Public Market Energy Intensity and a Design of an Energy Efficient, Effective, Healthy and Vibrant Public Market Infrastructure

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Abstract

Typical public markets in the Philippines are untidy, musty, and energy inefficient. This paper addresses the evaluation framework for energy intensity and general redesign of Philippine public markets considering low energy intensity, effective, healthy and vibrant conditions, and pleasing aesthetics as primary design considerations. Ten public markets were audited and evaluated. The average embodied energy is 4.7 PJ/m² and average monthly operation energy intensity is 19.2 MJ/m². Optimizing the existing designs resulted to a 10.6 percent lower embodied energy and 64 percent lower operation energy intensity than the average of the study samples. However, considering the better criteria, an actual design has an embodied energy 10 percent more as expected but 55 percent lower operation energy intensity than the average of the study samples. It is recommended that the building code of public market include solar photovoltaic array and water heater, cold storage, bio-digester, solid waste disposal system, wastewater treatment, deodorizing and passive ventilation, and natural lighting.

Keywords: public markets; building energy efficiency; energy consumption opportunities

I. Introduction

Public market is a place, building or structure of any kind which is owned and or operated by the local government. Public market is the physical venue where suppliers and buyers make trade transactions. The Code on Sanitation of the Philippines (P.D. 856, 1975) and the Implementing Rules and Regulations to Govern the Processing of Application for Locational Clearance of Markets (Housing and Land Use Regulatory Board, 2000) have listed the basic requirements for constructing and maintaining public markets which should keep them clean, sanitary, safe and efficient. However, the current state of public markets in the country is untidy, musty, and energy inefficient. Ill-maintained facilities and poor sanitation are threatening the safety and health of the people who avail of the facilities of public markets.

This paper aims to study the energy intensities of public markets and design a public market with low energy intensity, with effective, healthy and vibrant conditions, and with pleasing aesthetics as primary design considerations. The design adheres to the mandatory specifications like public toilets, parking space, cooling and refrigerating system, and proper waste handling

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facility (P.D. 856, 1975; HLURB, 2000) and also incorporates vital requirements to enhance the facilities to be more energy and resource efficient, healthier and safer.

Having a standardized design for public market will create a big impact. Aside from addressing the present problems in congestion, safety, sanitation and efficiency, its benefits will amplify to a larger scale. A public market is expected to serve 10,000 people (HLURB, 2000) and it was proposed that every local unit of the country should have a public market down to the barangays (S.B. 1319, 2010). There are 17 regions, 81 provinces, 145 cities, 1,489 municipalities and 42,036 barangays in the country (Department of Interior and Local Government, 2017) which means a total of 43,768 public markets. In addition, 1,878 (Philippine Statistical Administration, 2015) must be added for those barangays with population exceeding a multiple of 10,000 persons. Therefore, the minimum number of public markets should be 45,646 for both existing and to be established. The new public markets are envisioned to comply with the new design and existing ones will be rehabilitated since public markets play a vital role in the local economy and used by the majority of the citizens.

II. Methodology

The research activities started by reviewing the energy management requirements of public markets, auditing the market facilities using the energy audit framework developed by Manegdeg (2013, 2015), computing, evaluating and validating the data, understanding the influencing factors to energy consumption, formulating policy for effective energy management and designing a better public market infrastructure. The research flow diagram is shown in Figure 1.

The total energy requirement of a product by accounting the energy used to produce the product, is termed as the embodied energy. Equation 1 shows the relationship of the embodied energy with respect to the energy used in manufacturing and producing the raw materials:

$$E_{embodied} = m e_{intensity} \qquad (1)$$

where $\mathbf{E_{embodied}}$ (MJ or J) is the Embodied Energy, **m** (mass in kg or area in m^2 or volume in m^3) is the approximate total unit in weight or area or volume of the product, and $\mathbf{e_{intensity}}$ (MJ/kg or J/m^2 or J/m^3) is the energy intensity of the material from production to actual installation. In some cases, transportation and extraction of the raw materials are included in the value of the embodied energy. Most energy intensity values of the raw material used in the construction industry are publicly available. The total embodied energy of a public market sample is then computed by summing all the products of materials with their respective energy intensities. This is given by the Equation 2:

$$E_{total\ embodied} = \sum m e_{intensity} \qquad (2)$$

The energy consumption is arranged into major processes known as the energy cost centers. In the study, there are seven energy cost centers composed of the following: Air Conditioning (AC) / Ventilation, Cold Storage, Cooking, Data Processing, Food Processing, Lighting, and Security. The total energy consumption per process is achieved using Equation 3:

$$E_{process} = \sum P_{rating} f_{usage} N t \qquad (3)$$

where $\mathbf{E_{process}}$ is the total energy per process, $\mathbf{P_{rating}}$ is the power rating, $\mathbf{f_{usage}}$ is the usage factor, **N** is the number of units, and **t** for average time of use.

Energy consumption of the building is primarily based on the total electricity consumed by the equipment or operations by considering the number of units, efficiencies, way of usage, and energy rating. To come up with an acceptable design, the study aimed to incorporate the most efficient equipment available in 2017. With this, it is necessary to quantify the existing design of structures and performance of equipment. To do an assessment, profiling of the physical characteristics of the facility must be taken into account. Also, analysis of the user profile and requirement must be considered to have a higher chance of acceptance.

The framework, as shown in Figure 2, uses process analysis (Manegdeg, 2013, 2015). The public market was partitioned by process. The ranking of the processes was done using Pareto for those processes with 80 percent impacts on energy consumption. The parameters influencing the process were identified using cause and effect diagrams for the prioritized processes. The actual energy audits were conducted using measuring equipment.

The existing facilities of public markets are analyzed by computing the energy load based on the volume and configuration of the stalls and market in general. Equations 4 to 8 are used in the computation of the public market energy load:

$$q_{lighting} = P_{light} F_u F_b CLF \qquad (4)$$

$$q_{sensible\ load} = Gain_{per\ person} N_{persons} CLF \qquad (5)$$

$$q_{solar\ entering\ the\ transparent\ area} = A(\tau I_t + N\alpha I_t) \qquad (6)$$

$$q_{solar\ on\ opaque\ area} = U_w A(t_e - t_i) \qquad (7)$$

$$q_{wall\ heat\ gain} = UA(CLTD) \qquad (8)$$

where $\mathbf{q_{lighting}}$ is the heat generated from room lightings, $\mathbf{P_{light}}$ is the power rating of lighting equipment, $\mathbf{F_u}$ is the utilization factor, $\mathbf{F_b}$ is the ballast factor, and **CLF** is the cooling load factor. The heat generated from the occupants is accounted in the $\mathbf{q_{sensible}}$ load where $\mathbf{Gain_{per\ person}}$ is the heat gain per person and $\mathbf{N_{persons}}$ for the number of occupants. Solar heat penetration to the room is classified into solar entering the transparent area ($\mathbf{q_{solar\ entering\ the\ transparent\ area}}$) and opaque area ($\mathbf{q_{solar\ on\ opaque\ area}}$). Factors to be considered in solar heat penetration are Area **A**, transmittance **τ**, irradiation $\mathbf{I_t}$, fraction absorbed radiation by conduction and convection **N**, absorptance **α**, heat transfer coefficient of wall $\mathbf{U_w}$, and temperatures equivalent $\mathbf{t_e}$ and inside $\mathbf{t_i}$. For walls, the heat gain ($\mathbf{q_{wall\ heat\ gain}}$) is a function of Area, heat transfer coefficient **U**, and cooling load temperature difference **CLTD**. The formula and necessary tables are found in Stoecker and Jones (1982).

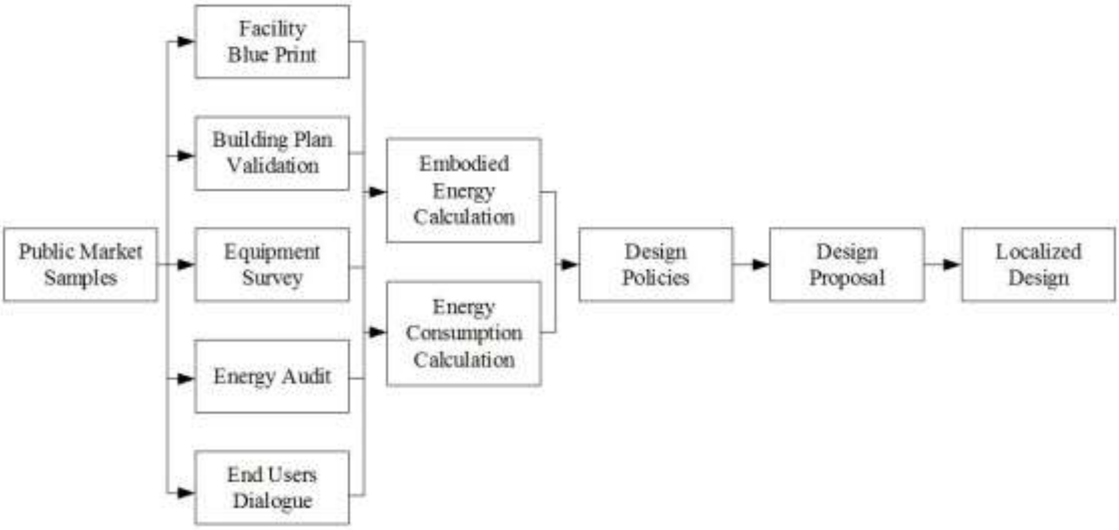

Figure 1. Research flow diagram.

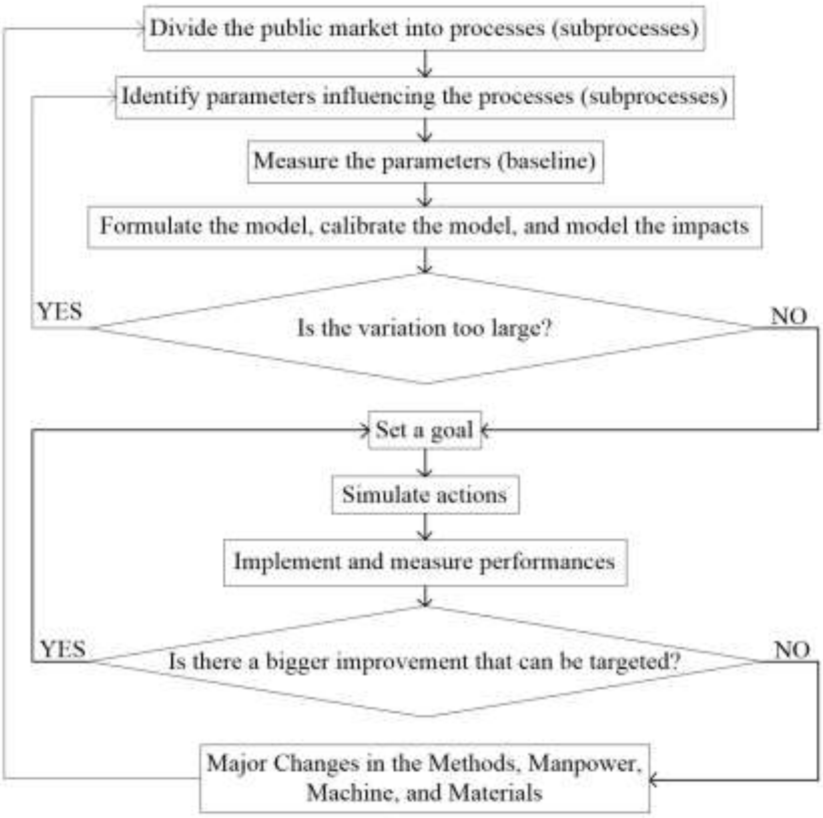

Figure 2. Energy audit framework.

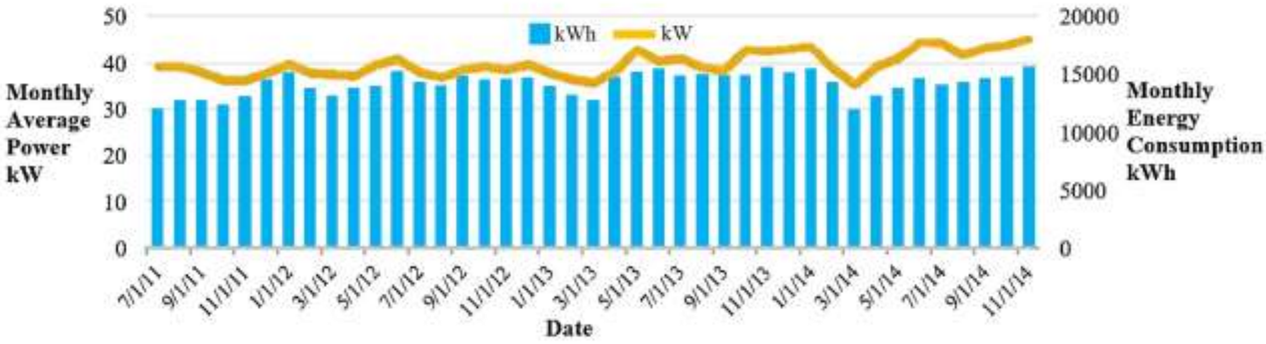

Figure 3. Average monthly energy consumption and average monthly power.

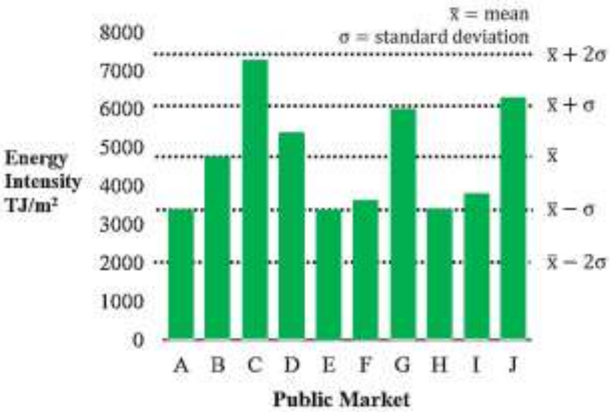

Figure 4a. Energy intensity of materials and construction.

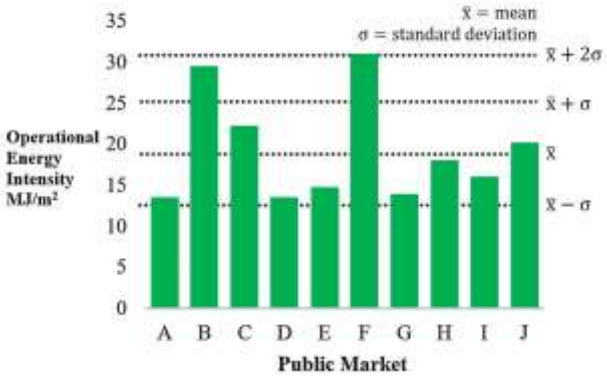

Figure 4b. Monthly operation energy intensity.

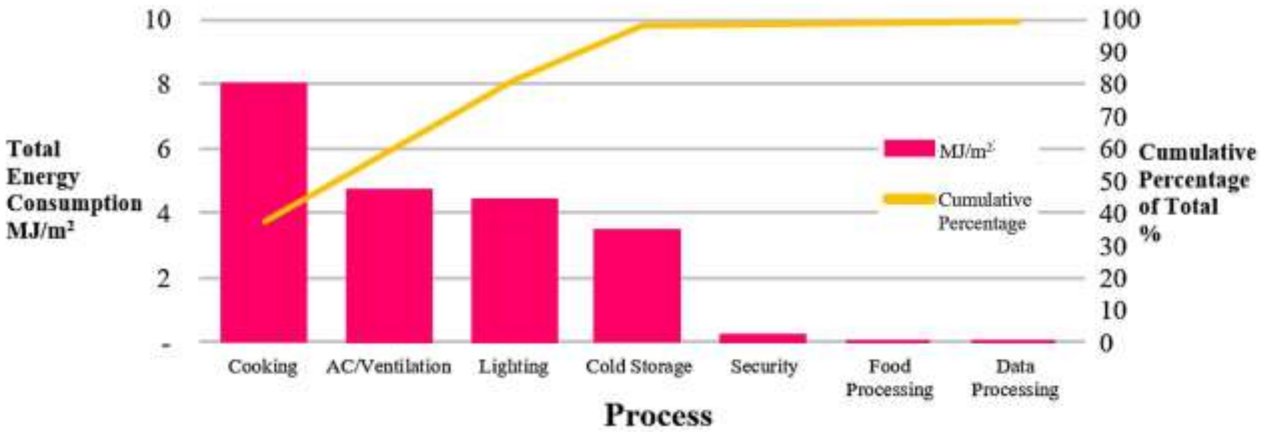

Figure 5. Pareto diagram of the processes.

The study identified contiguous area located in northern part of Quezon City and southern part of Bulacan to represent a highly and slightly populated area respectively. Sample public markets were obtained randomly in the area. Ten public markets were selected based on the criteria for inclusion as follows: all the public markets have an area between 500 to 7,000 square meters; have a dry, semi-dry and wet sections; operate every day; have permanent buildings; and have one power meter for the whole market facilities. Since there are no current standard specifications of a public market, the selected 10 public markets were used as baseline for the proposed design. The average values of specification parameters of each public market samples were computed. The proposed public market was designed as long as the embodied energy is less than 10 percent, and the operational energy expenditure is less than 20 percent.

In order to achieve the proposed design, the quantity of materials were decreased, and/or the materials were replaced with materials with lower energy intensities, and/or revised design was followed, that resulted to lower embodied energy. More energy efficient equipment were also used to decrease the operational energy expenditures. The total embodied energy and the operational energy of the proposed public market design were computed and compared to the 10 public market samples. The same framework was also used in computing the actual public market in comparison with the baseline.

The strategy to decrease the embodied energy is a function of reducing and/or changing the amount and types of materials and/or redesign. In order to come up with these measures, the designers, architects, and engineers shall strategize to adhere to the prescribed limitations of energy intensity by reduction and/or choice of materials and/or innovate on the design.

The impacts were modeled, and the model was calibrated and fine-tuned. A goal was set, the actions were simulated, and then if implemented, possible savings were calculated. The results were validated using the data previously consumed by the public markets from the local electricity provider for the last four years. The policy for effective energy management was formulated considering the level of energy savings and the ease of implementation.

Energy savings are calculated by comparing the computed existing consumption against the calculated efficient design. Equation 9 provides the formula in determining the percent savings:

$$\%\ Savings = \left(\frac{E_{current} - E_{designed}}{E_{current}}\right) x\ 100 \qquad (9)$$

where $\mathbf{E_{current}}$ is the average energy consumption of the 10 cases since there is no standard yet. $\mathbf{E_{designed}}$ is the approximate consumption of the proposed design in accordance to the recommended energy policies.

III. Results

The public markets have an average area of 58.6 percent of dry section, 21.5 percent of wet section and 19.9 percent of semi-dry section. The monthly average power in kW and the monthly operation energy consumption in kWh of the 10 public markets for 41 months from July 2011 to November 2014 are shown in Figure 3. The minimum monthly energy consumption is 12,012 kWh while the maximum is 15,708 kWh. The average monthly energy consumption is 14,234 kWh with a standard deviation of 990 kWh. The highest consumptions were during the Christmas seasons.

This study provides a framework of methodology for public market design standardization in terms of embodied energy and energy consumption, the surveyed and calculated energy values from the samples show the relatively low and high values by identifying the mean ±2 standard deviation (σ).

The public markets were constructed mostly of concrete, steel, wood, wire, polyvinyl chloride, and tiles. The embodied energy intensity of materials and construction in PJ/m² is shown in Figure 4a. The maximum embodied energy intensity is 7.3 PJ/m² while the minimum embodied energy intensity is 3.4 PJ/m². The mean embodied energy intensity is 4.7 PJ/m² with a standard deviation of 1.4 PJ/m². Figure 4a shows that four public markets are within the range of mean to mean minus one standard deviation, one public market is within the range of mean minus one standard deviation to mean minus two standard deviations, three public markets are within the range of mean to mean plus one standard deviation, and two public markets are within the range of mean plus one standard deviation to mean plus two standard deviations. Public market E is the most embodied energy efficient.

The monthly operation energy intensity in MJ/m² is shown in Figure 4b. The maximum operation energy intensity is 31 MJ/m² while the minimum operation energy intensity is 13.1 MJ/m². The mean operation energy intensity is 19.2 MJ/m2 with a standard deviation of 6.2 MJ/m². Figure 4b shows that six public markets A, D, E, G, H, I are within the range of mean to mean minus one standard deviation, two public markets are within the range of mean to mean plus one standard deviation, and two public markets are within the range of mean plus one standard deviation to mean plus two standard deviations. Public market D is the most operation energy efficient.

The Pareto diagram of the processes is shown in Figure 5. Cooking (37.9 percent), ventilation and air conditioning (22.7 percent) and lighting (21.2 percent) constitute at least 80 percent of the energy consumption. The causes resulting to high energy consumption include rotten goods; inefficient lighting, cold storage, ventilation, and air conditioning; lack of energy conservation awareness; lack of discipline; unfamiliarity with renewable energy; lack of strict implementation of policy and regulations; and no proper partitioning of sections.

Table 1. Design criteria.

Energy Efficient
▪ Air Conditioners must be inverter-type and EER ≥ 13 ▪ Lights must be LED-type ▪ Daylight must provide at least 24 percent of everyday lighting ▪ All opaque roof panels must have fiberglass insulation, while translucent panels must be heat-blocking polycarbonate sheets ▪ Refrigerators, chillers, and freezers must be inverter-type and EEF ≥ 330 ▪ Electric motors with efficiencies ≥ 90 percent ▪ All air circulation must be provided by high-volume low-speed fans ▪ Solar PV array must have an efficiency ≥ 19 percent ▪ At least 85 percent of hot water must be from a solar water heating system ▪ At least 30 percent of heat power must be from a bio-digester system ▪ All non-load-bearing walls must contain blown-in fiberglass
Healthy
▪ Building materials do not contain hazardous chemicals ▪ Particulates, allergens, molds, and volatile compounds are not present in the air ▪ Relative humidity and evidence of moisture are low ▪ Nitrates and coliform bacteria are not present in the water ▪ Sound level must be less than 70 dB
Vibrant
▪ Variety of goods and services are offered, i.e., wet goods, dry goods, food items, non-food items, clothes, toys, and specialty items ▪ Variety of spaces to display goods are existing, i.e., wet and dry stalls, gift shops, cook-and-eat areas, etc. ▪ Variety of activities suited for all ages and interests are available, i.e. shopping, eating, playing, lounging, exhibiting, entertaining, etc.
Aesthetic
▪ Visual design elements as specified by the designer such as color, form, and texture are applied ▪ Design principles as upheld by the designer such as unity or harmony, balance, scale and proportion, and contrast are applied
Effective
▪ The building possesses visual impact, legibility of building type and function ▪ The building possesses statement of arrival, clarity, and ease of ingress and egress ▪ The building possesses accessible wayfinding, stress-free and barrier-free circulation ▪ There exist services for comfort and convenience, i.e. parking, toilets, waiting areas, Person With Disability/elderly/ special facilities ▪ There are back of the house services, i.e. administrative office, storage, mechanical services, delivery bays, solid waste management, etc.

The design considerations for new public markets include the use of low embodied energy materials, passive cleaning, passive ventilation and deodorizing, maximize natural lighting, building facing east and west for the shorter-side of the facility, installing efficient equipment, solar panel, bio-digester, rain harvester and wastewater treatment (Santos and Robbins, 2006). Table 1 tabulates the suggested design criteria.

The design criteria were formulated based on public consultation, personal perception and industry practice, and the current available technology. During the data gathering and public market survey, the end users composed of vendors and officials, were asked about their perception of an ideal public market. The criteria within the five major descriptors provided the concept on how to design an ideal public market facility.

The embodied energy of the existing market is computed by accounting all the materials and corresponding energy intensities. By changing the materials from high energy intensity to low energy intensity, a guaranteed decrease in overall embodied energy of the public market is expected. Table 2 shows the comparison of embodied energy of proposed public market design versus a sample of the audited public market.

Embodied energy can be decreased by reducing and/or changing the materials. As shown in Table 2, adjusting the ground footing of the public market wall and ceiling support can reduce the usage of concrete for structural foundations. Optimizing the layout of these foundations based on the design methods and preference of designers, architects and engineers will decrease the need of some materials such as tiles, steel I-beams and trusses, chicken wires, and wood panels. Changing the materials will also significantly reduce the embodied energy provided that these changes will still deliver the prescribed services and functions of the replaced materials. This can be observed by replacing the door material from steel to wood composites or by means of material reduction, the steel door can be fabricated to be thinner and lighter.

The proposed public market design is shown in Figure 6. The proposed energy intensity and operation energy consumption are shown in Figures 7a and 7b optimizing the design of the current public markets. The proposed building design has an embodied energy intensity of 4.2 PJ/m^2 which is lower by 10.6 percent from the mean of the public market samples.

Suggested technical specifications of the equipment used in the proposed design public market are based on the publicly available technology as of 2017. The operation energy intensity is 6.9 MJ/m^2 which is lower by 64 percent from the mean of the public market samples. The proposed energy savings measures are shown in Table 3. The design recommendation provides information on how to reduce the operation energy consumption of the existing and proposed public market design. It is based on the current energy practice from the observed samples of the study. Table 4 shows the different design policies grouped according to the nature of process, which in this case, the energy cost centers determined as shown in Figure 5.

Table 2. Embodied energy savings due to change of materials.

Building Materials		Material	Embodied Energy (MMJ/m²)	Existing Embodied Energy (MMJ)	Proposed Embodied Energy (MMJ)	Change in Embodied Energy (%)	Material Strategy	Specific Action
Parameter	Value (m²)							
Footings	4056	Concrete	473	1,920,040	409,003	79	Reduction	Re-layout of foundations
Ground Floor Flooring	4056	Concrete	473	1,920,040	409,003	79	Reduction	Use of natural rocks
Tiles	4056	Tiles	225	912,600	-	100	Replacement	Only cement flooring
Vinyl	0	Vinyl (PVC)	53	-	-	-		
Supporting Column (1st floor)	4056	Concrete	797	3,232,068	688,488	79	Reduction	Re-layout of foundations
Supporting Column (1st floor)	0	Steel I-Beam	426	-	-	-		
Supporting Column (1st floor)	0	Steel Trusses	174	-	-	-		
Supporting Column (1st floor)	0	Wood Joist	158	-	-	-		
Roofing Beam	4056	Concrete	797	3,232,068	-	100	Reduction	Re-layout of ceiling
Roofing Beam	0	Steel I-Beam	426	-	-	-		
Roofing Beam	0	Steel Trusses	174	-	149,968	-	Addition	Replacement for concrete support
Roofing Beam	0	Wood Trusses	237	-	-	-		
Roofing	4056	Steel Roofing System	947	3,840,081	818,005	79	Replacement	Optimization of roofing support
Ceiling	4056	Ceiling 1	199	807,955	-	100	Reduction	Use of natural lighting (open roof)
Interior Walls	0	Wood	237	-	-	-		
Interior Walls	0	Chicken Wire	316	-	43,173	-	Addition	Replacement for concrete blocks
Interior Walls	3106	Concrete block	1499	4,656,035	921,013	80	Replacement	Reduction of concrete blocks usage
Door	4056	Steel Panel	2367	9,600,202	2,045,013	79	Replacement	Replacement of wood panel
Door	0	Wood Panel	947	-	-	-		
Supporting Beam (2nd floor)	96	Concrete	544	52,261	470,353	800	Addition	Reduction of concrete by using steel for structural integrity
Second Floor Flooring	96	Concrete	947	90,889	818,005	800	Addition	
Supporting Column (2nd floor)	96	Concrete	600	57,563	518,070	800	Addition	
Supporting Beam (3rd floor)	0	Concrete	544	-	-	-		
Third Floor Flooring	0	Concrete	947	-	-	-		
Supporting Column (3rd floor)	0	Concrete	600	-	-	-		
TOTAL EMBODIED ENERGY (MMJ)				**30,321,803**	**7,290,094**	**76**		
ENERGY INTENSITY (MMJ/m²)				**7,303**	**4,219**	**42**		
AVERAGE ENERGY INTENSITY (MMJ/m²)				**4,743**	**4,219**	**10.6**		

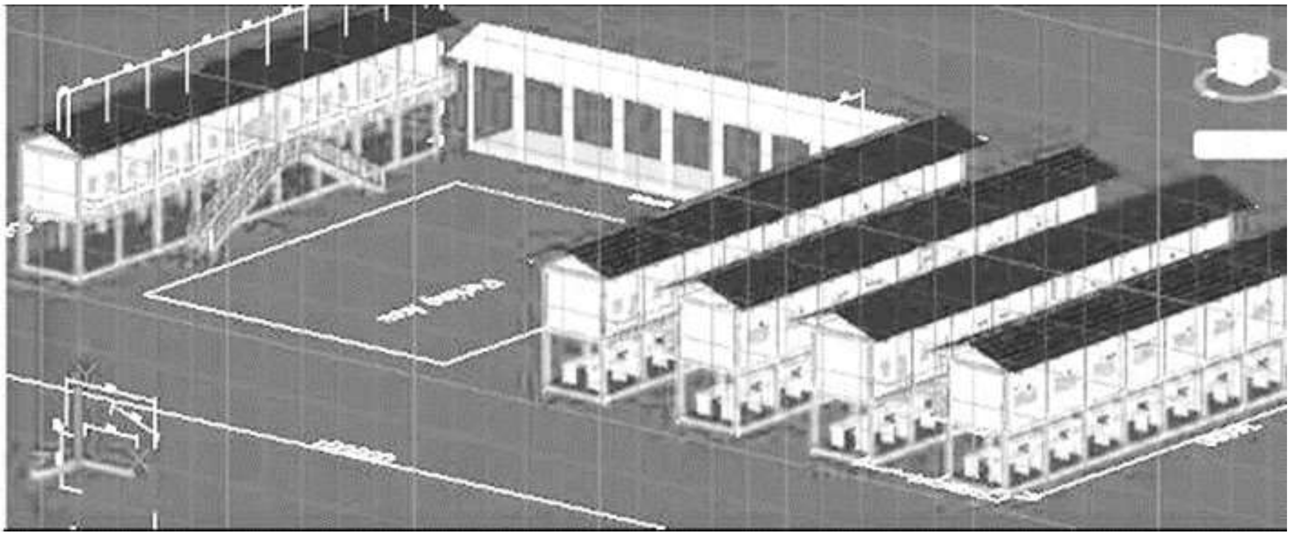

Figure 6. Proposed public market design.

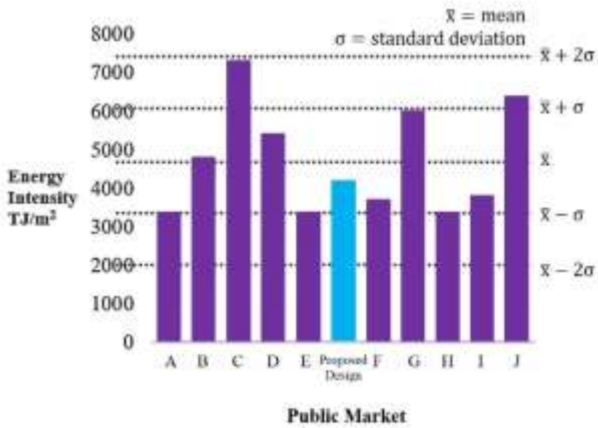

Figure 7a. Proposed public market design energy intensity of materials.

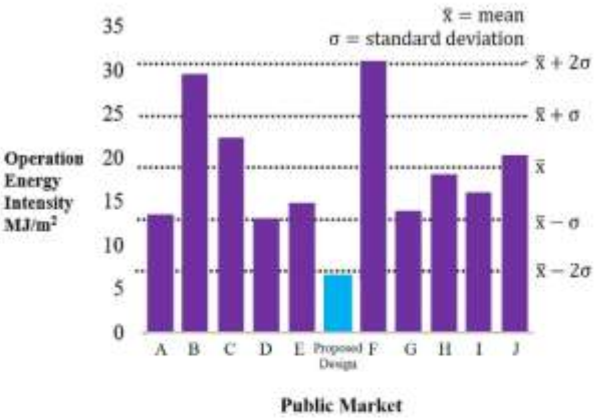

Figure 7b. Proposed public market design monthly operation energy intensity.

Table 3. Energy savings measures.

Energy Policy	Energy Savings	
	(MJ/month)	(PhP/month)
Bio-digester System for Cooking and Baking [1]	8195	9106
Solar PV System	5132	14256
Solar Water Heater [2]	4413	4903
LED lighting	3254	9039
Eco Ventilators [3]	2961	8226
Heat-blocking Translucent Roof Panels [4]	2662	7395
Fiberglass Roof Insulation	2468	6855
Structural Heat-insulated Panels [5]	1974	5484
High-EEF Refrigerator, Chillers, and Freezers [6]	1808	5024
Daylight Harvesting [7]	1775	4930
High-EER Air-conditioners [8]	1015	2820
Stand Fans Replacement (ceiling fans)	430	1194
High Efficiency Motors [9]	167	463

Sources: [1] Linear E.A.S.T., 2012; [2] U.S. Department of Energy, 2005; [3] Ampelite, 2013; [4] Translucent Heat-Blocking Panels, n.d.; [5] Structural Insulated Panel Association, n.d.; [6],[8] Department of Energy, n.d.; [7] DiLouie, 2007; [9] The Carbon Trust, 2015.

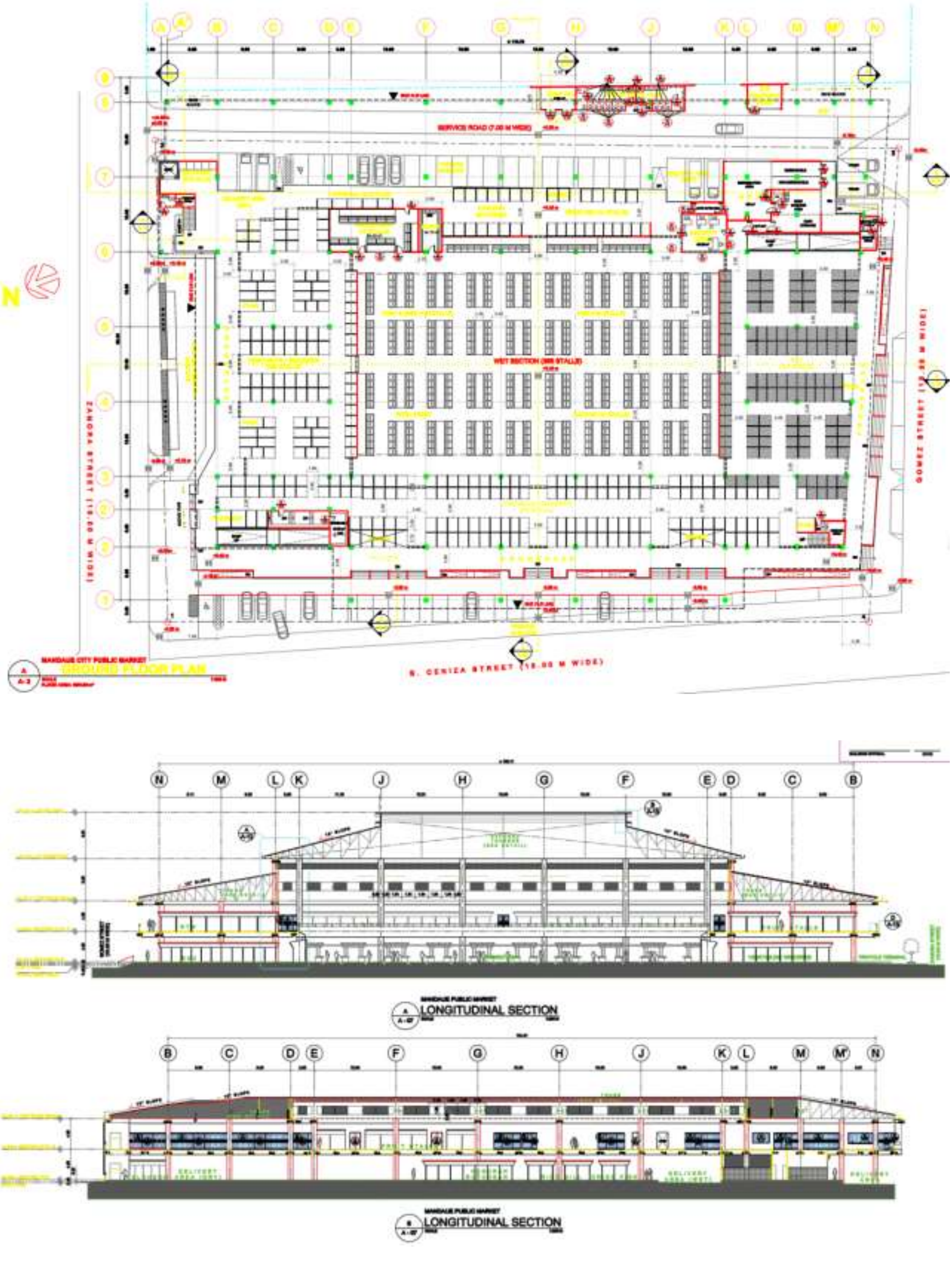

Figure 8. Actual public market design.

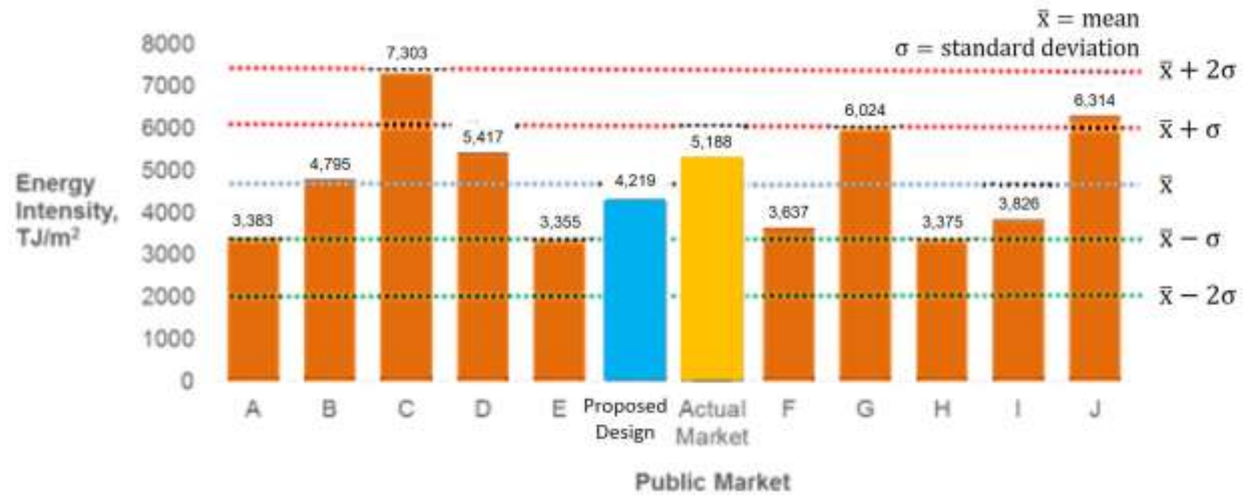

Figure 9a. Actual public market design energy intensity of materials.

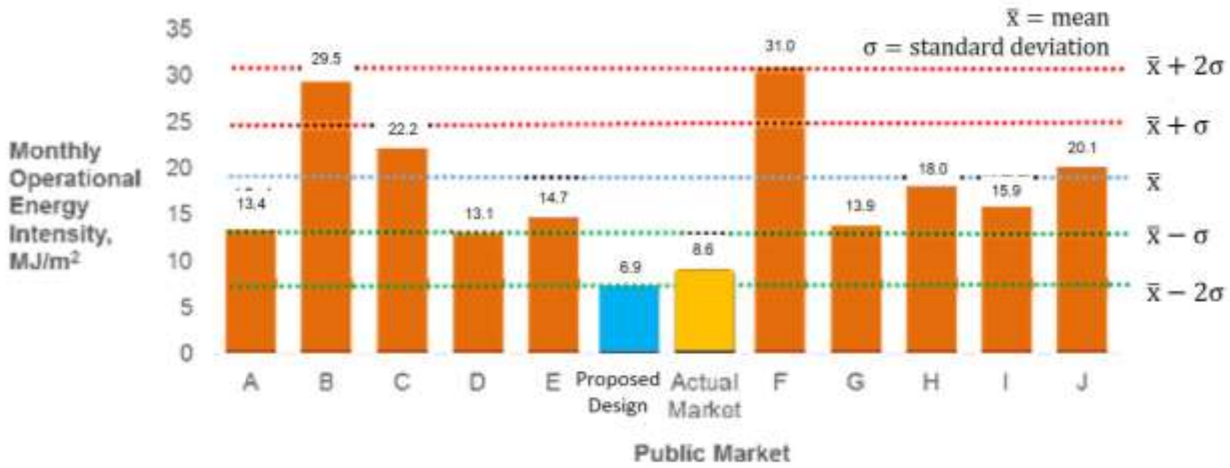

Figure 9b. Actual public market design monthly operation energy intensity.

Table 4. Energy policy savings.

Energy Cost Center	Existing Design Sample	Proposed Design	Energy Consumption Savings (%)
Lighting [1]	Incandescent Bulb and Fluorescent Light (100W and 40W)	LED Lights (15W)	85 or 62.5
Ventilation	Air conditioning EER (10)	Air conditioning EER (13)	30
Cooking [2]	Electric Stove (4.4 KW)	Induction Stove (2.8KW)	36.4
Data Processing [3]	Desktop PC (175W)	Laptop (60W)	65.7

Sources: [1] Based on 2018 Philippine LED market; [2] InductionPros.com, n.d.; [3] Stone, n.d.

An actual public market design adherent to the proposed framework incorporating the other parameters is shown in Figure 8. However, considering the better criteria in Table 1, the actual design has an embodied energy 10 percent more as expected, but 55 percent lower operation energy intensity than the average of the study samples. Figure 9a shows the actual public market design energy intensity of materials while Figure 9b shows the actual public market design monthly operation energy intensity.

IV. Conclusions and Recommendations

The average area of the dry section is 58.6 percent; the average area of the wet section is 21.5 percent and the average area of the semi-dry section is 19.9 percent. The average monthly energy consumption is 14,234 kWh. Among the processes, cooking registered the highest at an average of 37.9 percent, followed by ventilation and air conditioning at an average of 22.7 percent, and lighting at an average of 21.2 percent. The mean embodied energy intensity is 4.7 PJ/m^2 while the mean operation energy intensity is 19.2 MJ/m^2.

The design considerations for new public markets include the use of low embodied energy materials, passive cleaning, passive ventilation and deodorizing, maximized natural lighting, building facing east and west for the shorter-side of the facility, installing efficient equipment, solar panel, bio-digester, rain harvester and wastewater treatment.

The proposed building design has an embodied energy intensity of 4.2 PJ/m^2 which is lower by 10.6 percent from the mean of the public market samples. The operation energy intensity is 6.9 MJ/m^2 which is lower by 64 percent from the mean of the public market samples. However, considering the better criteria, an actual design has an embodied energy 10 percent more as expected, but 55 percent lower operation energy intensity than the average of the study samples.

It is recommended that a full-blown audit be conducted in all public markets to identify more specific interventions; a thorough profiling of market usages be conducted to be able to optimize usage, space allocation, access priorities, and anticipate future energy loads. It is also recommended that minimum standards for materials, processes, equipment and appliances be immediately adopted and implemented. It is further recommended that the other design criteria be quantified using preferential model.

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