DESIGN DEVELOPMENT OF A POWER OPTIMIZATION SOFTWARE SIMULATION TOOL FOR SMART CITY BUILDING SERVICES

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ABSTRACT

Building services claimed to consume over 40% of all the energy produced in Malaysia regardless of fuel source type (Hassan et al., 2014). Such building services includes illumination, air-handling unit (AHU) or HVAC system, and water heater. These building services would require auditing and reevaluation at designated milestones of a building's life to propose possible improvement methods for the services with new available technology for power optimization and energy reduction. In this paper, a simulation tool is proposed to be developed to calculate the existing building service energy practices of a building and derived optimization methods for each of the services. The extent of this research covers major building services such as illumination, AHU and heating elements by proposing various optimization methods for the services with today's available technologies. This simulation tool, envisioned to have an intuitive graphical user-interface (GUI), acquires the input data of existing service practices via user input on a room-by-room analysis and calculate each service of its power consumption and annual energy usage with selectable improvement methods to improve or optimize the power consumption and energy usage of respective services, the corresponding cost savings, carbon reduction, cost of optimization and the return on investment (ROI). This simulation tool is designed to generate the results in the form of spreadsheet, graphs, and a generalized single-line diagram based on the analyzed service practices of a building.

Keywords: Power Optimization; Building Services; Software Utilization

Introduction

Of the 40% of energy consumed by building services both for residential and commercial buildings, a typical breakdown of that energy goes to HVAC system taking up 41%, 14% in water heater, 11% for illumination, 13% for electronics & computers, and the remaining are consumed by other services such as refrigeration and other heating elements (Center for Climate and Energy Solution, 2009). At designated milestones of a building's life, the existing services could be technologically outdated compared to current new available services that are more efficient in its power consumption. Besides that, smart city has slowly been the focus of many city development plan around the world which desire future cities to be efficient in every aspect that would increase the quality of human living and achieve sustainability (Lee, Phaal, and Lee, 2012). Conducting an energy audit for building services especially for large buildings such as multi-stories and high-rise are time consuming and tedious. A tool could be develop by utilizing software to analyze a building's existing service practices of its energy usage and derived power optimization methods at the same time for the services. The motivation for this research and the intention of the development of this tool is the realization that energy demand, especially for buildings in city, will ever be increasing due to economic and population growth. Energy resources has to be utilized and kept under control due to this ever increasing demand. The criteria for smart city power development is first covered in this paper followed by the design of the simulation, methodology of the development and conclusion. The objective of the research is to identify the practicality of this simulation tool to be use for the purpose of studying a building's energy consumption, propose optimization methods and deriving the results for the optimized energy consumption of the building.

Criteria For Smart City Power Optimization

There have been attempts to define a smart city as currently there are no one standardized definition. One defines a smart city as the combination of Internet of Things (IoT) and digital city (Su, Li, and Fu, 2011). This definition proposed that the IoT consisting of ubiquitous information network of smart sensor, smart control and smart safety networks are built on a digital city framework consisting of the internet, information technology (IT) and triple play in telecommunication. Another proposed a framework where technology lies at the center of a smart city framework with other elements surrounding the element of technology (Chourabi, 2012). The proposed framework links suggested elements of technology, policy, organization, natural environment, governance, infrastructure and community in tiers to define a smart city. What can be drawn from these suggestions is that technology is a core component of a smart city. In the building of a smart city, technology in IT, networking and automation are highly considered in these two main distinct literatures. Besides that, the highly consideration of the health, safety and welfare of the public especially in occupant comfort such as good lighting and thermal comfort when satisfied through building service optimization ensures smart city initiatives are observed. Drawing from these existing smart city frameworks, the following are three proposed criteria that the design of a simulation tool to derived optimization for building services that are coherent with the current definitions of a smart city.

Technology: Technology lies in the heart of smart city initiatives. To ensure that the optimization of building services are aligned to the development of a smart city, power optimization of building services should be done with the use of technology as the core method rather than relying on other methods from an organizational, behavioral, social or legal standpoint. This ensures every optimization methods employed in building services are forward moving that contribute to technological and economically growth. For example, analyzing the air-conditioning service in an office, assume the office has installed a total 4 air-conditioning unit rated at 4 horsepower (HP), running 10 hours a day and 20 days a month. The monthly energy consumption cost would add up to more than RM234, 000 just to run the air-conditioning. If a new propose air-conditioning is proposed for optimization for the office rated at 3 HP, the optimized monthly energy cost will be reduced to just below RM 176, 000 which results in a significant amount of cost reduction.

Efficiency Metric. The metric unit for the output of each service are different usually with a common input of electrical unit. For example, the output of illumination is measured in lumens and air-conditioning in British thermal unit per hour (BTU/h) each having common input drawn from electrical power in watt or kilowatt (kW). Optimization would require a reduction in the input power in electrical unit without affecting the output of the service. Hence, the efficiency metric used for each building services are different and are required to be identified for calculating the efficiency or efficacy. Such efficiency metric includes electrical efficiency for most services expressed in percentage, luminous efficacy for illumination and seasonal efficiency energy ratio (SEER) for air-conditioning to identify a few. High efficiency services play an important role in smart city development in power optimization. Realization of these efficiency metric will be presented in the design of the simulation tool.

Software: Utilization of software in the power optimization of building services will be a part of the smart city framework where resources such as labor and time are also utilized. Where buildings are getting taller and larger in size, analyzing the traditional way of tabulating data on paper proved to be inefficient, time consuming and a waste of natural resources. Hence higher productivity will be achieved that will aid the analysis and calculations performed of building services by utilizing software to create the tool that will also contribute to a smart city framework.

Design Of Simulation Tool

A few key components are required in the design of the simulation tool. The first is to identify typical building services that are commonly used and practiced in various types of buildings. Besides that, new building service technologies that are more efficient are to be identified to be considered as valuable information in the simulation tool for optimization. Next, as each of these services have its own metric to measure its efficiency, the efficiency metric of each service are to be identified according to its output unit. This creates a pool of database that can be used by the simulation tool to conduct calculations and produce comparison of power usage of the existing and optimization methods. The final element is in the design of the simulation tool itself which is a computer program. The design would include the programming flow of how the building service energy practices will be calculated and tabulated. The working principle of how the simulation tool is designed to execute the calculation in a design sequence in a manner that will produce a simulation tool that is efficient, accurate and easy to use.

Building Services

Table 1 shows a list, but not limited, of some of the common building services used in buildings. Knowing what are the common building services and which services that consumed the highest power will help in the development of the database and identify the best optimization methods for the service. Table 1 also list the applications of the building services that are used in a building mainly to serve the occupants that occupy the building for various purposes such as living, work or leisure.

Table 1: Typical Building Services

Building Services	Applications
Illumination	Interior lighting scheme
Air-Handling Unit	Air-conditioning, air ventilation
Space heating	Space heating (for cold climate countries)
Water Heater	Bathroom shower and kitchen
Electrical Traction	elevator, escalator, water pumps
Power Management System	Management of the power distribution

Identifying the services would facilitate in the development of the database needed for the simulation tool to have a wider option of services to be analyze for power optimization.

Efficiency Metrics

Due to the diversity of applications in some of the building services, the metric for power consumption differs in the measured output for each service. The following are some of the efficiency metric considered of main building services.

Illumination: Illumination is the main building service that exist in every building making it one of the critical building service that has to be considered. Illumination efficiency is measured in term of luminous efficacy where the output in is lumens divide by the input power in watts by the lamp consumed that denotes the efficiency of the lamp. Equation 1 shows it in a standard equation form.

Luminous Efficacy = lumens/watt (1)

The illumination lumens output of each room in a building are designed during construction of the building and the lumens required should not be changed when power optimization is proposed. To optimize the illumination service, the optimization method requires lamp selection that has higher in luminous efficacy rating.

Air-Handling Unit: In some buildings, the air-handling unit are combined as one unit to produce air-conditioning and ventilation. When separated, the efficiency metric can be determine by the SEER for air-conditioning and efficacy for ventilation denoted in equation 2 and 3 respectively.

SEER = BTU/h/watt
(2)

Efficacy = CFM/watt
(3)

Certain optimization methods might not require a total upgrade of the service but an additional device that could be installed to optimize the service. The method would usually provide the percentage of how much more energy savings it could contribute. For such methods, equation 4 could be used to determine the new optimized wattage rating $W_{optimized}$, that corresponding to the current rating, $W_{current}$ and the increase optimization power savings represented by μ.

$W_{optimized} = W_{current}(100-\mu)/100$ (4)

Table 2 suggest a scenario of a room running the following services for 8 hours a day, 20 days a month with the current practice, output ratings and suggested optimization methods for each service. The efficiency metric are realized in the calculation as follow to determine the optimized power consumption, power savings, carbon reduction and the ROI.

Table 2: Example Parameters for Analysis

Service	Current Practices	Installed Capacity	Optimized Methods
Illumination	CFL Efficacy = 60 lumens/watt	6 lamps at 900 lumens	L.E.D Efficacy = 150lumens/watt Cost: RM 30
Air-conditioning	Multi-Split Non-Inverter SEER = 18	2 HP	Hybrid Chiller SEER = 30 Cost: 0.08 sens/BTU/h installed
Ventilation Fan	AC Driven Fan Efficacy = 60 CFM/Watt	1,200CFM	Air Quality Sensor capable of 15 % power Improvement. Cost: RM 30

The power consumption of the current practice are calculate as follow.
Using equation 1 for illumination practice,
Watt = 900/60
= 15watts

Equation 2 for air-conditioning to determine the installed capacity as the power rating is already given.
BTU/h = 18*2*746
= 26,656 BTU/h
Watt = 2*746
= 1,492watts

And equation 3 for ventilation fan,
Watt = 1,200/60
= 20watts
Total current monthly consumption = (15*6 + 1492 + 20)*8* 20
= 256.32 kWhr

The corresponding optimization methods selected in table 2, the improved energy consumption are:
Illumination,
Watt = 900/150
= 6watts
Air-conditioning,
Watt = 26,656/30
= 888watts
Ventilation Fan using equation 4 yield,
Watt = 20*(100-15)/100
= 15 watts
The total optimized consumption would be,
Optimized monthly consumption = (6*6 + 888 + 15)*8*20
= 150, 240 kWhr
The monthly power savings will equal to,
Power Savings = Current monthly consumption – optimized monthly consumption
= 256.32 – 150, 240
= 106.08 kWhr

The carbon reduction taking the emission rate of 0.554 kg/kWhr consumed,
Carbon reduction = 106.08*0.554
= 58.768 kg is reduced.

Cost of optimization,
Illumination = 30*6
= RM 180
Air-conditioning = 0.08*26656
= RM 2,132.48
Ventilation = RM 30
Total cost = 180 + 2,132.48 + 30
= RM 2,342.48

Taking the tariff rate of 3.93sens per kWh consumed, the ROI duration for the optimization would be,
ROI = Total cost of upgrade/(annual power savings)
= 2342.48/(12*106.08*0.393)
= 4.68 years

Table 3 summarizes the calculation for the calculated optimization results.

Table 3: Calculated Optimization Results

Service	Power Savings (kWh)	Carbon Reduction (kg)	Cost of Optimization (RM)	Return of Investment, ROI (years)
Illumination	8.64	4.79	300	-
Air-conditioning	96.64	53.54	2,132.48	-
Ventilation Fan	0.8	0.44	30	-
Total	106.08	58.768	2,343.48	4.66 years

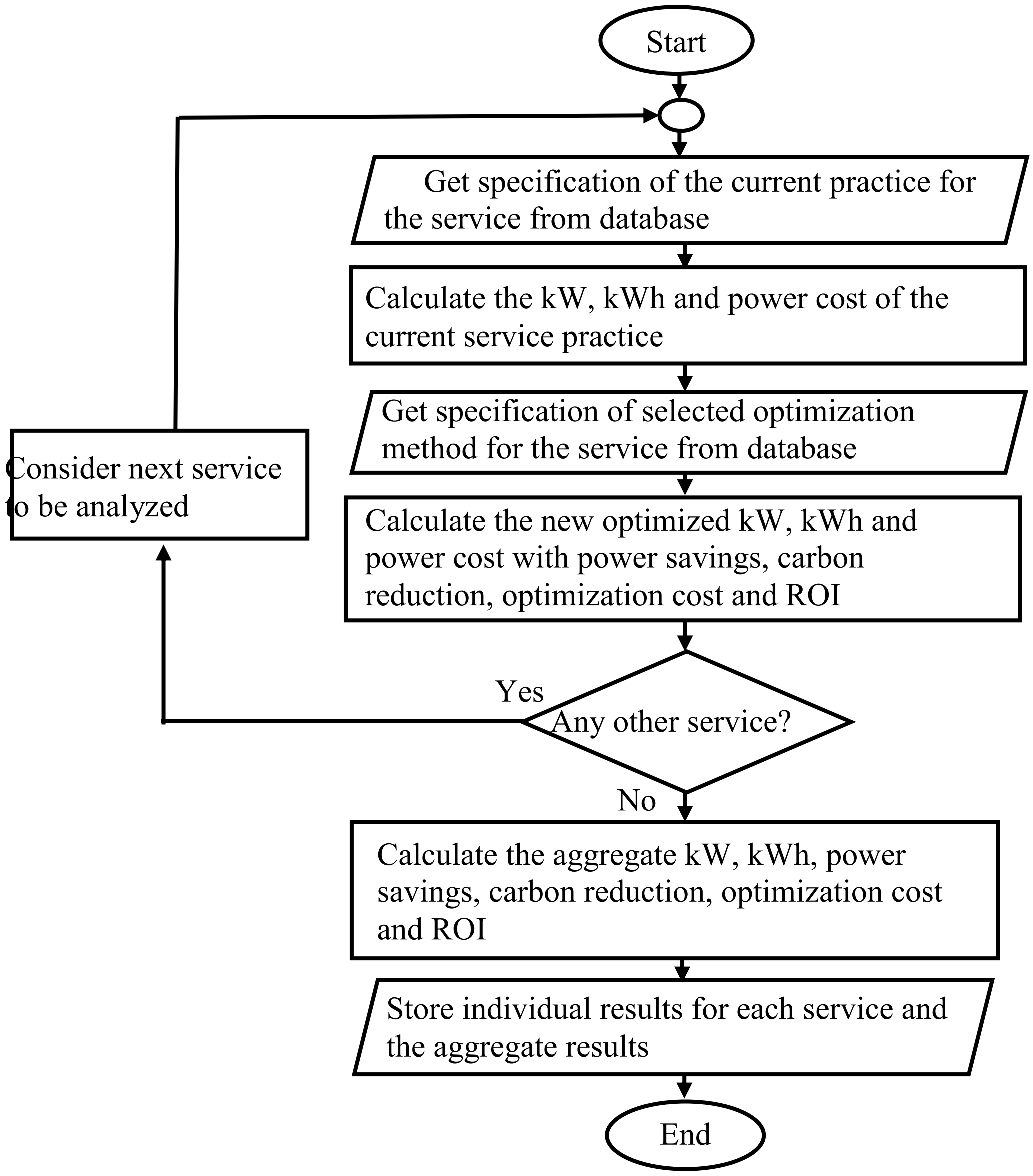
At the back-end of the simulation tool, these calculations are computed multiple times with more variety of services and rooms according to the number of considered services in the analysis and the number of rooms in the building.

Generated results such as the one in table 3 provides the optimization result parameters that will tabulate and show the power savings, carbon reduction, cost of optimization and ROI that will be used for analysis if the optimization is feasible to be done to achieve energy reduction for the building. The decision for optimization of the services in a building can be done with the generate results based on the results shown in table 3.

Program Flowchart

Figure 1 shows the calculation flow of the simulation tool. The simulation tool can be altered in many ways such as to exclude or include services in the calculation in the GUI or the ability to analyze the optimization methods independently. The core structure of the program will be as Figure 1.

Fig 1. Flowchart of the calculation performed by the simulation tool

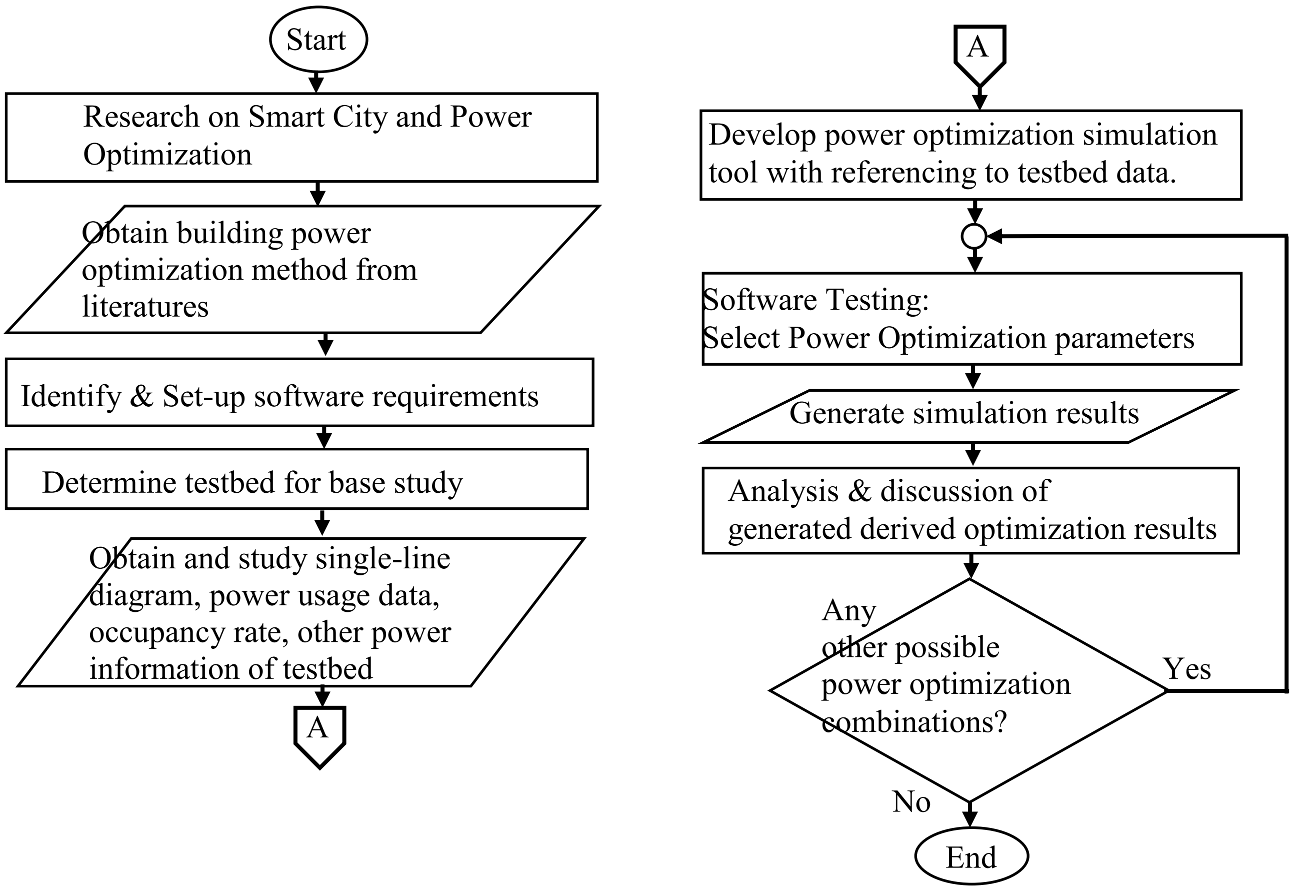


With the aid of a GUI, the user would insert the information of each service in a building with selection capability of existing practice and optimization method. With all the data inserted, the program will start by calculation the power consumption of the room with respect to the existing practice of the service for an estimate daily and monthly usage. The next part, the program will calculate the new energy consumption when a particular or group of service are selected for optimization. Besides that, the program will also calculate how much power will be reduced, the carbon reduction, cost of the optimization for improving the service and the ROI based on the selected optimization method for each service. The process continues for all the numbers of room in a building where all the services in a building especially in large buildings are considered. After that, the user will generate the results statically through charts, single-line diagram, and in a spreadsheet form.

Methodology Of Development

Figure 2 shows the methodology development of the simulation tool. The development could be separated into three distinct parts. First part focuses more on the research on building services and various optimization methods that could be proposed and implemented. Each service has its current practices and optimization methods that could be proposed. For example, T5 and L.E.D lamps are new lamp technology that saves power, hybrid chillers for air-conditioning and solar water heater are some of the new optimization methods.

Fig.2. Methodology Flow of Development



This moves on to determining a testbed for study. The testbed serves two purpose. First as a base study building in identifying the current practices in the building and using it to test the simulation tool for power optimization. This helps with the development of the simulation tool in the variables of service selection, the current practices and optimization for each building services. The data for base study provides information such as the current practices such as the type of lamp or air-conditioning technology used, what is the installed capacity, and how often it is being used.

The final elements include the development of the simulation tool itself. The developer has the freedom to choose the development software platform that he is most proficient and familiar with. The back-end calculations includes the efficiency metric that will calculated both the power consumption of the current practices and the optimization methods which generates the results in various form such as charts, spreadsheet and a single-line diagram for analysis and comparison. The simulation tool can be tested on the selected testbed that was used for study or to be tested on an entirely new building for analysis.

The expected results will be a developed simulation tool that could analyze a building current practices of the services and derived corresponding optimization methods that determine the feasibility of cost for optimization for the services. This will allow decision making if the proposed optimization methods are cost worthy to be implemented with the appropriate duration of the ROI. Besides that, regulatory bodies could enforce carbon emission regulation of buildings where this simulation tool will be suitable for analyzing the amount of carbon that is produced by the services and how much will it be reduced for various optimization methods.

Conclusion

The design of the simulation tool has been established along with identifying all the necessary elements and data for its development. The expected outcome would be a simulation tool that is able to tabulate large amount of data of existing building service practices of a building and derived improvement methods for the services especially for high energy consuming services. The generated results would be in a form of spreadsheet, charts and a generalized single-line diagram that would display important results for analyzing how much energy and carbon emission could be reduced along with the cost of improving the services with the duration of the payback period based on the selected optimization methods. This simulation tool could be of good use to energy auditors for auditing the energy usage in buildings or building owners desiring to upgrade and optimize the building services for power optimization which also contributes to the initiatives and framework of smart city development. This tool would also benefit policy makers to know the benchmark of a building's energy consumption and carbon emission by the building services to set policies that ensures buildings in cities does not overconsume energy due to inefficient service and ensuring a city's infrastructure are in constant development based on smart city initiatives. The limitation of this research only focuses into electrical building services where building services also includes fire detection and protection, gas or drainage systems which are non-electrical services. Besides that, a few foreseen possible limitations of the tool is it might not satisfy all building types as each building type has different core services such as residential which are mainly air-conditioning and water heater while factories has machines and equipment as its main service that consume the most of the energy.

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