# The impact of building envelope design on thermal performance of office buildings in Egypt

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ABSTRACT

This paper introduces research being carried out to support effective energy efficient design in Egypt. It is based on deriving results of multiple parametric simulations of energy performance of office buildings in Cairo and Alexandria. This is used to examine how to optimise potential by reference to peak summer and winter loads. The outputs will later be used to inform the development of a decision support tool based on graphical interpretation.

## 1. BACKGROUND

Egyptian architecture has had a long history of beneficial interaction with its environmental context, including climatic factors. However a gradual westernisation of its features and appearance has been occurring since the 19th century reflecting trends in many other aspects of the country. This has been more evident in recent decades (Salama, 1999), particularly in office buildings. The main evidence of the process is firstly the envelope treatment which has tended to incorporate modern imported materials, mostly glass in large areas; and secondly is the inevitable consequence of the increased reliance on mechanical/artificial means to provide comfort. This has resulted in the major contribution of the building sector (over 40%) to the country's energy consumption (EEHC, 2006), yet the trend continues.

## 2. BUILDING DESIGN PROBLEMS

### *2.1 Problem Definition*

There is an abundance of literature that provides guidelines for the design of buildings and their envelopes to achieve comfort in hot climates; however the impact in local Egyptian practice seems rather insignificant. This could be due to the nature of most of these guidelines, which may make it difficult to see quickly how to reduce energy consumption or achieve related cost efficiencies.

A survey of building design professionals carried out by the authors has already indicated some of the areas in which more support for design choices is required. The apparent lack of quantitative studies addressing the appraisal of current local architectural practice in Egypt in terms of energy consumption for office buildings should therefore be addressed. The potential to moderate negative impacts by either using alternative glass types or improving the thermal insulation properties of opaque elements requires better exploitation. In addition, the significance of orientation and shading seems not to be understood despite their generally positive impacts in hot climates.

### *2.2 Study aim*

This study aims to examine three envelope design issues:
- The common local practice of using highly glazed envelopes.
- Impacts of different envelope measures such as variation of glazing type and insulation (which is claimed by local practitioners to balance glazing area).
- Effect of orientation and shading parameters; whether by external shade or by overshadowing protection.

The main investigation relates the factors above to glazing area (represented as the window-wall ratio or 'wwr') so as to understand the significance of the parameters' impacts, both combined with, and compared to, the increase of envelope glazing area.

The main output criteria from the simulations are the calculated loads for cooling, heating (and the sum of both) for typical days which represent peak summer and peak winter conditions. It is intended that the outputs from the studies might be used to produce a form of graphical decision support tool. This has been inspired as a development from some of the techniques used for European situations such as the LT Method (Baker and Steemers, 2000); but here to produce a tool suited to local practice.

### *2.3 Study Methodology*

The main method of investigation is a software thermal simulation tool. It uses a dynamic calculation method basis and includes detailed assessment of solar radiation on building surfaces particularly for window areas (LIT, 1999). The investigation compares a base case with a parametric study. The investigation has thus far been used to establish performance at extremes of the climatic spectrum to predict the peak demand for cooling and heating loads and produces hourly values for temperatures, loads and solar intensities. It is based on inputs from OEP (1998), ASHRAE (2005) and Rennie and Parand (1998)

*2.4 Study scope and assumptions*

The climatic context of this study is the two main Egyptian cities of Cairo and Alexandria where office buildings, particularly those with the described features, are mostly located.

The base case of the study represents local typical office spaces, marginally modified to allow investigation all of the above mentioned parameters. The focus is on the external façade and the enclosing internal surfaces of the space are considered thermally isolated adiabatic elements through which no thermal exchange occurs. Working hours and internal loads are proposed according to typical office spaces. The base case spaces are shown in Figure 1 and Table 1 describes its main features. The parameters and options are shown in Table 2.

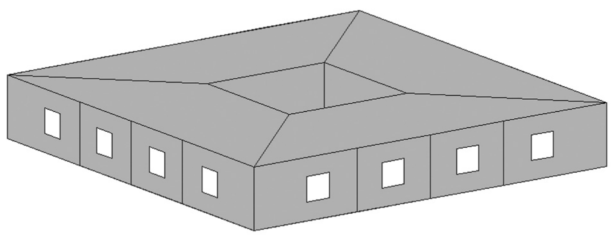

Figure 1: Simplified base case office space

Table 1: The base case description

| Base case | Description/ Values |
|---|---|
| Open office Space | 200 $m^2$ (façade: 30m x 3m) |
| Climatic contexts | Cairo |
| Envelope | |
| Glazing ratio | 10% |
| Glazing type | Single clear |
| Opaque U-value | 1.67 W/C$^o$.m$^2$ (0.25 m hollow clay brick) |
| Orientations | 4: main four orientations |
| Shade | (none) |
| Overshadowing by neighbouring buildings | (none; free standing building) |
| Internal Loads | 30 W/$m^2$ (working hours 09-17) |
| tion RateInfitra | 0.4 ach |

Table 2: The range of parameters investigated

| Investigated Parameters | no | Values/ options |
|---|---|---|
| Climatic context | 2 | Cairo, Alexandria |
| Envelope | | |
| Glazing ratio | 5 | 10%, 20%, 40%, 60%, 80% |
| Glazing type | 4 | Double clear; Reflective –Heat Absorbing; Double Low-solar e +clear |
| Opaque U-value | 2 | 1.3 W/C$^o$.m$^2$ ; 0.49 W/C$^o$.m$^2$ |
| Orientations | 4 | SE; SW; NE; NW |
| Shade | 1 | Overhang over windows, with 0.25 PF (protection factor) |
| Overshadowing by neighbouring buildings | 3 | Next building: Placed at 3m, same height Placed at 3m, 6m higher Placed at 6m, 6m higher |

A total of 140 simulations have been carried out to assess the impacts of different wwr (glazing ratios) and their interaction with other envelope parameters.

## 3. RESULTS

The loads for each case determined from the thermal simulations have been compiled and represented in graphs to visualize the impacts. Each graph represents the relation of applying each parameter against different values of wwr.

*3.1 Glazing Ratios*

Figure 2 shows the impact on heating and cooling loads of the increase of wwr. This seems to be particularly evident in the cooling requirements for east and west facing facades indicating their higher sensitivity to amount of glazing. The southern orientation requires similar cooling to the northern orientation.

The heating load generally decreases with increasing wwr, except for the northern orientation where it increases. For the southern orientation, the heating load decreases with the increase of wwr to reach zero at 40% wwr and beyond. In western and eastern orientations, heating loads increase with wwr up to about 40% after which the relation is relatively static.

Figure 3 shows the Alexandria climatic context results where heating loads are higher, cooling loads are lower.

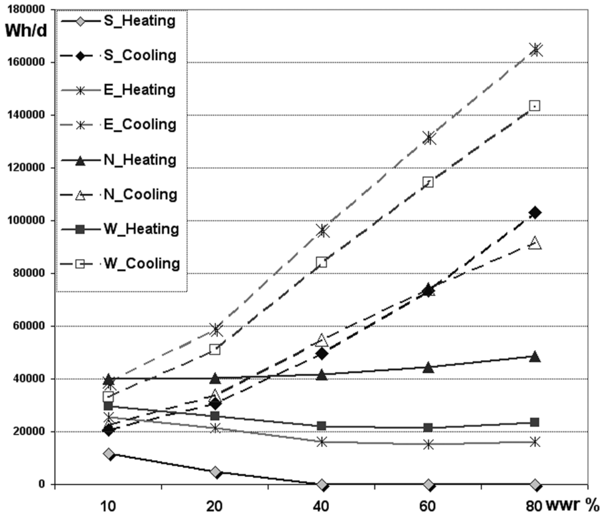


Figure 2: Cooling and heating loads for different wwr for main orientations in Cairo

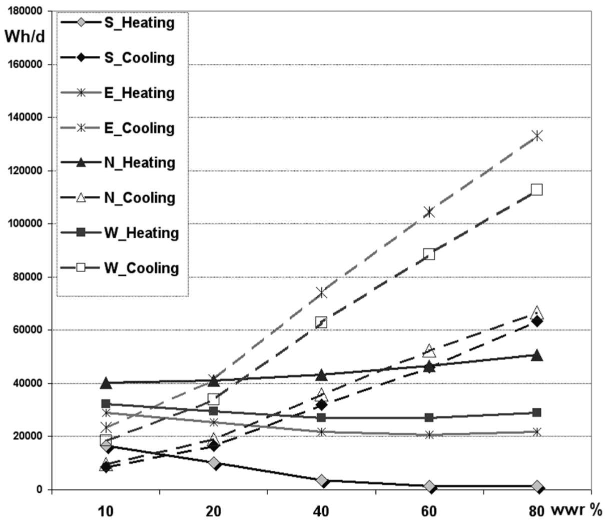


Figure 3: Cooling and heating loads for different wwr for main orientations in Alexandria

*3.2 Glazing Types*

The study investigated four glazing types for windows in addition to the single clear glass of the base case. These were: double clear glazing (which provides considerably better insulation value); reflective single glazing; heat absorbing single glazing; and double Low-solar e + clear glazing (which is more selective to solar radiation spectrum).

Single clear glazing produces the highest cooling loads for all orientations and represents the worst option of all studied types. The high solar gain combined with poor insulation is the problem.

Double clear glazing results in similar cooling loads and patterns to single clear glazing; it even causes slightly higher cooling loads for wwr higher than 60% in northern, eastern and western orientations, and 20% in southern orientation. This occurs because of the increased insulation effect that retains solar gain in the building. It results in lowest heating loads which decrease with increased wwr (contrary to most other types). Due to its varying operation the results do not lead to clear conclusions for all facades and this glazing type should be used with some care.

Reflective single glazing results in the lowest cooling loads but highest heating loads for all orientations with all wwr values.

Heat absorbing (tinted) single glazing represents a poor option (causing second highest loads for cooling and heating).

Low-e + clear double glazing represents the second best option individually for both heating and cooling. Overall for all orientations and all wwr values it represents the best option.

Figure 4 shows results for the western facing orientation (generally the worst case in the simulations). 'S' represents single glazing; 'D' - double clear; 'Abs' - heat absorbing; 'Ref' - heat reflecting; and Low-e the double with one low e pane.

Here all the five glazing types cause cooling loads to increase proportionally with wwr; the increase varies with glass type (the highest caused by single and double clear glazing), followed by heat absorbing glass, low-e double glazing and then reflective glazing.

For heating loads the western orientation shows different relationships. Reflective glazing results in the highest loads which increase most rapidly with wwr; heat absorbing glazing causes heating loads to increase less steeply with wwr for most orientations. The other three types cause heating loads to decrease with wwr increase for all orientations but north where this is true only for the double glazing types (both clear and low-e).

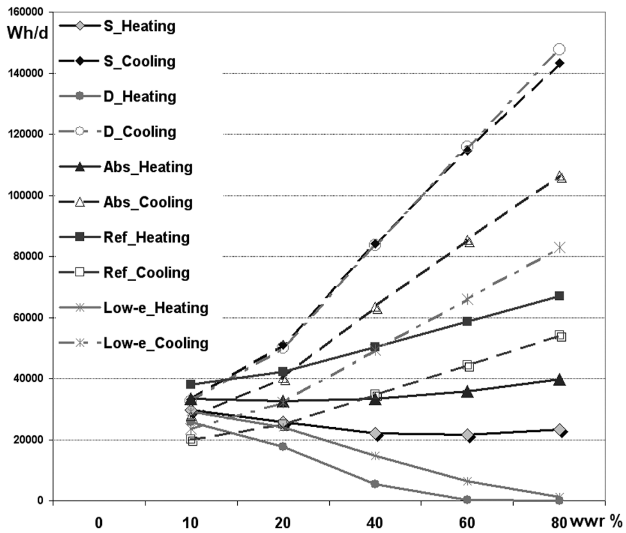


Figure 4: Cooling and heating loads for different wwr, using different glazing types for western orientation in Cairo

The Alexandria climatic context results in similar patterns although generally of less required cooling loads and relatively higher required heating loads compared to Cairo. The impact of these results is that it could be difficult to recommend particular combinations of glazing that will produce optimum results in all situations. Orientation, glazing type and wwr all play a part. This would indicate a need for a more sophisticated decision aid for design.

*3.3 Opaque area insulation*

The first investigation is for the Cairo climate, where improving insulation of opaque wall elements either by the use of a cavity wall (with a 5cm thickness air space), or by using polystyrene filled cavity. Results indicate that it only a modest reduction in cooling loads for wwr up to 20% in western and eastern orientations occurs, but with increases of cooling load for northern and southern orientations. Figure 5 shows a set of results for western orientation of the façade. To give some idea of combine heating and cooling impacts the sum of the two is also shown. (Identifiers on the chart are: B C - basic case; 12-5Air-12 - air cavity; 12-5Poly-12 - insulation filled cavity; H - heating; C - Cooling; Sum - sum of heating and cooling). A similar pattern of results was found for the Alexandria climate.

Figure 5: Cooling heating and total loads for different wwr, using modified opaque element insulation for western orientation in Cairo

*3.4 Orientation*

In both Cairo and Alexandria, all orientations have similar cooling load patterns increasing with wwr. The loads increase in the following order: southern, northern, south western/ south eastern, north western/ north eastern, eastern and western orientations respectively. Southern orientations (southern and south eastern/ south western) also have lowest heating loads while northern orientations (northern and north eastern/ north western) have the highest heating loads which, contrary to other orientations, increase with the wwr.

In order to try to visualise the combined performance heating and cooling totals have been summed and used with a novel chart shown in Figure 6. This would seem to indicate that the southern orientation is the best, and north western/ north eastern orientations the worst.

The results also indicate that for all orientations the rate of cooling demand change with wwr is higher than this for heating demand, thus at low wwr, cooling requirements are more similar for all orientations than heating requirements.

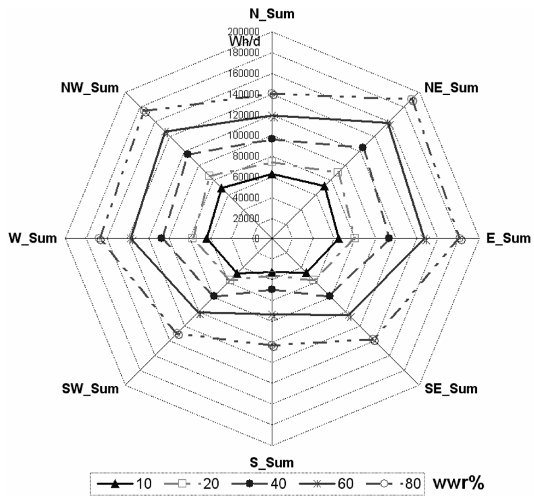


Figure 6: Combined heating and cooling loads required for different wwr, in different orientation in Cairo

*3.5 Shading*

As expected, in both Cairo and Alexandria climates, the use of an overhang with projection profile of 1:4 reduces required cooling needs but also increases required heating loads, but seems in overall terms to be beneficial. This impact is more significant with higher wwr and is also more evident in southern, eastern/western orientations (figure 7) but less in northern orientations.

*3.6 Overshadowing by neighbouring building*

In both Cairo and Alexandria climatic contexts, the higher and the closer the nearby buildings, the more overshadowing they provide which generally reduces cooling demand to a greater extent than the increase of heating demand. This applies for all orientations except southern (where increased overshadowing reduces solar gain and increases heating demand).

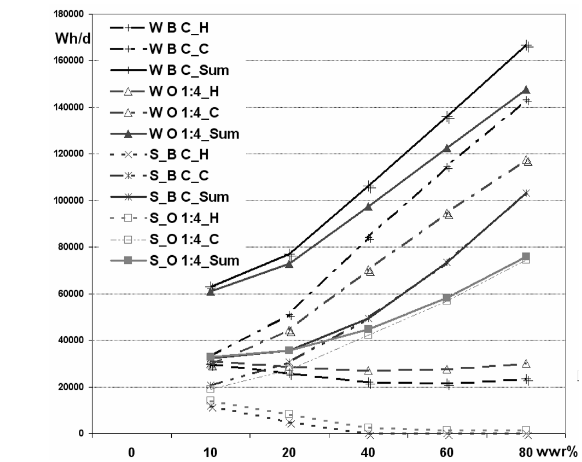


Figure 7: Required loads for different wwr, in western (W) and southern (S) orientations; with and without overhangs (O 1:4) in Cairo

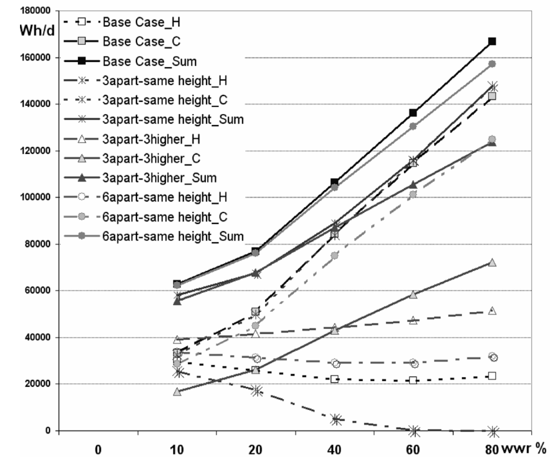


Figure 8: Required loads for different wwr, for western orientation with overshading from nearby buildings in Cairo

## 4. CONCLUSIONS

The study shows the following:

The glazing ratio, expressed as wwr, proved to be a crucial factor in most calculations of cooling load for office and for most orientations. The impact on heating loads is felt most by northern orientations. The change in loads can be from two- to three-fold the amount when moving from 10% to 80% wwr depending on the orientation. Use of different glass types can help moderate the impacts of increased wwr; for instance reflective glazing considerably reduces loads (80% wwr reflective glazing requires cooling loads that are only slightly higher than required by 20% wwr of single glazing for western orientation). Other glazing types can also offer reductions: 80% wwr for low-e double glazing is equivalent to 40% wwr of single glazing while 80% wwr of heat absorbing glazing is equivalent to less than 60% wwr of single glazing for western orientations in Cairo. The results also indicate that glazing type is more crucial for higher wwr.

Improving insulation properties of the opaque parts of a building does not seem to reduce cooling loads but does reduce heating loads particularly with low wwr values; however the reduction is insignificant for high wwr values.

Orientation proved to be a crucial factor for all wwr values for heating loads, while for cooling loads it is less significant (particularly with low wwr values.

Shading proved its value as an important measure for use with highly glazed envelopes; using a 1:4 projected overhang reduced cooling loads particularly for high wwr.

The climatic impact of nearby buildings proved to be beneficial in reducing cooling loads, increasingly with increased wwr, for all orientations reducing the differences between orientations in low wwr values. The southern orientation is an exception as increased overshadowing (by a 3m higher, 3m distant building) deprives the envelope of desired solar exposure resulting in greatly increased heating requirements and resulting in a different overall profile. Of the studied options, a 6m distant building of the same height results in the least overall loads for wwr up to 40%, higher than which, more protection by a building of the same height but closer (3m distant) provides least overall loads.

The Alexandria climatic context generally showed similar results for all parameters though requiring relatively higher heating and less cooling than the Cairo climatic context.

## 5. FUTURE DEVELOPMENTS

As stated at the outset the purpose of the overall study has not been simply to compare basic office configurations for energy performance but more importantly to derive information that can help in decision support tools for the Egyptian building designer.

Currently under development are graphical interpretations of year-round performance for the two cities of Cairo and Alexandria.

It should also be mentioned that this study focused on thermal performance of the office space, an important but individual component of the overall environmental design. An inevitable related aspect is the visual environment which depends on the envelope configuration, thus an integrated study of visual performance is now required, and is being carried out by the authors of this study.

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