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Design to Thrive

What heavy weight buildings in hot climates can tell us about their thermal performance

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Abstract: Concrete, masonry walls and stone finishes are high density materials and have high thermal capacity, they are referred to as heavy-weight construction or thermal mass, which is the main construction type in Lebanon. Although thermal mass construction is usually recommended in hot climates in order to reduce internal temperature fluctuation, its actual thermal behavior in Lebanon is not well documented through direct observation, relying instead on its theoretical performance.

This study's main objective is to characterize the actual thermal performance of such construction, in the context of building occupancy and intermittent A/C usage. The paper starts with a brief introduction of the residential typologies in Lebanon followed by the description of the three thermally monitored apartments, in use or empty, located in one same neighborhood of Beirut, Lebanon. The monitoring was undertaken during summer 2015 using hourly data loggers.

The analysis of the recorded data provides a clear and empirical understanding on: 1. how heavy weight buildings interact within the hot and humid climate of Beirut; 2. how the effect of regulating the internal thermal fluctuation is shown; and 3. what are the most influential factors that would further enhance thermal performance of thermal mass construction.

Keywords: Thermal-mass, building-performance, residential, Lebanon, warm climate

Introduction

This paper investigates the thermal performance of apartment buildings within the coastal climate of Beirut, Lebanon. Three apartments are here presented out of a sample of five, which have been thermally monitored during summer 2015. The analysis of the recorded data provides an empirical understanding on how typical residential buildings using heavy to medium-weight construction perform within the warm and humid climate of Beirut. Furthermore, this analysis shows the effect of the thermal mass associated to the heavy-weight construction in regulating the internal temperature fluctuation, and the factors that can further influence and enhance the thermal performance of the typical Lebanese construction.

Typology

Two main types of residential units prevail in Lebanon, the detached house type and the apartment building. The apartment typology is the most common, located in buildings of four

to eight floors. The average area for a small apartment is 120sqm including two bedrooms, a family den, a kitchen, main living and reception area and two to three WCs (CDR, 2004). Open balconies are an intrinsic part of the apartment, however they are commonly glazed and turned into conservatories in order to provide extra space (Melki, 2009).

A/C is extensively used for cooling, to the extent that finding a free running, occupied apartment to monitor is difficult. The individual split-system A/C is the most commonly used type.

Thermal Mass

The term Thermal Mass refers to any material that has the capacity to absorb, store and release heat (Littlefield, 2007; Szokolay, 2004). Concrete, masonry walls and stone finishes are high density materials with high thermal capacity, hence the term heavy-weight refers to that type of construction, which is the main construction type in Lebanon. Thermal performance of heavy-weight construction in hot climates is described as taking longer to warm up when exposed to solar gains and slower to respond to temperature variation (Littlefield, 2007; Szokolay, 2004). In the same way, it takes longer to cool down and lose the extra heat. This stored heat will dissipate during the night, when air temperatures are lower. This situation is ideal to maintain a comfortable indoor temperature when the temperature difference between day and night is considerable. Furthermore, Szokolay (2004) considers it a practical free-running solution to keep internal conditions within comfort. When it comes to expressing the thermal properties of thermal mass, the U-value is not relevant, instead the time lag, decrement factor and admittance or Y-value (Szokolay, 2008) are more appropriate for such materials. The time lag, expressed in hours, is the delay between the ambient temperature peak and the peak temperature of the space where thermal mass is applied. The decrement factor is the ratio of the actual heat reaching the thermal mass, and the heat that would be post emitted, and, since it is a ratio it is non-dimensional. The admittance or the Y-value expresses the thermal mass ability to store heat within itself, while ambient temperature fluctuates, it is expressed in W/m^2K although the same unit as the U-value, yet it expresses a different physical property, the larger it is the less internal thermal fluctuation is to be expected.

With the absence of local references for any of the above thermal property values of the different local construction materials and types, both Szokolay's (2008) and CIBSE Guide A (2006) are used to calculate or to find the nearest construction match for U-values and Y-values of the different types of walls and slabs encountered within the monitored buildings, as shown in the table 1. It can be noted that although the walls in apartment 3 have a better U-value than in apartment 1 and 2, all the apartments have similar admission values.

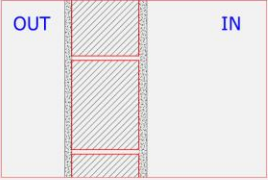
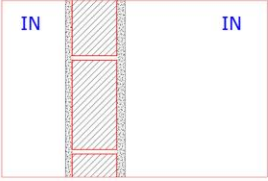
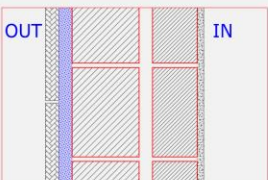
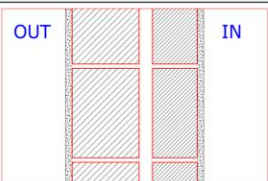
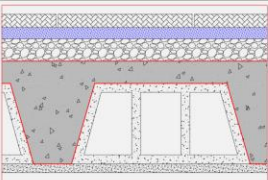
Methodology

During summer 2015, three different apartments have been thermally monitored, for a period of two weeks to three months, these are located within one of Beirut's suburban neighbourhood of Ain er-Remeneh, the period of monitoring stretched from August to October. The historical weather files for the entire monitored period is available from the main, official weather station, located at the nearby airport some 3 to 4 Km away.

The fieldwork was mainly based on the monitoring of thermal performance of selected rooms in each apartment, interviews of the occupants and observations. Instrumentation for the thermal monitoring of the various apartment included 16 Gemini Tiny Tag data loggers for

Dry Bulb Temperature and Relative Humidity. Four of these included probe sensors specially recommended for outdoor monitoring.

Table 1. Ranges of U-Values and Y-values for the wall and slab constructions contained within the research

Construction Type	Building	U-Value (W/m ² k)	Admittance Y-Value (W/m ² k)
 <p>21mm Ext render + 150mm Hollow Concrete (dense) Block + 21mm Int Plaster</p>	1 & 2	2.13	3.7
 <p>21mm Ext render + 100mm Hollow Concrete (dense) Block + 21mm Int Plaster</p>	1, 2 & 3 (internal partitions)	2.57	3.4
 <p>30mm Stone Cladding 25mm Cement Mortar 150mm Ext Hollow Concrete (dense) Block 30mm Air Gap 100mm Int Hollow Concrete (dense) Block 21mm Int Plaster</p>	3 (east)	0.54	3.4
 <p>25mm External Render 150mm Ext Hollow Concrete (dense) Block 30mm Air Gap 100mm Int Hollow Concrete (dense) Block 21mm Int Plaster</p>	3 (west)	0.55	3.4
 <p>30mm Stone Tiling 25mm Cement Mortar 50mm Aggregates 230mm Hollow Concrete Slab Cast in-Situ 21mm Int Plaster</p>	1, 2 & 3	1.96	5.5

Climate

Beirut is located on the eastern Mediterranean coast. Based on the Koppen-Gieger classification (Kottek et al; 2006), it falls within the Csa zone, which stands for warm temperate winter and no precipitation in the hot summer. From the representative Beirut weather file (Meteronorm 7), the following descriptive statements can be derived. Beirut has long hours of sun that provide high solar irradiation. Summer humidity fluctuates between 60 and 80% with an average above 70%, peaking during the night. August is the hottest month with maximum dry bulb temperature reaching 33°C and a minimum of 25°C. Furthermore, the diurnal difference ranges between 5 and 7°C. Summer months extend from June till mid-October, with an average monthly temperature ranging between 25 and 28°C, and maximum temperature reaching 33°C (July, August) and minimum 20°C (June, October). The average annual wind velocity is less than 3m/s with monthly averages varying between 2.5 to 3.2m/s.

Case Studies fieldwork analysis

Apartment #1 – Full time cooling

This 1960s east facing apartment building has five floors with 4 apartments per floor. In each apartment, the floors and ceiling slabs are tiled and plastered concrete respectively, whereas the walls are plastered hollow concrete blocks. Windows are single glazed panes with steel frames, which are, according to the occupants, permeable to wind, and thus infiltration is high. The monitored apartment is located on the third floor, and it was surveyed from mid-September till end of October, monitoring internal temperature in a continuously cooled space. The apartment is for a family of three, with all occupants spending much of their day at home. The apartment has an east orientation for the living and bedrooms. Individual, old window type A/C is continuously on in the living/dining space.

Apartment #2 – Mixed-mode cooling

This building was also built in the 1960s and it is made of 5 floors, with two apartments on each, the ground floor is for commercial use. The main façade where the living areas are facing is south-west oriented. Its eastern façade is blank and exposed. The building is made of concrete slabs, plastered hollow concrete block walls, and all the windows are single glazing with timber frames. The monitored apartment is on the fourth floors, hence an intermediate floor. The apartment has two bedrooms, one main living area, a dining area and a kitchen, for a family of four. Father is at work all day, as well as one of the sons, whereas the other, a university student is more often at home. Mother is mainly at home. Data loggers for dry bulb temperature are located in the living area, the bedroom and the semi outdoor space with a perforated lightweight brick called *clostra*. The monitoring took place between from August and early October.

The apartment has individual A/C units installed in each bedroom and the living-dining area. The latter one is seldom used, whereas the bedrooms' A/C are used during the night at random times and for varying length. Otherwise in the living area a fan and the open windows are used to provide some comfort from the heat and humidity. When A/C is used in whatever room, the internal timber door is closed in order to keep the coolness contained.

Apartment #3 – Free running, Unoccupied

This monitored apartment is within a newly constructed building and is still unfurnished and unoccupied. The building has an East orientation for the living areas, and is made of concrete slabs and double cavity hollow concrete block walls. As per the current planning regulation, the east façade is clad with natural white and yellow stones; whereas the west facade is rendered and painted. Data loggers for dry bulb temperature are placed in the main living area on the east side, as well as in one room on the west side. The monitored phase spanned from August to the end of October. This apartment is on the 7th floor of a 9-story building, hence an intermediate location, and since it is unoccupied, neither A/C nor any other power or heat source is available. Furthermore, based on the recommendation of the building owner, one data logger is placed in the staircase leading to the underground basement, an area that is never used by any of the building's inhabitants. This area is ventilated through the main entrance gate without being hit by direct sun light.

In table 2 below the different cooling modes of each room is listed as well as the calculated overall room admittance, which sums all the products of the respective surface areas of external and internal walls along with the floor and ceilings multiplied by the corresponding admittance of each, and is expressed in W/K (Balcom, 1983).

Table 2. Recap of each monitored room cooling mode and the corresponding calculated weighted Y-values

	Internal Space	Cooling Status	$\Sigma [Y*Area]$ (W/K)
Apartment #1	Dining	Full time	180
	Entrance	Full time	257
Apartment #2	Dining	Seldom	311
	Bedroom	Mixed mode	374
Apartment #3	Living	Free running	348
	Bedroom	Free running	197

Results

The current study investigated the thermal performance of existing apartments with different envelope construction, cooling patterns and living habits.

Apartment 1 has continuous cooling which pushes the indoor temperatures almost always within a 29°C average, yet due to poor envelope performance, high infiltration levels, and undersized old A/C, there is a discrepancy between the cooling set point at 26°C and the actual recorded temperature, which is shown to fluctuate above 29°C in the early afternoon when the sun start to hit the external west wall, and windows nearer to the data logger (Dining temperature - days 266, 267 and 268). The Entrance area presents a temperature profile that is more stable as not affected by direct solar gains. On the night of day 268 to 269 the cooling is turned off till late morning, without windows opening, but the expected high infiltration is taking the temperature trend parallel to the outdoors' with 1K warmer, whereas once the sun is up and till midday internal temperatures are considerably cooler from 3 to 4k

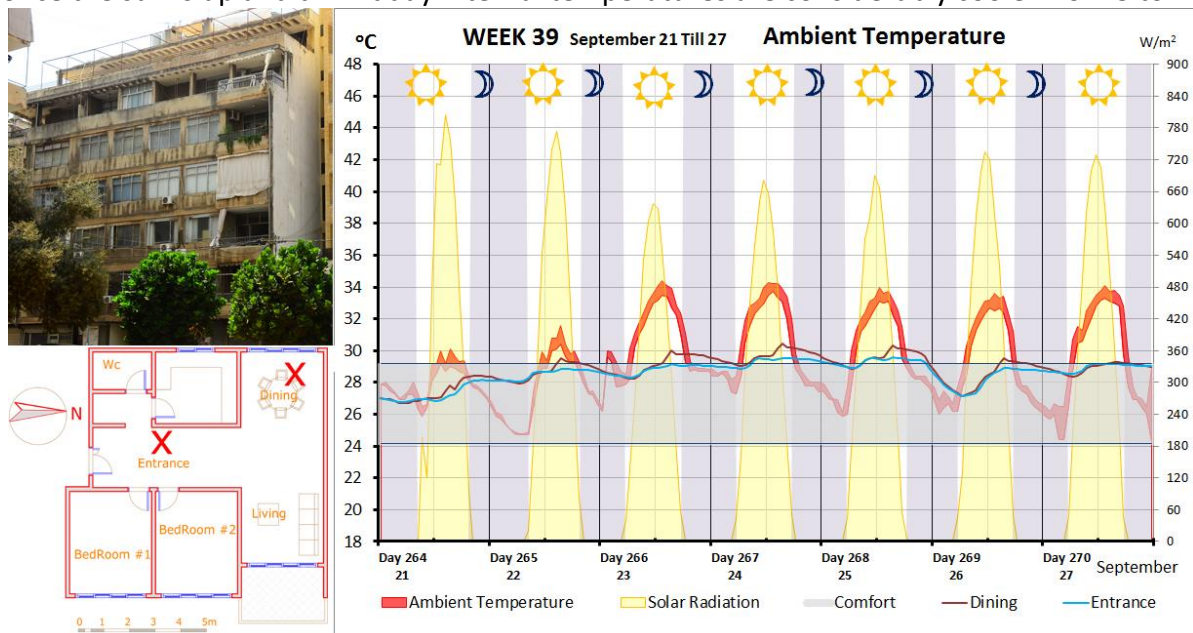


Figure 1. Building of apartment 1 in continuous cooling mode with the corresponding plan showing location of data loggers, along with the thermal graph for week 39

Discussions of observation are focused herein on week 32, August 1 till 7 for apartments 2 and 3.

Apartment 2 in mixed mode cooling, three spaces have been observed: the bed room, the dining area and the *clostra*, which is a sheltered semi-outdoor space. Extended night cooling and limited daytime cooling provide the bedroom with temperatures lower than the external temperature, yet when there is no night cooling, internal temperatures are 2 to 3 K

higher and following the same trend as the external temperatures. Cooling in the dining area is limited to no more than a couple of hours on alternate days. Observations show that maximum day and night temperatures have limited fluctuation of no more than 4K when outdoor ambient air temperature fluctuation reaches 9K. Internal daytime temperatures are down to 4K lower; whereas night temperature are warmer than outside temperature. The *clostra's* thermal behavior is similarly 2 to 3K cooler than the outdoors' day temperature and 2K warmer during the night, with a day/night fluctuation of 4-5K higher than the living area.

Looking closely on day 216, both the time lag and the decrement factor are clearly shown: the former is the time difference (horizontal axis) between the day's ambient peak temperature after midday (1pm) and both the *clostra'* and the dining's peak a couple of hours later (around 3pm). The latter is the temperature difference from the 34°C peak ambient temperature to the 31-32°C peak temperature of the dining and *clostra's*.

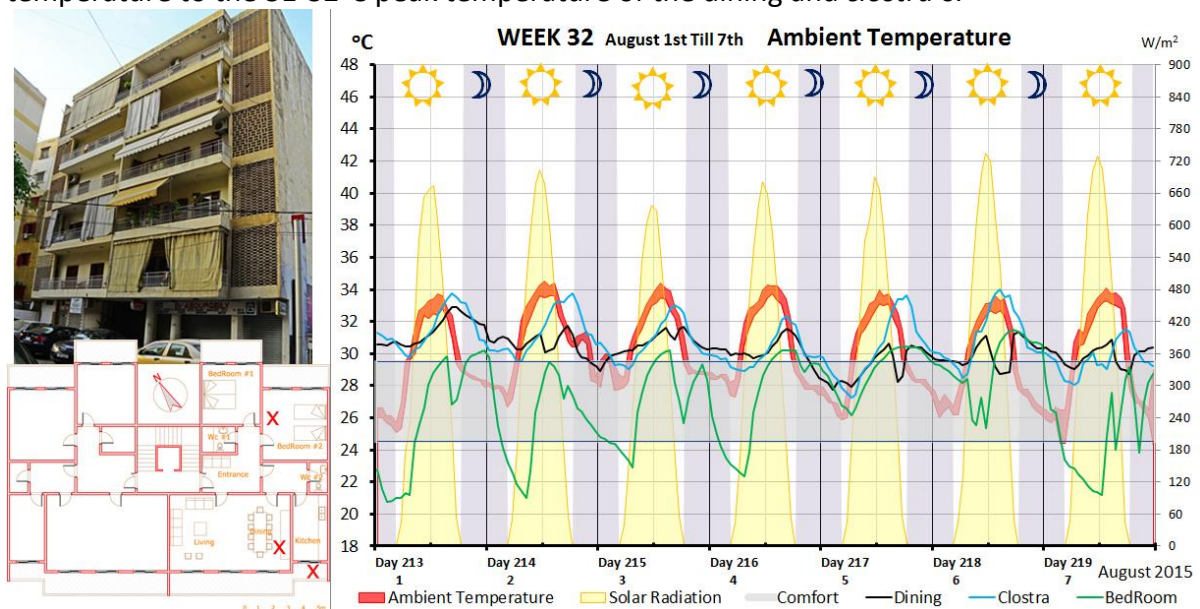


Figure 2. Building of apartment 2 in mixed mode cooling with the corresponding plan showing location of data loggers, along with the thermal graph for week 32

In the free running and unoccupied **apartment 3**, the dry bulb temperature of the living area and bedroom are recorded where the windows are kept 50% open. In addition, ground floor staircase leading to the basement is also monitored. Sun hit the living area data loggers directly around early afternoon and gave instantaneous thermal peaks, yet that aside, the temperature trend can be read with 2K cooler during the day and 3K warmer during the night, with a fluctuation ranging between 2 and 3K. As for the bedroom's day temperature, they are similarly 2K cooler than the outdoors but 4K warmer than the night temperature, and the daily fluctuation is only 2K; much less than the outdoors' 9K fluctuation. This reduced fluctuation is the effect of the surface admittance. Finally, the air temperature within the staircase leading to the basement is cooler than the apartment temperature and 2K cooler than the outdoors during the day and 2K warmer during the night with max fluctuation of 3K.

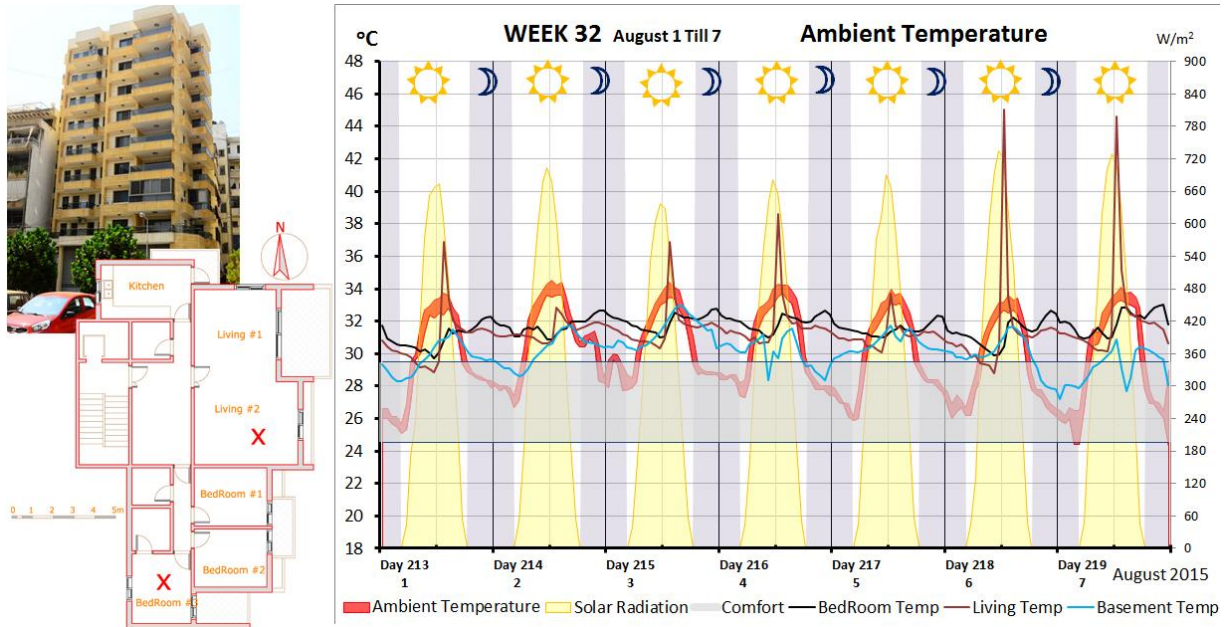


Figure 4. Building of apartment 3 free running with the corresponding plan showing location of data loggers, along with the thermal graph for week 32

Discussion

The above observations are the direct result of the thermal mass all those buildings have in common, combined with some ventilation. This is happening with high infiltration while A/C is running in apartment 1, windows are open when A/C is off in apartment 2 and apartment 3 has no A/C and windows are kept open. Based on the official weather station the wind is more often still during the day, whereas during the night it can reach an average velocity slightly above 2m/s, this creates low night air exchange varying from 0.9 to 4.5ach as shown in figure 5 and based on Szokolay (2008) and Brown (2001) calculation methods. Those air exchange are not enough to flush all the stored heat within the thermal mass during the night.

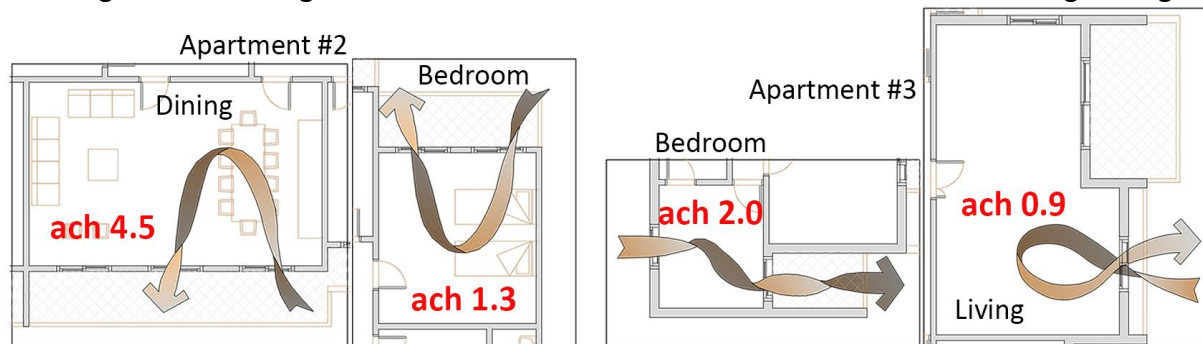


Figure 5. Calculated air exchange per hour (ach) in the different monitored rooms of apartment 2 and 3, based on the recorded air velocity of 2m/s. Also, the visualization of the internal air patterns is shown.

Concentrating on dining room of apartment 2 and living of apartment 3 with the data shown in table 3, the following observations can be stated: (1) the effect of almost similar Y-Values and weighted admittance responsible for heat storage within the envelop is shown in the day's cooler internal temperature. (2) The insufficient night air exchange is not able to get the internal temperature as low as the outdoors; yet the higher air exchange in the dining is maintaining its temperature cooler than in the living with much lower air exchange. (3) This lead to the role of the envelope's U-value with apartment 3 low value of $0.54\text{W/m}^2\text{K}$ that is not aiding in the dissipation of the night remaining heat and thus contributing to warmer

internal temperature compared to apartment 2 which has higher U-Value at 2.13W/m²K, that are further helping in heat dissipation.

Table 3. Comparative data for dining room and living area

Apart	Room	Orientation	Y-Values (W/m ² K)		Walls U-Values (W/m ² K)	Weighted admittance (W/K)	Air exchange (ach)	Cooler Δt Day (K)	Warmer Δt Night (K)
			Walls	Slabs					
2	Dining	South	3.7	5.5	2.13	311	4.5	4	2-3
3	Living	East	3.4	5.5	0.54	348	0.9	2	4

Conclusion

The paper reviewed the theoretical background of the thermal mass effect, as reducing the internal thermal fluctuation and keeping the day temperature cooler than the outdoors. It also explained the relevant physical properties that best express the thermal behavior of thermal mass and calculated the admittance or Y-value of the encountered relevant construction in the different monitored cases. Next the research thermally monitored three different apartments within the same Beirut neighborhood, with different cooling modes. Based on these observations the research showed how exposed thermal mass with Y-values ranging from 3.4 and 5.5 W/m²K combined with limited night air exchanges varying from 0.9 to 4.5 ach are able to: (1) reduce the internal temperature fluctuation from the outdoors' 9K to less than half at 4 and even 2K, (2) keep the internal day temperature between 2 to 4K cooler than the outdoors' but also are (3) not able to flush the night excess heat with night temperature 2 to 4K warmer than the outdoors'. (4) Reduced night time ventilation and low wall U-values of 0.54 W/m²K reduce the effect of night thermal flushing compared to a higher U-value of 2.13.

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