A COMPUTATIONAL CASE STUDY ON THE THERMAL IMPROVEMENT POTENTIAL OF RESIDENTIAL BUILDINGS IN TEHRAN

Mohammad Reza Dara, Dariush Wossugh, Ardeshir Mahdavi

Department of Building Physics and Building Ecology,
Vienna University of Technology, Austria

ABSTRACT

This paper investigates the implication of alternative design and retrofit options for thermal performance (heating and cooling demand reduction potential) of existing residential buildings in Tehran, Iran. For the investigation three typical existing residential buildings were selected. Subsequently, parametric simulation were conducted to explore the impact of various thermal retrofit measures on the heating and cooling demand as well as the overheating tendencies in the selected buildings.

INTRODUCTION

Energy use in Iran is rather high (approximately 85 GJ per capita per annum). Roughly 40% of total energy consumption of the country is due to buildings (IFCO 2009). As a significant increase in the – currently subsidized – energy prices is to be expected, thermal retrofit of existing buildings will become highly important. Thermally relevant building construction guidelines have been adopted since 2001, but most of the existing buildings do not comply with the new standards.

In this context, the present paper investigates the implication of alternative design and retrofit options for thermal performance (heating and cooling demand reduction potential) of existing residential buildings in Tehran. For the investigation three typical existing residential buildings with different layout plans were selected. Information was collected regarding local micro-climatic conditions, site circumstances, building material properties, construction details, technical data regarding devices for cooling, heating, lighting, appliances and user-related data (patterns of presence, operation of appliances and building control systems).

This information was fed into digital simulation models of the above mentioned buildings. Subsequently, parametric simulation were conducted to explore the impact of various thermal retrofit measures (e.g., better insulating envelope components, better glazing in terms of U- and g-values, deployment of external shading elements, use of natural ventilation and passive night-time cooling method) on the heating and cooling demand as well as the overheating tendencies in the selected buildings.

The simulation results demonstrate the theoretical improvement potential due to the explored thermal retrofit scenarios and measures.

METHOD

To compare the implications of various thermal retrofit measures, parametric simulation was applied. The objective was to identify those alternatives, which reduce heating and cooling loads of (and overheating tendencies in) existing apartments in Tehran. Three typical, recently constructed apartment buildings were selected. Figure 1 shows schematic floor plans of these apartments, referred to here as M, S, and Y.

The external walls of these buildings typically consist of (from outside to inside): granite stone (2 cm), mortar (2 cm), brick (20 cm), mortar (2 cm), and plaster (2 cm). This and other default constructions assumption (see table 1) was used to simulate the base line case. Options involved different levels of insulation (EW2, R2, P2), various glazing types (G1 to G4), external blinds (BL1 with assumed 90% solar gain reduction and an operation schedule based on sun position, deployed during the summer months), and ventilation regimes V1 (base case), V2 (active operation mode), and V3 (passive operation mode).

To obtain reliable information regarding internal gains, in ten different apartments detailed interviews were carried out to document the extent of occupancy as well as the operation of luminaires and domestic appliances. This led to the definition of two different internal gain assumptions (see Table 2). The first relates to a family of four (IG1), whereas the second represents a family of two (IG2). For each of these 2 internal gain types associated hourly load profiles were developed. IG1 was applied to two-third of apartment units in buildings M and S. The remaining units as well as units in building Y were assumed to be of type IG2.

Note that the existing buildings are characterized by marble or granite slabs on the facade. Retrofit via addition of insulation on these stone facades is not feasible. Thus, for the purposes of the present study, the envelope improvement options assume insulation is added on the inside surface of the elements.

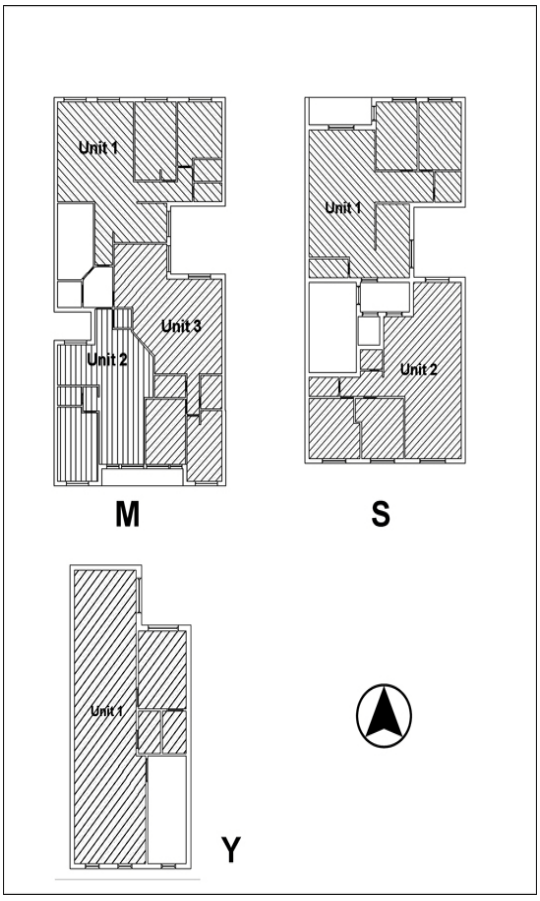

Figure 1. Schematic floor plans of the selected apartments (M, S and Y).

For the purposes of the parametric simulation runs, over 25 different combinations of the options summarized in Table 1 were generated. In the present paper, 11 scenarios out of this set are considered (see Table 3). A numeric thermal performance simulation tool (EDSL TAS 2009) was used to perform the simulations. Tehran climate was defined in terms of a weather file for the reference year 2008. Two types of simulations were performed:

- Active building operation assumption (leading to simulated heating and cooling loads)
- Passive (free running) building operation assumption (leading to estimated overheating tendency).

Overheating tendency was operationalized in terms of the indicator Mean Overheating (OH_m) as per equation 1. :

$$OH_m = \sum_{j=1}^{n} \frac{\theta_{i,j} - \theta_{ref}}{n} \qquad [1]$$

Here $\theta_{i,j}$ refer to the mean indoor air temperature (°C) at hour j (averaged over all simulated zones in each floor), θ_{ref} the reference indoor air temperature for overheating (26 °C) and n the total number of hours during the simulation period (from April 1st to October 31st). Note that the term $\theta_{i,j} - \theta_{ref}$ considered only for hours when $\theta_{i,j}$ is greater than θ_{ref}.

To compute the mean overheating, three different ventilation options were considered. The first set represents base case (see V1 in Table 1). The second set involves a night-time ventilation rate (see V2 in Table 1). The third set assumes, as compared to V2, higher ventilation rates (see V3 in Table 1).

To calculate heating and cooling demand, the thermostat setting was assumed to be between 19 and 26 °C. Cooling loads were computed for ventilation schemes V1 and V2.

*Table 1. Overview of the simulation assumptions and improvement options (*denotes existing construction features)*

ITEM	CODE	DESCRIPTION
General information	M	15 Apt. in 5 Floors, North-South
	S	10 Apt. in 5 Floors, North-South
	Y	4 Apt. in 4 Floors, North-South
Roof	R1*	No insulation; U = 3.27 $Wm^{-2}K^{-1}$
	R2	20 cm insulation; U = 0.22 $Wm^{-2}K^{-1}$
External wall	EW1*	No insulation; U = 1.70 $Wm^{-2}K^{-1}$
	EW2	7cm insulation; U = 0.57 $Wm^{-2}K^{-1}$
Floor over parking area	P1*	No insulation; U = 0.51 $Wm^{-2}K^{-1}$
	P2	20 cm insulation; U = 0.17 $Wm^{-2}K^{-1}$
Glazing	G1*	Single glazing; g = 0.78; τ_v = 0.79; U = 5.46 $Wm^{-2}K^{-1}$
	G2	Double glazing; g = 0.78; τ_v = 0.79; U = 2.80 $Wm^{-2}K^{-1}$
	G3	Double glazing; g = 0.41; τ_v = 0.62; U = 2.80 $Wm^{-2}K^{-1}$
	G4	Double glazing; g = 0.48; τ_v = 0.71; U = 0.92 $Wm^{-2}K^{-1}$
Blinds	B0*	No blinds
	B1	External blinds
Ventilation	V1	ACH = 0.6 h^{-1}
	V2	Winter: ACH = 0.6 h^{-1}; Summer (08:00 to 23:00): ACH = 0.6 h^{-1}; Summer (23:00 to 08:00): ACH = 2 h^{-1}
	V3	Winter: ACH = 0.6 h^{-1}; Summer (08:00 to 23:00): ACH = 1 h^{-1}; Summer (19:00 to 08:00): ACH = 10 h^{-1}

Table 2. Internal gain assumptions

CODE	DESCRIPTION
IG1	Family of 4 (2 adults, 2 children); occupancy: 5.1 W.m^{-2}; equipment and lighting: 8.6 W.m^{-2}
IG2	Family of 2; occupancy: 3.2 W.m^{-2}; equipment and lighting: 7.7 W.m^{-2}

Table 3. Overview of the 11 simulation scenarios

SCENARIO	GLAZING	BLIND	WALL	ROOF	FLOOR OVER PARKING
1	G1	B0	EW1	R1	P1
2	G1	B1	EW1	R1	P1
3	G2	B0	EW1	R1	P1
4	G2	B1	EW1	R1	P1
5	G3	B0	EW1	R1	P1
6	G4	B0	EW1	R1	P1
7	G4	B1	EW1	R2	P1
8	G1	B0	EW2	R1	P1
9	G1	B0	EW1	R2	P2
10	G2	B1	EW2	R2	P2
11	G4	B1	EW2	R2	P2

RESULTS

Figure 2 shows the simulated annual heating load of all buildings 11 scenarios as specified in table 2. The associated heating load reductions (in percentage) are shows in Figure 3.

Figure 4 shows the annual cooling load for all buildings and scenarios (ventilation scheme V1). Associated cooling load reductions are shown in Figure 5. Figure 6 shows annual cooling with veneration set V2 (see table 1). The associated cooling load reductions are shown in Figure 7.

Figure 8 to 10 show simulated mean overheating values for ventilation sets V1 to V3 respectively.

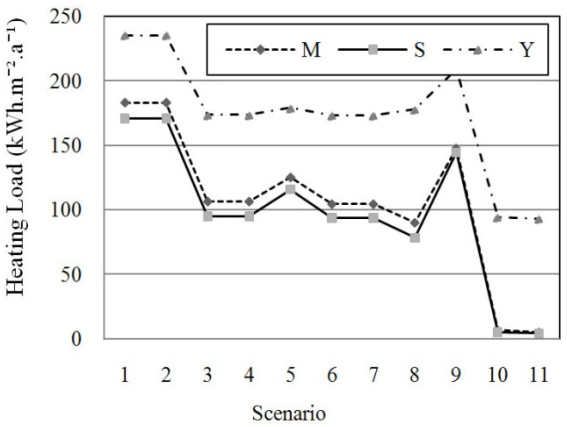

Figure 2. Simulated annual heating load (in kWh m⁻²a⁻¹) for 11 scenarios (see table 2)

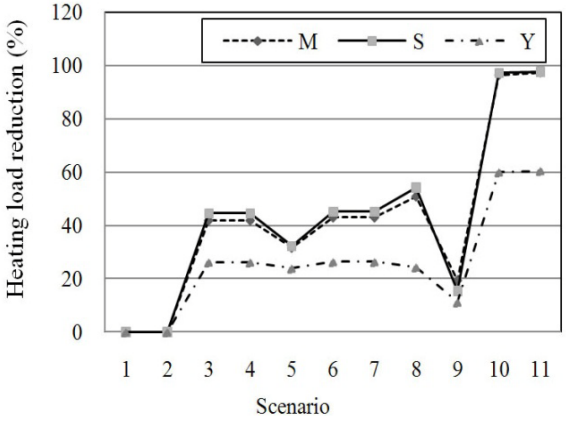

Figure 3. Simulated heating load reduction

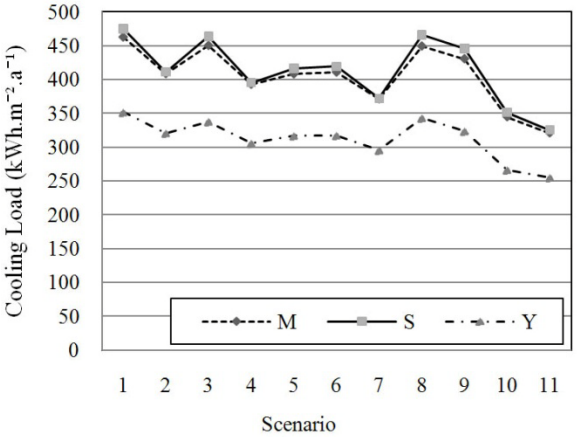

Figure 4. Simulated annual cooling load (in kWh m⁻²a⁻¹) (ventilation scheme V1)

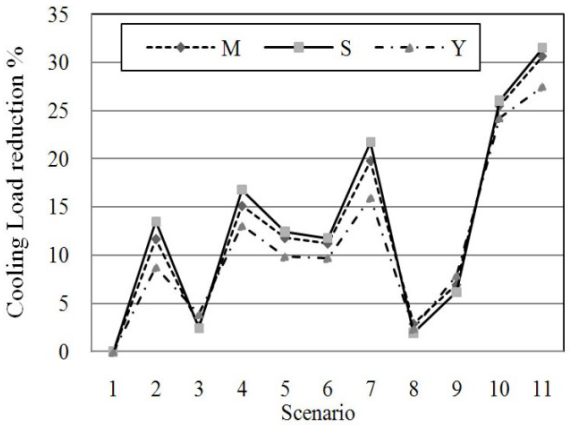

Figure 5. Simulated cooling load reduction (ventilation scheme V1)

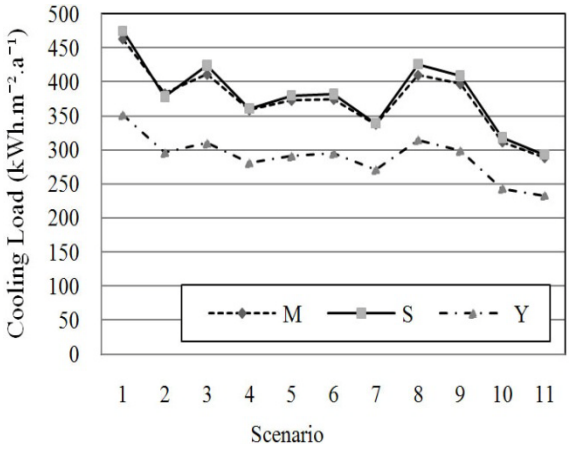

Figure 6. Simulated annual cooling load (ventilation scheme V2)

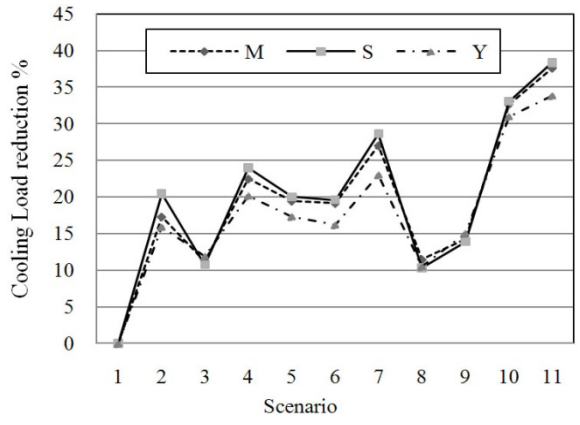

Figure 7. Simulated cooling load reduction (ventilation scheme V2)

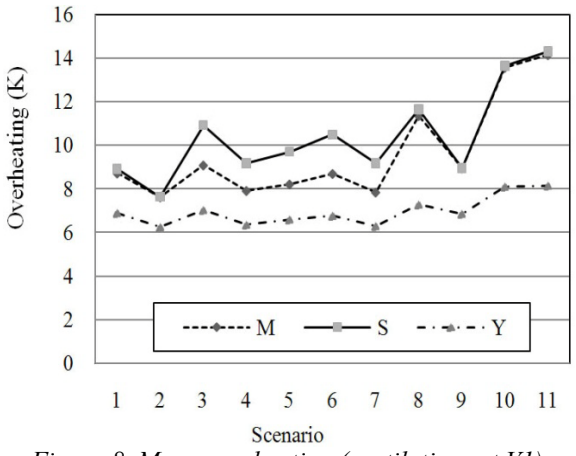

Figure 8. Mean overheating (ventilation set V1)

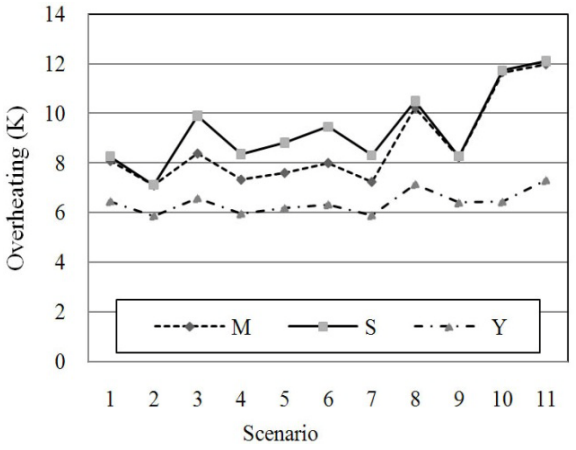

Figure 9. Mean overheating (ventilation set V2)

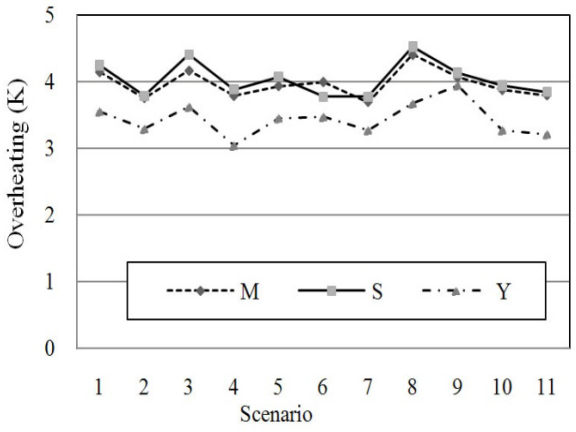

Figure 10. Mean overheating (ventilation set V3)

DISCUSSION

The heating load reduction potential due to thermal retrofit options is significant (see Figures 2 and 3). A combination of various measures allow to reduce heating load down to about 95% for buildings M and S and about 60% for building Y (as compared to the base case: scenario 1, Table 3). The difference between buildings M and S to building Y is mainly due to internal gains and corresponding reduction in required heating. These results imply that a drastic reduction (or even elimination) of mechanical equipment for heating in Tehran might be feasible.

The cooling load reduction is likewise remarkable (see Figures 4 and 5). It amounts to about 32% for buildings M and S and about 28% for building Y. Even better results can be achieved via the alternative ventilation set V2, namely 37% (buildings M and S) and 34% (building Y).

Results highlight the importance of solar protection toward cooling load reduction. As it can be seen from Figures 5 and 7, the scenarios with higher cooling load reduction (2, 4, 7, 10, and 11) involve the deployment of blinds. Amongst the scenarios, which do not involve blind deployment, only those with solar protection glazing (low g-values), namely scenario 5 (glazing G3) and scenario 6 (glazing G4) offer noteworthy levels of cooling load reduction.

A comparison of the cooling loads for ventilation schemes V1 (see Figures 4 and 5) and V2 (see Figures 6 and 7) implies that higher air exchange rates during summer nights might further reduce cooling loads (across all scenarios).

Thermal insulation of opaque building envelope components, without effective glazing and shading provides only modest improvement in terms of cooling load reduction (see scenarios 8 and 9, Figures 4 to 7). But given the absence of a negative effect on cooling load (no increase, modest reduction) and the positive effect on heating load (significant decrease), the application of thermal insulation is to be recommended.

A purely passive mode of building operation in the summer time results in rather high overheating levels (see mean overheating results in Figures 8 to 10). Nonetheless, high night-time ventilation rates (ventilation scheme V3) can lead to a significant reduction of overheating, down to values around 3 to 4 K.

CONCLUSION

The results of a parametric simulation study of the thermal performance of typical residential buildings in Tehran were presented. The results suggest that, through a combination of design and operation features (better envelope components, deployment of shading elements, use of natural ventilation and passive night-time cooling) a significant reduction of heating and cooling load can be achieved. Specifically, heating systems could be significantly downsized or possibly even eliminated.

However, provision of thermally comfortable indoor environments in summer period via purely passive means represents a difficult challenge given the prevailing climatic conditions, the urban context, and the existing construction practices.

Ongoing research addresses a number of related questions. Measurements in building before and after thermal retrofit measures should help empirically verify the simulation-based conjectures stated in the present paper.

Moreover, an ongoing effort examines the implications of adding thermal insulation on the inside surface of external building envelope elements (walls, roofs, etc.). It has been argued, that inside insulation may cause problems due to heightened heat transfer via thermal bridges and well as potential water vapor condensation risk inside the external building components, particularly in the colder months of the year. The initial results of our investigation in this matter indicate that that the later risk is rather low: calculated quantities of condensed water vapor inside walls in the winter period (for Teheran conditions) are low, such that – given proper detailing – any condensation should be dried out during the warmer months of the year. Moreover, calculated minimum surface temperatures of linear thermal bridges under standard indoor and outdoor conditions did not reveal any surface condensation risk.

ACKNOWLEDGMENT

The authors would like to acknowledge the support of "europerl" (Perlit Production LTD) toward conducting research (development of perlite-based insulation panels for external walls and roofs) related to the themes discussed in the present contribution.

REFERENCES

EDSL 2009. Thermal simulation application TAS. Environment Design Solution Limited. URL: www.edsl.com. (site visited November 2009)

IFCO 2009. Iranian fuel conservation company (IFCO). URL: www. ifco.ir. (site visited November 2009)