SIMULATION-BASED ASSESSMENT OF ENERGY AND ENVIRONMENTAL PERFORMANCE OF OFFICE BUILDINGS IN LEBANON

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ABSTRACT

This paper explores the implications of alternative design options for the thermal performance of office buildings in Beirut and Tripoli, Lebanon. Five typical office buildings were selected for the investigation. Multiple design alternatives were considered involving various lighting, glazing and shading types, shading schedules, thermal insulation options, and ventilation scenarios. A numeric thermal simulation application was used to model the performance of these alternatives parametrically. Simulation results were expressed in terms of annual sensible and latent cooling loads, annual heating loads, and overheating (passive building operation scenario). The results show the significant degree to which design measures could reduce the energy demand of (and overheating tendencies in) office buildings in Lebanon.

INTRODUCTION

Given the Mediterranean climatic characteristics of Lebanon (see Figure 1), energy requirements for Heating and cooling of office buildings represent a growing burden for both the environment and the economy. The efforts to reduce the energy requirements of buildings are highly important, as Lebanon has little fossil fuel resources. Thus, the bulk of needed energy must be imported. However, current practices in building design and construction are not particularly geared towards higher energy efficiency. Traditional regionally-adapted building methods have been mostly abandoned in favor of contextually problematic building construction styles and the increased use of energy-intensive air-conditioning technologies. Moreover, the building design process is not sufficiently informed via the use of advanced performance-based design methods and tools.

In this context, the present contribution explores the implications of various alternative design options in view of the thermal performance (cooling requirements, overheating tendencies) of office buildings in Beirut and Tripoli. Five typical offices that are representative of the majority of existing office buildings in Lebanon were selected for the investigation (B1 to B5). Multiple design alternatives were considered involving various lighting, glazing, and shading types, shading schedules, insulation options, as well as different thermal mass and ventilation scenarios.

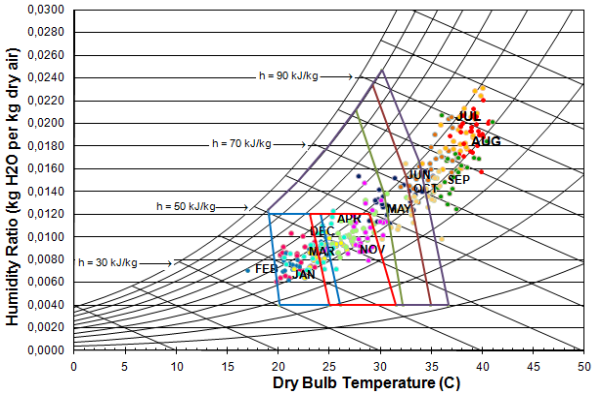

Figure 1 mean hourly outdoor temperature and relative humidity values in Beirut for a representative day in each month of the year (based on data generated via Meteotest 2008)

APPROACH

Parametric simulation was selected as a means of comparing the thermal performance of a number of building design options. Based on a preliminary study of typical (contemporary) office floors in Beirut and Tripoli, five floor plans were selected, as illustrated in Figure 2.

The U-value assumptions for the external walls (base case) are summarized in Table 1. The glazing properties (base case) are summarized in Table 2. The total internal gains for people, lights, and equipment were assumed to be 5 $W.m^{-2}$ during the unoccupied hours. Total people and equipment load was considered to be 32 $W.m^{-2}$ during the occupied hours (see Table 3). The thermostat settings for heating and cooling load computations are shown in Table 4.

Table 1
External Wall U-values (base case scenario)

Building	U-value ($W \cdot m^{-2} \cdot K^{-1}$)
B1	1.6
B2	3.2
B3	1.9
B4	2.1
B5	2.1

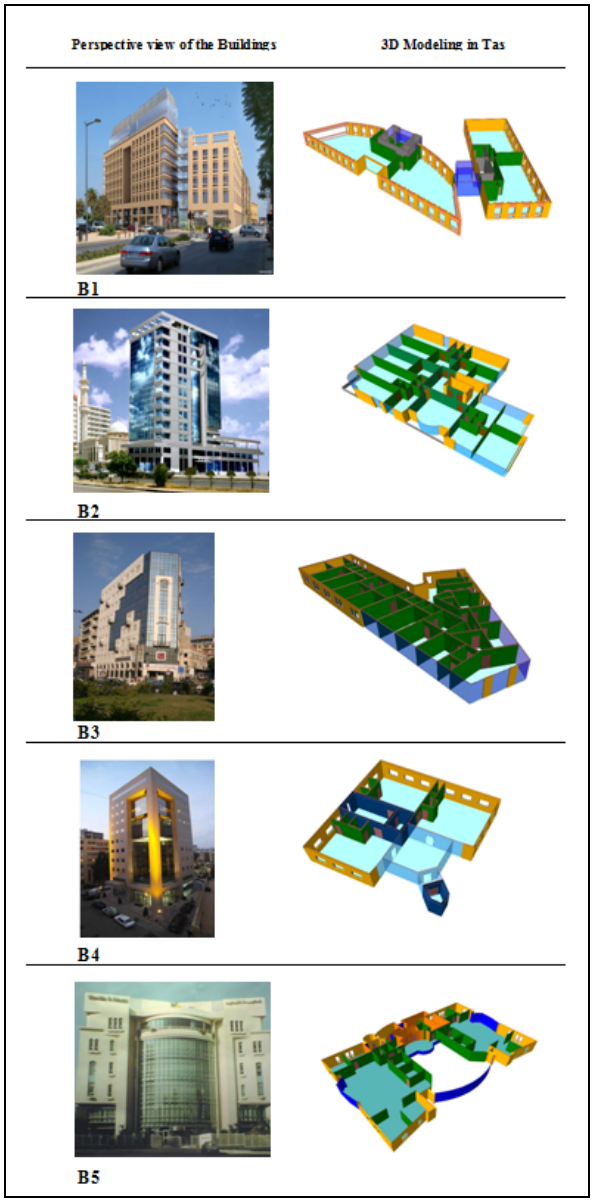

Figure 2 Buildings' external and 3D floor models in the simulation application

Table 2
Glazing U and g values (base case scenario)

Buildings	Glazing	U-value [$W \cdot m^{-2} \cdot K^{-1}$]	g-value
B1	Gb1,1	2,8	0,59
	Gb1,2	5,3	0,71
	Gb1,3	2,7	0,57
B2	Gb2	5,7	0,42
B3	Gb3	5,7	0,36
B4	Gb4,1	3,3	0,15
	Gb4,2	5,4	0,28
	Gb4,3	5,7	0,28
B5	Gb5	2,8	0,36

Table 3
Simulation assumptions(ventilation, internal gains) for the base case scenario

Parameter	Occupied	Non-occupied
Infiltration (h^{-1})	0.2	0.2
Ventilation (h^{-1})	1	0
Lighting Gain ($W.m^{-2}$)	10	2
Occupancy (sensible) ($W.m^{-2}$)	7	0
Occupancy (latent) ($W.m^{-2}$)	5	0
Equipment (sensible) ($W.m^{-2}$)	10	3
Equipment (latent) ($W.m^{-2}$)	0	0

Table 4
Assumed control settings for indoor air temperature and relative humidity (base case scenario)

Parameter	Occupied	Non-occupied
Temperature [°C]	21 – 25	16 – 30
Humidity [%]	30 – 70	0 – 100

The objective was to identify those building design and operation alternatives that would reduce the cooling requirements and overheating tendencies of office buildings in the climatic context of Beirut and Tripoli. The selected options are described below. In all scenarios, the office working hours were assumed to be from 8:00 to 17:00 (Monday through Thursday and Saturday) and 8:00 to 11:00 (Friday).

Three lighting gains scenarios were considered for parametric simulations (see Table 5): L1 represent the base case, L2 denotes energy efficient lighting, and L3 is similar to energy efficient lighting scenario (L2) but involves daylight usage when shades are not deployed.

As far as the external insulation level of the opaque part of the buildings' envelope is concerned, two options were considered, namely the existing conditions (Ib: no insulation) and the option involving the addition of 7 cm polystyrene (I7).

As to thermal mass considerations, two conditions were considered. The existing condition (base case: Mb) involves the use of carpet as floor finish. To consider an option with increased thermal mass, simulations were performed also under the assumption that carpets are removed (Mnc).

Table 5
Overview of the lighting gains options [W.m^{-2}]

Option	Occupied	Non-occupied
L1	10	2
L2	5	2
L3	2	2

Four ventilation (air exchange) schemes were considered (see Table 6). Note that ventilation schemes V2 to V4 considered increased night-time ventilation via operable windows.

Table 6
Overview of the ventilation schemes

		Air change rate (h^{-1})	
Option	**Period**	**Occupied**	**Non-occupied**
V1	Summer	1	0
	Winter	1	0
V2	Summer	1	3
	Winter	1	0
V3	Summer	2	5
	Winter	1	0
V4	Summer	1	10
	Winter	1	0

Four shading options were considered (see Table 7). The fix shades involved overhangs and fins designed according to sun path diagram. The moveable blinds (Si, Se) were operated according to the schedule depicted in Table 8.

Table 7
Overview of the shading options

Option	Description
S_0	No shading
S_i	Internal blinds
S_e	External blinds
S_f	Fix shades (overhangs, fins)

Table 8
Blinds operation schedule

Orientation	Blinds deployment hours
North-East	5:00- 10:00
East	5:00- 11:00
South-East	7:00- 13:00
South	9:00- 15:00
South-West	11:00- 17:00
West	13:00- 19:00
North-West	15:00- 19:00

Two glazing options (G0.22 and G0.14) were considered for parametric studies (see Table 9).

Table 9
Overview of the glazing options

	U-value [W·m^{-2}·K^{-1}]	g-value
$G_{0.22}$	1.7	0.22
$G_{0.14}$	2.35	0.14

An overview of all simulated scenarios is provided in Table 10.

Table 10
Overview of the simulation scenarios

Scenarios	Shadings	Ventilations	Lightings	Insulations	Reduced Mass	Glazing
1	S0	V1	L1	Ib	Mb	Gb
2	S0	V1	L2	Ib	Mb	Gb
3	S0	V2	L1	Ib	Mb	Gb
4	S0	V3	L1	Ib	Mb	Gb
5	Si,a	V1	L1	Ib	Mb	Gb
6	Se,a	V1	L1	Ib	Mb	Gb
7	Sf	V1	L1	Ib	Mb	Gb
8	S0	V1	L1	I7	Mb	Gb
9	S0	V1	L1	Ib	Mc	Gb
10	S0	V1	L1	Ib	Mb	$G_{0.22}$
11	S0	V1	L1	Ib	Mb	$G_{0.14}$
12	S0	V3	L1	I7	Mb	Gb
13	S0	V3	L1	Ib	Mc	Gb
14	Si,a	V1	L1	Ib	Mb	Gb
15	Se,a	V1	L3	Ib	Mb	Gb
16	Se,a	V2	L3	Ib	Mb	Gb
17	Se,a	V3	L3	Ib	Mb	Gb
18	Se,a	V4	L3	Ib	Mb	Gb

Simulations were performed using the numeric thermal simulation application EDSL [1]. The input information concerning Beirut's and Tripoli's climate was generated using METEOTEST [2]. Two kinds of simulations were performed: i) Simulation of cooling loads (active building operation assumption), ii) Mean overheating (free-running building operation assumption). The thermostat settings (for the calculation of sensible cooling loads) were assumed to be 21 to 25 °C (occupied hours) and 16 to 30 °C (unoccupied hours), the humidty control settings settings (for the calculation of latent cooling loads) were assumed to be 30 to 70% (occupied hours) and 0 to 100% (unoccupied hours) (see Table 11).

For the computation of the mean overheating (OH_m), the following definition was used:

$$OH_m = \sum_{j=1}^{n} \frac{\theta_{i,j} - \theta_r}{n} \quad (1)$$

Here $\theta_{i,j}$ denotes the mean indoor air temperature (°C) at hour j (averaged over all simulated office zones in the floor), θ_r the reference indoor air temperature for overheating (°C), and n the total number of occupied office hours over the course of the simulation period. Note that the term $\theta_{i,j} - \theta_r$ was considered only for those hours when $\theta_{i,j} > \theta_r$.

Mean overheating (OH_m) was computed for two different sets of assumptions pertaining to the applicable values for the reference overheating temperature θ_r. The first set is based on a constant reference overheating temperature of 26°C. The second set uses the concept of Neutrality Temperature (Auliciems 1981), which is derived as a function of the mean monthly outdoor air temperature (see Table 11).

Table 11
Assumptions (Set 2) regarding reference overheating temperature θ_r (in °C).

	Beirut	Tripoli
April	25.7	25.4
May	26.7	26.5
June	27.5	27.5
July	28.5	28.5
August	28.7	28.7
September	28.4	28.2
October	27.7	27.3
November	26.4	25.8

RESULTS

Figure 3 shows the simulated annual heating load (in $kWh{\cdot}m^{-2}{\cdot}a^{-1}$) for all 5 buildings and 18 scenarios as specified in Table 10.

Figure 4 shows the simulated annual latent cooling load (in $kWh{\cdot}m^{-2}{\cdot}a^{-1}$).

Figure 5 shows the simulated annual sensible cooling load (in $kWh{\cdot}m^{-2}{\cdot}a^{-1}$). The associated simulated annual sensible cooling load ($kWh{\cdot}m^{-2}{\cdot}a^{-1}$) (in percentage of the respective base cases) are shown in Figure 6.

Figure 7 shows the same results in terms of sensible cooling load reduction (as percentage of base case) are shown in Figure 7.

Figure 8 shows Simulated Mean overheating (K) with θ_r = 26°C. The associated Mean overheating reduction (in %) is shown in Figure 9.

Figure 10 shows Simulated Mean overheating (K) for with reference overheating temperature (θ_r) assumptions as per Table 11. The associated Simulated Mean overheating reduction (in %) is shown in Figure 11.

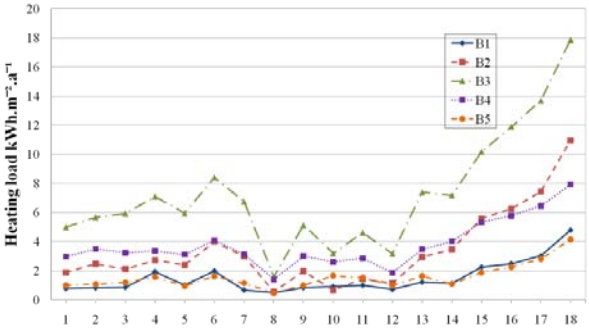

Figure 3 Simulated annual heating load ($kWh.m^{-2}.a^{-1}$)

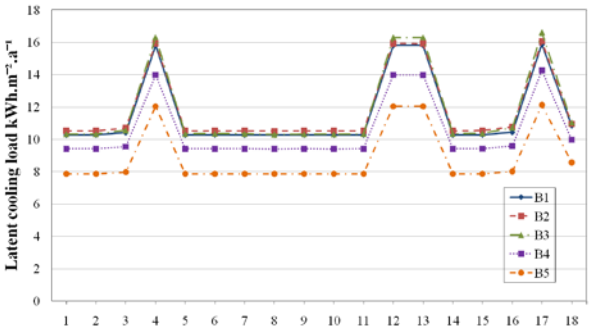

Figure 4 Simulated annual latent cooling loads ($kWh.m^{-2}.a^{-1}$)

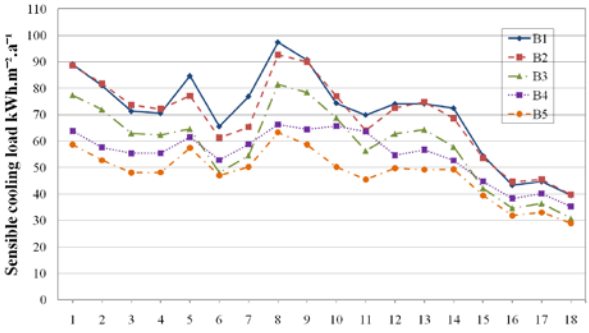

Figure 5 Simulated annual sensible cooling load ($kWh.m^{-2}.a^{-1}$)

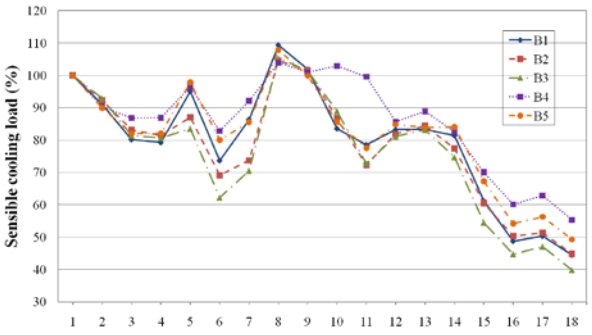

Figure 6 Simulated annual cooling sensible load (in percentage of the respective base cases)

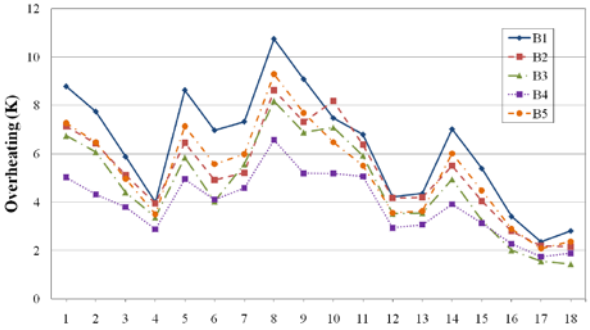

Figure 10 Simulated Mean overheating (K) (see Table 11 for assumptions regarding θ_r)

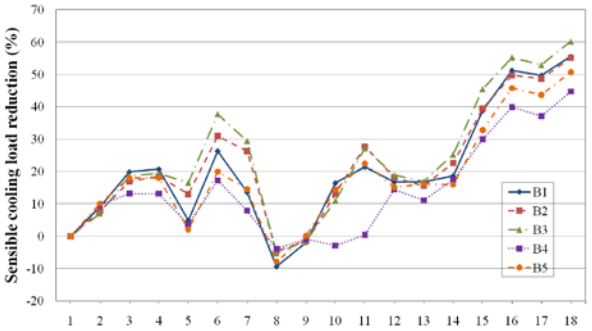

Figure 7 Sensible cooling load reduction (in percentage of the respective base cases)

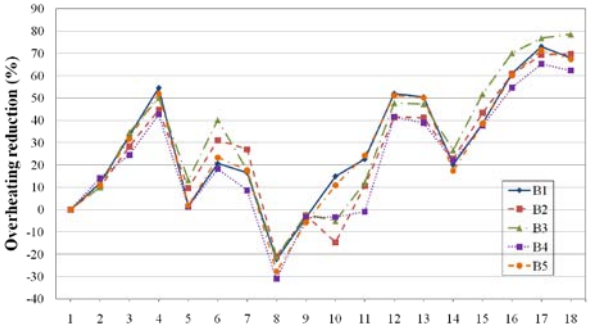

Figure 11 Simulated Mean overheating reduction (in %)(see Table 11 for assumptions regarding θ_r)

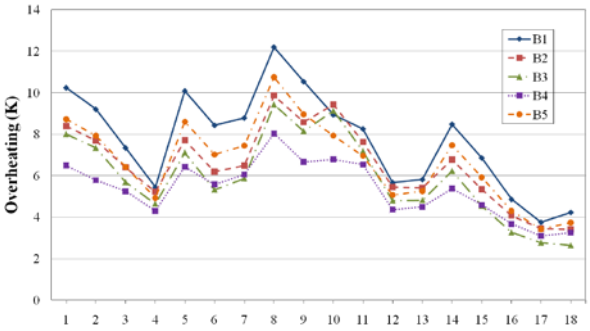

Figure 8 Simulated mean overheating (K) (θ_r=26°C)

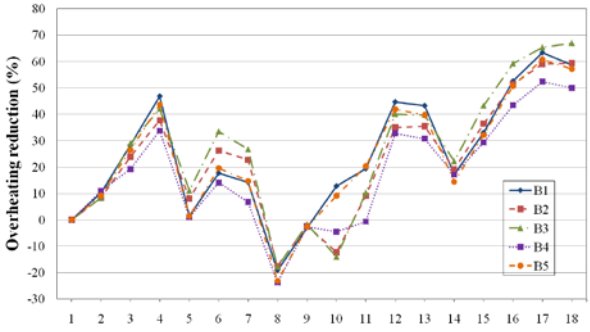

Figure 9 Simulated Mean overheating reduction (in %) for θ_r=26°C

DISCUSSION

The results of the above described parametric simulation study imply the following:

- Through a combination of building's features, the sensible cooling load reduction potential of many of the scenarios considered is significant (Figures 6 and 7). As compared to the base case, cooling load reduction can reach 45% (B4) or even 60% (B3). The comparatively better performance of B4 is mainly due to the better glazing system with low g-value. Overheating reduction is also substantial (67% in case of B3 and 52% in case of B4).
- Installation of a more efficient electrical lighting system (L2) has a positive impact in reducing the buildings' sensible cooling loads and overheating (scenario 2).
- The deployment of external shades with proper opearting schedules (designed under consideration of the applicable sun path diagram) is a key ingredient of the better performing scenarios: the top performing scenarios amongst all scenarios considered include external blinds.

- An increase in the buildings' external insulation via the addiction of 7cm polystyrene (scenario 8) did eliminate the buildings' heating loads, but led to a 10% increase in sensible cooling load. This can be explained via the heat retaining effect of better-insulated walls. Increased nighttime natural ventilation (V3) combined with external Insulation (I7), did improve the thermal performance of the buildings (scenario 12). Cooling load was reduced up to 19% and overheating up to 39%. Moreover, heating load reached a minimal value of 1 $kWh.m^{-2}.a^{-1}$.
- An increase in the buildings' thermal mass (Mnc) as simulated via the virtual removal of the floor carpeting (scenario 9), did not affect the buildings' cooling loads. Addition of nighttime natural ventilation (V3) and thermal mass (Mnc) improved the thermal performance of the buildings (scenario 13): sensible cooling load was reduced up to 17% and overheating up to 43%.
- A clear improvement results (in terms of cooling load reduction) from the installation of better window products. This is mainly due to their better shading effectiveness. The glazing's U-value does not appear to play a decisive role: glazing type G0.14, which has a low g-value but a higher U-value, results in 28% cooling load reduction up and 20% overheating reduction (scenario 11).
- Alternative improvement scenarios – in the passive operation mode – substantially reduce the mean overheating in the offices up to about 2 K, depending on the scenario and the reference overheating temperature assumption. Though not exactly identical, there is a clear congruence (see Figures 5 and 8) between the ranking of the scenarios in view of lower cooling demand (active operation regime) and lower overheating tendency (passive operation regime)
- Increasing nighttime natural ventilation during the summer from 3 ACH (V2) to 10 ACH (V4) moderately improved the thermal performance of the buildings. The sensible cooling load was reduced 5% and the overheating 8%. The combination of higher thermal mass or external insulation with increased nighttime ventilation was insignificantly better than natural ventilation alone.
- Combinations of selected modifications (such as external shades, natural ventilation, and efficient electrical lighting) lead to a significant reduction of buildings' cooling loads. As simulation results for combined measures (scenarios 16, 17 and 18) demonstrate, sensible cooling loads could be reduced (depending on the building) somewhere between 37 and 60% and overheating between 43 and 67%.

CONCLUSION

This paper presented the results of an extensive simulation-based study of the thermal performance improvement options in 5 typical office buildings in Beirut and Tripoli. It could be demonstrated that, through a combination of design features (particularly better glazing, shading solutions and natural ventilation and efficient electrical lightings strategies), a significant reduction of the cooling loads can be achieved. As far as the potential of a passive operation mode is concerned, given the current building typology and practices, provision of thermally comfortable indoor environment in the summer period requires coordinated measures including sufficient thermal mass, day-time shading, night-time ventilation, cross-ventilation possibility, sufficient room height to allow for stratification, and judicious use of air movement inducing fans. Moreover, flexible thermal comfort requirements (consistent with the implications of the adaptive thermal comfort theory) and a fitting dress code (involving climatically adapted clothing with low clo-values) would have to be considered.
Future studies will extend the scope of the study to include other building types (e.g. residential buildings). Moreover, onsite monitoring of indoor and outdoor environmental conditions are expected to provide data toward calibration of the simulation models applied, thus adding to the credibility of the simulation-based results and conclusions.

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