Impact of increasing the depth of urban street canyons on building heating and cooling loads in Tel Aviv, Israel

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Seismic vulnerability

Images: http://www.eitanot.co.il

- Israel lies along the Dead Sea Transform, an active rift which caused ten earthquakes of magnitudes between 6 and 7.2 in the region in the last thousand years.
- Much of the residential housing was built before seismic building codes were enforced in 1980.
- National Guideline Plan 38 incentivizes their structural reinforcement by offering building additions, typically the addition of several floors to existing 2-4 story buildings.

Research objectives

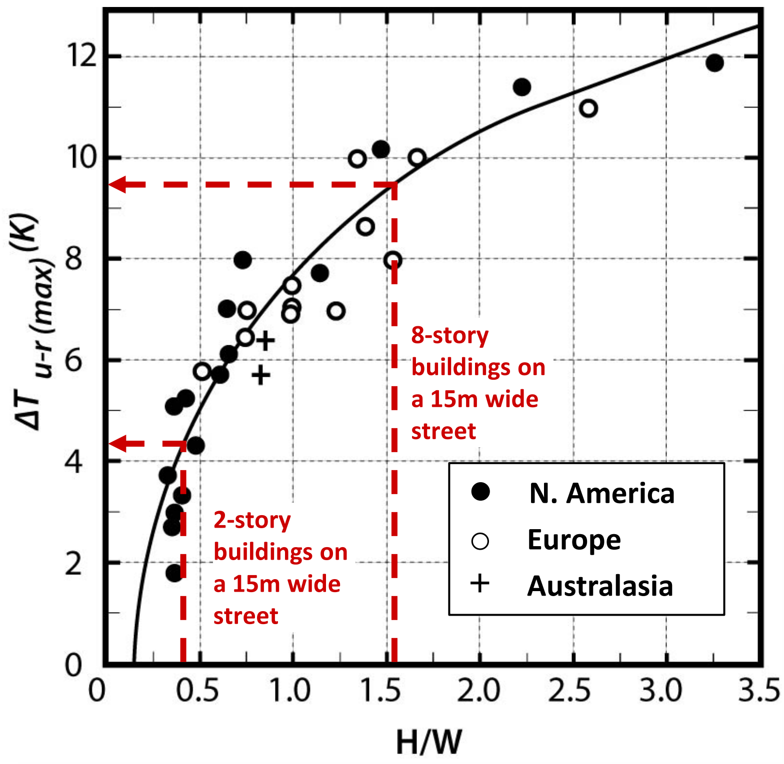
We know that the aspect ratio (H/W) of streets affects microclimate in cities, especially the urban heat island, but also wind speed.

QUESTIONS:

How will addition of several floors to existing buildings affect :

a. building energy consumption

b. thermal comfort in non-airconditioned apartments



Maximum intensity of the nocturnal UHI (Oke, 1987)

Methodology

The Canyon Air Temperature (CAT) model is used to generate 8760 hourly values of air DBT, RH and wind speed to create an 'urbanized' TMY for

ENERGYui:

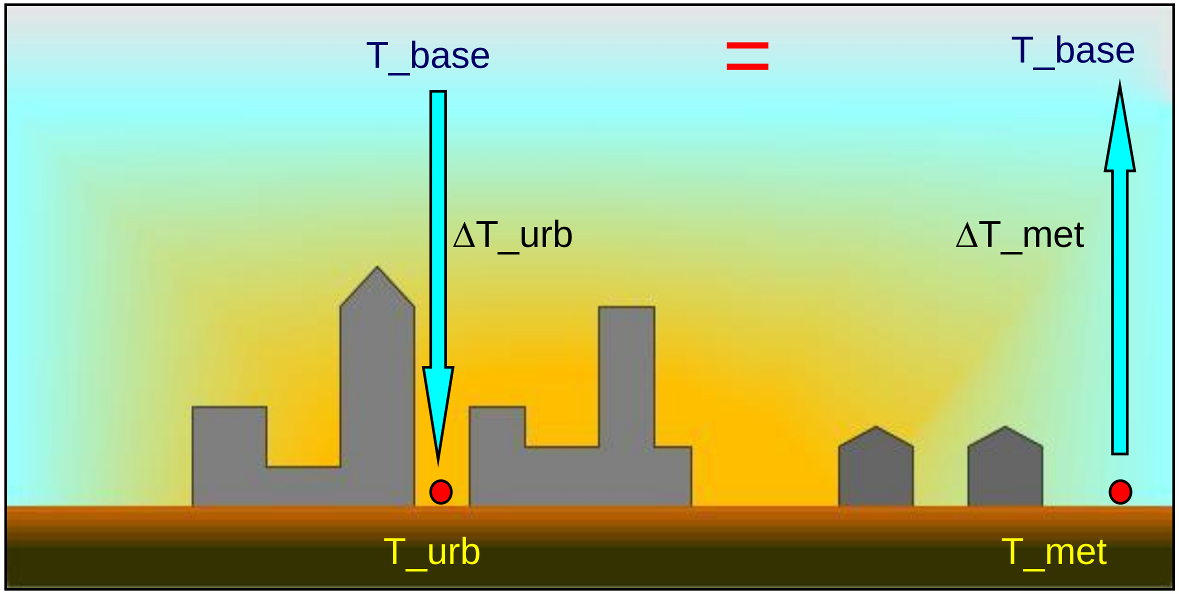
simulate building energy requirements in fully AC apartments

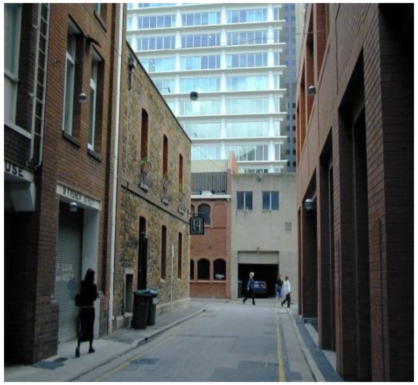
Climatic Cooling Potential (CCP):

estimate potential for night ventilation in non-AC apartments

Conceptual basis of CAT model

(Erell & Williamson, 2006)





$T_{base} = T_{met} + \Delta T_{met}$

$T_{urb} = T_{base} + \Delta T_{urb}$

- Surface energy balance calculated for 'canyon volume' at each site
- Effect of stability on energy exchange with air above roof height modelled by empirical resistance factor.
- Parameterizations used to simplify inputs.

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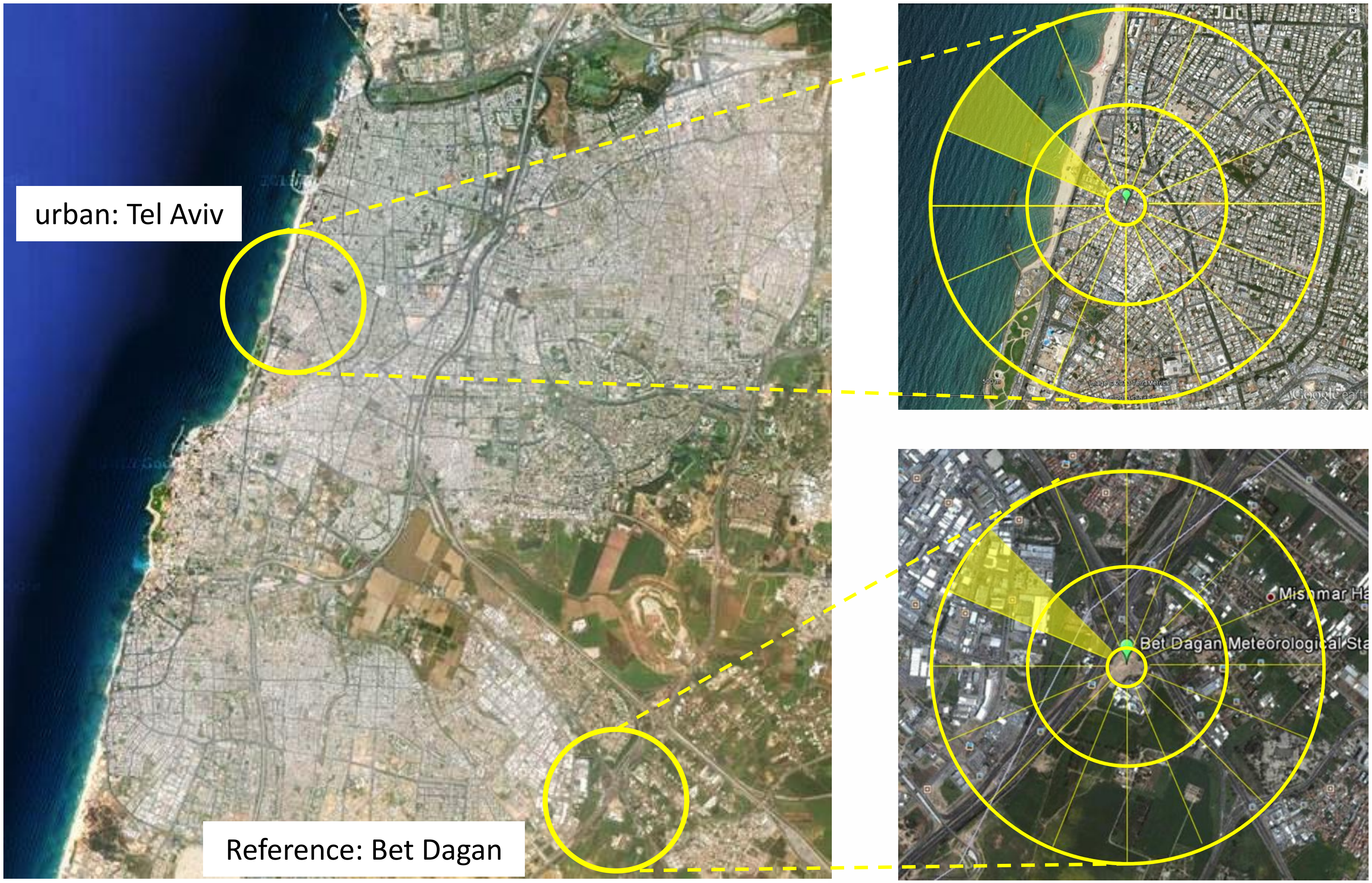
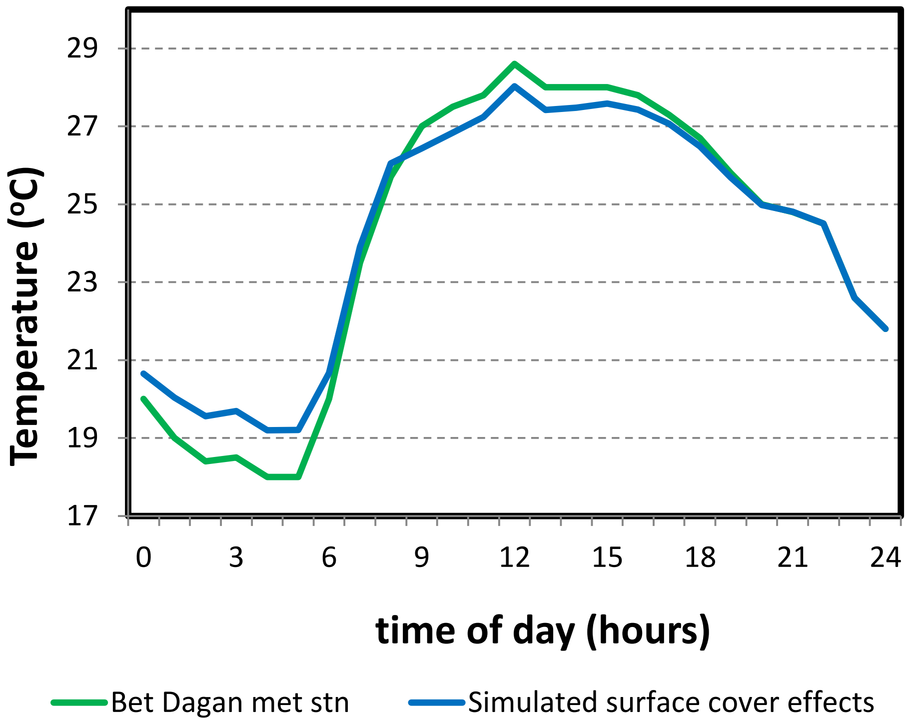
Advection of moisture



CAT simulation (i): effects of moisture and surface cover

("Bet Dagan by the sea")



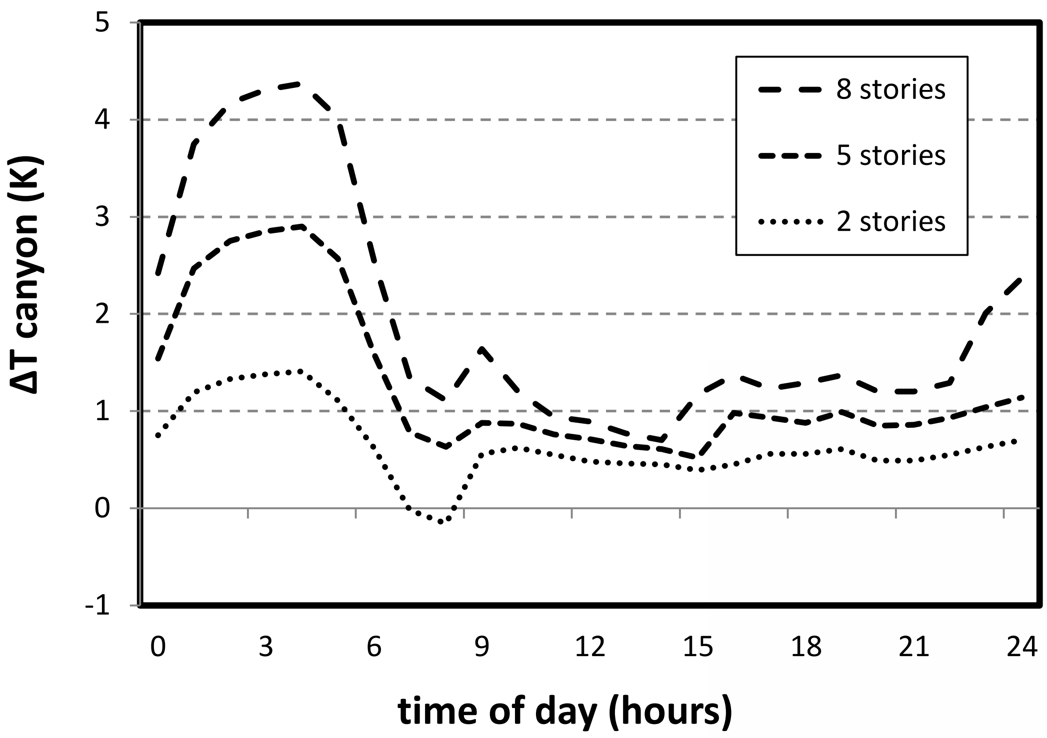
Temperature differences Bet Dagan - Tel Aviv (°C, July avg)			
	daily max	daily avg	daily min
IMS data	**1.90**	**0.10**	**-1.60**
CAT prediction	**0.11**	**-0.06**	**-0.52**

Data: Israel Meteorological Service, 1995-2009
http://www.ims.gov.il/

Bet Dagan is 7 km inland: It is cooler at night and hotter by day than Tel Aviv.
CAT under-estimates both trends (it is not a meso-scale model!).

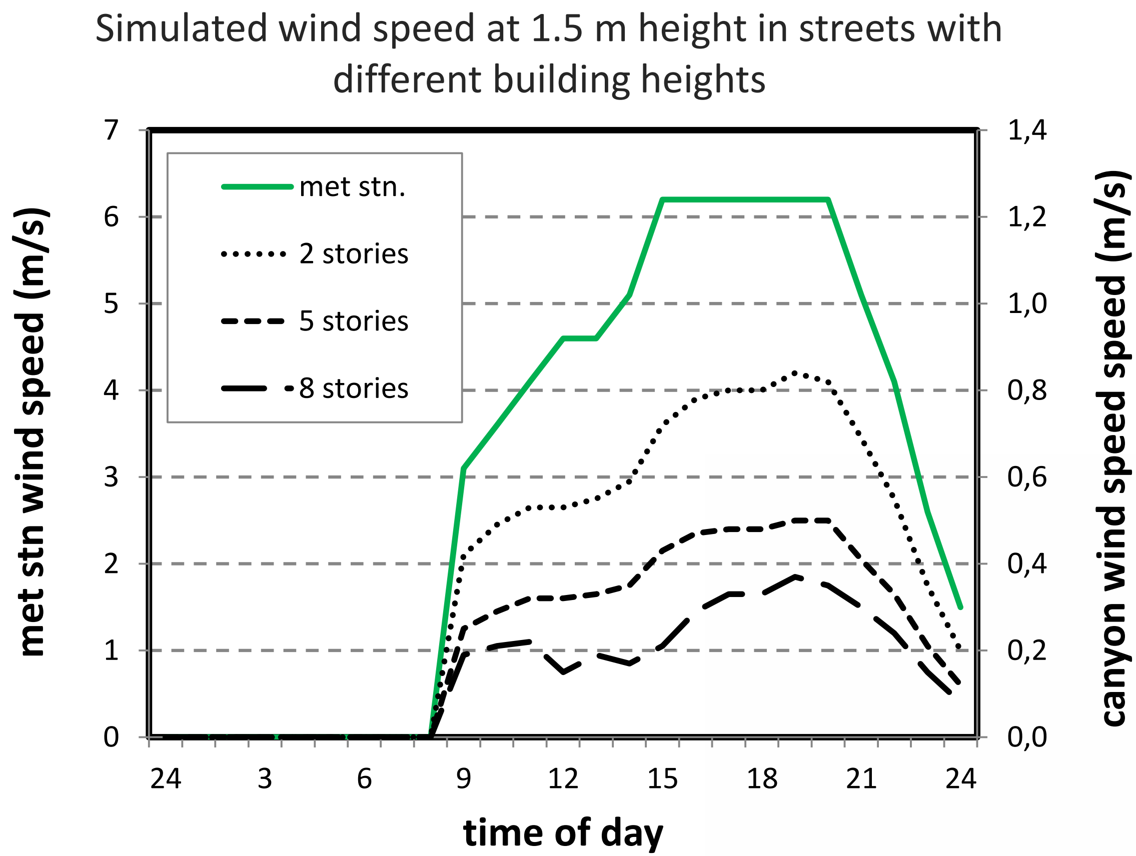
CAT simulation (ii): Urban effect on dry bulb temperature

Simulated temperature difference: Tel Aviv – Bet Dagan



Intra-urban temperature variation due to geometry is largely a nocturnal phenomenon.

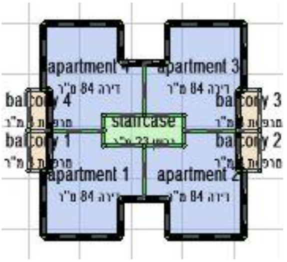
CAT simulation (iii): Urban effect on wind speed



Height increase from 2 to 5 floors reduces wind speed at street level substantially.

ENERGYui

- Building thermal simulation interface for EnergyPlus.
- Designed for Israel Standard 5282 – Energy Labelling of Buildings.
- Occupancy, internal loads and HVAC set points (20^{o}C winter, 24^{o}C summer) are fixed.
- Shading by adjacent buildings of equal height was modeled by adding non-conditioned extensions to the building



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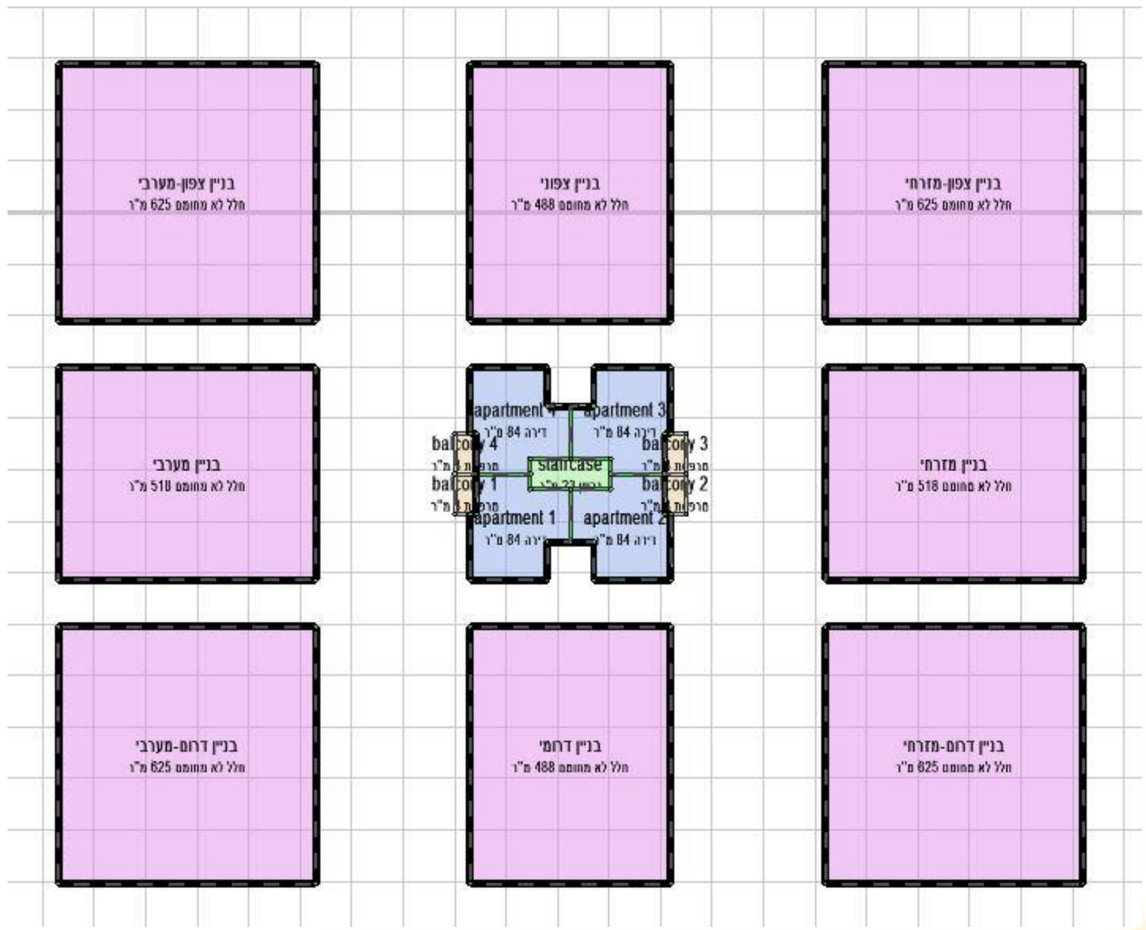
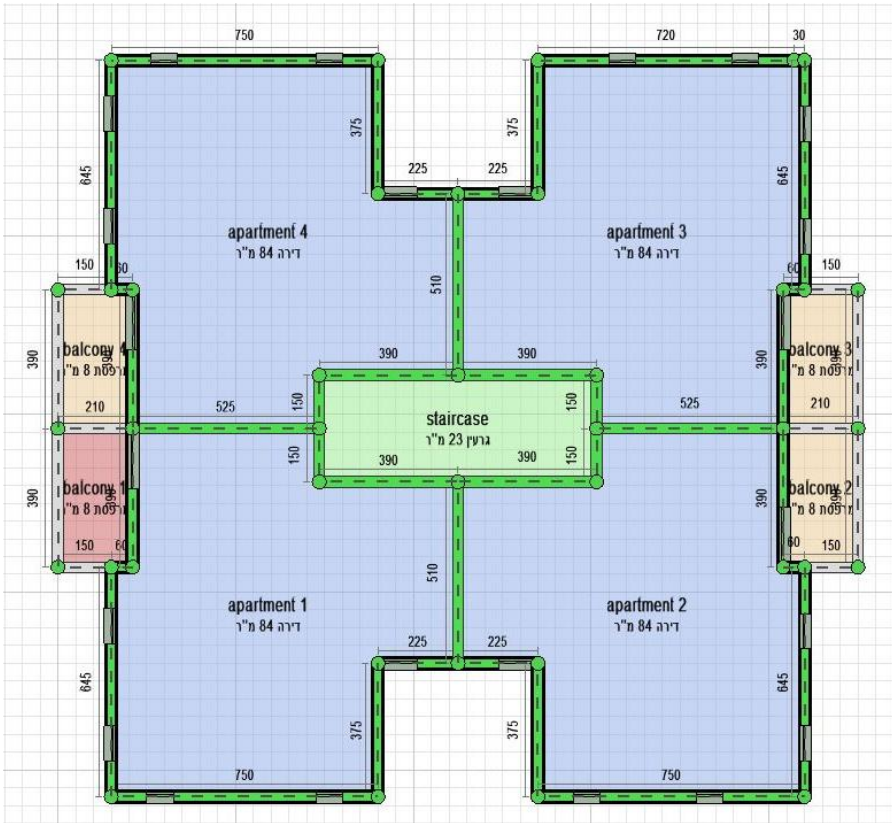
- To isolate urban effects, added floors are assumed to be identical to existing ones.



Effect of mutual shading by adjacent buildings



Differences in estimated annual AC demand for a 7-story building (kWh/a)

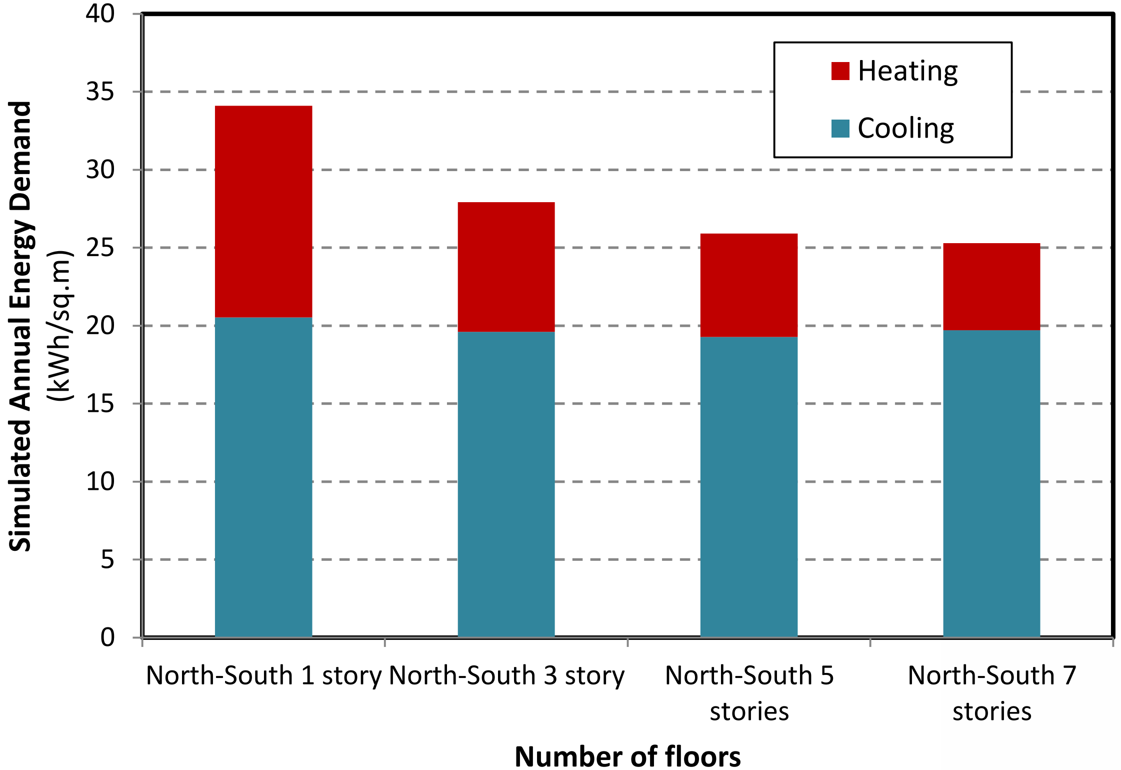
	cooling	heating	total AC
no shading	37,340	21,696	59,037
mutual shading	34,171	24,621	58,792
% change	**-8.5**	**13.5**	**-0.4**

comment:

Windows in the case study building are small, and distributed uniformly on all facades. Larger windows and a non-uniform distribution (as in ‘solar’ buildings) would

- display a much larger shading effect
- have a different balance of heating and cooling
- be more affected by occupant control of shading

Annual energy demand for AC building

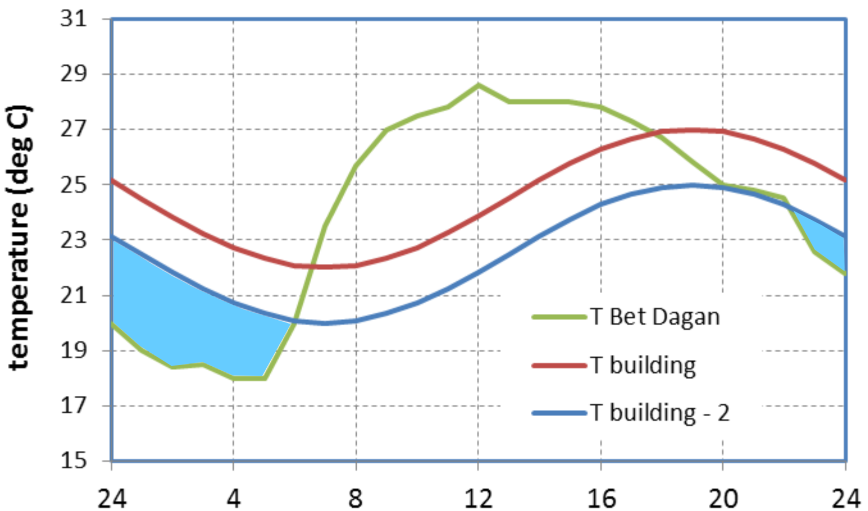


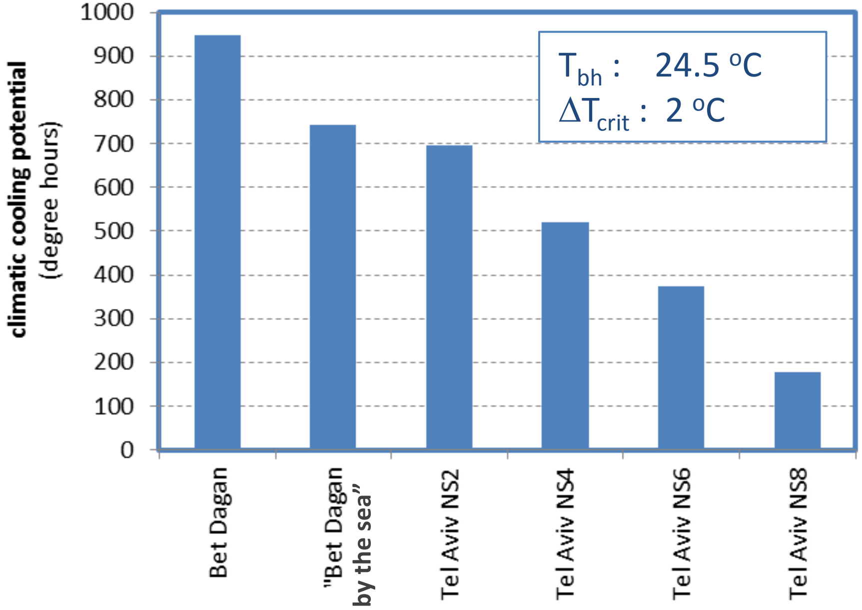
Average annual HVAC load in 7-stories building [kWh/m^2]	
1st floor	16.6
Middle floors	23.5
Top floor	43.0

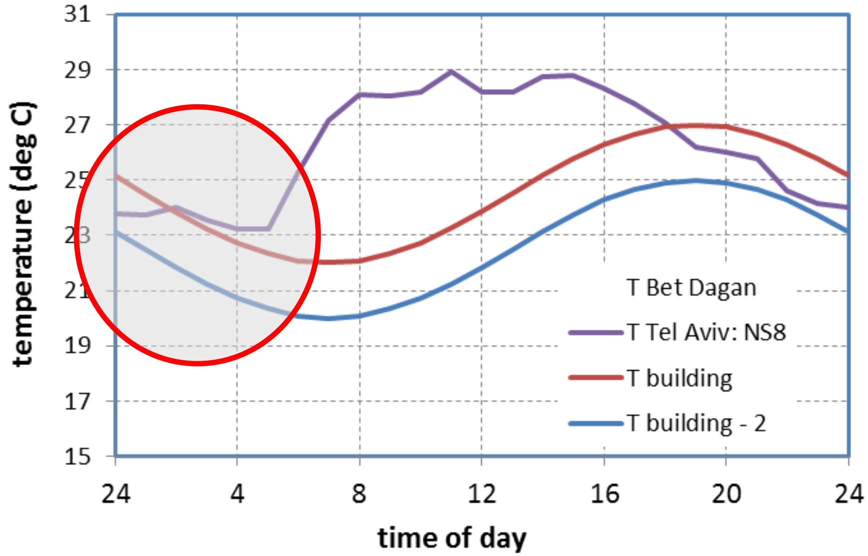
In spite of increased air temperature, adding floors actually reduces average A/C loads

Effect on climate cooling potential of non-AC building

The climate cooling potential (Artmann et al., 2007) is the difference between the hourly indoor air temperature, approximated by a sine curve, and concurrent outdoor air temperature, summed over the cooling period.







Discussion

- Taller buildings more efficient than lower ones because of exposed roof.
- The effect of mutual shading by adjacent buildings depends on the details of the fenestration and glazing design, such as size of windows, glazing properties, shading elements installed and occupant controls.
- The simulated buildings have a poor thermal envelope. Better construction during retrofit is likely to yield even smaller differences among buildings of different heights, especially if roof insulation is improved.
- Buildings were only modelled under conditions where all surrounding buildings were of the same height. Additional complexity resulting from varied building height was not accounted for.
- The model accounts for the reduced solar gains in winter as well as in summer, but assigns a fixed lighting schedule. The effect of this simplification is marginal because Israel is a sunny country.

Conclusions

There is probably no clear-cut conclusion…

Interpretation of the findings depends on assumptions regarding AC use – which in turn depends on occupant behaviour.

- The increase in building height will lead to higher air temperature at night and a reduction in wind - but may not necessarily increase overall energy demand, or even just the air conditioning loads.
- Negative effects of the increased UHI are manifested in non-AC buildings – or in AC buildings that suffer equipment failure.
- Although modelling and simulation should address the inter-related behaviour of buildings and the urban environment – these are now typically separate exercises, carried out by different people (if at all).

Take home message (?)

I do not see any real benefit in "mitigating the urban heat island". I would rather see objectives such as improving comfort or reducing GHG emissions. These goals may be best achieved through a variety of methods – of which urban climate modification is one option (and not always the most effective one).

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The climatic cooling potential in a non-AC building

The CCP is defined as follows (Artmann *et al.*, 2007):

$$CCP = \frac{1}{N}\sum_{n=1}^{N}\sum_{h=h_i}^{h_f} m_{n,h}(T_{b,n,h} - T_{e,n,h})$$

$$\begin{cases} m=1h \text{ if } T_b - T_e \geq \Delta T_{crit} \\ m=0 \text{ if } T_b - T_e < \Delta T_{crit} \end{cases}$$

h	-	time of day
T_b	-	building temperature
T_e	-	external temperature
ΔT_{crit}	-	temperature difference at which ventilation begins

$$T_{b,h} = 24.5 + 2.5\cos(2\pi\frac{h - h_i}{24})$$

T_{bh}	-	Building temperature assumed to oscillate around 24.5 °C
h_i	-	time at which ventilation may start (typically – 19 hrs)