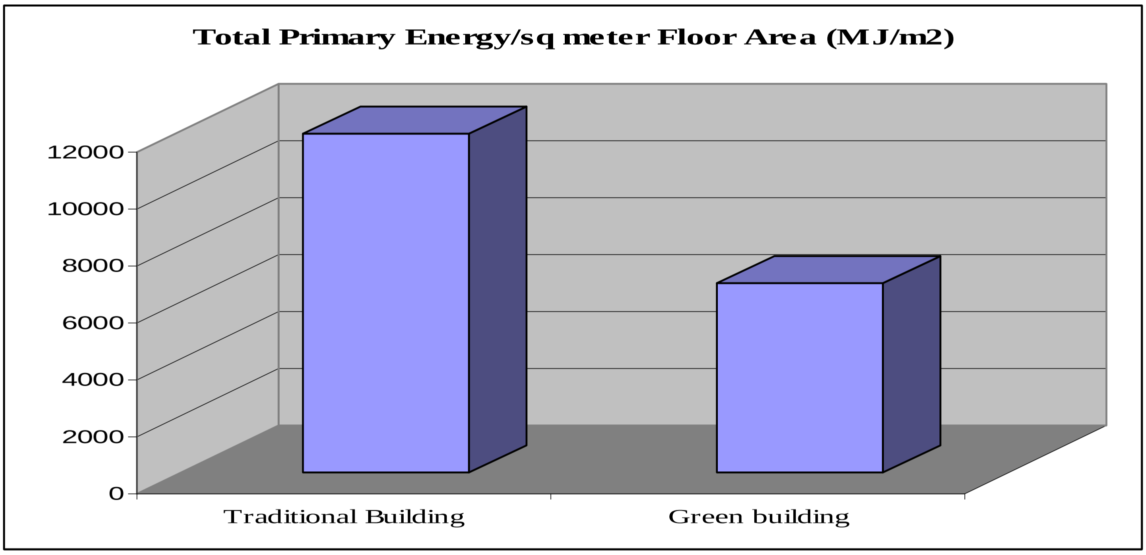

Figure 3. Calculated total primary energy input.

Analysis of the evaluation reveals positive results for the green residential building as compared to that of the traditional building. As shown in the calculated results, total primary energy needed including the primary energy associated with the consumption of electricity can reach as much as 2,700 gigajoule for the green building and approximately 3,000 gigajoule for the traditional building respectively. In terms of primary energy per unit of floor area, results of the calculation indicate a much bigger advantage for the green building design. As shown in the calculation, total primary energy can be approximately 7,000 MJ/m^2 for the green building and approximately 12,000 MJ/m^2 for the traditional building respectively. Thus, the green building consumes approximately 40% less in terms of overall primary energy as compared with that of the traditional building.

Improved environmental quality. The use of natural ventilation design and proper orientation of the building were integrated into the design of the green building. Simulations were made to determine the optimum level of daylight and some features of the design utilize insulation features to stabilize the indoor air temperature of the building. The climatic parameters such as prevailing wind speeds, solar insolation levels, relative humidity and pressure differences were measured to obtain proper ventilation of the building. Figure 4 shows temperature measurements of the building.

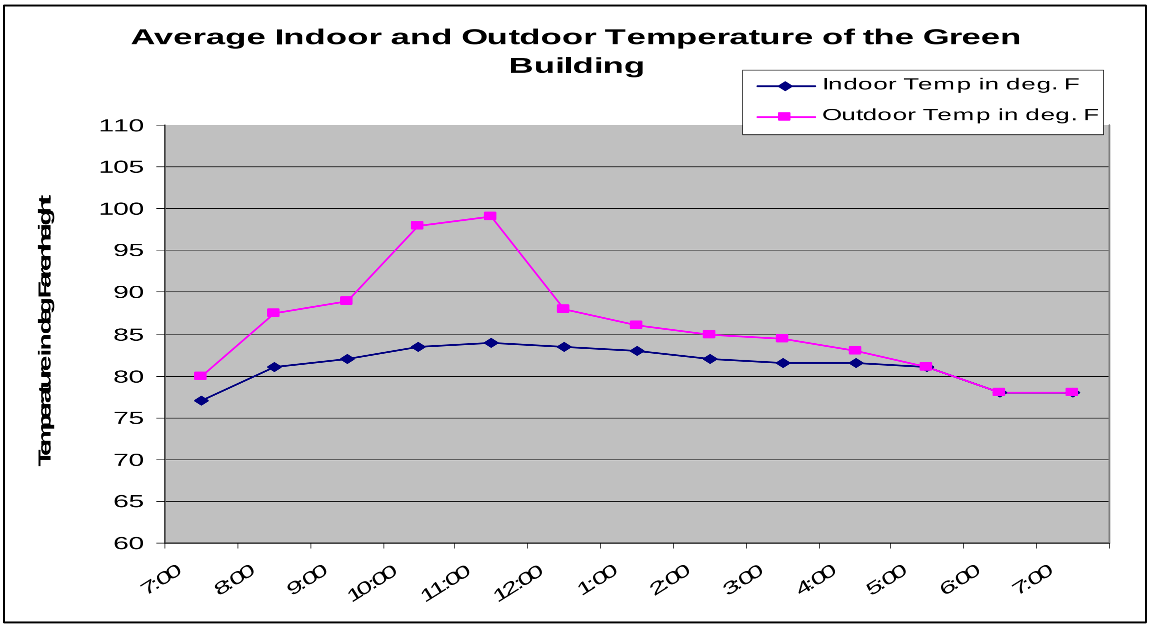

Figure 4. Measured indoor and outdoor temperature of the green building.

As illustrated in the graph and observed in the green building, indoor temperature is almost stable during the measuring periods in spite of rapid variations in the outside air temperature. The foregoing results can be attributed to a number of factors inherent in the green building design. One of such factor is the efficient natural ventilation occurring in the building and the use of proper insulation materials that reduces energy gain coming from the roof during the day time. Temperature measurement were not taken during the period starting 7:00 PM up to 7:00 AM, nonetheless is safe to assume from observation of the building occupants that temperature drops below of that measured at 7:00 PM in the previous day. It has been observed that due to prevailing indoor air speeds inside the building, considerable number of the windows and doors in the northern portion of the house is closed to maintain a comfortable temperature inside the house.

Social acceptance. In order to measure the social acceptability of the green building, survey questionnaires were administered to a number of varied respondents on the following aspects: as to overall satisfaction, specific features and some psychological features.

Figure 5 shows the perceived level of acceptability of the human factor of the sustainable building design in terms of overall satisfaction. As illustrated in the statistical analysis there is a very high level of acceptability as to the present impression of the building, the orientation and location of the building and layout of the building, the construction cost and the energy usage, water use and materials selected for the construction.

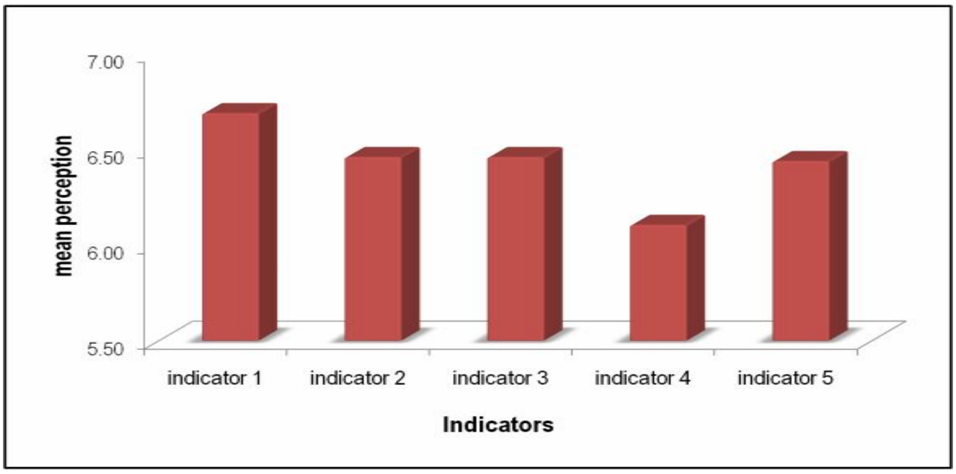

Figure 5. Mean perception of respondents in terms of overall satisfaction.

Figure 6 shows the percentage responses of the respondent in terms of overall satisfaction. As shown in the graph, approximately 65% responded highly acceptable with, 29% of the respondents responded very acceptable and about 6% responded slightly acceptable in terms of the five indicators evaluating overall satisfaction.

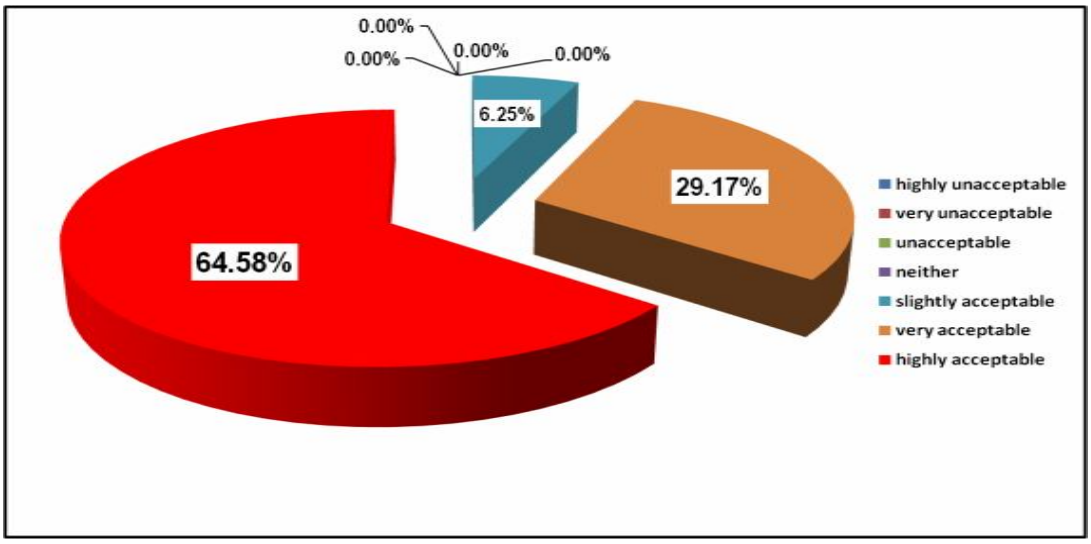

Figure 6. Percentage responses of respondents in terms of overall satisfaction.

Conclusions. A sustainable strategy in the selection and site development integral to design, construction and implementation of green building has been developed. In the site selection and development, the following are the strategies; the proper orientation of the green residential building; the incorporation of the green roof top and the restoration/plantation of different species of plants within the site. The results reveals the following: that the building has been observed to be properly oriented with minimum levels of lighting consumption and sufficient lighting designs, and that with the implementation of the green rooftop and restoration and plantation of different species of plants a considerable amount of carbon has been offset for the growing of the plant at approximately 470 tons of carbon for the 20-year time horizon.

In the use of water, the results indicated that with the incorporation of a water storage tank and the consequential use of rainwater, the dependency of the residential building for commercial water has been significantly diminished. It has been observed that the normal amount of rainfall can supply the needed requirement of supplying adequate amount of water to sustain the plants in the green rooftop and that of the planted trees and other species in the site.

For the construction and implementation of a green building that consumes less energy and reduced cooling loads, the sustainable strategies includes the use of daylight and the use of highly efficient electrical features. The results have indicated that green building has reduced its energy consumption of approximately 40% per unit of floor area when compared with that of the traditional building design. In terms of energy savings, it has been projected that due to the use of the foregoing strategies, the green building can save up to 1,800 kilowatt-hours of energy annually, and the increased construction cost due to the application of these strategies may be recovered at approximately eleven years of operation of the building. The study further reveals that in terms of environmental benefits, the green building may abate the associated equivalent carbon emissions to the atmosphere as much as 30 tons of equivalent carbon dioxide for the 20-year assumed life span.

With respect to the selection and conservation of resources associated to the construction of the green building, the parameters considered are the associated carbon dioxide emissions in the construction and operation of the green building and the associated primary energy needed as input into the construction. The study reveals that when compared to the traditional building, it has the potential to reduce approximately 40% associated carbon dioxide emissions and 40% primary energy for the construction of the green building. The calculated estimates reveal that with this strategy, it can mitigate approximately 21,000 kg of carbon dioxide of emissions to the environment and approximately 2,100 gigajoule of primary energy is avoided.

A sustainable strategy which improved the environmental indoor quality of the residential building has been employed in the construction of the green building which is the most critical component of the study. The strategies involved are the incorporation of design features that utilizes natural air circulation and the use of such features combining with advanced ultra-high efficient cooling units that achieved the maximum natural ventilation possible. This has been evident with the resulting stability of the indoor air temperature and the achievement of thermal comfort even at the normal relative humidity prevalent in tropical climate.

As to acceptability of the green building, the survey results as per statistical analyses reveals high level of acceptance of respondents in terms of the overall satisfaction features, the general and the specific features and the given psychological indicators of the design.

Thus, consistent with the research direction and the specific objectives, the advantages of the green residential building has been quantified in terms of architectural, technical, economics and its benefit to the environment. Its social acceptability has been proven as indicated in the survey results. Hence, it can be concluded that the construction and operation of a truly sustainable house has been achieved.

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Authors:
Rey Diegas Galua, Mindanao University of Science and Technology, College of Engineering and Architecture, Philippines, Cagayan de Oro City, Lapasan Highway, 9000, e-mail: rgaluasds@gmail.com
Ermelinda Goc-ong Tobias, MSU-Iligan Institute of Technology, College of Science and Mathematics, Department of Biological Sciences, Philippines, Tibanga, Iligan City, Andres Bonifacio Street, 9200, e-mail: egtobias2008@gmail.com
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