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# A Sustainable Impact of Retrofitting the Educational Buildings in Chiang Mai University, Thailand

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# A Sustainable Impact of Retrofitting the Educational Buildings in Chiang Mai University, Thailand

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**Abstract**

Many educational buildings were constructed since 15 years ago on the campus of Chiang Mai University ( CMU). Their operation systems from previous decades consumed excess resources, including energy and maintenance costs. Retrofitting is part of the Smart university project. Four buildings were chosen to be the very first green buildings of CMU, following the Thai Green Building Institute's (TGBI) Thai's Rating of Energy and Environmental Sustainability (TREES) criteria for buildings under operation. The criteria cover eight issues: building management, eco-friendly site planning, water savings, energy management, construction materials and resources, Indoor Environment Quality (IEQ), environmental impact and green innovation. These buildings are large, with areas of more than 10,000 $m^2$, and they consume more than 2,887 MWh of electricity per year. The retrofit project costs 150,000,000 Baht (almost 4 million euro) in total. The impact of this project can be understood in terms of meeting four specific goals: First, the retrofit will achieve a 25% reduction in electricity usage, equivalent to 25,438 kWh or 4% of total University electricity consumption. Second, clean energy is proposed to account for 20% of building consumption from the solar panel system. Third, the project will reduce carbon emissions to 383 tonnes of $CO_2$ equivalence, or 2,598 MJ of embodied energy. Finally, considering the energy consumption and the budget, the payback period for the project is expected to conclude in 19 years.

**Keywords:** Building, Carbon reduction, Retrofitting, Sustainable impact.

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## Introduction

Among engineering and architectural societies, the awareness of energy and environmental crises has been increasing. While renewable energy technology will not develop as quickly as energy demand will increase in the near future, currently energy production still relies heavily on the consumption of fossil resources, which have a negative impact on the environment. Burning coal and oil for electricity, results in the large amount of greenhouse gases threatening human beings. The use of fossil fuels for transportation, including the use of gasoline to power automobiles, presents a massive risk of destroying ecosystems (in terms of embodied energy equivalent) and human health (through the effects of pollution). The global energy crisis is in fact thoroughly associated with the environmental crisis.

Although new construction projects have adopted green design concepts and renewable energy in their plans, most buildings in Thailand still use conventional energy management techniques, such as split-type air-conditioners. Energy consumption in both the residential and commercial building sectors accounts for more than 20% of the country's total energy consumption. Thailand's Ministry of Energy reports that energy consumption from buildings increased from 9,520 kilotonnes of oil equivalent (ktoe) in 1993 to 17,538 ktoe in 2015 (Department of Alternative Energy Development and Efficiency, 2016). Architectural construction also shares an important role as one of the main factors of environmental problems, ranging from excessive resource depletion and global warming to negative impacts on human health and well-being. When raw materials are extracted for building construction, pollution and waste from construction sites may be released into the environment. After construction is completed, those who occupy a building may produce further environmental impacts, through the use of formaldehyde-product furniture or chemical substances for cleaning. Therefore, it is not possible to claim that buildings are sustainable without energy and environmental assessment during both the design and operational periods.

Thailand's government sector takes responsibility to support green building design. The Ministry of Energy developed energy regulations and launched a green rating tool in 2007. Energy regulations have been implemented for large buildings (with more than 10,000 $m^2$ floor area) to have less than 30–50 watts per $m^2$ of overall thermal transfer value (OTTV) for walls and to have less than 10–15 watts per $m^2$ of roof thermal transfer value (RTTV), depending on building types (Ministerial regulations No. 55 for energy conservation buildings B.E. 2552, 2009). The very first green and environment rating tool in Thailand was conducted in 2009, namely Thai's Rating of Energy Conservation and Environmental-Friendly Assessment Manual (Department of Alternative Energy Development and Efficiency, 2009). This assessment tool was the first serious step to gain people's interest in reducing buildings' energy consumption.

Almost five years later, Thai Green Building Institute (TGBI) launched TREES (Thai's Rating of Energy and Environmental Sustainability) to guide the construction industry to use environmentally friendly designs that can increase occupant well-being and productivity comprehensively (TGBI, 2014). This tool concerns how to balance sustainable building design practices with the need to provide occupants with a good quality of life and/or strong productivity.

However, Thai building codes are still not strictly applicable for government buildings built before 2009, including public universities. Currently, there are 156 institutions for higher education in Thailand, and 80 of these are public institutions operated by the government (Office of the Permanent Secretary, 2017). Most buildings at these universities were built without energy conservation or environmentally friendly concepts in mind. This paper tries to analyse the environmental impact of the retrofit projects for four large educational buildings to make them sustainable. It is part of the SMART city project launched by CMU in 2017.

## Literature Review

Many rating tools can be used for green-building assessments. Some countries establish their own green-building rating tools, as they have climates and concerns different from those of other regions. Building Research Establishment Environment Assessment Method (BREEAM) is used in the United Kingdom (UK), Green Star is used in Australia, Comprehensive Assessment System for Building Environmental Efficiency (CASBEE) is used in Japan, Indian Green Building Council (IGBC) is used in India, Built Environment Assessment Method (BEAM) Plus is used in Hong Kong, Green Building Index (GBI) is used in Malaysia and Green Mark is used in Singapore (Illankoon et al., 2017; Vyas and Jha, 2016). Although many countries have their own rating tools, international rating tools are also used and implemented, particularly in Asia Pacific. Leadership in Energy and Environmental Design (LEED) is a worldwide rating tool focused on overall energy consumption (United States Green Building Council, 2014). LEED was established by the United States Environmental Protection Agency (EPA) (2014), and it is used in several regions around the world, such as India (Vyas and Jha, 2016) and Thailand (TGBI, 2017).

International rating tools have similar green-building criteria, such as site, water, management, energy, material, waste and pollution and indoor air quality (Illankoon et al., 2017; Papajohn et al., 2016). However, international rating tools do not address two key issues. First, they do not address how to retrofit an old building to make it a green building. Second, they do not address the environmental benefits green buildings.

Rating tools in each country emphasize different things depending on the needs of building design in regions. Several rating tools give majority of percentages of total credit scores to energy consumption management. For example, Green Mark allocates 49%, GBI allocates 39%, BEAM Plus allocates 34%, LEED allocates 30% and IGBC allocates 29% of total credit scores for saving energy consumption (Illankoon et al., 2017). However, three rating tools allocate smaller percentages of total credit scores to energy consumption saving. BREEAM (2014) gives 23% to energy and 17% to management. Green Star allocates 24% to energy and 17% to IEQ (The Green Building Council of Australia, 2015). CASBEE (2014) uses a different proportion. IEQ and green building techniques are CASBEE's main focus, being proportion as 32% and 25%, respectively. The reason for the unusual allocation is an increase in sick building syndrome (SBS) in Japan (Nakayama and Morimoto, 2009).

*Rating Tools for Existing Buildings*

The TGBI (2017) adopted LEED for existing buildings. The rating tools' environmental impact criteria were based on the TGBI, TREES and carbon reduction calculations of embodied energy.

TREES-EB ( TGBI, 2017) has eight assessment sections: 1) Building Management (BM), 2) Site and Landscape ( SL), 3) Water Conservation (WC), 4) Energy and Atmosphere (EA), 5) Materials and Resources (MR), 6) Indoor Environmental Quality (IEQ), 7) Environmental Protection (EP), 8) Green Innovation (GI).

<u>Building Management</u>

Building management is the most important issue for existing buildings, because in order to be successful, it requires cooperation from every stakeholder: owners, architects, interior designers, landscape architects, engineers, contractors, building occupants and the communities surrounding the project. The green buildings must be proven to release only low levels of pollution into the surrounding neighbourhood. The occupant guidelines and maintenance plan for energy and water conservation are necessary during operation.

The outcome from this section will help the ongoing activities at the green buildings continue smoothly. Well-managed buildings will have positive effects on the owners' and occupants' financial savings, health and well-being.

<u>Site and Landscape</u>

The site for an existing building cannot be changed, but the surrounding context can be improved to support sustainability. Management plans to reduce private car use and decrease urban heat island impact, are important factors in achieving this goal. Six subsections include the following approaches: establish the project on developed land; reduce the use of private cars; practice sustainable site planning; infiltrate storm water and take measures to prevent flooding; in urban areas, reduce heat island effects from project development and the landscape; and keep up building exterior maintenance.

<u>Water Conservation</u>

Existing fixtures and faucets can be replaced with new ones designed for water conservation. Meters also need to be installed in individual parts of the building to monitor water consumption. The amount of rain water collected from the expected rainfall in the site is concerned. Enacting water-saving management plans will help saving water significantly, because building occupants are one of the main prodigality factors.

Energy and Atmosphere

Energy use from buildings can cause significant pollution, especially in Thailand, where electricity is mainly produced from fossil fuels. Even though the electricity produced from clean energy sources (such as solar energy, wind or water) is strongly supported by TGBI, these methods account for only a small proportion of Thailand's energy production. Capturing energy using solar cells is one of the main worthwhile renewable energy options to consider. TREES-EB gives the most points for this section with the maximum total score of 27 points, and it has two prerequisite topics: (1) building a survey and energy conservation plan, and (2) meeting minimum building energy efficiency.

Materials and Resources

Materials and resources for existing buildings are different from those listed in TREES' new-construction version (TREE-NC), since they cannot be fully replaced. For existing buildings, only temporary materials are expected to be a green material. The purchase process needs to specify low-environmental-impact products. Using products that are certified with a green label or identified as having a low carbon footprint are the main priority. This section requires collaboration between owners, tenants and building occupants.

Indoor Environmental Quality

Sick building syndrome (SBS) is a human health condition that can be caused by poor indoor environmental quality. In the UK, many health insurance companies cover this issue in their policies for SBS claims (Youclaim, 2017). According to related research, on average people usually spend more of their time in buildings than outdoors (Bernstein et al., 2007). If an indoor environment is polluted, it will affect building occupants' health and well-being, which might also affect their ability to work. They may end up paying medical fees or be absent from work, and consequently this could negatively affect productivity for their organization.

Indoor environments can be assessed by four criteria: thermal comfort, natural lighting, view, and indoor air quality free of any toxins or contaminants. These criteria aim to promote a good environment and quality of life. They require direct measurement and assessment in the actual existing building; calculations or computer simulations of these factors are insufficient to determine indoor environment quality.

Environmental Protection

To prevent long-term negative impacts on ecosystems and health, Environmental Protection Strategy for Construction (Office of Natural

Resources and Environmental Policy and Planning, 2016) must be strictly followed. The project must pass the requirements in prerequisite topics before considering getting the points in credit topics. The prerequisite topics emphasize ecological and natural resources protection by managing and controlling pollution from building construction and waste management during building operation.

Green Innovations

In addition to the initiatives in these seven sections, an existing building may propose other techniques which are not mentioned in TREES. These additional techniques can earn special points in the assessment. The details of each special technique or innovation must be presented specifically. The extra points are available for each technique that can present greater efficiency than the mentioned maximum level in the prior seven sections. If the green project has a TREES-A on the team, an additional point will also be available.

*Overall Environmental Impact*

Energy reductions and the environmental benefits of green buildings are discussed in a different aspect. The green building should not only consume low energy, but it should also have low environmental impact. To compare the environmental benefits of green buildings, each parameter must be converted into a comparable unit. This paper proposes embodied energy. Embodied energy is the sum of energy used to produce a product or build a building. It is usually calculated to predict a building's energy consumption over its lifespan or to find the best scenario for reducing environmental impact. Embodied energy is measured in units of megajoules per kg for energy consideration and kg of carbon dioxide per kg for carbon footprint. This paper presents a reduction in embodied energy and carbon footprint, comparing between a base-case without retrofitting and a case with retrofitting. The embodied energy index refers to the Inventory of Carbon and Energy (ICE), Sustainable Energy Research Team (SERT), Department of Mechanical Engineering, University of Bath, UK (Hammond and Jones, 2008). A complete list of construction materials and their embodied energies was published by Geoff and Craig in 2008.

The embodied energy equivalence equation is used to calculate the amount of electricity produced from burning fossil fuel. One MWh of electricity produced by fossil fuel in Thailand is equal to 3.6 MJ and 0.53 $tCO_2$ (TGBI, 2016). The environmental impact can be calculated from the reduction of electricity in use and converted to MJ and $tCO_2$ (see equations 1 and 2).

Electricity 1 MWh = 3.6 MJ --------Eq. 1

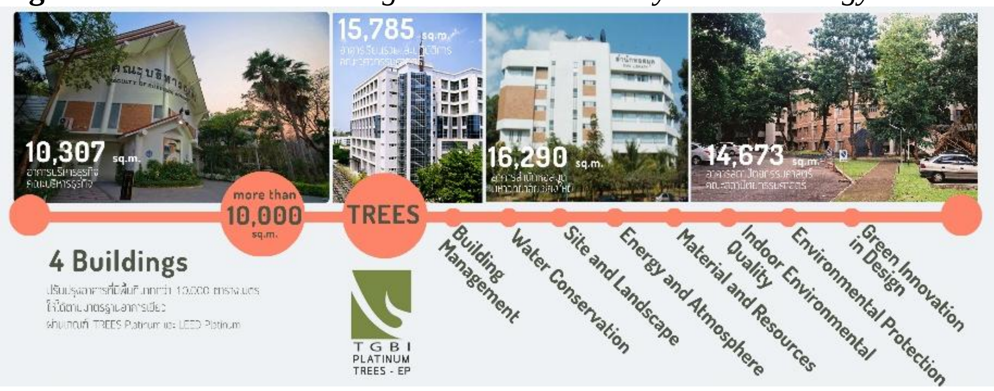
Electricity 1 MWh = 0.53 $tCO_2$ --------Eq. 2

## Methodology

According to the CMU SMART City – Clean Energy project, four large educational buildings were chosen to be retrofitted prototypes for the Platinum green building reward. A building is considered large if it has more than 10,000 $m^2$ of total floor area. At CMU, these four educational buildings are the Faculty of Architecture (10,307 $m^2$), Faculty of Engineering (15,785 $m^2$), Faculty of Business Management 16,290 $m^2$) and Main Library (14,673 $m^2$).

To be rewarded a Platinum level in TREES-EB, the buildings each require evidence of improvement for 75 points out of 100 points, in terms of calculation, simulation and a management plan. Each of the four CMU buildings was analysed in eight sections, as mentioned earlier. For example, the project aims to reduce energy consumption by 25% and water consumption by 20%. However, becoming a TREES Platinum building does not prove levels of environmental impact. This paper discusses environmental impact in four issues, including electricity reduction, clean energy production, carbon reduction and economical return. Figure 1 shows four smart buildings in CMU Smart City.

**Figure 1.** *Four Smart Buildings in CMU Smart City - Clean Energy*




Source: CMU (2017).

## Results

The results from each section are presented here for all four buildings. These four buildings have similar scores from 76 to 80 points, sufficient for Platinum level. The score details are in Table 1.

**Table 1.** *Total Scores of Four Buildings Rating in TREES-EB*

| Issue | | Details | Points (Req.) | ARCH | ENG | BUS | LIB |
|---|---|---|---|---|---|---|---|
| BM | | **Section 1: Building Management** | **6 (1)** | **3** | **3** | **3** | **3** |
| BM P1 | | Green building preparation | Req. | / | | | |
| BM 1 | | Promoting green building | 1 | 1 | 1 | 1 | 1 |
| BM 2 | | Building manual and building operation and maintenance training | 1 | 1 | 1 | 1 | 1 |
| BM 3 | | Building management monitoring and evaluation | 1 | 1 | 1 | 1 | 1 |
| BM 4 | | TREES-NC or TREES-CS certified building | 3 | 0 | 0 | 0 | 0 |
| SL | | **Section 2: Site and Landscape** | **17** | **17** | **17** | **17** | **17** |
| SL 1 | | Locate project on the developed land | 1 | 1 | 1 | 1 | 1 |
| SL 2 | | Reduce using private cars | 3 | 3 | 3 | 3 | 3 |
| SL 3 | | Sustainable site planning | 5 | 5 | 5 | 5 | 5 |
| | SL 3.1 | Appropriate and sufficient ecological open space | 2 | 2 | 2 | 2 | 2 |
| | SL 3.2 | Plant 1 big tree per 100–200 $m^2$ of open space (do not relocate natural big trees from other sites) | 2 | 2 | 2 | 2 | 2 |
| | SL 3.3 | Use local or native plants appropriately | 1 | 1 | 1 | 1 | 1 |
| SL 4 | | Infiltration of storm water and flooding prevention. | 4 | 4 | 4 | 4 | 4 |
| SL 5 | | Reduce heat island effects in the urban area from project development | 3 | 3 | 3 | 3 | 3 |
| | SL 5.1 | Green roof or vertical garden | 2 | 2 | 2 | 1 | 1 |
| | SL 5.2 | Hardscape area received direct solar radiation not more than 50% of the total hardscape area | 1 | 1 | 1 | 1 | 1 |
| SL 6 | | Landscape and building exterior maintenance | 1 | 1 | 1 | 1 | 1 |

**Table 1.** *Total Scores of Four Buildings Rating in TREES-EB (cont.)*

| Issue | | Details | Points (Req.) | ARCH | ENG | BUS | LIB |
|---|---|---|---|---|---|---|---|
| WC | | **Section 3: Water Conservation** | **8 (1)** | **8** | **8** | **8** | **8** |
| WC P1 | | Water saving policy | Req. | / | | | |
| WC 1 | | Water saving and water use efficiency | 6 | 6 | 6 | 6 | 6 |
| WC 2 | | One to two water end uses sub-metering | 2 | 2 | 2 | 2 | 2 |
| EA | | **Section 4: Energy and Atmosphere** | **27 (2)** | **15** | **16** | **16** | **16** |
| EA P1 | | Building survey and energy conservation plan | Req. | / | | | |
| EA P2 | | Minimum building energy efficiency | Req. | / | | | |
| EA 1 | | Building energy efficiency | 16 | 5 | 5 | 5 | 5 |
| EA 2 | | Renewable energy<br>Produce renewable energy not less than 0.5–3.5% of energy cost in the building | 4 | 4 | 4 | 4 | 4 |
| EA 3 | | Energy conservation measure application: saving result 20%, 30%, 40% | 3 | 3 | 3 | 3 | 3 |
| EA 4 | | Refrigerant in air conditioning systems that does not harm ozone layer<br>(do not use CFC and HCFC-22) | 1 | 0 | 1 | 1 | 1 |
| EA 5 | | Building energy management system | 3 | 3 | 3 | 3 | 3 |
| | EA 5.1 | Basic BMS systems | 1 | 0 | 1 | 1 | 1 |
| | EA 5.2 | End-use energy metering: 30%, 60% | 2 | 1 | 1 | 1 | 1 |
| MR | | **Section 5: Materials and Resources** | **17** | **17** | **17** | **17** | **17** |
| MR 1 | | Policy and participation in building management | 5 | 5 | 5 | 5 | 5 |
| | MR 1.1 | Purchasing policy and participation of occupants: 30%, 60% | 2 | 2 | 2 | 2 | 2 |
| | MR 1.2 | Purchasing policy and participation of occupants: 30%, 60% | 2 | 2 | 2 | 2 | 2 |
| | MR 1.3 | Purchasing estimation and waste proportion | 1 | 1 | 1 | 1 | 1 |
| MR 2 | | Environmental friendly purchasing | 6 | 6 | 6 | 6 | 6 |
| | MR 2.1 | Purchasing: ongoing consumables: 30%, 60% | 2 | 2 | 2 | 2 | 2 |
| | MR 2.2 | Purchasing: electrical appliances: 30%, 60% | 2 | 2 | 2 | 2 | 2 |
| | MR 2.3 | Purchasing: furniture: 30%, 60% | 2 | 2 | 2 | 2 | 2 |
| MR 3 | | Environmental friendly waste management | 6 | 6 | 6 | 6 | 6 |
| | MR 3.1 | Waste management: ongoing consumables: 30%, 60% | 2 | 2 | 2 | 2 | 2 |
| | MR 3.2 | Waste management: electrical appliances: 30%, 60% | 2 | 2 | 2 | 2 | 2 |
| | MR 3.3 | Waste management: furniture: 30%, 60% | 2 | 2 | 2 | 2 | 2 |
| IE | | **Section 6: Indoor Environmental Quality** | **14 (1)** | **14** | **14** | **14** | **14** |
| IE P1 | | Ventilation rate in the building<br>Ventilation rate: pass the standards | Req. | / | | | |
| IE 1 | | Reduce impact from pollution | 5 | 5 | 5 | 5 | 5 |
| | IE 1.1 | Air Intake is not located at the position that has heat or pollution | 1 | 1 | 1 | 1 | 1 |
| | IE 1.2 | Negative pressure for printing room, photocopying room, chemical storage and cleaner storage | 1 | 1 | 1 | 1 | 1 |
| | IE 1.3 | Prevent pollution from outside to inside of the building | 1 | 1 | 1 | 1 | 1 |

**Table 1.** *Total Scores of Four Buildings Rating in TREES-EB (cont.)*

| Issue | | Details | Points (Req.) | ARCH | ENG | BUS | LIB |
|---|---|---|---|---|---|---|---|
| | IE 1.4 | Smoking area is located outside the building and not less than 10 m from doors, windows or air intakes | 1 | 1 | 1 | 1 | 1 |
| | IE 1.5 | The efficiency of air filter: Pass the standard | 1 | 1 | 1 | 1 | 1 |
| IE 2 | | Quality of life promotion achievement | 4 | 4 | 4 | 4 | 4 |
| | | | | | | | |
| | IE 2.1 | Indoor air quality measurement results | 1 | 1 | 1 | 1 | 1 |
| | IE 2.2 | Ventilation system operation measurement | 1 | 1 | 1 | 1 | 1 |
| | IE 2.3 | Cleaning efficiency | 1 | 1 | 1 | 1 | 1 |
| | IE 2.4 | Occupant satisfactory survey | 1 | 1 | 1 | 1 | 1 |
| IE 3 | | Indoor lighting system control Separate artificial lighting circuits for every 250 $m^2$ or as required | 1 | 1 | 1 | 1 | 1 |
| IE 4 | | Use natural light in the building; 45%–65% of regularly occupied spaces shall be renovated to achieve enough natural light | 2 | 2 | 2 | 2 | 2 |
| IE 5 | | Thermal comfort 50%–70% Temperature and relative humidity at the air conditioned area are to conform to the standard of air conditioned and ventilation systems | 2 | 2 | 2 | 2 | 2 |
| EP | | **Section 7: Environmental Protection** | **5** | **5** | **5** | **5** | **5** |
| EP 1 | | Low environmental impact products in fire suppression systems No CFC, HCFC or Halon in fire suppression systems. | 1 | 1 | 1 | 1 | 1 |
| EP 2 | | Condensing unit/cooling tower position: positions of condensing unit (compressor or cooling tower) shall be located far from the nearby area | 1 | 1 | 1 | 1 | 1 |
| EP 3 | | External glazing: visible light reflectance not more than 30% | 1 | 1 | 1 | 1 | 1 |
| EP 4 | | Control disease involved with the building: comply with the Notice of the Department of Health, Ministry of Public Health of Thailand: Procedure to control Legionella in cooling tower of the building in Thailand. | 1 | 1 | 1 | 1 | 1 |
| EP 5 | | Wastewater quality measurement result | 1 | 1 | 1 | 1 | 1 |
| GI | | **Section 8: Innovation** | **6** | **1** | **1** | **1** | **1** |
| GI 1 | | Techniques which are not specified in the rating system | 5 | 1 | 1 | 1 | 1 |
| GI 2 | | TREES-A in the working group | 1 | 0 | 0 | 0 | 0 |
| | | **Total** | **100 (5)** | **80** | **81** | **81** | **81** |

Note: ARCH refers to Faculty of Architecture building, ENG refers to the main lecture building of the Faculty of Engineering, BUS refers to Faculty of Business building and LIB refers to main library building.

*Management Plan*

'The Chiang Mai University committee for Energy and Environment' created a plan to develop the campus physical environment, and all stakeholders committed to this plan. Some of the buildings were selected to be retrofitted to become automatically controlling and environmentally sustainable. The plan to remodel the buildings was made public, and the current and future students and staff members were informed. Management, maintenance and follow-up plans were developed for building operation. The committee also defined a clear task for responders in charge of energy and water resource conservation. All buildings achieved three points (Table 1), because the initiative did not involve a TREE-certified expert.

*Site and Landscape*

Some of the site and landscape sustainability goals for the CMU buildings had already been met. The construction sites had been established on developed land where urban facilities were already provided in a 500 m radius from the main entrance of the project. Going forward, reduction of the use of personal cars is the primary site and landscape concern. Free public transportation (an electrical cart) is provided every three minutes, developing to cover the whole university area. The bicycle parking spots were also be enlarged. Percentage reduction of private car and motorcycle use of regular occupants is projected to be 75%. However, some architectural students will still use a large vehicle to deliver their oversized products.

Site sustainability was developed through three procedures. An increase in ecological open space area was enhanced to 25% of the buildings' footprints, and 40% of that ecological open space was green area. The number of large trees per open space area was improved to be two large trees per 100 $m^2$ of open space. All of the plants placed in the landscape were localised to the microclimate and environment. Each of the four buildings can collect at least 15% of storm water that falls on its site surface. Most of the ground materials are infiltration surface. According to the heat island effect, green roof will be increased to be 30% of the roof area for the buildings in three years. Even though green wall is still inapplicable, because wall structures in the existing buildings are not available for installation, 50% of the outdoor hardscape area is designing to be shaded.

Maintenance for landscape and building exterior policy required a major development. For example, more than 20% of the chemical quantity in paints and other chemical substances would be changed to low-VOC products. Maintenance practice policy was also improved to use environmentally friendly development for pest control, landscaping and chemical fertilizer. All four buildings achieved full scores of 17 points (Table 1), because the buildings were constructed on developed sites and were fully serviced by public-shared bicycles and eco-vehicles.

*Water Conservation*

Water conservation building policies should be implemented. A plan requires a 30% reduction of water use and consumption from the baseline amount. Smart water end-use meters are to be installed to measure 100% of the water end-use type. A digital flow meter is used in this project. The water conservation plan is also implemented for controlling occupant's water-use behaviour. Water conservation is proposed to be completed in five years and will cost 10 million Baht.

*Energy and Atmosphere*

All four buildings are under the CMU Committee for Energy and Environmental. The smart monitoring and controlling systems, called 'easy smart meter' and 'digital power meter', have been installed, and all meters will be completely operational by the end of 2018. Easy smart monitors, which use smart-controller research by CMU and the Energy Research and Development Institute (ERDI), was installed in buildings to monitor energy and water consumption. Additionally, remote sensing systems were installed to send consumption information to building control centres. The buildings were monitored for energy, renewable energy and water resources consumption. Solar panels with a capacity of up to 80 kWp were planned to be installed on all four buildings' rooves. Renewable energy was expected to provide 525,600 kWh/y from solar cell, and it was equal to 5% of electric in-use. Energy consumption is planning to save at least 25% when all features are operated, compared with an existing case. Solar cell application costs were one million Baht. The energy conservation plan was also implemented for helping occupants further reduce their energy consumption. Three buildings achieved 16 points. The remaining building, which was ARCH, achieved 15 points (Table 1). Much of ARCH's air-conditioning system was a split system with an R-22 refrigerant. Some models are not compatible with non-CFC refrigerants.

*Materials and Resources*

Resources for renovation required a proportion of local, reused and recycled materials. Local materials must account for 10-20% of the resource net purchase budget. Reused and recycled materials were also considered and must make up the equivalent of 5-10% and 10-20% of the resource net purchase budget, respectively. More than half of roof and deck materials were expected to be unchanged. An equivalent of more than 30% of all construction materials purchased, was low environmental impact products. Of those low environment impact materials, 10-20% of them received Thai green label and Thai Carbon footprint label. The four buildings achieved 17 points.

*Indoor Environmental Quality*

Four buildings were planned to renovate their building performance following the lists. The four buildings achieved 14 points (Table 1).

- Refresh air intake ratios must meet the standard. Fans, exhaustion, and air conditioners were concerned as a solution in some areas.
- Air intake openings must be located more than 10 m in distance or 3 m in height from heat sources and pollution areas, including smoking areas. A room with chemical containers had to be negative pressure**.** Filter capacity in-use needed 25-30% filtered performance.
- Air quality measurement requested a test in every room.
- Artificial lighting systems must have a separated control system in every 250 $m^2$ area. Natural light was adopted in 65% main function area.
- More than 30% of users were asked about their satisfaction on comfort status via an online system provided by the Information Technology and Services Centre (ITSC), CMU. Thermal comfort needed to be satisfied by 70% of main areas to meet the standard.

*Environmental Protection*

There are five issues in this section. First, the CFC, HCFC and Halon in the fire suppression systems must be replaced by the non-CFC system. Cooling tower and compressor units needed to be located 3.5 m from nearby land plots. The reflection value of all glass windows needed to be less than 30%, or provided more than 70% visible transmission. A *Legionellae* bacteria control plan was also required for human health concerns, following regulations of the Department of Health, Ministry of Public Health, Thailand. A wastewater management plan was also in progress. Finally, grey water had to be treated for 5 mg/l biological oxygen demand (BOD) and did not exceed 20 mmg/l total suspended solid (TSS) before releasing to public water resources. The four buildings achieved full scores of five points.

*Green Innovations*

Although two innovations were proposed for the smart-building system, only one could be used. The first building performance–control system innovation was smart-building control devices. The innovation could not be considered, as it had already been used in Energy and Atmosphere Section. Personal Control System created by College of Arts, Media and Technology (CAMT), CMU, was an application applied for individual thermal control (CAMT, 2017). Temperature, lighting and sound systems could be controlled from a smart device belonging to the occupants. The application could save more than 20% in energy consumption. Only one score was given for the Personal Control System.

Although the CMU project does not have a TREES-A or TREES specialist in the working group, current staff members are expected to become TREES-A in 3 years. All sections in four buildings are expected to complete in 5 years with 150 million Baht.

## Discussion

The impacts of the retrofitting buildings were projected based on energy conservation. At least 80 points were given to each smart building. Even though the CMU SMART City project proposed to reduce the carbon footprint by 55% in 20 years, four smart buildings could take carbon reduction as maximum of 25% of their energy consumption (CMU, 2017). In 2015, energy consumption in CMU was 78,734 MWh/y. Only 4% of that was from a total of four proposed buildings consuming energy 2,887 MWh/y (see Table 2). These buildings were expected to demonstrate a 25% reduction in energy consumption by 2030. Table 2 shows that the energy consumption in the architecture building and the business management building in 2015 were similar. Energy was consumed by 351,848 kWh and 363,978 kWh in the architectural building and the business building, denoted to 23.98 kWh/m$^2$/y and 35.31 kWh/m$^2$/y, respectively. The solar roof and smart metering system were expected to reduce energy consumption by 87,962 kWh in the architectural building and 90,995 kWh in the business building, which is equivalent to 317 MJ and 47 t$CO_2$. The engineering building and the main library consumed much more energy. Energy consumption was 539,965 kWh in the engineering building and 1,631,683 kWh in the main library, equal to 34.21 kWh/m$^2$/y and 100.16 kWh/m$^2$/y, respectively. Their energy consumption was also compensated to operate with a solar roof and a smart metering system. It should be decreased by 134,991 kWh and 407,921 kWh, which are equivalent to 485.97 MJ and 1,468.51 MJ, and 71.55 t$CO_2$ and 216.20 t$CO_2$ in the engineering building, respectively.

**Table 2.** *Embodied Energy and Carbon Footprint Reduction Expected in the Retrofitting Buildings*

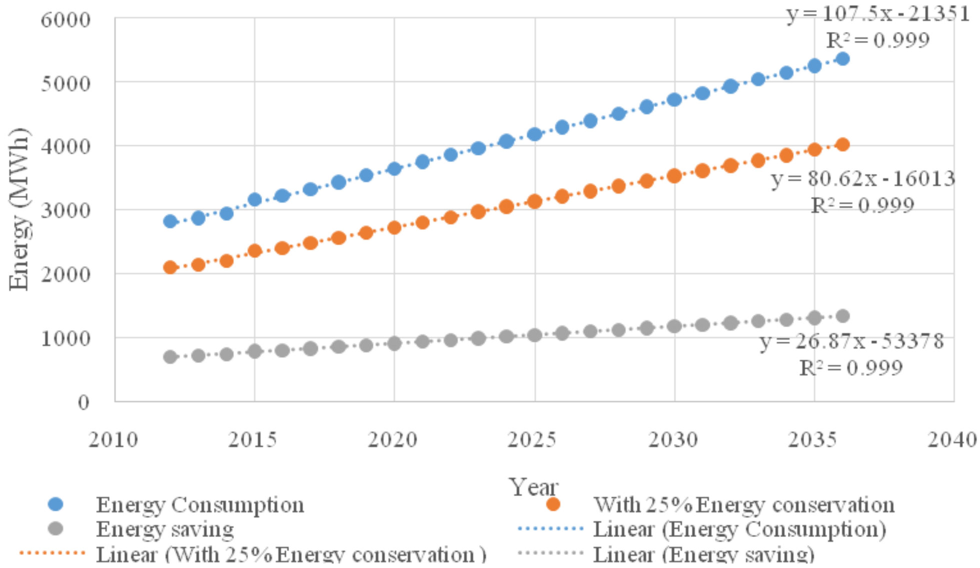
| Bld | Energy consumption (kWh/y) | Floor area (m$^2$) | E saving 25% (kWh/y) | Embodied energy reduction in 5 y (MJ) | Carbon reduction (t$CO_2$/y) |
|---|---|---|---|---|---|
| ARC | 351,848 | 14,673 | 87,962 | 316.66 | 46.62 |
| ENG | 539,965 | 15,785 | 134,991 | 485.97 | 71.55 |
| BUS | 363,978 | 10,307 | 90,995 | 327.58 | 48.23 |
| LIB | 1,631,683 | 16,290 | 407,921 | 1,468.51 | 216.20 |
| | 2,887,475 | 57,055 | 721,869 | 2,598.73 | 382.59 |

Note: ARC = Faculty of Architecture, ENG = the main building, Faculty of Engineering, BUS = Faculty of Business Management, and LIB = Main Library

Regarding the overall energy conservation in the next 20 years, consumption is expected to be 25,738 MWh reduction. It is one-third of the total energy consumption in 2015. Figure 2 illustrates the linear regression of CMU energy consumption based on total energy consumption in 2012-2016. The increase in energy consumption has an upward trend. It can

become 5,360 MWh by 2036 or 167% compared to energy consumption in 2016. Note that the linear regression is used to estimate the future energy consumption, regardless of a better energy efficiency technology (Eq. 3), with $R^2 = 0.99$.
Energy consumption estimation = 107.5 * year – 213510 --------Eq. 3

**Figure 2.** *Linear Regression of 4-buildings Energy Consumption in 2012-2016*




The economic impacts on electrical bills are sufficient. According to the large amount of land and floor area in CMU, the overall electric bill in 2015 was 78 million Baht. To have 25% reduction in these four expected buildings, the electric bills of these buildings could be reduced by up to 19 million Baht per year. Referring the construction cost of the retrofitting project, 150 million Baht are prepared for several construction phases in five years. If considering direct return rate after the first 5-year, the project can be paid back within the thirteenth year. However, the economic consultant advises that the payback period for energy conservation would be in 19 years, due to several retrofit phases and other economic factors.

Although the payback period of the retrofitting project is considered in long term, the impact from energy reduction can be claimed sustainable. The 2,598 MJ embodied energy reduction is equivalent to the 50-year embodied energy of 120 $m^2$ ceramic floor tiles construction in a two-storey house built in Thailand (Wankanapon et al., 2013).

## Conclusions

The educational buildings have typical function and are controlled by government sector. Four buildings in Chiang Mai University are planning to be retrofitted as a smart building prototype. Of 78,734 MWh/y energy consumption in CMU, four proposed buildings consumed 2,887 MWh/y in 2015. Although four large buildings take responsibility for energy consumption at only 4%, the energy reduction is estimated to be equivalent to a 50-year embodied energy of a ceramic floor tile. The 25% reduction of electricity is expected to save 25,438 MWh by 2036. It is equivalent to one-third of university energy consumption in 2015. The environmental impact from this project is assessed at 2,598 MJ embodied energy and 382.59 $tCO_2$ carbon footprint reduction. The construction will cost 150,000,000 Baht (almost 4 million euro) in total for all retrofitting projects during five years. It is estimated to pay back in 19 years.

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