Establishing the 'DEA Energy Management System' for Individual Departments within Universities - An Exploratory Study

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Abstract

The energy management of existing buildings has become a critical research topic worldwide. The mixed use of a single university facility by different departments is prevalent in Taiwan and has complicated the energy management task. Individual departments need a tool capable of assessing their energy efficiencies from 'management' perspective. This study explores the 'space type' and 'internal benchmark' research concepts as well as the 'data envelopment analysis' method to establish the 'DEA Energy Management System (DEMS)' to assist individual departments within universities in assessing the energy efficiencies of their facilities from 'management' perspective. The DEMS proposed considers each 'space' in a given 'time' (such as a month) as a DMU. Then, regression analysis is performed on data of the independent variables related to the 'existing environment' and 'occupancy' factors, and data of the dependent variable (actual energy consumption EUI) of all DMUs. The regression equation derived is then used to calculate the 'predicted EUI' for all DMUs. The 'actual EUI' is considered as the input data, and the 'predicted EUI' as the output data of the DEMS, on which data envelopment analysis is conducted to produce three types of energy efficiency scores (overall efficiency, scale efficiency, and pure technical efficiency) to indicate the energy efficiencies of all DMUs. The 'pure technical efficiency' scores reveal the 'energy management effectiveness' of all DMUs. Those DMUs on the efficiency frontier are the most energy efficient ones and are given with the highest pure technical efficiency score of 100%; and those DMUs that are away from the frontier are less efficient ones and are given with efficiency scores less than 100%. Energy efficiency assessments can also be performed to compare the energy management effectiveness among different space types as well as those of individual space types over time. The DEMS will be implemented in the Department of Architecture of NTUST in Taiwan to illustrate how it can be used to assist individual departments within universities in assessing the energy management effectiveness of their spaces and in improving the energy efficiencies of their facilities. The implementation research tasks to be conducted are planned and outlined.

Keywords: space type, internal benchmark, existing environment factors, occupant and management factors, energy management effectiveness

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1. Introduction

1.1 Background

‘Energy management’ has become an important facility management issue for universities in Taiwan. Individual departments within universities are usually held responsible for managing the energy efficiency of their facilities. This becomes an even more challenging task when several departments occupy the same facility and that individual departments lack reasonable energy consumption benchmarks or indices. Although Taiwan government has issued average EUI indicators for different categories of universities as energy benchmarks, nonetheless, these single indicators are unable to assist facility managers in further assessing the energy efficiencies of their facilities, spotting the over-consumed areas and causes, and identifying the subject and directions of energy management (Tu and Lin, 2012). As a result, the average EUI indicators are not as practical and effective for 'energy management' purpose.

Similarly, several energy efficiency scales, such as the average energy use intensity (EUI) of various types of building, have been established to indicate the energy efficiency of existing buildings, or regarded as the external benchmarks or energy saving targets for existing buildings in different countries (US Green Building Council, 2009; Lee et al., 2007; Poel et al., 2007; Bohdanowicz and Martinac, 2007; Chung et al., 2006; Haji-Sapar and Lee, 2005). These energy efficiency scales might be able to indicate the energy performance at the ‘building’ level; yet they fail to inform a ‘department’ or 'institution', who occupies only certain floors of a building, much about the energy efficiency of its facility at the 'floor' level.

To be effective in building energy management, it's essential to first realize there are three groups of factors that may affect the energy consumptions of individual departments. The first group of factors are 'existing environment' factors, including existing climate factors (such as temperature and relative humidity) and existing building infrastructure factors (such as building enclosure, opening, types and performance of lighting, HVAC and various equipment). Since the 'existing environment' conditions of a facility most likely remain unchanged over the course of its building life cycle, their effects on annual energy consumptions can be considered stable and predictable. 'Occupancy' factors, such as use patterns, work and equipment needs, and environmental quality requirement, are the second group of factors and are the deciding factors that differentiate energy consumptions among various space types (different functional use), given the fixed 'existing environment' conditions. For each type of space, the effects of 'occupancy' factors on energy consumptions can also be regarded as predictable as well, since its occupancy use patterns are more or less stable over time. Finally, 'management' factors, such as department's operation strategy and occupant's energy consciousness, are the third group of factors that have critical and variable effects on building energy consumption. Individual departments with active energy management strategies are likely to further reduce their building energy consumptions, and vice versa.

Within the same building (same 'existing environment' conditions), two departments with different 'occupancy' needs are likely to consume different amount of energy, and it will be unreasonable to say that the department consuming less energy is more energy efficient than the other. This study thus argues that it is critical to take into account the 'management' factors while assessing the energy efficiencies of individual departments within universities. For effective energy management, individual departments are in great need of a tool capable of first assessing their energy efficiencies from 'management' perspective to identify problem areas and improvement plans exhibiting immediate energy saving effects, before any other expensive energy saving measures such as building renovations are taken.

1.2 Research objectives

To assist individual departments in their complex energy management tasks, this study adopts the research concepts of 'space type' and 'internal benchmark' proposed by Tu and Lin (2012). The concept of 'space type' allows us to explicitly observe and distinguish the effects of 'occupancy use patterns' on energy consumptions among different space types. When a standard energy consumption can be identified for each space type, then the standards energy consumptions of all space types can be aggregated as the 'internal benchmark', which becomes a reasonable energy references for individual departments.

The data envelopment analysis (DEA) has been generally used in the performance assessment of resource usage. In the field of building energy management, it has been adopted to assess the energy efficiencies of several building types, such as hotels (Önüt and Soner, 2006), commercial buildings (Chung et al., 2006) and school buildings (Filippin, 2000). This study believes that it is potentially applicable to energy efficiency assessment of various 'space types' within individual departments.

The objectives of this study are to adopt the ‘space type’ and ‘internal benchmark’ research concepts, and to explore the idea of applying the ‘Data Envelopment Analysis’ method in establishing the ‘DEA Energy Management System (DEMS)’ to assist individual departments within universities in assessing the energy efficiencies of their facilities from the 'management' perspective. The underlying DEA theory as well as the methods of the DEMS in assessing the 'energy management effectiveness' of individual departments are described. The DEMS is to be implemented in the Department of Architecture of a national university (NTUST) in Taiwan. The future implementation research tasks are outlined in this study and assessment results will be reported later.

2. Theory of data envelopment analysis (DEA)

Data envelopment analysis (DEA) is a method developed to empirically measure the relative productive efficiencies of multiple 'decision making units' (DMU), such as organizations, firms or institutions, when the production process presents a structure of multiple inputs and outputs (Charnes et al., 1978). DEA measures the efficiency of a DMU by evaluating its input level relative to its output level, and comparing them against those of other DMUs. Conceptually, a DMU is considered as 'efficient' if it can produce more outputs with less inputs. A numerical efficiency score is given to each DMU, defining its relative efficiency. DEA identifies the most efficient DMUs as the benchmarks which form a 'frontier' (line ABC in Figure 1) against which the relative performance of all other DMUs can be compared.

Those DMUs on the frontier are the most efficient ones and thus are given with the highest efficiency scores 100%, and all other DMUs are considered less efficient (such as D in Figure 1) and are given with efficiency scores less than 100% . A DMU can be made efficient either by reducing the input levels and getting the same output (input orientation) or by increasing the output level with the same input level (output orientation). In addition to providing efficiency scores, DEA can inform the less efficient DMUs of their potential benchmarks and efficiency improvement targets. For example, it is suggested that D in Figure 1 consider S as its benchmark and improve its efficiency by reducing its input level from L4 to L3 while remaining at the same output level Q.

DEA has been applied to assessing the performance of organizations such as banks, hospitals and corporations. Besides, some researches have used DEA for 'project selection' purpose (Sohn & Moon，2004；Cook & Green, 2000；Sowlati et al., 2005). The main advantage to this method is its ability to accommodate a multiplicity of inputs and outputs. It is also useful because it takes into consideration returns to scale in calculating efficiency, allowing for the concept of increasing or decreasing efficiency based on size and output levels. A drawback of this technique is that model specification and inclusion/ exclusion of variables can affect the results (Berg 2010). This study argues that DEA can be potentially applied to assessing the energy management effectiveness of various space types within individual departments.

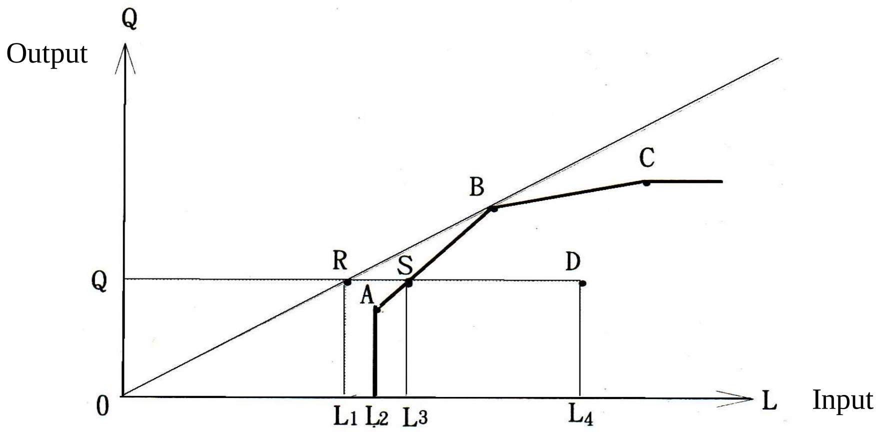

Figure 1: DEA identifies A, B, C as the most efficient DMUs which form the 'frontier', and suggests that DMU D move towards S by reducing its input level from L4 to L3.

3. Establishing the DEA Energy Management System (DEMS)

3.1 Approaches of DEA application in energy efficiency assessment

3.1.1 The 'space-time' DMU definition

This study considers each 'space' in a given period of 'time' (a given month, week, or day) as a DMU and assess the 'energy management effectiveness' of all DMUs (Figure 2). To be more specific, a DMU is defined as 'a space in a month' in this study. In other words, the monthly input and output of a space (type) will be used to assess its energy management effectiveness; and each space in different months are considered as different DMUs. The 'space-time' DMU definition allows us to assess and compare the energy management effectiveness among different space types or that of a particular space over time. In other words, this approach allows us to identify 'the best practice or worst case' among different space (types) or those of a particular space (type) over time.

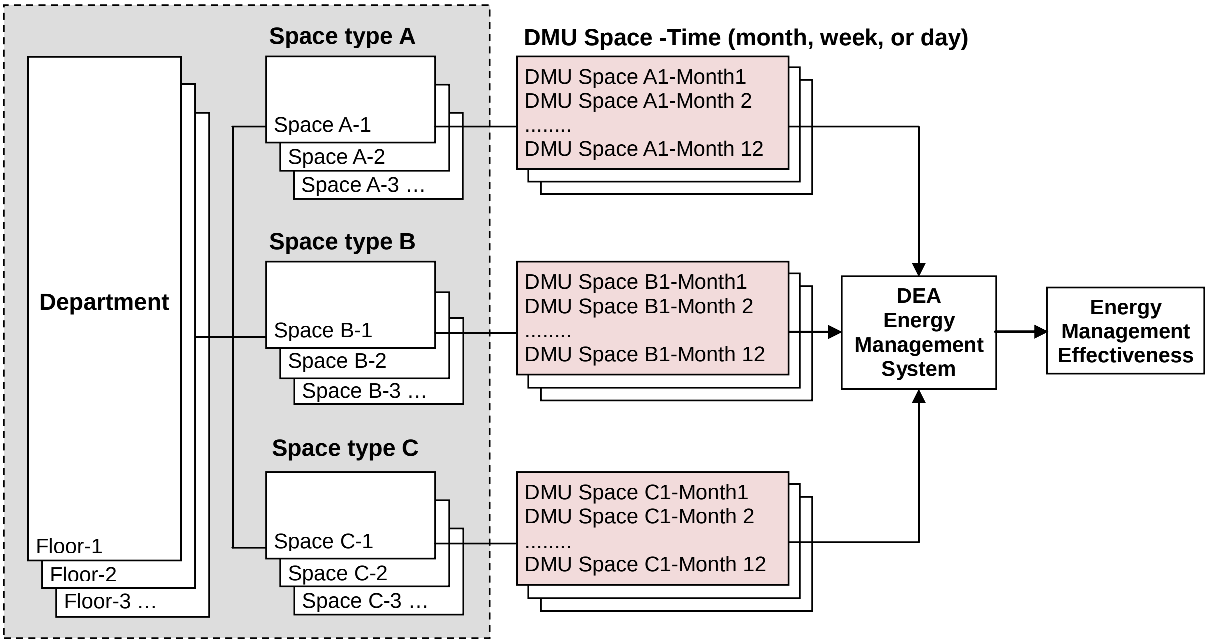

Figure 2: Each 'space' in a given period of 'time' is regarded as a DMU whose energy management effectiveness is further assessed by the DEMS.

3.1.2 Multiple regression analysis

As mentioned earlier, the actual energy consumption of each space is an interacting result of three groups of factors, i.e., the 'existing environment' factors, the 'occupancy' factors and the 'management' factors. For each space (type), since its 'existing environment' conditions most likely remain unchanged over time, and its unique 'occupancy' use patterns are rather stable over time, their effects on energy consumptions can be considered predictable. If the data of the 'existing environment' and 'occupancy' factors (independent variables) of all DMUs in a department can be collected and multiple regression analysis performed on their actual energy consumptions (dependent variable), a regression model can be identified and used to predict the energy consumption of each DMU. For each DMU, the difference between its 'actual energy consumption' and 'predicted energy consumption' can be interpreted as the effect of those 'management' factors. If the 'actual energy consumption' of a DMU is larger than its corresponding 'predicted energy consumption', it could be due to poor 'energy management effectiveness or conduct'; and vice versa. The 'energy management effectiveness' of all DMUs can then be further assessed by the data envelopment analysis.

In this study, 'monthly actual EUI' (Wh/m^2-month) is defined as the dependent variable of the regression model to be analyzed. On the other hand, the independent variables include ten 'existing environment' factors such as monthly highest temperature (°C), monthly highest relative humidity (%), space/room orientation (0~360°), room area (m^2), envelop surface area (m^2), envelope U-value (W/m^2K), fenestration percentage (%), light fixture density (w/m^2), equipment density (w/m^2), and HVAC density (w/m^2); as well as two 'occupancy' factors such as occupant density (person/100m^2) and space utilization hours (hr/month).

3.2 The DEMS procedure

The DEMS assesses the energy management effectiveness of all DMUs by analyzing their input levels relative to their output levels. The data envelopment analysis will be conducted to produce the overall efficiency, scale efficiency, and pure technical efficiency scores for all DMUs to indicate their energy efficiencies from different perspectives.

3.2.1 Data envelopment analysis

This study designates the 'predicted EUI' as the 'output', and the 'actual EUI' as the 'input' of the DEMS. Figure 3 shows a scatter plot of the input (actual EUI) and output (predicted EUI) data of certain hypothetical DMUs (space-time). The solid line in Figure 3-a is the regression line derived from the multiple regression analysis. The DMUs above the regression line are considered as 'energy efficient' DMUs. For instance, X in Figure 3, given the same level of output (predicted EUI), has a lower energy input level (actual EUI = x) than its expected input level (actual EUI = y) and is therefore regarded as an efficient DMU. It's logical to reason that the reduction in X's actual EUI could be due to certain positive 'management' factors such as higher level of energy manager's involvement. On the other hand, Z in Figure 3 has a higher energy input level (actual EUI = z) than its expected input level (actual EUI = y) and is therefore regarded as an inefficient DMU, possibly due to certain negative 'management' factors such as lower level of occupant energy consciousness.

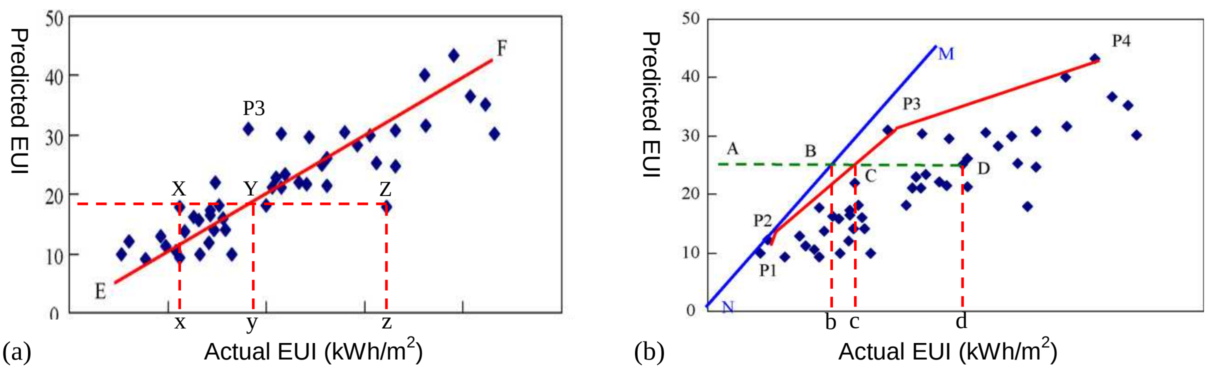

Figure 3: (a) Scatter plot of actual EUI and predicted EUI of a group of DMUs and the regression line derived; (b) the efficiency frontier of the same group of DMUs.

In Figure 3-b, the line connecting the forefront points of all DMUs, i.e., P1, P2, P3, and P4, forms their 'efficiency frontier'. All the points on the efficiency frontier are regarded as the most energy efficient DMUs (spaces at certain time) and are given the highest efficiency score of 100%. They are the benchmarks for those DMUs away from the frontier which are not as efficient and are given with efficiency scores less than 100% (the lower the scores, the less energy efficient they are).

3.2.2 Energy management effectiveness scores

According to the DEA methodology (Charnes et al., 1978; Chauhan et al., 2006), the following three types of efficiency scores can be produced for all DMUs to indicate their energy efficiencies. Point D in Figure 3-b is used to illustrate their meanings:

1. Overall efficiency: The line MN in Figure 3-b represents the envelope of the data set with constant returns to scale (CRS). It is a straight line that connects the origin and the most forefront data point on the frontier (P2). Those points on line MN are considered as efficient and has the highest 'overall efficiency' score of 100%. Those points that are not on line MN are given with 'overall efficiency' scores less than 100%. The 'overall efficiency' score of DMU D is defined as AB/AD (Figure 3-b). One can interpret that AB is the 'ideal input' required to produce the output B on MN (actual EUI = b), if constant returns to scale were to prevail. In the DEMS case, the 'overall efficiency' score of DMU D indicates its overall energy management effectiveness relative to other DMUs. The 'overall efficiency' scores reflect the effects of three groups of factors, i.e., the 'existing environment', 'occupancy' and 'management' factors.
2. Scale efficiency: The line connecting the most efficient DMUs P1, P2, P3 and P4 in Figure 3-b represents the envelope of the data set with variable returns to scale (VRS), which represents a more realistic phenomenon in reality. 'Scale efficiency' is therefore defined to quantify the effect of the presence of VRS in the DMUs. The 'scale efficiency' of D is defined as AB/AC (Figure 3-b), representing the ratio of its 'ideal minimum EUI' (AB) to the 'minimum EUI' (AC). In the DEMS case, the 'scale efficiency' scores reflect the influences of the 'existing environment' and 'occupancy' factors on energy efficiency (since the 'predicted EUI' is calculated by the regression model with the both groups of factors).
3. Pure technical efficiency: The 'pure technical efficiency' is the 'overall efficiency' that has the effect of 'scale efficiency' removed. Those points on the frontier are given with the highest 'pure technical efficiency' score 100%. The 'pure technical efficiency' of D is defined as AC/AD (Figure 3-b) and is calculated by dividing its 'real minimum EUI' (AC) by its 'actual EUI' (AD). In the DEMS case, 'pure technical efficiency' scores indicate the energy management effectiveness of all DMUs and reflect the effects of the 'management' factors on energy efficiency.

With the above three types of efficiency scores, the DEMS allows individual departments to know the energy efficiencies of all spaces within their facilities from different perspectives, and further identify appropriate energy saving targets. For example, DMU D will be given an 'overall efficiency' score of AC/AD; and be advised to move towards point C (pure technical efficiency score of 100%) and try to reduce its actual EUI from d to c (Figure 3-b).

In addition, the DEMS will assist individual departments in analyzing and comparing the energy management effectiveness among different 'space types' to understand the differences and the effects of various ' management' factors on energy efficiencies among different space types. Finally, the DEMS is able to analyze and compare the energy management effectiveness of a certain type of space over time to understand the pattern or trend of its energy efficiency over time and to identify critical 'management' factors that have great effects on its energy efficiencies over time.

3.3 The DEMS implementation: future research tasks

This study intends to further implement the DEMS in the Department of Architecture (DA) of a national university (NTUST) in Taiwan, and use it as a case to demonstrate how the DEMS can assist individual departments within universities in assessing the energy management effectiveness of their spaces and in improving the energy efficiencies of their facilities. The implementation research tasks to be conducted are planned and outlined.

3.3.1 The DEMS implementation subject

There are about 350 occupants in the Department of Architecture of NTUST (17 full time faculty members, 10 research assistants, three full time administrative staff, 200 under-graduate students, and 120 graduate students). The department occupies the 7th, 8th and 9th floor of the *Research Building* on campus. There are a total of 66 spaces in the DA of NTUST, taking up a total of 3,386 m^2 of floor area. These spaces can be classified into five major types according to their ‘functional uses’: administrative office, faculty office, research lab (for graduate students), design studio (for undergraduate students), classroom (excluding spaces such as workshop, lobby, corridor, elevator, toilet and staircase). Each space type is characterised by its unique occupancy patterns (Table 1).

NTUST is located in Taipei City with a humid subtropical climate. The average temperature in summer is 29.4 °C and in winter 11 °C. Summers are hot (133 days in a year with maximum temperature exceeding 30 °C) and humid (mean relative humidity 74.0~81.1%), and accompanied by occasional rainstorms and typhoons. Winters are short and mild. Taipei’s average annual sunshine is 1,408 hours (67% of the time is cloudy), and average annual precipitation is 2,325 mm (46% of the days rain).

Table 1: The five space types and their occupancy patterns in the DA, NTUST.

Space type	User type Density	Equipment type Density	Occupancy time (wk, day) Length of daily use
Classroom	Students Medium density	Office equip. Low density	Variable (wk), intermittent (day) Short-to-long hours
Admin. office	Admin. personnel Low density	Office + special equip. Medium density	Constant (wk), continuous (day) Medium hours
Faculty office	Faculty Low density	Office + special equip. High density	Variable (wk), continuous (day) Short-to-medium hours
Research lab	Graduate students Medium density	Office + special equip. Medium density	Variable (wk), intermittent (day) Medium-to-long hours
Design studio	Undergrad. students High density	Office equip. Medium density	Variable (wk), intermittent (day) Short-to-long hours

3.3.2 Intelligent energy monitoring system installed

An intelligent energy monitoring system was installed in the DA in August 2011. The system was set up to record the electricity consumption data of lighting, equipment, and HVAC on each of the three floors. In addition, the system also records the electricity consumptions in five typical spaces, each representing one of the five major space types: RB-809 classroom, RB-810 administrative office, RB-905 faculty office, RB-906 research lab, and RB-909 design studio. The logged data can be tabulated into hourly, daily, or monthly data tables for reference. As shown in Table 2, the monthly actual EUIs of the five spaces and those of department average are summarized (data from January to December 2012).

Table 2: The monthly actual EUIs (kWh/m²) of the five space types and the department average in the DA (data from January to December 2012).

	2012 Jan	**2012 Feb**	**2012 Mar**	**2012 Apr**	**2012 May**	**2012 Jun**	**2012 Jul**	**2012 Aug**	**2011 Sept**	**2012 Oct**	**2012 Nov**	**2012 Dec**	**Total kWh/m²**
RB-809 Classroom	4.8	4.0	6.5	6.7	13.4	9.3	6.9	5.5	11.3	9.3	8.6	5.2	**91.5**
RB-810 Admin. office	4.2	4.2	5.6	5.5	7.3	7.5	9.6	7.4	8.4	6.6	6.8	5.3	**78.3**
RB-905 Faculty office	2.8	3.6	4.0	4.4	5.3	6.9	8.3	5.9	6.5	4.3	3.8	3.9	**59.5**
RB-906 Research lab	4.2	4.2	4.7	6.2	8.4	10.1	14.6	9.7	10.7	12.4	13.1	7.4	**105.6**
RB-909 Design studio	2.3	2.2	4.0	5.3	7.4	9.6	10.9	2.5	5.4	10.0	7.8	5.9	**73.4**
Department average	**4.2**	**3.6**	**6.2**	**8.1**	**10.4**	**10.2**	**11.2**	**7.7**	**8.1**	**9.1**	**8.5**	**6.3**	**93.7**

3.3.3 Future research tasks planned

The monthly electricity consumption data of the DA in 2012 is ready for comprehensive data analysis. This study plans to perform the following research tasks of the DEMS implementation, and present the actual implementation and analytical results thereafter:

1. DMU definition: For a full year, there will be a total of 60 DMUs (= 5*12) in this study.
2. Regression analysis: Multiple regression analysis will be performed on the ten 'existing environment' and two 'occupancy' independent variables ('management' factors NOT included) and one dependent variable 'month actual EUI'.
3. Calculate the 'monthly predicted EUI' of five types of spaces: The derived regression equation will be used to calculate the 'monthly predicted EUI' (Wh/m^2-month) of the 60 DMUs by feeding the values of independent variables of all DMUs into the equation.
4. Data envelopment analysis: The DEA-Solver-Pro software will be used to conduct data envelopment analysis on the input (monthly actual EUIs) and output (month predicted EUIs) of all DMUs.
5. Energy efficiency assessment of all DMUs: The overall efficiency, scale efficiency and pure technical efficiency scores of all DMUs will be inspected. Pure technical efficiency

scores will be used to identify benchmark DMUs (on the frontier) as well as those that are least energy efficient. For the least efficient DMUs, the causes and problems will be speculated (low pure technical efficiency scores mean less effective in 'energy management', and the related 'management' factors will be examined) and their energy saving targets will be identified.

6. Energy efficiency assessment among different space types: The energy efficiency scores of five space types will be analyzed and compared to realize the most and least effective space types (in terms of 'energy management'), as well as to understand the differences among different space types and the 'management' factors that may have caused them.
7. Energy efficiency assessment of each space type over time: The energy efficiency scores of each space type over 12 months will be analyzed in order to understand the its energy management effectiveness over time and identify the 'management' factors that may have caused them.

After implementing the DEMS and obtaining the analytical assessment results, this study will further discuss the potential and the limitations of the DEMS. It's expected that certain problems may arise during the DEMS implementation process. For example, how should the energy efficiencies between spaces with different envelope construction be compared? Such issues will be addressed and future research tasks to improve the DEMS will be outlined.

4. Conclusions

This research explores the ‘space type’ and ‘internal benchmark’ research concepts, and the ‘data envelopment analysis’ method to establish the ‘DEA Energy Management System (DEMS)’ to assist individual departments within universities in assessing the energy efficiencies of their facilities from the ‘management’ perspective. DEA is a method that assesses the efficiencies of a number of decision making units (DMU) by analyzing and comparing their input levels relative to output levels.

The DEMS proposed considers each ‘space’ in a given ‘time’ (such as a month) as a DMU. Then, regression analysis is performed on data of the independent variables related to the ‘existing environment’ factors (such as highest temperature, highest relative humidity, space orientation, room area, envelop surface area, envelope U-value, fenestration percentage, lighting fixture density, equipment density, and HVAC density) and 'occupancy' factors (such as occupant density and space utilization hours), and of the dependent variable (actual energy consumption EUI) of all DMUs. The regression equation derived is then used to calculate the ‘predicted EUI’ for all DMUs. The ‘actual EUI’ is considered as the input data, and the ‘predicted EUI’ as the output data of the DEMS. Finally, data envelopment analysis is conducted on the input and output data to produce three types of energy efficiency scores (overall efficiency, scale efficiency, and pure technical efficiency) to indicate the energy efficiencies of all DMUs. The ‘pure technical efficiency’ scores reveal the 'energy management effectiveness' of all DMUs. Those DMUs on the efficiency frontier are the most energy efficient ones and are given with the highest pure technical efficiency score of 100%; and those DMUs that are away from the frontier are less efficient ones and are given with efficiency scores less than 100%. Energy efficiency assessments can also be performed to compare the energy management effectiveness among different space types as well as those of individual space types over time.

The DEMS will be implemented in the Department of Architecture of NTUST in Taiwan to illustrate how it can be used to assist individual departments within universities in assessing the energy management effectiveness of their spaces and in improving the energy efficiencies of their facilities. The implementation research tasks to be conducted are planned and outlined, and the actual implementation and analytical results will be presented thereafter.

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