ENERGY, ECONOMICS AND ARCHITECTURE

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ABSTRACT

We present a method, a model and a simple design tool for evaluating the construction, investment and energy costs of different possible design alternatives for grouping apartment units into a multifamily residential building. The added investment cost of each design alternative, compared with a bench-mark solution, is expressed in terms of Additional Annualized Mortgage Payment (AAMP) and is traded-off against possible saved Additional Annual Electricity Payment (AAEP) for in-house climate control. Assembling all possible examined building configurations in a graph, the axes of which are the AAMP and the AAEP, allows the designer to choose the preferred building configuration from the point of view of the consumer and the planning authorities. Such a graph can serve as a design tool that allows the architect to decide about the best building configuration, preferred proportion, orientation and number of floors, that yields the minimum energy consumption on one hand, or the minimum initial building cost on the other. On top of it, lines of equal total AAMP and AAEP can be drawn on the graph. The family of solutions that lies on the minimum annual payments can be selected. The existence of a family of solutions means that the solution is not unique, hence the optimization process does not impair the freedom of the architect to create a variety of design alternatives; on the contrary, it may inspire new innovative ideas.

INTRODUCTION

A significant part of the population in Israel lives in multifamily large residential complexes. Energy conservation considerations may be local, say what is best for a single particular unit, or global, namely optimizing the energy consumption over the entire apartment complex. The latter approach is particularly attractive to and endorsed by government supported organizations.

Very often, high rise buildings are proposed as a mean of achieving high urban density. However, tall buildings may cause environmental problems like high wind velocities in open spaces around them, as well as extended shadows over nearby houses and open spaces (HELIOS, 1999, 2000). Moreover, the construction cost of high-rise buildings, is steep (Tan, 1999, Gat, 1995). When all these factors are taken into account it is not a priori clear that the desired high urban density can be achieved by tall buildings along with an acceptable solution to the above mentioned environmental problems. Recent studies have shown that a reasonable density may be achieved with six stories high buildings while preserving the solar rights of neighboring buildings, as well as open spaces among them (Capeluto and Shaviv, 2001).

A characteristic feature of a multifamily residential building is the fact that each apartment unit may have different thermal behavior. The thermal performance of such units depends heavily on the unit's orientation and the area of its external elements like walls, roof and floors (Lekov and Balcomb, 1988, Shaviv and Capeluto, 1992). For example, an internal apartment in a middle floor in the temperate cool climate of Jerusalem requires energy for heating and cooling, while the energy required to provide comfort conditions in a corner apartment under the roof is mostly spent on heating and is much higher than what is required for an internal apartment (see Fig.1).

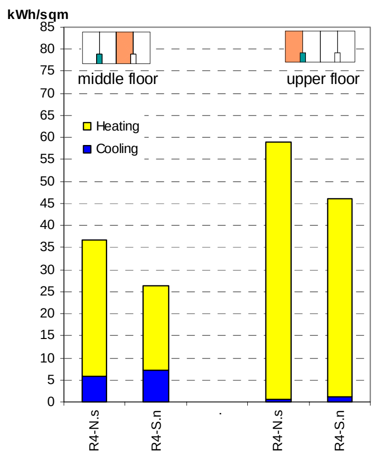


Figure 1 The annual energy consumption of a residential unit in Jerusalem that its main orientation is facing North (N.s) or South (S.n).
Left: an internal apartment in a middle floor.
Right: A corner roof apartment

When the analysis is restricted to a single residential unit, it was found that the unit's proportion have a small influence on its thermal behavior (Shaviv and Capeluto, 1992). However, this situation changes when we consider the configuration of the whole residential building. Here, the building's proportions have a profound effect on the global energy consumption. This behavior is due to the fact that the number of the inner apartments with almost no external walls can vary relative to the number of external apartments with large external envelope (Capeluto and Shaviv, 1994).

Construction costs are also sensitive to the area of the external envelope, roof and walls. In most cases, as the area of the external envelope decreases, so does the construction cost of these elements. However, this saving is negligible compared to the construction costs associated with the height of the building (Gat, 1995, Tan, 1999, Trump, 1987). Few questions arise:

1. Does the multifamily residential building have an optimum massing configuration, from the point of view of energy and construction cost, and if so what is the recommended shape in a given climatic zone?

2. Does the best building form, from the point of view of the energy and construction cost depend on the plan of the building, its height, or on the building orientation?

To answer the above questions, we developed a method, a model and a design tool Mulres-Energy (Capeluto and Shaviv, 1994) that allows a systematic evaluation of different building configurations. Results for various possible design solutions, for the temperate cool Mediterranean climate (like Jerusalem) are presented. Such results can facilitate the designer and the authorities in reaching a decision as to which floor plan and building massing configuration is most appropriate for the temperate cool Mediterranean climatic zone, creating a urban fabric with a variety of building types.

ENERGY ASPECTS OF HOUSING DESIGN

In the framework of developing an Energy Code for buildings in the different climatic zones of Israel, we checked a basic residential unit, changing systematically different design variables in order to obtain minimal energy consumption. During the process of developing recommended values for each design variable, the thermal performance of many different types of apartment units were evaluated (Shaviv et al., 2002). The required energy for cooling and heating for each unit type was calculated using an hourly dynamic simulation model ENERGY developed by Shaviv and Shaviv (1977, 1978a,b, Shaviv, 1984) and the results were stored as a database for the model Mulres-Energy. Thus, the model Mulres-Energy is based on accumulated knowledge.

In this research, we restricted the values that can be assigned to the residential unit by using only the recommended values for each design variable according to what is required by the Energy Code for residential buildings in Israel. A more general approach to this problem could be to optimize at the same time the values that should be assigned to the unit and to the building massing configuration. However, this extension is outside the scope of this paper. Thus, we assumed a wall insulation of 3cm (U=0.611 W/m^2 ^{o}C), roof insulation of 4cm (U=0.437 W/m^2 ^{o}C) and no mechanical night ventilation. The window size was assumed to be 10% of the floor area, and well exposed to the sun (Yezioro and Shaviv, 1994, Capeluto and Shaviv, 2001) during winter (SC=0.90) while partially shaded during the hot season by means of external shutters (SC=0.50). All units were assumed to be identical, and differ from each other only in the following design variables:

1. The plan location – a parameter, which influences the area of the external walls.

2. The section location – under the roof, or middle floor.

3. The building orientation – 8 possibilities: N, NE, E, SE, S, SW, W, NW. The orientation is defined according to the direction of the living room, which determined also where the main glazing is located.

Some typical results of the calculated energy consumption of the residential unit are presented in Figs.2 and 3.

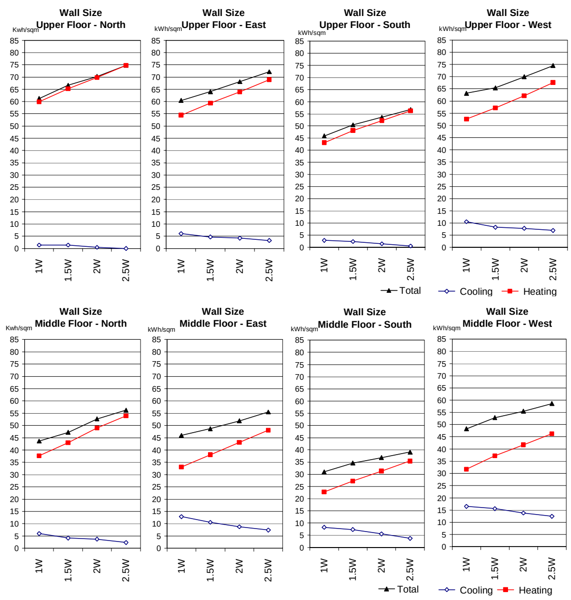


Figure 2 The influence of increasing the external envelope of a residential unit on the yearly energy consumption for different orientations

From the above mentioned residential unit, we constructed various plans; some of them are shown in fig.4. The whole building configuration was determined by applying for each plan type, in all possible orientations, different number of floors. All together 222 different building's configurations were examined.

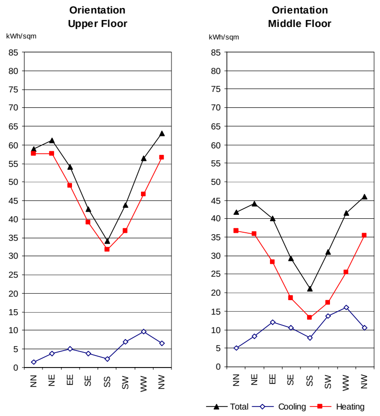


Figure 3 The influence of the building orientation on the yearly energy consumption of a residential unit

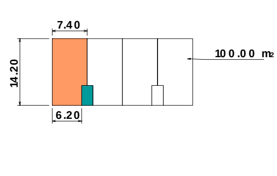
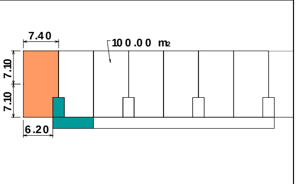
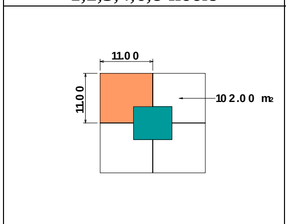
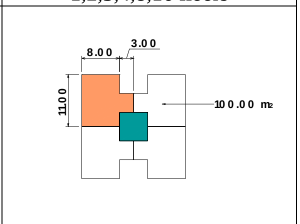
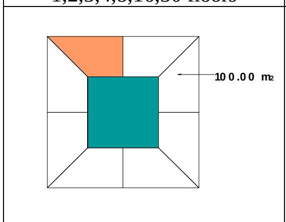
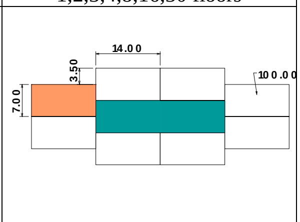
	
Row Building (R4) 4 Apartments 1,2,3,4,6,8 floors	Row Building (R8) 8 Apartments 1,2,3,4,8,16 floors
	
Compact Building (C4) 4 Apartments 1,2,3,4,8,16,30 floors	H Building (H4) 4 Apartments 1,2,3,4,8,16,30 floors
	
Compact Building (C8) 8 Apartments 1,2,3,4,8,16,30 floors	Double Row (DR8) 8 Apartments 1,2,3,4,8,16,30 floors

Figure 4 Different building type plan configurations for multifamily residential building

Fig.5 presents an example of a Double Row building with 8 apartments in each floor, with different number of floors, facing the 4 different orientations. One can see that up to 8 floors, increasing the number of stories improves the energy consumption. However, above 8 floors, an effective plateau is reached and the height of the building has almost no influence on its energy consumption.

Based on energy consumption consideration only, the best solutions were obtained for the following building configuration (see Fig.6): Row buildings with 4 and 8 apartments in each floor and with the main facade oriented to the south. Moreover, the taller the building is, the less energy it consumes. The second best solutions are the Double Row buildings with facades facing S and N. These results are typical to a temperate cool climate. In the hot-humid climate of Tel Aviv, buildings with few apartments and few stories high were found to be the best solutions (Capeluto and Shaviv 1994).

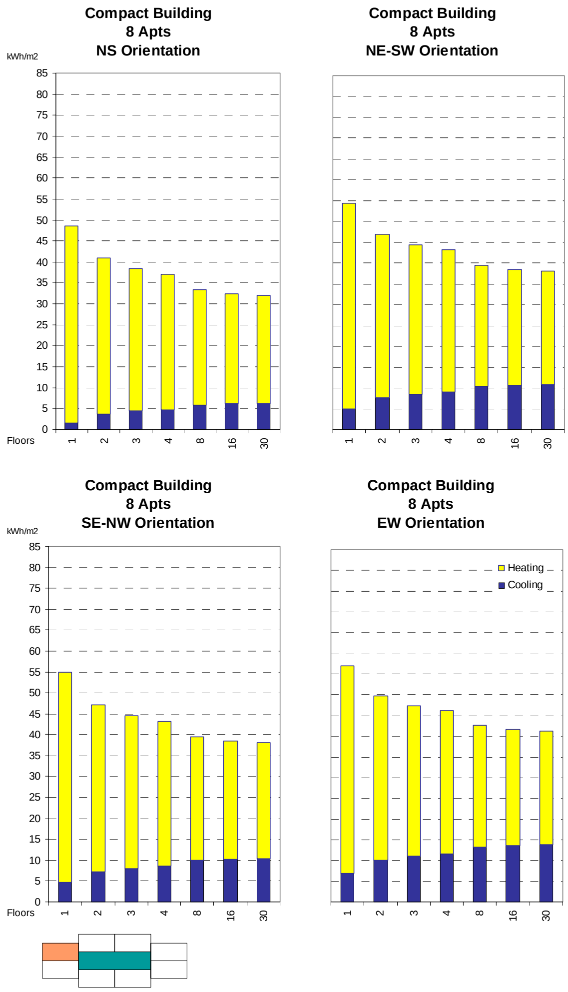


Figure 5 Double Row Building (DR8) and different number of floors

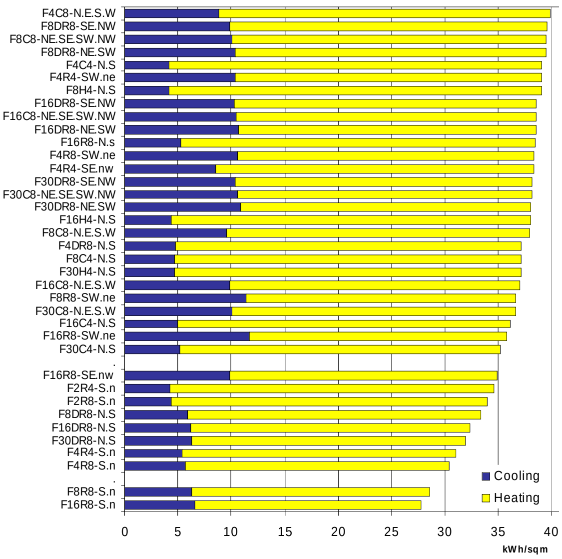


Figure 6 The best energy consumption solutions for different building configurations (F16R8-S.n means: 16 Floors, building type R8, with main orientation facing S)

ECONOMIC ASPECTS OF CLIMATE ORIENTED HOUSING DESIGN

Optimal building configurations obtained so far are based on energy consumption considerations only. These results were obtained by systematic variations of three design variables, namely: (i) building type; (ii) building orientation; and (iii) building height (number of floors). But as these three variables are manipulated, they often have additional consequences other than energy, i.e. construction cost.

We have found that energy consumption (per sqm) for climate control diminishes as the number of floors increases (see Fig.5). But these energy savings are small and further decrease when the height exceeds 8 floors. On top of it, it is negligible when compared with the additional construction cost associated with tall buildings. Marginal costs of construction increase at the rate of 2%-3% per floor (Tan, 1999), and can reach 200% at a height of 30 floors. This is equivalent to an average per sqm cost of 150%. Since financing costs are an exponential function of construction duration and the latter is a function of building size and height, tall buildings become very expensive to erect and the real estate market supplies such buildings only at very exclusive and expensive locations. Maintenance costs of very tall buildings are known to be very high due to the highly complex mechanical systems needed to serve such structures.

Accordingly, building height is governed mostly by market considerations more than by any other consideration, and thus it may be an exogenous parameter, rather than a design variable, to the climatic design process (see also Figs. 7 to 9).

Construction standards definitely contribute to building hedonics and value as well as to resource utilization. However, once all design variables are assumed according to the requirements of the building Energy Code, they become irrelevant for our comparison of building types, and are therefore neutralized (considered equal) in what follows.

Thus we are left with the remaining two decision variables, building type and building orientation, and we need a method to select their optimal values.

Estimating Construction and Investment Costs

Equation 1 is a simple model for estimating the basic construction cost of building types appearing in the energy consumption model. This cost model is based on the idea that buildings are made up of complete systems (structure, external wall cladding, mechanical, HVAC, etc.). The expected weights of these systems μ_i bear a stable relationship to each other (Pereira, 1986). This relationship can change in specific instances when we know for sure that a given component $x_i^{'}$ deviates markedly from the average quantity x_i .

$$C_0 = C \cdot \left[1 + \mu_1 \left(\frac{x_1^{'}}{x_1} - 1 \right) + \mu_2 \left(\frac{x_2^{'}}{x_2} - 1 \right) + ... + \mu_m \left(\frac{x_m^{'}}{x_m} - 1 \right) \right] \quad (1)$$

According to eq.(1), an expression for a component whose quantity does not deviate vanishes. For the various building types under study, we know that they differ from each other by the size of their external walls and rooftop, both measured per sqm of built floor area. So the manifestation of eq.(1) reduces to a two elements expression where x_1 represents external wall and x_2 represents roofing.

$$C_0 = C \cdot \left[1 + \mu_1 \left(\frac{x_1^{'}}{x_1} - 1 \right) + \mu_2 \left(\frac{x_2^{'}}{x_2} - 1 \right) \right] \quad (2)$$

Roofing (per sqm of built floor-area) declines with the number of floors and so it would appear that we have a perpetual saving as more floors are added. Construction costs as well as energy losses are declining simultaneously and we may have an incentive to add floors without limit. As mentioned above, this blissful assessment is un-informed: height entails exponential marginal costs that overshadow the small and declining savings due to a (per sqm) shrinking roof component. Let λ be the rate of cost increase per floor, then the cost of one square meter on floor N is given by the expression:

$$C(N) = C_0 \cdot e^{\lambda N} \quad (3)$$

C(N) is equivalent to marginal cost. To convert it to the average cost AC(N) we sum it up over all the floors, and divide by the number of floors N:

$$AC(N)=\frac{1}{N}\int_{n=0}^{N}C_0\cdot e^{\lambda n}dn=\frac{C_0}{\lambda N}\cdot\left[e^{\lambda n}\right]_{n=0}^{N}=C_0\frac{\left[e^{\lambda N}-1\right]}{\lambda N} \quad (4)$$

We need two more symbols in order to convert the average per sqm cost to the average per sqm investment cost, i.e. the cost including the interest on the construction loan.

- T is the time it takes to complete the project
- k is the interest rate

We assume stream of T equal payments from the bank to the contractor, summing up to the total cost. The payment at time t gathers interest during T-t periods. Thus, AIC(N) the accumulated investment cost for each square meter of built space is:

$$AIC(N)=\frac{1}{T}\int_{t=0}^{T}C_0\frac{\left[e^{\lambda N}-1\right]}{\lambda N}\cdot e^{k(T-t)}dt= \\ \frac{1}{T}C_0\frac{\left[e^{\lambda N}-1\right]}{\lambda N}\int_{t=0}^{T}e^{k(T-t)}dt=C_0\frac{\left[e^{\lambda N}-1\right]}{\lambda N}\cdot\frac{\left[e^{kT}-1\right]}{kT} \quad (5)$$

A MODEL FOR EVALUATING INITIAL INVESTMENT COSTS VS. ENERGY SAVINGS

In this section we introduce different approaches to present the life cycle cost analysis for estimating the initial construction and investment costs, depending on building type, orientation and building height and the potential reduction in annual electricity payments. The results are presented in Figs.7 to 9.

Life Cycle Cost Analysis as a Function of the Building Height

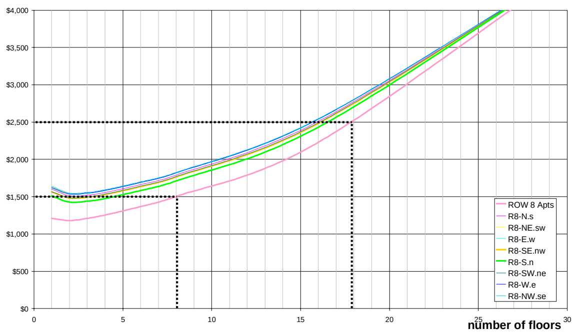


Figure 7 Life cycle cost - investment cost and energy in present value, as a function of building orientation and number of floors (building type is R8. The lower line is construction cost, all other lines includes also energy cost)

The lower line in Fig.7 shows marginal investment cost without energy cost. Investors can use this line to determine the optimum number of stories according to market values. For example, in a location, where one expects people paying as much as 1500$/sqm it will be economically viable to built up to 8 floors. However, in more expensive areas of the city, where higher values can be expected, it is worth for the investor to build higher buildings. For a market value of around 2.500$/sqm the optimum building height is 18 floors. Each sqm added to a building higher than that, will increase the price to a level beyond the attractiveness of the location and hence will not attract potential consumers. If the minimal possible selling price should be obtained, then only 2 stories should be built. Even if we add the value of the additional marginal cost according to the building orientation, caused by the energy consumption into this graph (the upper lines in Fig.7) these conclusions remain unchanged. Fig.7 shows also that once the capitalized initial construction cost is added to the energy cost, it is very difficult to distinguish and choose the best building orientation. This is because the potential energy savings due to a better building form and orientation is negligible compared with the investment cost. The conclusion is that such common representation of life cycle cost is not valid for our problem of choosing the best building configuration.

Energy - Money Graph: Energy Consumption vs. Investment Cost Graph (EC-IC space)

A second approach is to use the same equations detailed above, but to place each Type-Orientation Pair (TOP) within the two dimensional space of Investment Cost (IC) and Energy Consumption (EC). Each of these variables is measured in units per square meter of built space (see Fig.8). As the number of stories is determined mainly by the market value, we will present different EC-IC space for various buildings heights. In this work we limit our discussions to 4 and 8 floors buildings (denoted by F4 and F8).

Fig.8 left shows a given TOP placed in a 2 dimensional decision space for a 4 floor building. On the right, we see TOP for 8 floor building. Clearly, as is expected from Fig.7, the investment cost of all types of 4 floors is lower than any types of 8 floors. Thus, the best investment-cost wise is the 4 floors, 8 dwellings to a floor, compact type building (F4C8), but this type consumes much more energy than building types F8R8S.n or F8R4S.n (see Fig.8). As expected, the 8 floors, South oriented Row type with 8 dwellings to a floor (F8R8S.n) is the best energy wise. However, building type F4R8S.n consumes just a little bit more energy than F8R8S.n, but costs much less to construct. So the question remains, what is better to build?

The kind of data presented in Fig.8 combines developer's and consumer's considerations. The developer will generally prefer a reduction of construction and investment costs even if it results in higher energy consumption (i.e. he will choose type F4C8) while the consumer and local authorities will be interested in a solution which reduces costs and saves energy. However, energy saving vs. the higher cost should be traded off to reach a decision.

To clear the ambiguity, we need a design tool that will easily show us in the TOP space, what are the best design alternatives. For that reason we propose in this paper a new approach, which allows the evaluation of the potential energy savings and the initial cost saving according to the building type, orientation and number of floors.

Money – Money Graph: Additional Annual Electricity Payments vs. Additional Annualized Mortgage Payments Graph (AAEP-AAMP space)

If we insist on a complete ranking for the whole set of types and orientation pairs, we need a common yardstick. Of course, the simplest way is the use of money. Regarding ***energy consumption*** - for every building height there is an optimal solution with maximum energy savings. We use this solution as an energy-benchmark, and measure yearly energy consumption per sqm as additional to this base case. For example, this benchmark for 8 floors building can be F8R8-S.n, as it consumes less energy. Using this base case one can evaluate the Annual Additional (or saving) Electricity Payments in $/sqm (AAEP) to the consumer for heating and cooling his apartment. Assuming that the cost of 1 kWh of electricity is Ecost ($/kWh/sqm), we get:

AAEP ($)=AAEC (kWh/sqm)*Ecost ($/kWh) (6)

where AAEC is the Additional (or saving) Annual Electricity Consumption.

According to Fig.8 type F4C8-N.E.S.W (solution A) consumes about 10 kWh/sqm more energy than type F4R8-S.n (solution B). Therefore, for a 120 sqm flat and according to mid-cost electricity scenario (scenario 2) in which Ecost=20cent/kWh, the solution B will produce to the consumer a $240 yearly saving in his electricity bill, compared with solution A. It must be stated that solution B will save also resources to the country and contribute to reduce CO2 emissions. AAEP is presented in the vertical axis of the graph in Fig.9.

Regarding ***construction costs*** - we can use the 4 floors, 8 dwellings to a floor, compact type building (F4C8-N.E.S.W), which is the cheapest type, as a cost-benchmark, and measure annualized investment costs as increments from that base-case. We can assume that the consumer will finance these cost differences by taking a larger loan from the bank. Let's define AAMP in US dollars/sqm, as the **Additional Annualized Mortgage Payment** per sqm compared with the base-case F4C8-N.E.S.W (solution A). AAMP is presented in the horizontal axis of the graph in Fig.9.

In the previous example, comparing the solution A (F4C8-N.E.S.W) and solution B (F4R8-S.n), gives the consumer annual electricity saving of $240. However solution B costs about $20/sqm more than solution A. For a 120 sqm flat, the additional annual loan return, due to this difference, will be $215, assuming the regular interest rate in Israel of 6-7.5%. Now the question about what the customer should prefer is very clear. The **Additional Annualized Mortgage Payment** for Solution B compared with solution A is less than the **Additional Annual** saving in the **Electricity Consumption** bill and probably he will demand the energy conscious flat. An increased demand of this kind of preferable design alternative by customers could produce also an increased offer of these good solutions by authorities and investors.

Fig.9 shows a given TOP placed in a 2 dimensional Money – Money decision space for a 4 and 8 floors buildings. The vertical axis is the ***Annual Additional Electricity Payment (AAEP)*** in $/sqm and the horizontal axis ***is the Additional Annualized Mortgage Payment (AAMP*****)** in $/sqm compared with the base-case. The TOPs on the left are 4 floors high, and on the right are the TOP for 8 floor buildings. TOPs closer to Y axis are solutions with minimal construction-investment cost; on the other hand points closer to X axis represent solutions with minimal energy consumption. Therefore, points closer to the origin correspond to best design alternatives in both energy and investment costs considerations.

We use three different electricity cost scenario. Low-cost scenario, in which Ecost=10cent/kWh, Mid-cost scenario - Ecost=20cent/kWh, and High-cost scenario - Ecost=10cent/kWh. For each electricity cost scenario we can draw equal-cost lines.

In order to compare between two different design alternatives, it is possible to check near which of the equal-cost line they are located. The closer the TOP is to the origin, the better solution it is. As for example, solution A is located on the right hand side of the $2 line, while solution B is located on the left hand side, hence solution B is preferable.

Although one can expect that equal-cost tradeoffs do not cross building height clusters as building height is optimized with regard to real-estate value (see Figs.7 and 8), we still can find in Fig.9 some exceptions (compare F4H4-E.w with F8C8-N.E.S.W according to scenario 2). However, in most cases, once the height of the building is selected regarding the real-estate value, cost comparisons of type and orientation pairs reflect sub-optimization of the selected number of building floors.

CONCLUSIONS

1. It is possible to present to the planning authorities, designers, and consumers the envelope of possible solutions for grouping apartment units into a whole multifamily residential building, compared under energy and economic considerations.

2. Based on the results, as presented in the graph of the solutions investigated, it is possible to single out, already at the very early pre-conceptual design stage, the best building configuration.

3. The best solution for grouping apartments units into a whole multifamily residential building is not necessarily the one with lowest initial construction costs or lowest energy consumption cost. There exists a trade-off between these two factors. Moreover, the preferred solutions may vary according to the cost of electricity.

4. The equal-cost tradeoffs lines presented in the ***AAEP-AAMP space*** (Fig.9) serve as a simple design tool that facilitates designers and building authorities in determining the preferable solution from economically and or climatically points of view.

5. Since the ***AAEP-AAMP space*** presents all solutions investigated, it does not impair the freedom of the architect to achieve a variety of solutions; on the contrary, it can inspire new ideas.

6. Similar graphs can be easily generated for other locations, weather conditions, and electricity cost or design variables.

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REFERENCES

Capeluto I.G., Shaviv E. 2001. On the Use of Solar Volume for Determining the Urban Fabric, Solar Energy Journal, Vol. 70, No. 3, Elsevier Science Ltd., pp. 275-280.

Capeluto I.G., Shaviv E. 1994. MULRES-ENERGY: A CAD Tool for Determining the Optimum Configuration of Multifamily Residential Buildings, in PLEA94 - Architecture of the Extremes. Proc. of the 11th PLEA International Conference, pp. 277-284.

Capeluto I.G. and E. Shaviv, 2001. "On the Use of Solar Volume for Determining the Urban Fabric", "Solar Energy" journal, Vol. 70, No. 3, pp. 275-280 Elsevier Science Ltd.

Gat D. 1995. Optimal Development of a Building Site, Journal of Real Estate Finance and Economics, Vol. 11, pp. 77-84.

HELIOS Ltd. (Shaviv, Yezioro and Capeluto). 1999 The Influence of High-Rise Buildings on their Energy Consumption and Urban Shading (research report in Hebrew), ordered by the Ministry of the Interior.

HELIOS Ltd. (Shaviv, Yezioro and Capeluto) 2000. Environmental Report Review, Sun and Winds, Nof Carmel Towers (in Hebrew). Ordered by the Ministry of the Environmnet,.

Pereira, P. E. (ed). 1986. Dodge construction systems costs. McGraw-Hill Cost Information Systems.

Lekov A.B, Balcomb J.D. 1988. Passive Solar Guidelines for Bulgaria. A Multistory Concept, Proc. of Passive Solar Architecture, Ljubljana, Yugoslavia, pp. 156-166.

Shaviv E., Shaviv G. 1977. A model for predicting the thermal performance of buildings. WP ASDM-8 report. Faculty of Architecture, Technion IIT, Haifa, Israel .

Shaviv E., Shaviv G. 1978(a). Designing buildings for minimal energy consumption. Computer Aided Design Journal 10(4):239-247

Shaviv E., Shaviv G. 1978(b). Modeling the thermal performance of buildings. Building and Environment 13: 95-108. Oxford, Pergamon.

Shaviv E. 1984. The performance of a passive solar house with window sunspace systems. Energy and Buildings 7, Elsevier Sequoia, pp. 315-334.

Shaviv E., Capeluto I.G. 1992. The Relative Importance of Various Geometrical Design Parameters in Hot-Humid Climate, ASHRAE Trans., Vol.98, AN-92-1-1, Baltimore, pp. 589-605.

Shaviv E, Capeluto I.G., Yezioro A., Becker R., Warszawsky A. 2002. Thermal Performance of Buildings and the Development of Guidelines for Energy Conscious Design. Part I, Design Guidelines for Residential Buildings, Research Report 022-733, Ministry of National Infrastructures, Faculty of Architecture, Technion IIT, Haifa, Israel (in Hebrew).

Tan W. 1999. Construction Costs and Building Height, Construction Management and Economics, Vol. 17, pp. 129-132.

Trump D., Schwartz T. 1987. The Art of the Deal, New York, McGraw Hill, page 223.

Yezioro, A. & E. Shaviv. 1994 SHADING: A Design Tool for Analyzing Mutual Shading Between Buildings. Solar Energy, Vol. 52, Number 1, Pergamon Press Ltd., USA (pp. 27-37).

Figure 8 Comparing alternative TOPs in EC-IC space. The vertical axis presents the annual energy consumption per sqm while the horizontal axis shows the construction cost per sqm.

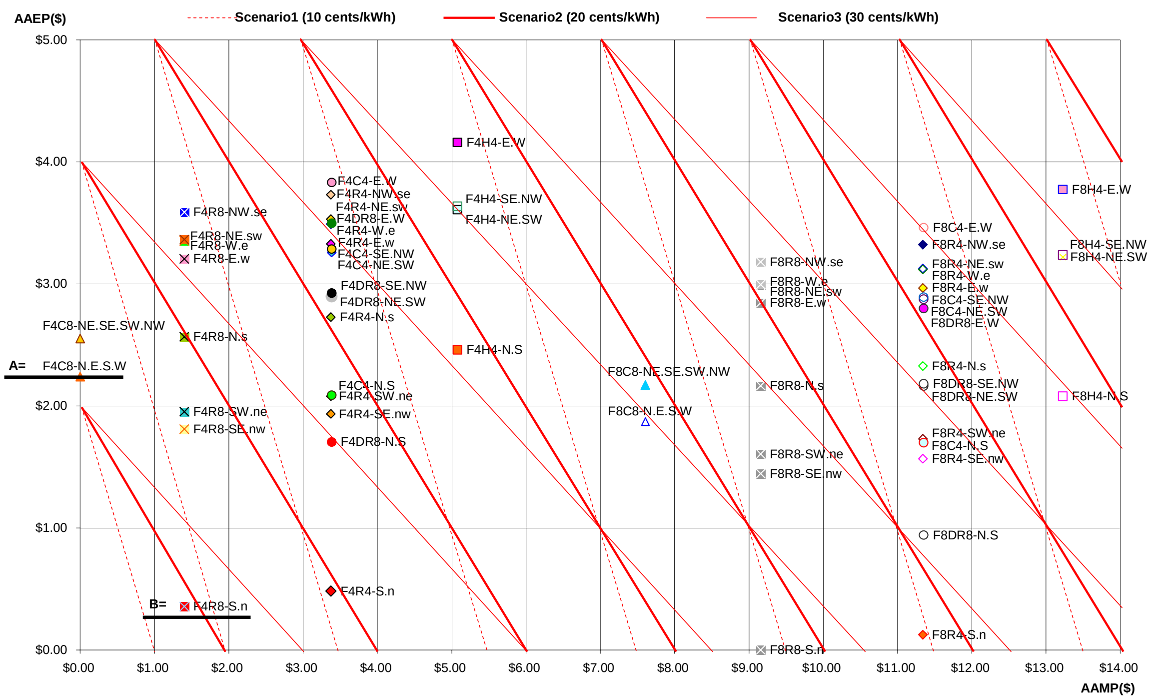

Figure 9 Comparing alternative TOPs in AAEP-AAMP space. The vertical axis is the Additional Annual Electricity Payment(AAEP) in $ per sqm and the horizontal axis is the Additional Annualized Mortgage Payment (AAMP) in $ per sqm compared with the base-case.