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# DEVELOPING CRITERIA AND VARIABLES FOR EVALUATING THE EFFECTS OF VEGETATION ON SINGLE-FAMILY HOUSES

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## ABSTRACT

*This paper describes the methodology used to measure the effects of surrounding vegetation, building construction and human factors on a small number of individual houses and a large number of single-family houses. The primary data were obtained from fieldwork and site measurements during a two-stage process. All supporting data for this study was sourced from various Malaysian government departments. Fieldwork in the first stage focused on five individual single-family houses. Quantitative measurements were taken to record the construction of the buildings, their surrounding vegetation, human factors, and weather data during the daytime. In this report only five houses of different ages and types of landscaping were chosen to compare the effect of landscaping on the thermal performance of the house. These five houses had used different styles and designs of tropical landscaping, which could produce different conditions of micro-climates. The air temperature, relative humidity and wind speed data were obtained from the exterior and interior of houses during similar weather conditions to ensure they could be accurately compared. This data was automatically recorded at half hour intervals by static and mobile sensors of the data loggers. The albedo data for every type of building were also measured during the day time. In the second stage, the fieldwork measurements were divided into four categories: building construction, landscaping, human factors, and weather data. The annual energy consumption for every house was also evaluated by analysing electricity consumption for different single-family houses ranging in age from 3 to 40 years. The target number of respondents was 50 houses. Statistical calculation and analysis was used to measure and evaluate the energy saving.*

***Keywords:*** *Building construction, human factors, single-family houses, vegetation*

## INTRODUCTION

This study describes the methodology used to measure the effects of surrounding vegetation, building construction and human factors on a small number of individual houses and a large number of single-family houses. The primary data were obtained from fieldwork and site measurements during a two-stage process. All supporting data for this study was sourced from various Malaysian government departments. Fieldwork in the first stage focused on 10 individual single-family houses. Quantitative measurements were taken to record the construction of the buildings, their surrounding vegetation, human factors, and weather data during the daytime. In this report only five houses of different ages and types of landscaping were chosen to compare the effect of landscaping on the thermal performance of the house. These five houses had used different styles and designs of tropical landscaping, which could produce different conditions of micro-climates.

The air temperature, relative humidity and wind speed data were obtained from the exterior and interior of houses during similar weather conditions to ensure they could be accurately compared. This data was automatically recorded at half hour intervals by static and mobile sensors of the data loggers. The albedo data for every type of building were also measured during the day time. In the second stage, the fieldwork measurements were divided into four categories: building construction, landscaping, human factors, and weather data. The annual energy consumption for every house was also evaluated by analysing electricity consumption for different single-family houses ranging in age from 3 to 40 years. The target number of respondents was 50 houses. Statistical calculation and analysis was used to measure and evaluate the energy saving.

## LITERATURE REVIEW

The research methodology was divided into the two fieldwork stages using a process called triangulation. This is where more than one research method or type of data is used to answer the research questions (Evans & Gruba, 2002). In this study, two stages of methodology were used to answer two research questions. According to Yin (2003), at least three principles for collecting data must be used from the six possible sources of documented evidence. The three main sources chosen for collecting data in this study were interviewed, direct observation, and physical artefacts evidence.

To measure the effect of surrounding landscaping on the thermal performance of a house, site measurements were made of the physical features that surrounded the building, and equipment was used to record weather data inside and outside of the houses (Wong & Yu, 2005). The outdoor weather data included temperature, relative humidity and wind speeds while the indoor data focused on temperature and relative humidity (Koch-Nielsen, 2002). Finally, in assessing the influence of landscaping on reducing the amount of energy used for air-conditioning was to calculate the average proportion of electricity used for cooling (Akbari, 2002). Data on landscaping, building construction and energy use of air-conditioning systems, and the number of occupants in each house was obtained through observation and interviews with the homeowners.

## METHODOLOGY

### Study location


Figure 1: Putrajaya and Shah Alam located at approximately 101ºE and 3ºN
Source: (Malaysia, 1993)

The single-family houses sampled, were randomly chosen from two well planned Malaysian cities: Putrajaya and Shah Alam (Samad, Zain, Maarof, Hashim, & Adnan, 2011). The city of Putrajaya is situated at latitude 2°N and longitude 101°E, at an elevation of between 75 and 94m, 25km south of Kuala Lumpur. While Shah Alam is located at latitude 3°N and longitude101°E, at an elevation of between 24 and 48m, about 25km west of Kuala Lumpur. The distance between Putrajaya and Shah Alam is approximately 23.7km. Five locations of low-density housing development were selected to be the case study areas. The specific locations used were in Precinct 14, in the Federal Territory of Putrajaya, and Sections 3, 6, 9 and 11 in Shah Alam, Selangor. Putrajaya is a well planned city, and is known as an "intelligent city" because of its extensive information and communication technologies (Malek, 2011). It was also planned as a garden city, with 38% of the city reserved for green space areas that emphasise and enhance the natural landscape. Shah Alam is the capital of Selangor State, and is also one of the most well planned cities in Malaysia (Aziz & Hadi, 2007). It has around 10% of its area dedicated to green space areas.

## The Study House

In Putrajaya and Shah Alam, the most common type of house is the two-storey single-family house that is surrounded by a garden. Generally, these types of house represent around 10 to 30% of all houses in a housing development.

Figure 2: Examples of modern tropical houses in the study areas ranging in age from 3 to 40 years with surrounding landscaping
Source: (Misni, 2010)

In this study the houses looked at were medium sized, single-family houses (around 300–600m$^2$). The garden area includes the entire space around the building and is private to the owner. This research was undertaken looking at single-family houses ranging in age from 3 to 40 years. The different ages were chosen because they provided differences in the maturity of the surrounding landscape, which affects the amount of energy used and thermal comfort and performance of the house.

## Weather Data

In the first stage of fieldwork, which included site measurements for 10 individual houses, weather data from the Malaysian Meteorology Department was gained for the same days as when the climate data was recorded in the houses. This weather data was required to compare it with the study location. The dates this data was gathered were the 16th and 17th of January, 2010 in Putrajaya, and the 23rd, 24th and 28th of February, 2010 for the Shah Alam study areas. The data included air temperature, relative humidity, rainfall, daily global radiation, cloud cover and wind. In the second stage of fieldwork, which included site measurements of 50 houses, weather data was obtained from the Malaysian Meteorology Department in 2008 and 2009. Weather data were recorded at two stations: Sepang Weather Station for the Putrajaya study area and Subang Weather Station for Shah Alam. Averages of this data were used to determine the exact tropical weather conditions in the study areas.

## Local Authority Records

Putrajaya Cooperation and Shah Alam City Council were the two local authorities involved in this study. They provided the master plans, construction details and landscaping information for the sample houses. In the Putrajaya study area, the whole housing development was designed and constructed by a developer. The sizes of the houses are slightly different, but are similar in design and are typical of tropical architecture. In Shah Alam, every homeowner is free to build their own house. Developers only provide the infrastructure and land for sale. Detailed plans for houses in Shah Alam are done privately. In this study, the architects, landscape architects and planners who managed the areas of study were interviewed to gather information about the general construction, basic building design, landscaping, and the exact date and age of construction for every development. This primary data was validated with on-site interviews, data collection, and observation of each of the sample houses.

## Electricity Uses Data

Domestic electricity tariff information was obtained from the Malaysian Electric Utility Company (National Energy Limited–TNB). Data for the monthly amount of electricity used by the 50 residential houses was collected as the cost of electricity in Malaysian Ringgit (MYR). These costs were converted into energy used in kWh based on current local tariff. Annual domestic electricity use in the city of Shah Alam was analysed to validate the amount of energy used in relation to the increase in air temperature and humidity levels in the two main seasons: rainy and dry. The increase in cooling energy use was closely related to air temperature changes in the hot-humid tropical environment.

## Satellite Images

Satellite images for the study areas were obtained from Remote Sensing Data Services, Malaysian Remote Sensing Agency, Kuala Lumpur. These satellite images were formatted in high resolution, ‘Quickbird’ data series (0.6m resolution), and were taken in 2007. The images show the natural condition of the housing estates and their surrounding landscapes. Vegetation information was observed by the author during the fieldwork stages, and was compared with the digital satellite images. The satellite images came from geographic information system (Archview@GIS). This data was compared with the master plans from each house’s local authority to confirm their location, orientation and surrounding landscape; and to record the overall condition of the houses and landscaping in each location.

## The Variables

### Building Orientation

The configuration of the house should be designed to ensure the comfort of its occupants and for energy efficiency. In a hot-humid tropical climate, proper house orientation in relation to the sun and its devices will enable energy savings and more comfortable conditions. In this study four main categories of wall orientation/direction are North, East, South and West and also the in between of the main directions include the Northeast, Southeast, Southeast and Northwest.

### Building Envelopes

Building envelopes include the walls, roof, glazing and floor foundation. Walls are the major part of the building envelope and in these houses faced in all directions, while the roof is the top covering and is exposed to the direct solar radiation throughout the day. In the tropics, heat gain through glass windows and doors is often the major source of solar heat gain. Hence, if such glazing located facing the direct solar radiation orientation, it should be minimized and shading maximized. Hence, not only were the materials of the building noted, but the direction of the glazing was also assessed. The measurements taken in the study areas were the areas of building envelopes include walls, roof, glazing and floors.

### Surrounding Vegetation

Strategically placed shade trees around the building can potentially modify micro-climate and building energy use through shading. This shading can minimize the amount of radiant heat absorbed and stored by buildings and other built surfaces. Shading in outdoor areas will be provided by all types of vegetation to the building envelopes and surrounding garden earth surfaces. The plants shading areas and their angles were recorded during morning, afternoon, and the peak time of the day. The measurement of evaporation and transpiration in the study areas refers to the amount of water vapor in the atmosphere. The evapotranspiration is gained as a result of evaporation from exposed water surfaces, moist ground and plant transpiration. The measurements in the study areas were relative humidity or absolute humidity reading. In a hot-humid tropical climate, wind is generally of moderate speeds and is not steady all the time. Strategic outdoor designs to promote wind are required. The strategic location of vegetation can capture and directing the flow of air and provide effective ventilation and convective cooling of surrounding gardens and building surfaces. The measurements taken in the study areas were wind speeds.

### Human Factors

Human factors in this study are the number of occupants who need cooling and their daily living habits of using air-conditioning system. The cooling energy use will be calculated based on the horsepower of the air-conditioning system, temperature setting and the duration of daily use.

## RESULTS AND DISCUSSIONS

## Stage 1

In this first stage, the measurements focused on individual houses. Research methods have been divided into three parts: selection of houses with suitable surrounding landscape; observation of building construction and landscape design; and field measurements of building construction, landscaping and day time weather data.

Case study one involved looking at the construction and surrounding landscape of three single-family houses aged 5, 10 and 30 years old in Shah Alam, Selangor, Malaysia. While their construction was similar, the design and size of each house varied because they were built in different eras of construction methods, and styles of architecture and landscaping. As mentioned before, the design and construction of single-family houses in Shah Alam are up to each homeowner to decide on. The 30 year old house was located in Section 6, Shah Alam, and was surrounded with mature tropical landscaping, while the 10 year old house was located in Section 11, Shah Alam, and was surrounded by tropical landscaping of intermediate age. The 5 year old house was located in Section 9, Shah Alam, and was surrounded by immature tropical landscaping. The houses were labelled as mature, ordinary, and new landscaped houses. The three housing estates were close in location, as they were around 3km apart. The three ages of construction were chosen because they provided different vegetation maturity and landscaping styles, which would have different effects on the thermal performance of the houses by shading, evapotranspiration and channeling wind.

In case study two, two similar house constructions and locations were chosen, but the landscape of each house was totally different. This was to help demonstrate the effects of the surrounding landscape on a house's thermal performance. These houses were located in Precinct 14, Putrajaya, Malaysia, and were labelled as a heavily landscaped house and a sparsely landscaped house. The heavily landscaped house had strategic landscaping, while the sparsely landscaped house had a minimum of landscaping in the garden. A heavily landscaped house will usually produce cooler ambient air than a sparsely landscaped house. This is because large quantities of vegetation located in strategic areas of a property could lower the ambient air temperature by providing shade, channeling wind and through evapotranspiration. A well designed tropical house will also reflect heat from solar radiation from the building envelope, while providing shade for every opening and by being orientated to allow wind to blow through the building's interior spaces.

## Local weather recording

In case study one, which was conducted in Shah Alam, weather recordings were carried out during daytime on the 23$^{rd}$, 24$^{th}$, and 28$^{th}$ of February, 2010. These dates were chosen because they had similar weather conditions each day, with six to eight hours of sunshine during the day and drizzle at night. In case study 2, which was conducted in Putrajaya, the weather recordings were carried out during daytime on the 16$^{th}$ and 17$^{th}$ of January, 2010. The weather on these two days was similar, with sunshine for the whole day, and the soft rain starting at 19.30 hours. Cloud is very typical of this tropical region, measuring approximately 6.9–7 okta. The study measured climatic parameters and the physical characteristic of the four azimuths of the houses. Each measurement point represents an area of 90m², and an approximate radius of 3m to 10m around the fixed/mobile weather station. The measurements were taken at 30-minute intervals in all locations a meter above the ground and in the shade. The albedo data for every type of building envelope was also measured during the daytime.

## Exterior space

The weather measurements taken for both studies were not influenced by shadows or reflected solar radiation. The basic measuring equipment that was used to do the field measurements included:

- *Two sets of mobile TSI VelociCalc Plus Meters, model 8386, data loggers and sensors.*
- *Two sets of portable Model Babuc A code BSA014, multi-data loggers and sensors.*
- *Two sets of Lux meters PCE-172.*
- *Two sets of compasses and measuring tapes.*
- *A set of digital cameras and drawing equipment.*

## Interior space

Four sets of Electronic Mini Thermo hygrograph, model Testo 175-T2 were used to measure air temperature and air humidity data inside the buildings. This equipment was set automatically, and placed at a metre above the floor near the windows that faced the four azimuths on the ground floor of the houses. The purpose of these measurements was to compare with outside weather data.

## Energy use measurements

This experiment used quantitative measurements to document the energy used for air conditioning, while considering the influence of surrounding vegetation, including trees, shrubs, vines, groundcover and lawn. Data about the internal temperature of each house was obtained during days with similar climate conditions. This was to ensure the data for houses with different designs and landscaping was comparable. Interviews with home owners and observations revealed that air conditioning units were used in every room of the houses looked at. The type of air-conditioning units used and their horse power were recorded, and energy consumption for these units was given by the owner of the house. The cost for air conditioner use has been determined by National Electricity Limited (TNB). This, along with an analysis of the reduction of ambient temperature and air conditioning consumption during the day and on the hottest afternoons, would reveal the potential savings associated with the corresponding landscape.

## Landscape element measurements

The study of all landscape elements was conducted through observation and interviews with the owner of each house. Landscape elements and house plans were drawn in detail and to scale. Landscape elements included soft landscape and hard landscape. The location of every type of vegetation was recorded at five meter intervals extending out from the building from each of four azimuths, as shown in Figure 3. Tree azimuth classes were defined with reference to building wall orientation. According to Simpson (2002), a wall is cardinally oriented if the normal distance to the wall is within ±45°E of a cardinal direction (North, East, South or West), otherwise, it is inter-cardinal (NE, SE, SW or NW). A detailed landscape plan was recorded for every type of vegetation because shading, evapotranspiration and wind flow are all affected by different types of landscaping.

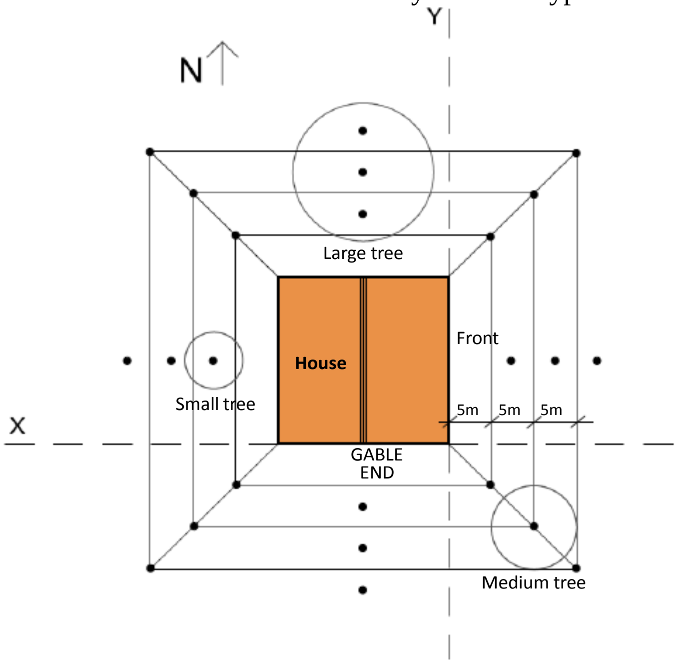


Figure 3: House configuration and the five metre intervals of vegetation measurements and other landscape elements around the house
Source: (Simpson, 2002)

## Data Analysis

Once all of the data were collected, master spreadsheets were developed using Microsoft Excel 12.0 and Origin 8.0. All vegetation data gathered from the four azimuths of each house and was recorded numerically in this spreadsheet as percentages or figures. This data was analysed based on a few variables, including vegetation structure and typology or biomass, which was representative of the real conditions of vegetation on the site. The actual amount and biomass of every type of vegetation could appear as an average or mean to represent the surrounding landscape and design for every sample house. The types of equipment used for cooling, and resident's living habits were given different codes and numerical values in the spreadsheets to convert the actual values to energy consumption. Energy consumption for cooling was represented as a total value for the study period of kWh in Malaysian Ringgit (MYR). All drawings used as supporting documents were generated by Autodesk Revit Architecture 2011 and AutoCAD 2011.

All exterior and interior weather data gathered using devices such as the Babuc A, mobile TSI VelociCalc data loggers, and the Mini Thermo hygrograph were transferred and formatted for Microsoft Excel 12.0. The daily to yearly weather data obtained from the Malaysian Meteorology Department and monthly electricity costs data from National Energy Limited (TNB) were also put into this format. The best weather data from five individual houses was chosen for case studies 1 and 2, and the results of these studies were presented in various types of tables and figures using Microsoft Excel 12.0 and Origin 8.0 software.

## Stage 2

Survey data were divided into two categories: data was collected by interviewing the owners of the houses, and from measurements and observation of the properties.

### Homeowner interviews

Homeowner interviews were conducted to find information on human factors such as the amount of occupants, and lifestyle habits, including the time and numbers of air-conditioning units used every day. This provided information on the exact amount of cooling energy used in the house on a daily and monthly basis. These took approximately 10 to 15 minutes to complete, and asked three main questions. The first question asked about the number of residents in the house. The second question focused on a set number of electricity bills during the two main seasons in the tropics to evaluate the monthly and annual energy consumption for every house. Details about the type of air-conditioning systems used were also gathered, including each system's capacity, the total time it is used, the times it is turned on during the day and night, and the average temperature setting of the system. From this data the total amount of cooling energy used was calculated. Approximately 50 data collection sheets were filled in, and interviews completed from throughout the metropolitan Shah Alam and Putrajaya areas from January through March of 2010. Overall, only one-fifth of the number of householders approached cooperated and answered the interviews.

### Data collection

To obtain accurate data about each house in the study, the fieldwork information was collected through observation and by taking measurements. The aim of the fieldwork was to collect all the possible data about the physical characteristics of the house, including the structure and construction method, and the surrounding landscape. These were filled out after consent was gained from the participants. Primary data from homeowners through interviews, along with direct observations of each house's environment were essential. The main goal was to observe the physical characteristics of the properties, including building construction and the surrounding landscape, and the lifestyle habits of the occupants that could not be obtained without going to each property and contacting them directly.

## Building structure and construction

The first data collected was general information about the building structure and construction of each house in the study. This data can be validated against construction records from local authorities, but the on-site data collected is the most up to date information about the houses, as some houses in the sample have had extensions built, such as enlarged car porches and additional kitchen spaces. The year of construction and house sizes were the main data variables used to classify the houses to ensure there was a range of ages and that they were medium sized. Information about the main structure and materials used was gathered to ensure the houses had similar construction and materials.

Data on the building envelope of every house was also gathered. This included information on windows and doors, wall and roof area and colour, and insulation. This information is significant because the building envelope influences the amount of heat absorbed by a house, which indirectly influences the cooling system. Data collected about windows, sliding doors and common external doors included actual size, materials and locations. For wall and roof areas, the biggest building envelope surfaces of every building, the areas were calculated in square meters. Their colour was also noted, because colour provides different abilities to reflect sunlight, as well as an albedo value for every house sample. Every house in the study areas used a layer of aluminium foil as an insulation layer for roofing. Ceiling type and the material used were also noted, as these provide another insulation layer for the roof. Data about the type of ceiling was collected for every room in each house; include heights, ceiling types, materials, and colours.

## Landscaping

Data about the surrounding landscaping was divided into two types: soft landscape and hard landscape. Soft landscape included any type of vegetation that was planted around the houses, and is divided into five categories of vegetation: trees, shrubs, vines, groundcover and turf. Trees were divided into six types: roadside tree, roadside palm, garden tree, edible fruit tree, garden palm and bamboo. The explanation for every species of tree includes location, tree to building distance, trunk height and overall height, canopy size, shape, and the amount and size of the leaves. Shrubs, vines and groundcover were also categorized, as well as trees with slight differences in size. Turf species were stated and calculated in areas. The botanical name and common name for vegetation types were updated later using photographs. Hard landscaping in the study areas included paved surfaces, swimming pools, fish ponds, fountains, and shelters such as pergolas or gazebos. These are located among the soft landscaping, and are intended to complement and beautify garden design and provide space for outdoor activities. The data collected included recording the type of landscaping feature, its location and distance from the house, and construction material, size and colour and total area.

Table 1: Canopy Size, Shape, and Amount and Size of Leaves of Trees

| **Canopy size (diameter) (m)** | | **Shape** | **Amount of leaves (density) (%)** | | **Size of leaves (mm$^2$)** | |
|---|---|---|---|---|---|---|
| Small | Below 3 | Spreading | Few | Below 40 | Small | Below 150 |
| Small moderate | 3–7 | Round | Medium | 40–70 | Medium | 150–1000 |
| Medium | 8–11 | Columnar | Dense | Above 70 | Large | Above 1000 |
| Large moderate | 12–15 | Pyramidal | | | | |
| Large | Above 15 | Fountain | | | | |

Source: (Misni, 2012)

The final portion of the data collection sheet contained a space to sketch the house plan and surrounding landscaping elements to provide a detailed reference about their exact location and sizes. The plan of the house was also based on satellite images, master plans and detail drawings found from government departments. A scale of 1:200 was used as can be seen in Figure 3. This data collection took approximately three to four hours to complete per house, depending on the size of the house and surrounding landscape.

## Data Analysis

Quantitative methods were used to evaluate the result of the effect of vegetation, building construction and human factors on cooling energy used in a hot-humid environment. All of the data gathered from 50 houses and their surrounding landscapes, from five housing estates in two cities, was analysed using the Statistical Package for the Social Sciences (SPSS 19.0). Origin 8.0 software was used to generate figures and tables from SPSS data. The effects of the surrounding landscape, together with building construction and human factors data, were calculated and evaluated by these statistical analysis systems. The cooling energy used in an individual single-family house was revealed in parallel with the neighbourhood trends of energy used for cooling.

## CONCLUSIONS

The direct and indirect thermal impact of the vegetation surrounding single-family houses and their neighbourhoods in tropical climates was investigated using three research methods to collect data: interview, direct observation, and physical artefacts evidence. The primary data on the effects of vegetation on the thermal performance of buildings and their micro-climates on site were gathered to predict the effects of shade, evapotranspiration, and channeling wind on temperature and energy use. The secondary data was obtained from government agencies. These were used to validate that all of the primary data was accurate. In the first stage of fieldwork and measurements, the physical condition of five houses and their surrounding landscaping and weather data was recorded. The outdoor and indoor weather data were recorded for approximately 12 hours during the daytime in each of the four azimuths of the houses at 30 minute intervals using scientific equipment. In the second stage, 50 homeowners were interviewed to gain information about the human factors aspect of this study. On-site observations, data collection and information about building construction and the surrounding landscaping of each house were made manually and recorded by photographs. Statistical analysis was used to quantify and analyse the cooling-energy savings potential. This was based on the comparison between the surrounding landscaping, building construction and cooling energy use.

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# NOTES FOR CONTRIBUTORS

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Swan W, Khalfan MMA (2007). *Mutual Objective Setting For Partnering Projects in the Public Sector. Engineering, Construction and Architectural Management, 14(2): 119-130.*

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