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A PRESCRIPTION METHOD FOR THE DESIGN OF OFFICE BUILDINGS AN ENERGETIC – ECONOMIC APPROACH

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ABSTRACT

A new Energy Code for office buildings in Israel, currently under development, is presented. This code is based on a prescription approach, which can be easily applied as a tool for the design of office buildings through all the design stages including the early ones. The prescription approach suggested is based on the results obtained from an energetic-economic optimization model that provides a recommended and preferred prescription for office building under prescribed constraints. A sensitivity analysis of the optimized solution follows. The sensitivity analysis allows modifications of the recommended prescription allowing for the creation of a wide range of design alternatives and in addition to figure out what are the design variables with the highest impact on the building energy consumption and cost. The way of using the prescriptions as a building code is explained as well as the method to determine the energetic rank of the chosen solution.

INTRODUCTION

According to the Israel Electrical Company studies the partial contribution of building acclimatization and lighting to energy consumption (33% today) is going to grow in future years to about 50% (IEC, 1996). A previous research showed that an appropriate climatic-energy conscious design, using simple building elements and technology, may save up to 40% of the energy consumption used for acclimatization of buildings (Shaviv and Capeluto, 1992). Therefore, the potential of energy savings in buildings is very significant. As a result a conceptual framework for a new energy code for buildings was proposed (Becker and Shaviv, 2000) and worked out in details for residential buildings, as well as for office ones (Shaviv et al., 2002, 2004). The new energy code permits to design according to two approaches: the prescriptive approach, which defines different solutions to achieve energy conservation and the performance approach that defines the energy budget of the building that should be met. The energy code for residential buildings has already been approved by all required authorities and has become the new Israel Standard 5282, in which green stars are assigned for the first time to buildings that save energy (SII, 2005). This paper focuses on the currently under development energy code for office buildings. We limit the discussion here to the prescription approach only. The main difference between residential and office buildings is that in the latter daylight integration is an important factor (Choi et al., 1984; Shaviv, 1998). As the office built area in Israel will be tripled during the next two decades, an energy conscious office design is essential. A third type of energy code under development is for education buildings, like schools. Although daylighting is significant in schools as much as in offices, the fact that the internal heat gains are much higher, causes them to behave thermally different. Hence the recommendations for energy conscious design differ.

THE METHOD

In order to achieve a basic prescription of preferred solutions an energetic-economic optimization model for the design of office buildings was developed (Yezioro and Capeluto, 2005). Recently few optimization models for the design of energy conscious buildings have been developed in order to reach the optimal solution for a specific design (Wang et. al., 2003; Wetter and Wright, 2003). However, for a prescription based Energy Code it is important to define a group of sub-optimal solutions that will assure, on one hand energy savings within reasonable economic costs, and allows architectural design freedom on the other, rather than dictating a single solution.

The optimization model uses ENERGY (Shaviv and Shaviv, 1978a,b) as the basic simulation engine. ENERGY includes daylight and artificial lighting calculations since 1980 (Shaviv, 1980). Lately, (Shaviv, 1998) more accurate calculations were added for evaluating different lightshelves and external sunshades, by using RADIANCE (Ward and Shakespeare, 1998) to calculate the light distribution inside the office building, and SHADING for evaluating the Geometrical Shading

Coefficient (GSC) of the various shading devices under study (Yezioro and Shaviv, 1994). For the prescription based Energy Code, 27 different shading devices and lightshelves were examined (Figure 1).
The implemented optimization model takes into account 12 decision variables that were identified as those factors that influence the most the energetic performance of office buildings. Each one of these decision variables may obtain between 3 to 27 discrete values (see Table 1).

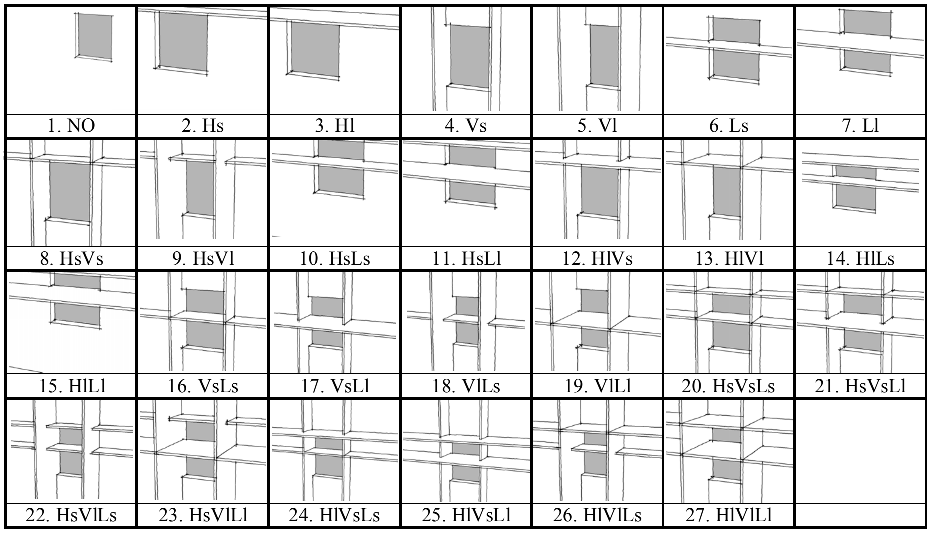


Figure 1 Different shading/lighting systems that were analyzed. H=horizontal louver, V=vertical louver, L=lightshelf; s=small=50 cm, l=large=100 cm

Table 1
Design variables list and their range of values

	Design Variable Name		Parameters	Range of Value
1	Orientation	**Or**	8	NN, NE, E, SE, S, SW, W, NW
2	Infiltration	**Inf**	4	0.75, 1.0, 1.25, 1.5 ach
3	Night Ventilation	**NV**	7	1, 4, 10, 20, 30, 40, 50 ach
4	External Wall	**Tm**	3	Light, Medium, Heavy wall
5	Insulation	**Ins**	6	**Heavy/Medium wall** / **Light wall** 0.00 cm polystyrene U=3.015 $Watt/m^2/{}^0C$ U=2.611 $Watt/m^2/{}^0C$ 2.00 cm polyestirene U=1.202 $Watt/m^2/{}^0C$ U=1.133 $Watt/m^2/{}^0C$ 3.00 cm polyestirene U=0.924 $Watt/m^2/{}^0C$ U=0.883 $Watt/m^2/{}^0C$ 5.00 cm polyestirene U=0.632 $Watt/m^2/{}^0C$ U=0.612 $Watt/m^2/{}^0C$ 7.00 cm polyestirene U=0.480 $Watt/m^2/{}^0C$ U=0.469 $Watt/m^2/{}^0C$ 10.00 cm polyestirene U=0.353 $Watt/m^2/{}^0C$ U=0.347 $Watt/m^2/{}^0C$
6	Albedo/Color	**Al**	3	0.45, 0.65, 0.85 * For the light wall case, the external envelope will be covered with glass. On this case the albedo will be referred as the reflection coefficient of the glazing.
7	Unit Depth	**Dp**	3	5.0, 6.7, 10.0 m
8	WindowSize	**Wa**	6	10%, 15%, 20%, 25%, 30%, 35% Window size = % from Unit area floor = 50 m^2
9	Glazing	**Glz**	6	**Code / Description / U($Watt/m^2/{}^0C$) / SC / Tv / Tv/Sc** DgCl Double Glazing Clear 3.57 0.86 80 0.93 DgGr Double Glazing Green 3.57 0.58 70 1.20 LE01 Low Emisitivity Glazing 1.40 0.43 68 1.58 LE02 Low Emisitivity Glazing 1.40 0.31 54 1.74 LE03 Low Emisitivity Glazing 1.40 0.27 41 1.52 LE04 Low Emissitivity Glazing 1.40 0.18 17 0.94
10	Blinds	**Blnd**	14	InBl - Internal Venetian blinds. Shading Coefficient: 0.6/ 0.7/ 0.8 ExBl - External blinds. Shading Coefficient: 0.2/ 0.3/ 0.4/ 0.5 InEB - Electrical internal rolling blinds. Shading Coefficient: 0.6/ 0.7/ 0.8 ExEB - Electrical external rolling blinds. Shading Coefficient: : 0.2/ 0.3/ 0.4/ 0.5
11	Sun Shades	**SunShd**	27	**See Figure 1**
12	Light Control	**Ctrl**	3	OnOn - Light On all the time OnOf - The control includes a number of light sensors and a control box. The light is switched On or Off for predetermined values Dim1 – Dimmer type 1 (a very efficient dimmer).

The objective for the optimization model is to reduce the energy consumption under given economic constraints. For that reason the Total Life Cycle Cost (**TLCC**) for each design alternative is calculated. The TLCC includes the energy cost of each design alternative and the construction cost of the 12 decision variables, plus their mantainance and replacement cost, according to their life time cycle (Alweyl, 1990). It also includes the cost of the air conditioning system according to the required size to keep internal thermal comfort, i.e. temperature and relative humidity, and the interest on the capitalized cost of all these building and mechanical elements. The energy code for office buildings focuses only on electrical energy consumption as most new office buildings are cooled and heated by air conditioning units.

The search for an optimal office was carried on a 50 sqm unit, located in a middle floor. The optimization model leads to a recommended prescription for the building. However, architectural constraints should be taken into consideration. As the recommended prescription may always be to face the main glazing to a certain orientation (for example, in cold climates the optimization model will always converge to south orientation) while architectural constraints may require different building orientations. Moreover, the optimization model may always lead to offices that have long external facades to allow daylighting, while existing lot proportions and economical constraints may impose deep offices. Therefore, the optimization model allows fixing the values of different design variables according to prevailing architectural constraints. For this reason it was found logical to preset the following variables: orientation (8 possibilities) and unit's depth (3 possibilities that yields office proportions of 1:2, 1:1, and 2:1). In this way the energy code allows the designer to face the building in different orientations and to design offices with various proportions. By freezing these two variables we get 24 different base cases. For each **base case** a suboptimal solution is created by the optimization model to achieve the preferred solution under these two architectural constraints; orientation and office depth. We call each obtained suboptimal solution a **Basic Prescription.** For each **Basic Prescription** a sensitivity analysis is then carried on by the model in order to enrich the range of possible solutions that could be implemented by the designer and in order to figure out what are the design variables with the highest impact on the building energy consumption and cost. Thus, a family of 90 different prescriptions, based on each **Basic Prescription** is created by the sensitivity analysis. These families of solutions are the basis for the proposed prescription based Energy Code for Office Buildings in Israel (Figure 3).

The existence of a family of prescriptions means that the solution is not unique, as one can expect from an optimization model. Moreover, it presents a large space of possible solutions that gives the designer the freedom to choose one that fits other constraints of the project, like architectural or economical ones. On top of it, it seems that many possible solutions may inspire the designer to achieve a new and better solution from the energy and economic points of view. The prescription method may be easily used by designers as a design tool in order to reach energy conservation in office buildings without compromising the architectural values. It can also be used by promoters and planning authorities for evaluating a proposed project.

The above mentioned 24 different **Basic Prescriptions** were calculated for each climatic zone in Israel, which are: the coastal plane (Zone A, presented by Tel Aviv), the inner plane (Zone B, presented by Be'er Sheva), the Mountain area (Zone C, presented by Jerusalem) and the Jordan Valley (Zone D, presented by Eilat). Thus, the Prescription Based Energy Code for Israel, comprizes of 4*24 graphs as presented in Fig. 3).

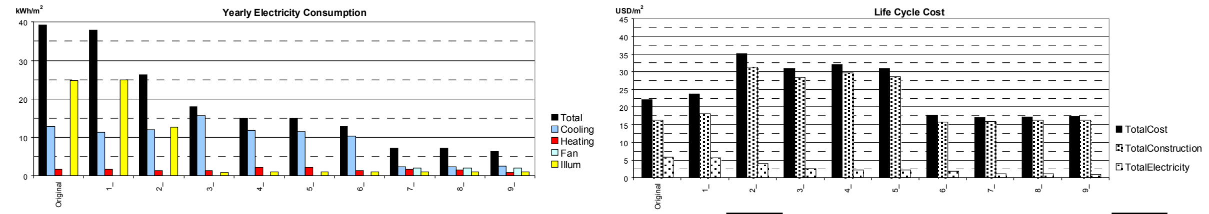
THE OPTIMIZATION PATH

The optimization model starts from an initial design solution that complies with current Israeli Standard St1045 requirements (SII, 1998) (We call this initial design solution **St1045**). The algorithm used is the Steepest Gradient. The algorithm is path oriented and in general may lead to a local sub-optimal solution. Therefore, the order of selecting and combining different parameters to create a prescription is important. The low cost and less architecturally influence parameters are selected first.

The optimization model creates and evaluates about 500 design alternatives until it converges to the optimal solution for the particular initial condition (Figure 2).

All preliminary optimization runs showed that in the optimal prescription the value assigned to infiltration was always 0.75 ach (air changes per hour) (the minimum allowed value) and the value assigned to the lighting control was Dimmer1, which is an expensive and very efficient dimmer. However, these two values are not easy to implement or to enforce as an ordinary solution. Therefore, it was decided to fix the Infiltration to a value of 1.0 ach and the Light Control to a value of On/Off. Moreover, as heavy external walls are much cheaper than the light external walls and also improve slightly the energy consumption of the building, the value chosen by the optimization model for external walls was always ‘Heavy’. For that reason, we fixed this value to the thermal mass. Thus we reduce the space of possible solutions to get the convergence to the **Basic Prescription** faster. On the other hand, in the sensitivity analysis these three variables, as well as the orientation and depth of the office, may get all the range of possible values.

Figure 2 presents an example of an optimization path, for Jerusalem in which the orientation, the Light Control and the Infiltratin are predetermined, while the other 9 variables remained free and can be changed during the optimization process. It is interesting to follow such a path in order to understand how the optimal solution was achieved, and which of the design variables has a significant influence on the energy consumption of office buildings.



No	Or	Inf	NV	TM	Ins	Al	Dp	Wa	Wh	Glz	Blnd	SunShd	Ctrl	Heater	Cooler	TOT	COOL	HEAT	FAN	LIGHT	CEnerg	Ccons	Ctot	No
0	SS	1.00	01	Light	0.05	.65	10.0	10	1.20	DgCl	InBl.8	______	OnOf	1000	2000	39.3	12.8	1.7	0.0	24.7	5.8	16.4	22.2	0
1	SS	1.00	01	Light	0.05	.65	10.0	10	1.20	DgCl	ExBl.2	______	OnOf	1000	2000	37.9	11.3	1.7	0.0	24.9	5.7	18.1	23.8	1
2	SS	1.00	01	Light	0.05	.65	05.0	30	1.60	DgCl	ExBl.2	______	OnOf	1000	2000	26.2	12.0	1.5	0.0	12.8	3.9	31.2	35.1	2
3	SS	1.00	01	Light	0.05	.65	05.0	30	1.60	DgCl	InEB.8	______	OnOf	1000	2000	17.9	15.6	1.5	0.0	0.9	2.7	28.3	31.0	3
4	SS	1.00	01	Light	0.05	.65	05.0	30	1.60	LE01	InEB.8	______	OnOf	1000	2000	15.0	11.7	2.2	0.0	1.1	2.2	29.8	32.0	4
5	SS	1.00	01	Light	0.05	.85	05.0	30	1.60	LE01	InEB.8	______	OnOf	1000	2000	14.9	11.5	2.3	0.0	1.1	2.2	28.7	30.9	5
6	SS	1.00	01	Heavy	0.05	.85	05.0	30	1.60	LE01	InEB.8	______	OnOf	1000	1500	12.8	10.3	1.4	0.0	1.1	1.9	15.7	17.7	6
7	SS	1.00	20	Heavy	0.05	.85	05.0	30	1.60	LE01	InEB.8	______	OnOf	1000	1000	7.2	2.4	1.6	2.0	1.1	1.1	15.9	17.0	7
8	SS	1.00	20	Heavy	0.05	.65	05.0	30	1.60	LE01	InEB.8	______	OnOf	1000	1000	7.1	2.5	1.6	2.0	1.1	1.1	16.2	17.3	8
9	SS	1.00	20	Heavy	0.10	.65	05.0	30	1.60	LE01	InEB.8	______	OnOf	500	1000	6.4	2.5	0.8	2.0	1.1	1.0	16.4	17.4	9

Figure 2 Energetic-Economic Optimization path for Jerusalem under the constraints- Orientation: South, Light Control: On/Off, Infiltration: 1.0 ach. The other 9 variables remained free for the model to change during the optimization process. Left: TOT-Yearly Electricity Consumption (kWh/m²/year); Right: Ctot- Total Life Cycle Cost (USD/m²/year)

According to Figure 2, in the first step the model proposes to change the Blinds from internal ones with SC=0.8 to external that have a SC=0.2. In the second step the depth of the unit was changed from 10.0 m to 5.0 m while increasing the window size to 30% of floor area. This change improves the daylight conditions in the office. In the third step the Blinds are set to electrical internal blinds with a SC=0.8. The meaning of the electrical blinds is that SC=0.8 only when there is more direct radiation than the desired one. In the fourth step the model changes the glazing for Low-E type 1 (clear). The next improvement was minor, changing the color of the external wall to a lighter one. In the sixth step, the envelope was changed from light to heavy. Then (seventh step) the night ventilation was increased from 1 ach to 20 ach, thus increasing the effectiveness of the night cooling. The next step changes, again, the albedo of the external envelope to a medium value, and the last step (ninth), the insulation was increased from 5 cm (U = 0.632 W/m^2/^{o}C) to 10 cm (U = 0.353 W/m^2/^{o}C). However, the achieved improvement is not major.

It is worth noting here that in this example the Total Life Cycle Cost of the initial standard solution (Ctot=22.2 USD/m^2/year) is higher than that of the improved solution (Ctot=17.4 USD/m^2/year- saving about 22%) despite the fact that the electricity consumption of the improved solution (6.4 kWh/m^2/year) is much smaller than that of the initial standard one (39.3 kWh/m^2/year - saving about 87%).

Note also that in both cases, the initial and the improved solutions, the electricity consumption for heating is low, because the South orientation allows the passive solar heating. Moreover, the reduction in the total life cycle cost is high, because the initial solution has light external walls, the cost of which is much higher than the cost of the heavy walls, which was selected by the model. For this reason we predetermined the thermal mass to the value ‘Heavy’, as otherwise one will always get reduction in the total construction cost, even though all other design parameters are more expensive to implement.

PRESCRIPTION BASED ENERGY CODE

The sensitivity analysis

The sensitivity analysis identifies the design variables with the highest impact on the building electricity consumption. On top of it, it allows a change in the recommended prescription and the creation of a wide range of design alternatives.

The sensitivity analysis for each **Basic Prescription** is performed by changing a single design parameter at a time. The parameter is allowed to vary over the entire range of values (Figure 3). The sensitivity analysis showed that for almost all cases the recommendation was to change the values of the

Infiltration and the Light Control variables to 0.75 and 'Dimmer1' respectively. These two parameters were predetermined and fixed during the optimization process (see **Best Sensitivity** in Table 2).

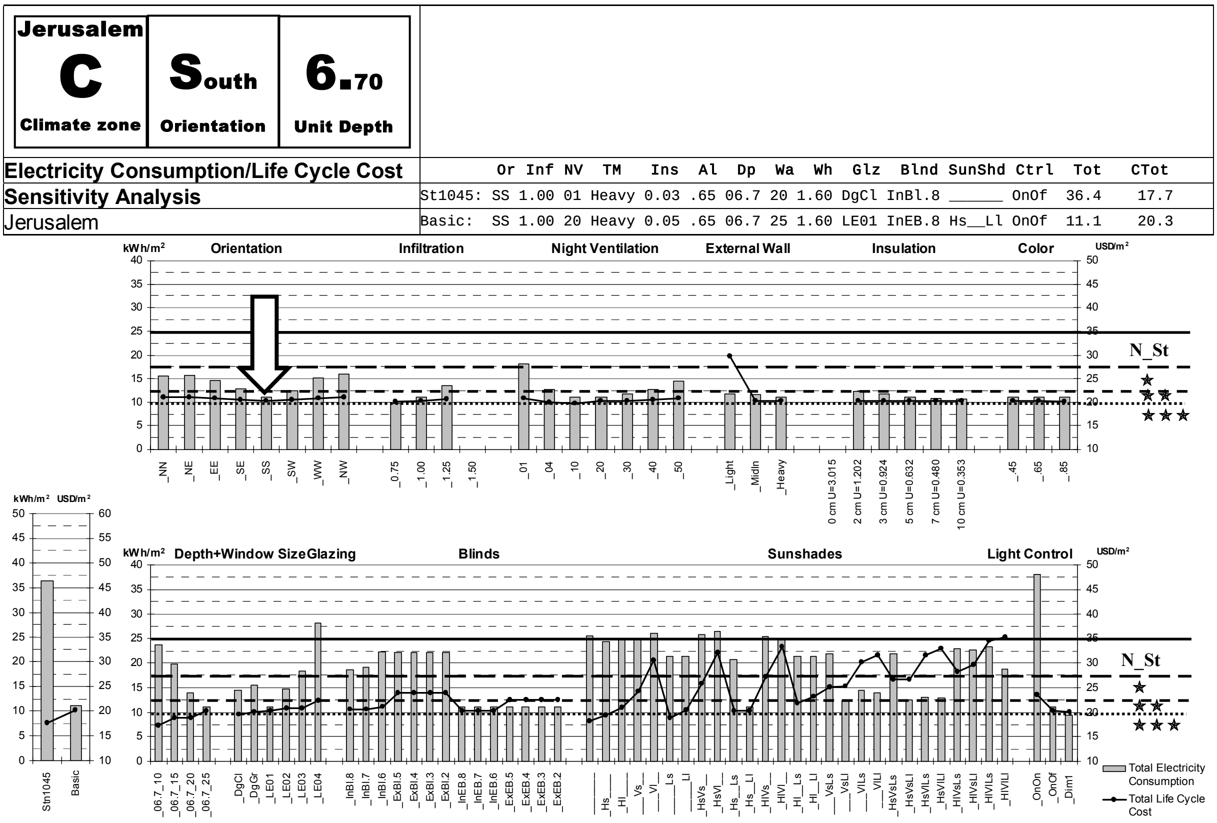


*Figure 3 Energetic-Economic sensitivity analyses for the **Basic Prescription: JERUSALEM, South Orientation, Office Depth of 6.70 m**. The columns presents the total electricity consumption for each design alternative and the continuous line presents the life cycle cost. The left axis is the yearly electricity consumption (kWh/m²/year), and the right axis is the capitalized life cycle cost (USD/m² year). Bottom Left: A possible prescription that stands with existing Israeli standard (**St1045**) compared with the **Basic Prescription** obtained.*

Table 2

*Results of the 24 **Base Cases** for Jerusalem. **TE:** Total Electricity consumption (kWh/m²/year, **TLCC:** Total Life Cycle Cost (USD/m²/year capitalized), **St1045:** Initial solution based on existing Israeli standard, **Basic Prescription:** best solution resulting from the optimization model, **Best Sensitivity:** best solution obtained by the sensitivity analysis. The design parameter that was changed from the Basic Prescription is shown in last column*

Jerusalem			St1045		Basic Prescription					Best Sensitivity Energy				
		Orientation	TE	TLCC	Level	TE	TLCC	% improv		Level	TE	TLCC	% improv	
Depth 5.0	1	**N**	30.95	18.09	*	13.39	20.34	56.7	NN 1.00 20 Heavy 0.05 .65 2:1 20 1.20 LE01 InEB.8 Hs__Ls OnOf	**	11.76	20.09	62.0	_Dim1
	2	**NE**	34.28	18.59	*	13.39	20.34	60.9	NE 1.00 20 Heavy 0.05 .65 2:1 20 1.20 LE01 InEB.8 Hs__Ls OnOf	**	11.84	20.10	65.5	_Dim1
	3	**E**	31.37	21.07	**	12.11	22.93	61.4	EE 1.00 20 Heavy 0.05 .65 2:1 20 1.20 LE01 InEB.8 Hs__Ls OnOf	**	10.66	19.93	66.0	_Dim1
	4	**SE**	28.46	16.78	***	9.05	19.61	68.2	SE 1.00 20 Heavy 0.05 .65 2:1 30 1.60 LE01 InEB.8 ____Ls OnOf	***	8.1	19.47	71.5	_0.75
	5	**S**	**22.94**	15.96	***	**7.13**	17.27	68.9	SS 1.00 20 Heavy 0.05 .65 2:1 30 1.60 LE01 InEB.8 ______ OnOf	***	**6.27**	17.14	72.7	_Dim1
	6	**SW**	29.9	17.31	***	9.26	19.95	69.0	SW 1.00 20 Heavy 0.05 .65 2:1 30 1.60 LE01 InEB.8 ____Ls OnOf	***	8.19	19.79	72.6	_0.75
	7	**W**	32.61	22.19	**	10.7	19.93	67.2	WW 1.00 20 Heavy 0.05 .65 2:1 20 1.20 LE01 InEB.8 Hs__Ls OnOf	***	9.38	19.74	71.2	_0.75
	8	**NW**	33.94	18.53	*	13.02	20.59	61.6	NW 1.00 20 Heavy 0.05 .65 2:1 20 1.20 LE01 InEB.8 Hs__Ls OnOf	**	11.45	20.36	66.3	_Dim1
Depth 6.7	9	**N**	44.16	18.19	*	15.52	21.26	64.9	NN 1.00 20 Heavy 0.05 .65 1:1 25 1.60 LE01 InEB.8 Hs__Ll OnOf	**	12.36	20.79	72.0	_Dim1
	10	**NE**	45.14	18.33	*	15.77	21.30	65.1	NE 1.00 20 Heavy 0.05 .65 1:1 25 1.60 LE01 InEB.8 Hs__Ll OnOf	**	12.64	20.83	72.0	_Dim1
	11	**E**	40.09	19.69	*	14.66	20.82	63.4	EE 1.00 20 Heavy 0.05 .65 1:1 25 1.60 LE01 InEB.8 Hs__Ll OnOf	*	11.77	20.39	70.6	_Dim1
	12	**SE**	37.55	16.89	*	12.8	20.55	65.9	SE 1.00 20 Heavy 0.05 .65 1:1 25 1.60 LE01 InEB.8 Hs__Ll OnOf	**	10.32	20.18	72.5	_Dim1
	13	**S**	36.38	17.65	**	11.05	20.29	69.6	SS 1.00 20 Heavy 0.05 .65 1:1 25 1.60 LE01 InEB.8 Hs__Ll OnOf	***	9.31	20.03	74.4	_Dim1
	14	**SW**	39.21	17.14	**	12.49	20.19	68.1	SW 1.00 20 Heavy 0.05 .65 1:1 25 1.60 LE01 InEB.8 Hs__Ll OnOf	**	10.69	19.92	72.7	_Dim1
	15	**W**	42.13	20.31	*	15.19	21.22	63.9	WW 1.00 20 Heavy 0.05 .65 1:1 25 1.60 LE01 InEB.8 Hs__Ll OnOf	*	12.86	20.87	69.5	_Dim1
	16	**NW**	**45.62**	18.40	*	15.96	21.33	65.0	NW 1.00 20 Heavy 0.05 .65 1:1 25 1.60 LE01 InEB.8 Hs__Ll OnOf	*	12.88	20.87	71.8	_Dim1
Depth 10.0	17	**N**	39.26	14.93	**N_St**	**23.77**	17.88	39.5	NN 1.00 20 Heavy 0.05 .65 1:2 15 1.60 LE01 InEB.8 Hl__Ll Dim1	**N_St**	22.41	17.68	42.9	_0.75
	18	**NE**	40.46	15.11	**N_St**	23.8	17.89	41.2	NE 1.00 20 Heavy 0.05 .65 1:2 15 1.60 LE01 InEB.8 Hl__Ll Dim1	**N_St**	**22.48**	17.69	44.4	_0.75
	19	**E**	37.73	16.24	**N_St**	22.97	17.45	39.1	EE 1.00 20 Heavy 0.05 .65 1:2 15 1.60 LE01 InEB.8 Hl__Ll Dim1	**N_St**	21.49	17.23	43.0	_0.75
	20	**SE**	34.74	13.95	**N_St**	22.38	15.94	35.6	SE 1.00 20 Heavy 0.05 .65 1:2 15 1.60 LE01 InEB.8 Hs__Ls Dim1	**N_St**	21.14	15.75	39.1	_0.75
	21	**S**	33.37	13.74	**N_St**	22.08	14.05	33.8	SS 1.00 20 Heavy 0.05 .65 1:2 15 1.60 DgCl InBl.8 Hs__Ls Dim1	**N_St**	21.15	13.91	36.6	_0.75
	22	**SW**	35.43	14.05	**N_St**	21.62	15.82	39.0	SW 1.00 20 Heavy 0.05 .65 1:2 15 1.60 LE01 InEB.8 Hs__Ls Dim1	**N_St**	20.32	15.63	42.6	_0.75
	23	**W**	38.17	16.62	**N_St**	22.08	17.63	42.2	WW 1.00 20 Heavy 0.05 .65 1:2 15 1.60 LE01 InEB.8 Hl__Ll Dim1	**N_St**	20.76	17.43	45.6	_0.75
	24	**NW**	40.54	15.12	**N_St**	23.65	17.87	41.7	NW 1.00 20 Heavy 0.05 .65 1:2 15 1.60 LE01 InEB.8 Hl__Ll Dim1	**N_St**	22.37	17.67	44.8	0.75
		Average	**36.43**	**17.29**		**15.99**	**19.27**	**56.3**			**14.28**	**18.9**	**60.9**	

New Standard and Green Stars

Four limits for each climatic zone were established: The first limit is proposed as the new minimum standard requirements (denoted by **N_St**). The other three limits qualify the design with one, two or three green stars. The limits assigned for the new energy standard and for the green stars were determined after the **Basic Prescriptions** for all the 24 cases for each climatic zone were derived by the model (see Table 2). A round number close to the energy consumption of the best **Basic Prescription** defines the upper limit for the 3 green stars. The lower limit for the new energy standard, on the other hand, was defined so as not to restrain the freedom of designing deep offices, which gave the worst energy performance office buildings in all orientation. The gap between these two limits was divided in order to define the criteria for asigning the one, two or three green stars. The gap between the different levels, in all climatic zones, was set in such a way that the top levels will require a higher effort from the designer in order to be qualified with more green stars.

Figure 3 shows that the **Basic Prescription,** obtained for the **Base Case** South Orientation and Office Depth 6.70 located in Jerusalem, qualifies the solution with 2 green stars (denoted by an arrow on the figure). The graph also shows that orienting the façade towards the SE or SW still rewards the solution with 2 green stars. All other orientations qualify the solution with one green star only.

An infiltration value of 1.0 ach (that was fixed in the basic prescription) rewards the solution with 2 green stars. However, reducing the value to 0.75 ach improves the performance of the basic prescription, rewarding the solution with 3 green stars. Increasing the infiltration value to 1.25 ach rewards the solution with only one green star, while a value of 1.5 ach doesn't stand with the minimum requirements of the proposed new standard and therefore is omitted from the graph.

Night ventilation with a value ranging between 10-40 ach rewards the solution with 2 green stars, while 4 and 50 ach receives only one green star. A value of 1 ach just stands with the minimum new standard requirements.

The external wall receives 2 green stars for all the range of values. Heavy envelope is a bit preferable than the other types. The Light envelope is much more expensive but does not improve the energy performance of the building. Choosing the light and more expensive envelope is done only for the merit of other considerations, like architectural or prestigious ones.

The color of the envelope is a free variable and can be determined without restraint by the designer. All the hues reward the solution with 2 green stars.

Insulation equal or bigger than 2 cm polystyrene (U value equal or lesser than 1.202 Watt/m^2/°C) rewards the solution with 2 green stars. U value greater than the value mentioned before, doesn't stand with the minimal requirements because of condensation problems on the wall during night time. However, adding more insulation does not reward the solution with more green stars. This is because using daylighting and reducing artificial lighting are the most important factors in reducing energy consumption of office buildings. The **Base Case** South Orientation with Depth 6.70 m can reach three stars reward only by adding a dimmer as Light Control.

Figure 3 shows clearly that the most influental design parameters are those that affect daylighting. It includes the unit proportion (i.e. the depth of the office), the size of the window, the shading devices; blinds or external sunshades with or without lightshelves, and the light control system.

The sensitivity graph, as is shown in Figure 3, is proposed as an easy to use design tool. It shows clearly the energetic-economic significance of different proposed prescriptions according to the energy consumption of the design alternative, as well as its life cycle cost.

Changing the Basic Prescription

Using the sensitivity graph (Figure 3) allows changing the **Basic Prescription** in order to create a new design alternative that may suit better the project specific constraints. It is important to stress that in this way it is possible to create a large variety of design solutions, without limiting the freedom of the architect.

In order to keep the energetic level of the **Basic Prescription** or even to improve it, a number of rules for changing this Basic Prescription were set:

a. Changing one design parameter only:

- If one wishes to change the value of only one desigh parameter, the energy performance and the life cycle cost of such an alternative is presented in the sensitivity graph, as well as the green stars that are assigned to it.

b. Changing more than one design parameter:

- For all the cases changes will be made one step only for all the design variables except for the Glazing and Sunshades variables.
- If after changing a design variable the energetic performance remains at the same level of the

Basic Prescription, it will not be considered as worsening/improving the overall conditions. Changing up to 3 variables will be allowed.

- If the proposed change improves the Basic prescription, it will be allowed to change an unlimited number of variables at the same time.
- If the proposed change worsens the Basic prescription and brings it to a lower level, it will be allowed to change up to 2 variables. The resulting prescription will be qualified according to the lower level achieved.

Determining the energetic mark of the whole building

The energetic mark for the basic unit and the calculation of the overall energetic mark for the building, are as follows:

1. The building plan is divided according to its façade orientations. In this way each division will be considered according to a given prescription that fits the appropriate orientation. Width and position of the building core will be determined according to the proposed plan. In the case of an open space plan the assumption is that the core occupies 30% of buildings width and can be located anywhere between the opposite facades of the building, like in case (b) (Figure 4).

2. The energetic mark for each division is set according to the appropriate prescription, the orientation and the units' depth for each division (Figure 5).

3. The overall energetic mark of the building is calculated as an arithmetic mean according to the following formula:

$$J = (Am * Sm + \ldots\ldots + An * Sn) / (Am + \ldots. + An)$$

Where:

J = The overall energetic mark of the building,

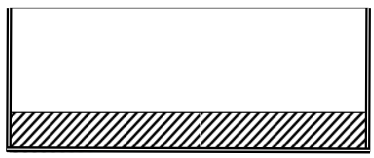
Am to An = The different areas of calculation (m^2),

Sm to Sn = The energetic mark of areas m to n, calculated in point 2.

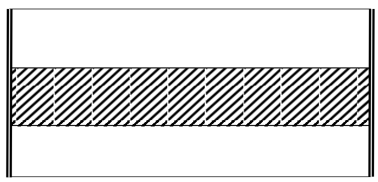
SUMMARY AND CONCLUSIONS

A prescription method for the design of office buildings in Israel was presented. This method was developed with the purpose to be implemented as a new Energy Code for buildings. Although prescription methods in general limit the freedom of the designer, as it provides exact rules of what can be done, the new prescription based code developed for Israel, tries to overcome this problem by presenting plentiful prescriptions. Thus, it doesn't impair the freedom of the designer. On the contrary, it shows the designer a lot of design options that can help him to figure out, at the early design stages, what are the best values to assign to the different design parameters. Thus, the architect can consider different architectural and functional constraints along with the energetic and economic considerations. These prescriptions were obtained as suboptimal solutions for different possible initial base cases (defined as **Basic Prescription**). A sensitivity analysis is then applied to the **Basic Prescriptions** creating a graph that presents a family of many design solutions. The prescriptions may be used as guidelines for the designers, promoters or planning authorities in the design or evaluation of any project. Four limits were established for each climatic zone: The first limit is the proposed new required standard. The other three limits qualify the design with one, two or three green stars. Some rules are presented to help the designers in determining how to change the **Basic Prescriptions** without loosing the rank obtained for it.

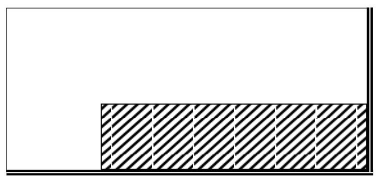
Although two approaches, performance and prescriptive, were suggested for the new energy code for building in Israel, the Israeli Authorities preferred to have first the prescriptive based code, as it is easier to implement. However, the performance based code gives more freedom for new innovative design solutions and therefore, this part of the code is now being under development, as well.



(a) Building with offices facing only one direction



(b) Building with offices facing two opposite directions



(c) Building with offices facing two different directions

Figure 4 Division of the plan according to façade orientations

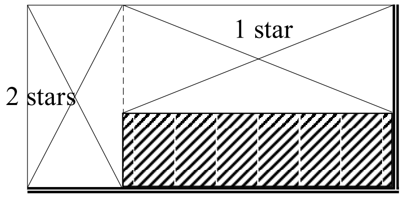


Figure 5 Energetic mark

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