Energy Optimisation Modelling for Urban Scale Master Planning

Introduction

Gateway City is a major city development in the emirate of Ras Al Khaimah (RAK) of the United Arab Emirates (UAE). The development covers a site area of over 1,100 ha. comprising an integrated city designed to service, support and supplement the capital city of Ras Al Khaimah. Master Planning and Urban Design for this project was carried out by ACLA Ltd, part of the Hyder Consultancy group. Cardiff University was appointed to carry out an Energy Optimization Study of the master plan layout.

The aim of the study was to analyse the overall impact of building structure related energy efficiency measures and to identify potential energy savings at an early master planning stage that could feed into subsequent planning and design stages. The objectives of the study were as follows:

- To identify energy performance of base case requirements utilizing current and existing standards appropriate for RAK and the UAE.
- To develop options for optimizing energy performance and to identify variations due to orientation, over-shadowing, and buildings of different height, internal gains and construction type (in relation to thermal performance).
- To explore how this information, which is at a city scale, can be automated to provide guidance for individual plot planning.

Figure 1 Plots by building types

For the purposes of energy modelling, buildings were categorised into commercial, residential and institutional types of uses. Figure 1 presents a plan of the development identifying each plot in terms of its building type. The additional 'mixed use' category is where two or more of the categories are within one plot. The utility category has not been included in the analysis at this stage.

Methodology

The data used in this study was derived from the Gateway City Detailed Master Plan Plot Schedule, as supplied by Hyder-ACLA Ltd (HK). This comprehensive source provided the following data per plot, from which cooling loads were modelled: plot number; land area; (m2); land use; building height (max. number of storeys); building heights for each plot; gross floor area by type of building; car parking area.

The impacts of different building height, orientation, over-shadowing, fabric, and levels of power usage on cooling load were examined. To predict the cooling load and thermal performance of a building the thermal and energy computer simulation model HTB2 (Alexander, 1996) was used. HTB2 is a widely used and tested simulation tool, for example, it is used in the Hong Kong Environmental Assessment Method, HK-BEAM (Burnett et al., 1997). In this study HTB2 has been linked with the Energy and Environmental Prediction tool, EEP, which is an urban master-planning model (Jones et al., 2000). EEP was originally developed for predicting energy demand at an urban scale for existing buildings and has now been modified to consider new urban scale developments.

In this study it has been assumed that the building cooling loads are met by a district cooling system. A number of aspects of the impact of building variants were investigated for all the variants, comprising: 8 orientations, 3 over-shadowing variants open normal and dense, 2 occupancy and internal gain patterns for each of commercial, residential and institutional, 5 fabric specifications from standard to low energy, and10 building heights from single storey to 19 storeys. The various combinations of these variations resulted in 7,200 simulation runs, each for a full year at a 20 second time step.

Results & Discussion

This study has identified the potential for energy savings at an early master planning stage. The following factors were considered in relation to the cooling load, with information on the variations presented in tables 1 to 3:

- Building orientation (façade facing 8 different directions);
- Over-shadowing by neighbouring buildings (Table 1);
- Construction performance in relation to levels of thermal insulation and glazing type (Table 2); and
- Internal heat gains from lighting, small power, etc (Table 3).

The first two factors relate to the performance of the building in relation to its position within a plot, that is, which direction a facade faces and its closeness to adjacent buildings. The last two factors are building specific and are not affected by location within the plot.

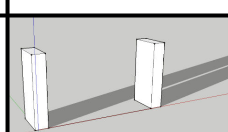
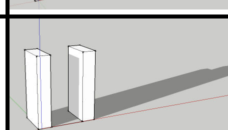
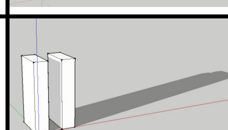
Table 1 Over-shadowing	**Visual representation**	**Variant**
Open 18 storey (54m) obstruction 100m away		**1**
Normal 18 storey (54m) obstruction 40m away		**2**
Dense 18 storey (54m) obstruction 20m away		**3**

Table 2 Construction Type	Fabric values	Variant
Standard Walls Glazing Solar heat gain coefficient	0.4 W/m2.K Double glazing (SHGC) 0.23	1
Standard with enhanced fabric Walls Glazing Solar heat gain coefficient	0.2 W/m2.K Double glazing (SHGC) 0.23	2
Standard with triple glazing Walls Glazing Solar heat gain coefficient	0.4 W/m2.K Triple glazing (SHGC) 0.23	3
Standard with Solar control Walls Glazing Solar heat gain coefficient	0.4 W/m2.K Double glazing (SHGC) 0.15	4
Low energy Walls Glazing Solar heat gain coefficient	0.2 W/m2.K Triple glazing (SHGC) 0.15	5

Table 3 Building type	Heat gains Low / High	Occupancy	Variant
Residential Low power usage	20 / 50W/m^2	00:00 – 09:00 & 17:00 - 24:00 Mon to Fri 00:00 – 24:00 Sat to Sun	**1 / 4**
Commercial Low power usage	30 / 50 W/m^2	07:00 - 18:00 Mon to Sat	**2 / 5**
Institutional Low power usage	25 / 50 W/m^2	07:00 - 18:00 Mon to Fri	**3 / 6**

Results for the potential range of cooling load reductions are summarised in the radar plots in Figures 2 to 4 for residential, commercial and institutional buildings respectively. They indicate the range of savings in relation to individual façade performance, taking account of overshadowing and orientation. The largest potential energy savings are from reducing internal gains, which includes, for example, the reduction in power used for lighting as well as the cooling load associated with lighting heat gains. The other potential savings for orientation, overshadowing and construction type are of the order of 20% on a façade based performance approach. Of course when combinations of energy saving measures are considered the savings will not be additive.

Results for variations in building height, orientation

The cooling load was calculated for each of the eight orientations for a 19 storey sample building, showing variation of cooling load with storey height and orientation. Example results are displayed in figure 5 for a residential building in the form of a radar plot for minimum over-shadowing by adjacent buildings (variant 3). It shows that changes in façade orientation can give rise to increases in cooling load of typically up to 20 to 23% with southwest facing facades having the largest cooling load and north facing facades the lowest. This indicates that where possible the main glazed facades of buildings should be oriented to face north (or north east, north west).

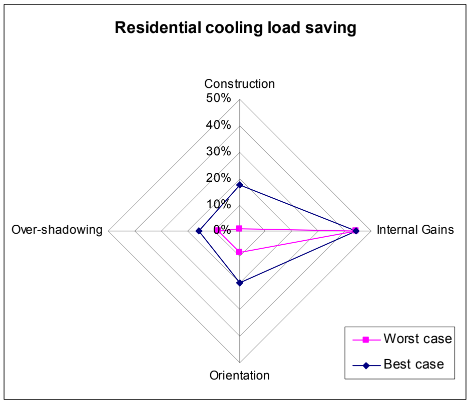


Figure 2 Residential cooling load savings

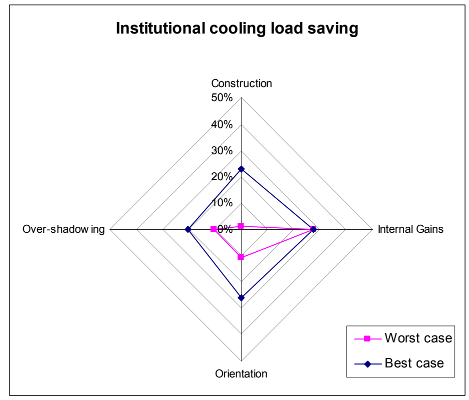


Figure 3 Institutional cooling load savings

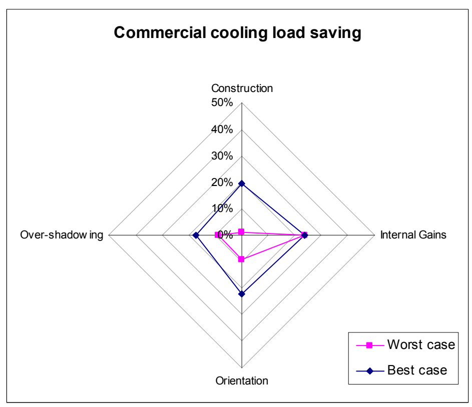


Figure 4 Commercial cooling load savings

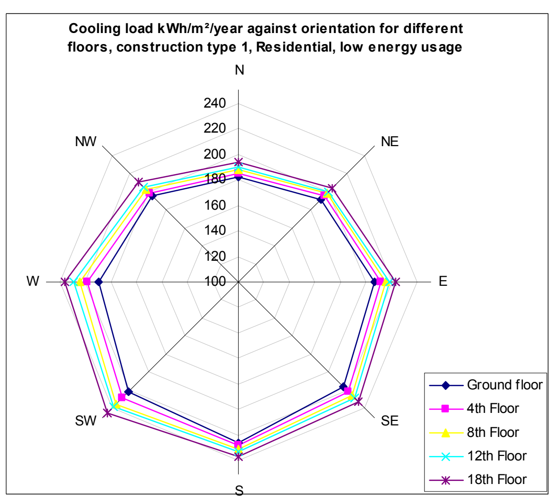


Figure 5 Residential building cooling load (kWh/m²/year) against storey

Results for variations in over-shadowing and orientation

Figure 6 presents the results for a residential building for variations in orientation and overshadowing (construction variant 1 and internal gains variant 1). The difference between the overshadowing variants varies according to orientation. Overshadowing of buildings by adjacent buildings can reduce cooling loads by up to 15 to 17% for southwest facing buildings and typically 5 to 8% for north facing facades. It is therefore recommended that where possible buildings are situated close to each other to provide shading of the facades.

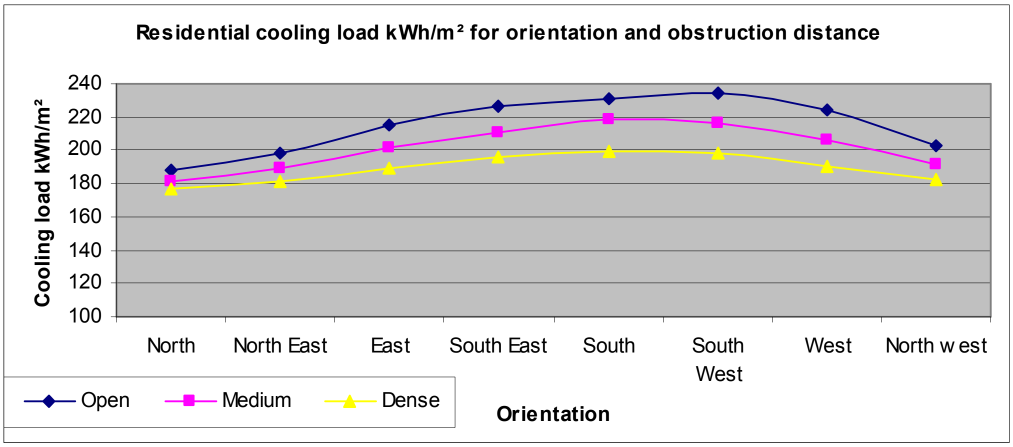


Figure 6 Cooling load versus orientation for different variants in over-shadowing

Results for different levels of internal gains and construction type

Reducing the internal power load from 50 W/m2 (high gains) to 20 to 30W/m2 (low gain) was shown to reduce cooling load by 46%, 26% and 30% for residential, commercial and institutional buildings respectively. The application of energy saving measures to the building fabric can reduce annual cooling loads by 7% to 14%,, 12% to 16% and 13% to 20% for residential, commercial and institutional buildings respectively for high to low internal power gains (Figure 7 shows results for low internal power gains). The combination of low internal power gains and energy saving fabric measures can reduce cooling loads by between 38 to 54%. In addition to the reduced cooling load, the reduction in internal power gains will also lead to considerable power savings due to the reduced direct power used by lighting, etc.

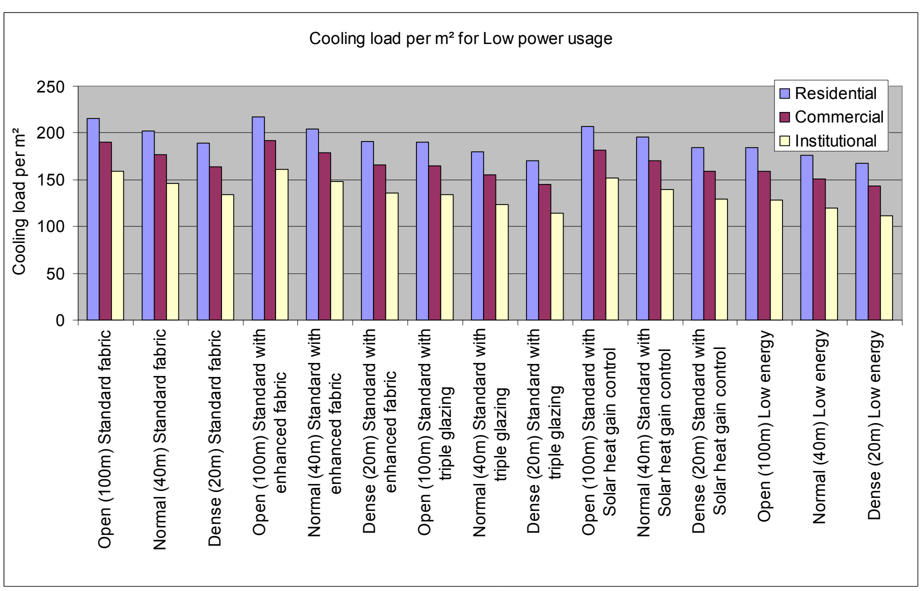


Figure 7 Cooling load per m^2 for High power usage

Summary of cooling load reductions
The potential cooling load reductions are summarised in Figure 8. They show the potential reductions for the factors considered, that is, building orientation, over-shadowing, construction thermal performance and internal load heat gains. The orientation and overshadowing are related to individual façade performance, so a whole building performance will need to take account of all facades. The building designs will include combinations of these four factors. However it should be noted that they are not additive and final cooling loads will be less than the sum of the individual potential load savings.

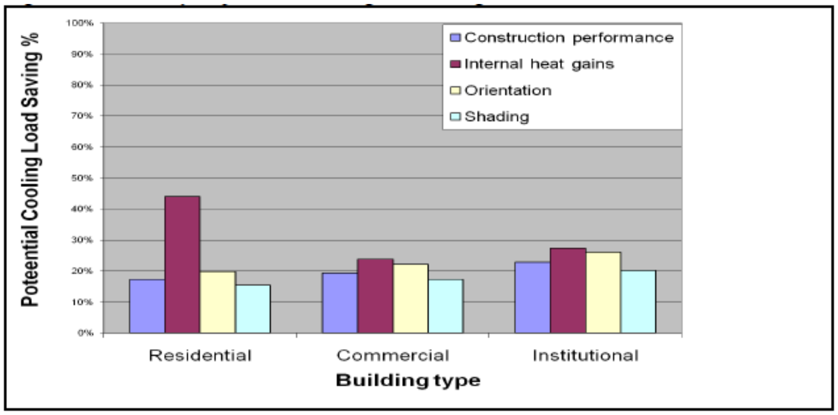


Figure 8 Summary of potential cooling load savings

Plot Development Controls
The analysis described above provides general early master-planning design guidelines for reducing energy demand and estimating the overall carbon footprint of the development. Following this, specific guidance for individual plots can be produced during the concept design stage using the same modelling techniques.

The aim of this plot guidance is to provide a simple procedure to reduce the cooling load of individual buildings on a plot in the master plan. Exploratory work was carried out based upon a typical plot map (Figure 9). The impact of a specific building design, for example, the red building in figure 9a on cooling load has been predicted for variations in orientation and overshadowing as indicated in figure 9b. . Figure 9b shows the relative building height, where h is the height of the chosen (red building) and the distance between the buildings is shown in metres. Where the building is marked “0h” this is direction is treated as 100m overshadowing or ‘nearly unobstructed’.

(a) *(b)*

Figure 9 3D view and plan of example plot

The procedure created is based around a cooling load radar diagram. For example Figure 10 shows results for the residential buildings. The radar plot is cooling load (kWh/year/m²) for each façade. The building lies on a north-east south-west axis and the circles represent the façade performance for the four facades of the building. The façade length to perimeter ratio is then used for each façade to produce a cooling load for the building in this case it is the average of the four values 185 kWh/year/m^2 of façade area.

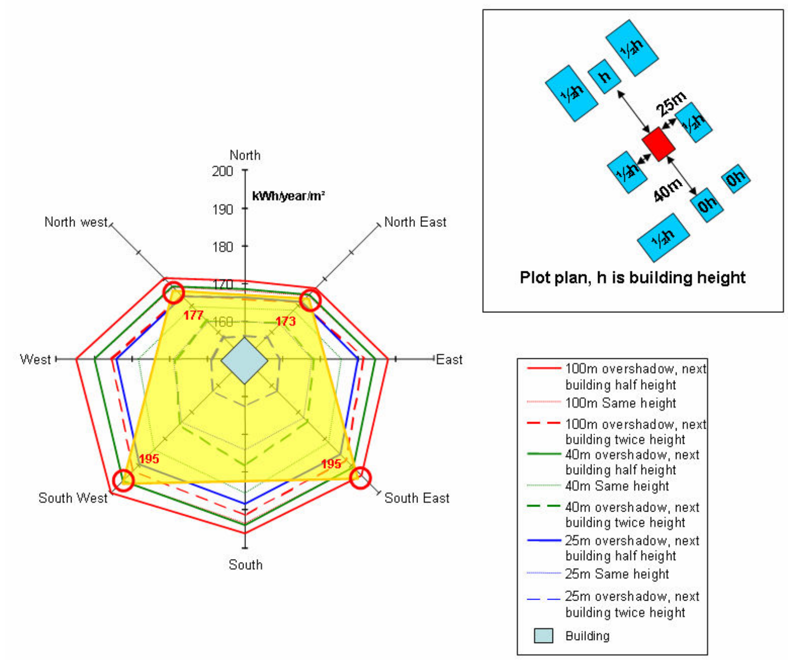


Figure 10 Example plot radar diagram cooling load in kWh/year/m^2

Conclusions

Energy optimisation modelling can provide considerable energy savings if applied at an early master planning stage.

The largest potential energy savings are from reducing internal gains, which includes, for example, the reduction in power used for lighting as well as the cooling load associated with lighting heat gains. The combination of low internal power gains and energy saving fabric measures can reduce cooling loads by between 38 to 54%.

The other potential savings for orientation, overshadowing and construction type are of the order of 20% on a façade based performance approach. However when averaging across all facades the total savings will be less.

It is recommended that all factors are considered at early stage master planning and that they are included in the brief for developers to incorporate in their designs. As the project advances it is recommended that more detailed predictions be carried out to expand the design guidelines for developers

References

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Burnett J, Jones P J and Yik F W H (1997) HTB2/Becon: A Building Energy Prediction Model for Air-Conditioned Commercial Buildings, Proceedings of Air Conditioning in High Rise Buildings 97, Volume I, Tongi University Press, Shanghai
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