Nearly zero energy - construction site temporary office buildings

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Abstract. In the UAE temporary offices and buildings utilised during the construction phase of a project are not connected to the grid electricity. Thus, leaving on site generation as the only option to power these buildings. On-site generation for these temporary buildings in the UAE is, more often than not, through diesel generators. Diesel generators are not the most efficient nor environmentally friendly source of power generation and produce large amounts of carbon dioxide. These temporary buildings have a continuous power consumption throughout the construction period of a project and this can lead to significant amounts of carbon emissions to the atmosphere and detrimental environmental impacts. To alleviate the issue, we have identified a typical site office building in Dubai and analysed its consumption and how to offset or reduce the reliance on diesel generation thus increasing the efficiency and sustainability of the site office by trying to target a near zero energy building. Through dynamic energy modelling simulations of the existing site office we were able to meet the nearly zero energy requirements by implementing envelope improvements, mechanical system efficiencies and on-site renewable energy generation. A financial feasibility assessment was conducted on the improvements determined to achieve the nearly zero energy target. This ensured that a holistic approach was taken upon selection of the improvements.

1. Introduction

With an ever-increasing awareness and focus on the efficiency of existing and new buildings, the temporary buildings and structures utilised during construction of projects and their associated environmental and sustainability impacts are often overlooked. During 2016 there was reported to be over 26,000 buildings under construction and over 28,000 in 2017 [1]. These temporary buildings are by in large prefabricated structures located on the project site for the duration of the construction period only. After completion of the associated project they are dismantled and relocated to another project site or sold on. As such, investment or upgrading of these buildings is typically not high on the agenda for the responsible party. However, the cost of operating these buildings, especially in hot arid climates such as in the UAE, can have a direct impact on the bottom line both in terms of cost and sustainability impacts. This is due to relatively high energy consumption, compounded by low levels of thermal insulation, leaking facade elements and oversized, inefficient mechanical systems. The analysis for this paper has investigated alternative solutions to the reliance on diesel generators for power and cost-effective improvements to the facade elements, with the goal to target a nearly zero carbon building. A nearly zero energy building as defined by the Emirates Green Building Council is a building with a site EUI of less than 90 kWh/m²/year [2].

A review of current literature on nearly zero and net zero buildings gives ample information on the how to achieve these targets for existing buildings. However, there is minimal accounts on the temporary buildings utilised in the construction of these buildings. In order to be considered truly net zero the construction and life cycle of a building should be considered.
2. Methodology
An existing site office with a gross floor area of approximately 2,300 m² located in the United Arab Emirates was chosen as the subject of this study. The three-storey site office comprises mainly of office spaces, meeting rooms, restrooms and a server room. The energy modelling tool Integrated Environmental Solutions – Virtual Environment (IES-VE) has been used for this analysis. The model orientation has been assigned as per actual plot orientations and ASHRAE weather file for Abu Dhabi (Climate zone 1B) has been used to determine external heat gains.

![Energy Model Image of Site Office](image1)

![Actual Image of Site Office](image2)

An operating profile for the energy model was created using annual energy metered data from consumption of a similar site office owned and operated by the same contractor. A separate 24x7 profile was modelled for the server room equipment usage. National holidays in the United Arab Emirates for the year have also been incorporated in the energy model. It was observed that the site office was never fully occupied and operates at a peak part load of 44%.

2.1 Creating an Existing / Baseline model
The first step of the study was to create a baseline energy model incorporating all existing site office conditions such as; building envelope, lighting power densities, equipment loads & HVAC design. Table 1 summarizes all the input parameters incorporated in the baseline model.

2.2 Targeted Improvements
Contrary to typical building retrofits, the general life span of a site office is significantly lesser (typically 2-3 years). Thus, careful consideration was given towards the associated cost for each of the targeted performance improvements. The improvements listed in Table 1 can be achieved with minimal incremental cost, hence conforming to the lifespan of the building. Energy Conservation Measures (ECMs) can be achieved as follows:

- **External walls and Roof** – Existing wall and roof build up consists of 50mm of rockwool insulation. Several iterations for variations in insulation thickness for the external walls and roof were simulated and the targeted performance parameters are selected based on financial feasibility. The targeted performance can be achieved with an additional 50 mm of insulation.
- **Ground Slab** – Existing ground slab build up does not include any insulation, leading to high heat gains. The targeted performance can be achieved with 100 mm of rockwool insulation.
• Glazing – The existing glazing design consists of a double-glazed system with clear glass (80% visibility) and high thermal conductivity. Reducing the visibility to 48% can lead to the targeted improvement without significant incremental costs.

• Lighting – Occupancy controls for non-regularly occupied spaces such as enclosed offices and meeting rooms can lead to a 10% reduction in lighting power density as per ASHRAE 90.1 Table G3.2(2).

• HVAC – No consideration towards system efficiency has been taken into account during the design of the existing building. The targeted improvements are high star energy rated DX systems sized in accordance to the envelope performance improvements.

• External Air Infiltration – The targeted air tightness performance is assigned in accordance with code compliance standards for the region.

| Table 1. Existing Design & Performance Improvement Parameters. |
|---------------------------------------------------------------|
| **Parameter**                                                | **Existing / Baseline Case** | **Proposed Case** |
| External Wall U-Value                                      | 0.76 W/m²K                  | 0.39 W/m²K       |
| Roof U-Value                                              | 0.75 W/m²K                  | 0.39 W/m²K       |
| Ground slab U-Value                                       | 8.89 W/m²K                  | 0.38 W/m²K       |
| Glazing U-Value                                           | 2.85 W/m²K                  | 1.63 W/m²K       |
| Glazing Solar Heat Gain Coefficient                        | 0.74                        | 0.32             |
| External air Infiltration                                  | 17 m³/hour/m²               | 10 m³/hour/m²    |
| Lighting power density                                    | 3.02 W/m²                  | 2.71 W/m² – Meeting rooms |
|                                                           |                             | 3.02 W/m² – All other spaces |
| Equipment - Connected Load                                 | 46.08 kW                    | 46.08 kW         |
| HVAC Systems                                              | DX Units - Standard market efficiency systems |
|                                                           | As actual installed capacities |
|                                                           | and specific fan power of 0.3 W/L/s |
|                                                           | COP - Min 2.79               |
|                                                           | DX Units - Highest efficiency systems available in the market |
|                                                           | Capacities sized as per ASHRAE 90.1 and specific fan power of 0.3 W/L/s |
|                                                           | COP - Min 3.45               |

3. Results
Two energy simulations have been conducted for the purpose of this study, one for each of the cases listed in Table 1. The following subsections detail the results obtained from the energy simulations;

3.1 Existing / Baseline Case
The simulation incorporated all existing site office parameters listed in Table 1. Results obtained from the energy model indicate an annual energy consumption of 518 MWh which translates to an Energy Utilization Index (EUI) of 230 kWh/m². As per energy consumption trends in the region, the cooling demands of the building are the largest contributors to the overall energy consumption followed by the

**Figure 4.** Monthly Energy Breakdown – Baseline

**Figure 5.** Energy Use Breakdown - Baseline
equipment loads. The monthly energy consumption breakdown indicates the peak cooling load and overall energy consumption during the harsh summer climates from May to October.

3.2 Proposed Case
Upon implementation of the performance improvements listed in Table 1, the results of the energy simulation show an annual energy consumption of 357 MWh which translates to an EUI of 158 kWh/m² and a 31% improvement over the existing case. The monthly energy consumption trend remains consistent with the cooling demands increasing during the summer months. Majority of the improvements are passive measures targeted towards reducing the impact of external climatic conditions and subsequently reducing cooling energy consumption, the percentage of the annual energy consumption attributed to space cooling decreased by 13%.

3.3 Comparative Analysis
The improvements in thermal envelope performance lead to a direct reduction in the cooling energy consumption as the thermal heat gains through each envelope component significantly reduces. A 96% reduction in heat gain through the ground slab is observed which can be accounted towards the uninsulated build up in the existing case. The overall impact of the envelope and air tightness improvements can be observed through the 52% reduction in annual cooling energy consumption. Table 2 details the percentage improvements achieved through the targeted proposed strategies.

| Parameter                                | Existing Case | Proposed Case | Percentage Improvement |
|------------------------------------------|---------------|---------------|------------------------|
| Walls – Conduction Gain                  | 34.8 MWh      | 18.4 MWh      | 47 %                   |
| Roof – Conduction Gain                   | 34.5 MWh      | 18.8 MWh      | 45 %                   |
| Ground Slab – Conduction Gain            | 203.8 MWh     | 7.7 MWh       | 96 %                   |
| Glazing – Conduction Gain                | 8.5 MWh       | 5.7 MWh       | 33 %                   |
| External Air Infiltration Gain           | 16.1 MWh      | 9.6 MWh       | 40 %                   |
| Cooling Energy Consumption               | 322 MWh       | 154 MWh       | 52%                    |

4. Solar PV On Site Generation
The existing site office has a roof area of 753 m², out of which it is assumed that 603 m² will be usable for the installation of high efficiency polycrystalline PV panels. The selected panels have a nominal rated power of 340 Wp and operate at an efficiency of 17.5%. The available roof area allows for the installation of 301 panels which will result in an annual generation of 1650 kWh per kWp based on simulations carried out on PVSyst incorporating the weather & environmental conditions of the site office. The cumulative annual generation for the PV array will result in a generation of 168,806 kWh.
5. Air Infiltration Gains
Due to the temporary nature of site offices, air tightness of the building is rarely prioritized. The specified air leakage target was set to maximum allowance as per local green building standards. The incorporation of the reduced air leakage rate in the energy model showed a 40% reduction in conduction gains due to air infiltration. This has a direct impact on the space cooling energy consumption due to decreased infiltration of hot and humid outdoor air.

6. Payback Calculations
The following Tables 3, 4, 5 and 6 indicate the associated savings and impact on capital expenditure (CAPEX). The calculations have been based on simple payback calculations, taking account of the current market cost for the materials, services and man power.

### Table 3. Passive Measures

| Recommended Improvements                                      | Incremental Cost (USD) | Energy Savings (kWh/annum) | Cost Savings (USD/annum) | Payback (Months) |
|---------------------------------------------------------------|------------------------|---------------------------|--------------------------|-----------------|
| Increasing Wall insulation from 50 mm to 100mm                | 5,332.31               |                           |                          |                 |
| Increasing Roof insulation from 50 mm to 100mm                | 3,696.08               |                           |                          |                 |
| Adding 100mm insulation to ground contact floor              | 7,392.16               |                           |                          |                 |
| Improving Glazing U-Value from 2.85 W/m2K to 1.63 W/m2K     | 1,492.75               | 176,497.60                | 57,710.38                | 4.86            |
| Improving Glazing Solar Heat Gain Coefficient from 0.74 to 0.32 |                       |                           |                          |                 |
| Improving air tightness to meet Local green building standard (10 m3/hour @ 50 Pa) | 5,449.59               |                           |                          |                 |
| Total Incremental Cost                                        | 23,362.90              |                           |                          |                 |

### Table 4. Active Measures

| Recommended Improvements                                      | Incremental Cost (USD) | Energy Savings (kWh/annum) | Cost Savings (USD/annum) | Payback (Months) |
|---------------------------------------------------------------|------------------------|---------------------------|--------------------------|-----------------|
| Energy efficient HVAC systems                                 | 20,223.43              |                           |                          |                 |
| Occupancy sensors in Meeting rooms & Enclosed offices         | 1,189.91               | 227,744.8                 | 74,466.96                | 12.71           |
| Rental cost for PV systems                                   | 57,506.81              |                           |                          |                 |
| Total Incremental Cost                                        | 78,929.15              |                           |                          |                 |

### Table 5. Cumulative Payback Analysis (OPEX only)

| Total Incremental Cost (Active + Passive Measures)             | 102,292.05 USD         |
| Total Energy Savings (Active + Passive Measures)               | 404,242.40 kWh/annum   |
| Total cost savings associated with energy savings              | 132,177.35 USD/annum   |
| Cumulative Payback                                             | 9.28 Months            |

### Table 6. Impact on CAPEX and Cost Savings

| Reduction in CAPEX associated with lower capacity HVAC systems | 60,961.30 USD          |
| Normalized reduction in CAPEX (per year)                      | 30,480.65 USD/annum    |
| Net Cost Savings                                              | 162,658.05 USD/annum   |
7. Conclusion

Upon implementation of all targeted performance improvements to the site office design, the expected annual energy consumption is 357 MWh which also translates to a 31% reduction over the existing design. The installation of rental PV systems throughout the life cycle of the site office further reduces the annual energy consumption to 188 MWh which translates to an annual EUI of 81 kWh/m².

According to the Emirates Green Building Council, which acts as the green building chapter for the United Arab Emirates and the MENA region, a building with an annual EUI of 90 kWh/m² or lower can be considered a Nearly Zero Energy Building.

The recent net / near zero buildings movement and all respective commitments focus entirely upon new or existing permanent buildings. The study clearly demonstrates that efficient design and construction of temporary buildings such as site offices can result in both monetary gains and reduced environmental impacts leading to a holistic approach towards net/near zero construction.

References

[1] Dubai Statistics Center, https://www.dsc.gov.ae/en-us/Themes/Pages/Housing-and-Building.aspx?Theme=40 – Buildings Under Construction by Type 2017 Accessed on the 30th March 2019

[2] Fayyad M, Jason J, 2017 Defining Nearly Zero Energy Buildings in the UAE – 2017