The Impact of Occupants' Exterior Shading Use and Window Opening on Summer Comfort in a Lowest-Energy Apartment Building

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ABSTRACT

A Viennese apartment building, KAM, was built in 2007 to minimum passive house requirements primarily designed to perform for heat conservation in winter. Less emphasis was placed on cooling in the warm months when planning the building due to the temperate continental climate of Vienna, Austria. Due to apartment owner complaints of overheating, exterior blinds were installed on apartment windows and doors on the topmost floor. Indoor temperature and humidity in four apartments have been monitored over three summer periods. The monitoring results are presented where mechanical ventilation with heat recovery is used in combination with exterior sun shading. The users in the case studies prefer using natural window ventilation to changing ventilation system settings. Indoor daily temperatures remain constant when windows are left closed and shading is used. Results from monitoring and interviews indicate the importance of considering summer cooling strategies in combination with user behavior in highly insulated buildings to control overheating in summer.

INTRODUCTION AND BACKGROUND

This paper analyses the effect of user behavior on the summer indoor comfort conditions in a passive house apartment building (KAM) in Vienna, Austria and continues monitoring of the indoor climate as described in (Bednar, Korjenic, et al. 2010).

A passive house has a super-insulated exterior envelope (including windows and doors) and is extremely airtight. To ensure good indoor environmental quality (IEQ), the buildings are equipped with highly efficient compact ventilation systems with heat recovery and air supply preconditioning using ground-source heat exchangers. Since 1995, the number of residential buildings using the passive house calculation method (PHPP) has increased exponentially in Austria. From 1995 to 2010, 11,800 buildings including both new construction and thermal renovations of existing buildings have been constructed to the passive house construction standard.

The majority of residences in Austria are in apartment buildings or row houses. One fifth of the population resides in Vienna, of which the majority lives in low-rise apartment buildings (Statistik Austria 2012). Thus, the studied building is selected as a representative case study for observing the effects of inhabitants' interactions with external shading devices on summer comfort.

The highest recorded summer air temperature during the three summer seasons was 36.1°C (97°F). However, the operative temperature is higher, taking the mean radiant temperature into account, and can reach over 40°C (104°F). During the hottest heat waves, the outdoor temperatures sink by 10 K (18°F) in the night. Theoretically, the residents can maintain cooler indoor temperatures by taking advantage of the night cooling by opening all their windows during the night.

BUILDING DESCRIPTION

KAM is a seven story condominium building with 88 flats built to the passive house standard as seen in Figure 1.

The building envelope is highly insulated with high airtightness (0.28 h^{-1}). The thermal transmittance values are summarized in Table 1. The building is a combination of a reinforced concrete shell with a prefabricated wood façade. In-

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terior partitions, insulated walls with 0.25 m (9 ¾ in.) mineral wool to an unheated interior atrium, and floor slabs are pre-fabricated reinforced concrete. The exterior envelope is highly insulated with two layers of mineral wool insulation, 30 cm + 5 cm (11.8 in. + 2 in.).

The ventilation system has a central pre-conditioned air supply through a ground source heat exchanger. Fresh air intakes and exhaust air outlets are located on the roof of the building. The air supply is distributed to each apartment containing a compact ventilation unit with a plate heat exchanger. Air supply volume can be regulated in the individual apartments (low, medium, and high). The building has been designed to take advantage of hybrid ventilation during warm periods, combining both mechanical and natural ventilation/shading strategies to cool the apartment interiors. The natural ventilation strategy is especially dependent on night cooling, taking advantage of the cooler evening temperatures and prevailing breezes from the southwest.

The monitored apartments are on the west and east facades, are stacked atop each other, and are located on the fifth and sixth (top) floors. The flats on the west façade have the same floor plan, as do the flats on the east side. Each flat has a balcony, and the glazed balcony doors to the bedrooms on

Figure 1   South (street view) and east facades of KAM.

the west side (W2) have exterior blinds. All windows and glazed doors are insulated triple-glazed with tilt and turn opening. The glazed area of the west apartments is 11.7 m² (125.7 ft²); the glazed area of the east apartments is 14.9 m² (160.8 ft²). The west flats are larger with 3 bedrooms and a floor area of 97 m² (1044 ft²); the east flats have two bedrooms and a floor area of 90 m² (969 ft²); the average flat size is 94 m² (1012 ft²).

HOUSEHOLDS

Table 2 summarizes the household sizes of the participating households in 2012. A post occupancy evaluation was conducted by Keul in May 2008, and it was determined that the average household size in the building is 2.1 people with a mean age of 37.6 years (Keul 2009). It has been observed that some residents moved into KAM to establish families. Two of the participating households increased in size from 2010 to 2012.

In Austria, there is no tradition of air conditioning or mechanical ventilation in residences. Cooling in hot months is usually provided by a combination of window ventilation, fans, and using interior and exterior window shading.

In 2011, W1 installed a set of large outdoor curtains hung at the edge of their loggia. All windows, except one living room window are shaded by the loggia above. Similarly, E1 does not have any exterior shading as all windows except one to the living room are also shaded by the loggia above. The occupants of E2 installed new exterior blinds in May 2011 stating that the shading from the originally installed blinds were insufficient for maintaining comfortable summer temperatures. In this paper, the flats are coded according to orientation, west (W) and east (E); and floor, 5th Floor (1) and 6th/Top Floor (2).

APPROACH

Self-Reported Cooling Behavior

In September 2012, personal interviews were conducted with the inhabitants to determine the occupants' daily self-reported natural ventilation cooling habits: window opening and shading use. It is interesting to note that all households reported owning indoor/outdoor thermo hygrometers, and that window opening decisions in summer are partially dependent upon outdoor temperature readings and time of day when direct sunlight enters the individual

Table 1.   Building Envelope Thermal Resistance Values (teamgmi 2004)

Building Assembly	Thermal Resistance SI, m²·K/W	Thermal Resistance US, ft²·°F·h/Btu
Roof	14	81
Exterior Wall	8	47
Floor Slab to Unheated Underground Garage	7	38
Windows	1	7

Table 2.   KAM Household Sizes in 2012

Apartment	Household Size
W1	4
E1	4
W2	4
E2	2

apartments. Generally, when the outdoor temperature is cooler than the indoor temperature and when the sun shone directly in the apartment, the inhabitants opened their windows.

The window opening and shading use for a typical day as determined from the interviews are summarized for each apartment in Figures 2, 3, 4, and 5.

E1 is the only household that reported short periodic ventilation after meals, where the window is fully open for five to 10 minutes, Figure 3.

W2 originally had outdoor blinds on only the bedroom windows. The homeowners retrofitted outdoor blinds on the balcony door from the living room in 2010. The occupants have additional air movement during the day with the tilted windows while blocking solar irradiation, Figure 4.
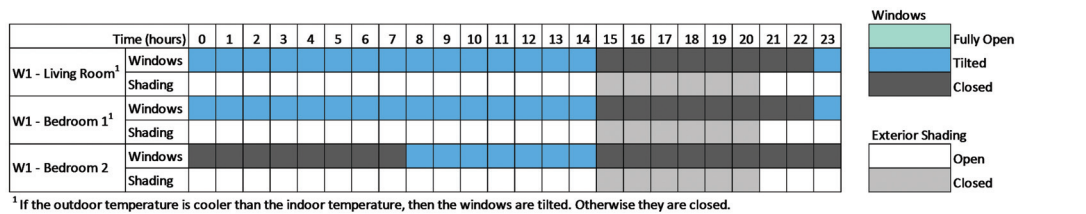

Figure 2   Apartment W1 window opening and shading schedule for a typical day.
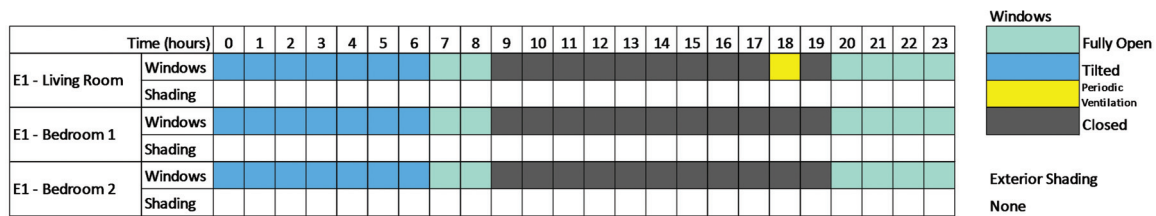

Figure 3   Apartment E1 window opening and shading schedule for a typical day.
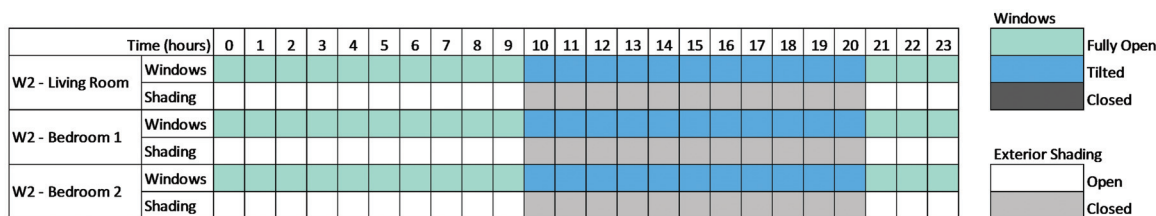

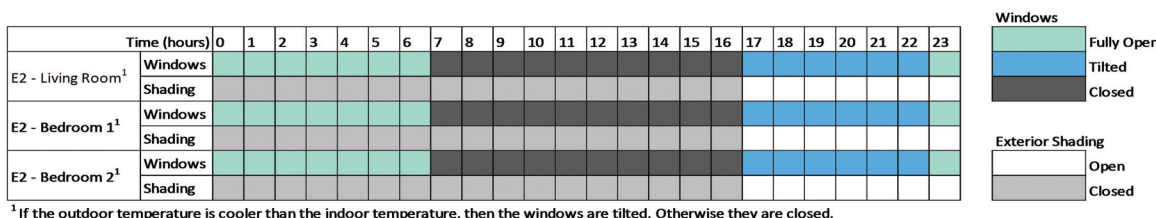Figure 4   Apartment W2 window opening and shading schedule for a typical day.

Figure 5   Apartment E2 window opening and shading schedule for a typical day.

Both the windows and exterior blinds are closed for the majority of the day. The apartment did not have any shading devices initially. In May 2011, exterior security blinds were installed. Not only heat is blocked but also daylight when the shading devices are used, Figure 5. Due to the exposed position on the topmost floor, the residents reported that it was necessary to keep the blinds down for the duration of the day to maintain cooler temperatures.

The general preference in all apartments is to leave windows open for as long as the occupants believe is possible as a fresh air supply is important, and fresh air from window ventilation is preferred to changing the ventilation system settings.

Longitudinal Monitoring in Four Apartments

Twelve T&D RTR-5 data loggers were placed in the four apartments measuring the indoor temperatures and relative humidities in three rooms: living room, master bedroom, and second bedroom/study. In this paper, temperature data from the summer seasons from June 1st to August 31st for 2010, 2011, and 2012 are compared, representing the third to fifth years of residency. Relative humidity values have been excluded as the indoor values range between 30% and 60%. Figure 6 shows the plans of the apartments where the data loggers were placed.

The results from 2012 are discussed in detail in Figures 8 to10. Data is shown in two groups: living rooms, and bedrooms/study. Outdoor conditions were obtained from a weather station in Vienna located 9 km (5.6 miles) from the apartment building. The daily ventilation and shading habits were compared to the measurement results.

Monitoring Results Analysis

The temperatures for the monitored apartments were visually depicted in two sets of graphs comparing outdoor temperatures to living room temperatures, and outdoor temperatures to bedrooms/secondary rooms for the hottest week of a chosen period. The data is then analyzed in more detail for the hottest day of the selected period. The temperature data was then compared in the two groups with indoor temperatures versus outdoor temperatures for each year.

RESULTS

The summer 2010 and 2012 outdoor temperatures are compared to the indoor temperatures in 1 K (1.8°F) temperature bins in Figures 7 and 8. In 2010, the living room temperatures in E2 are constantly in a range of 1 K (1.8°F) to 1.5 K (2.7°F) higher than all other apartments. The temperatures reflect a combination of factors: lack of exterior shading, predominantly closed windows, and exposed location at the highest level in the building. Bedroom temperatures are more closely grouped together for all apartments with the highest temperatures in study E2, Figure 7.
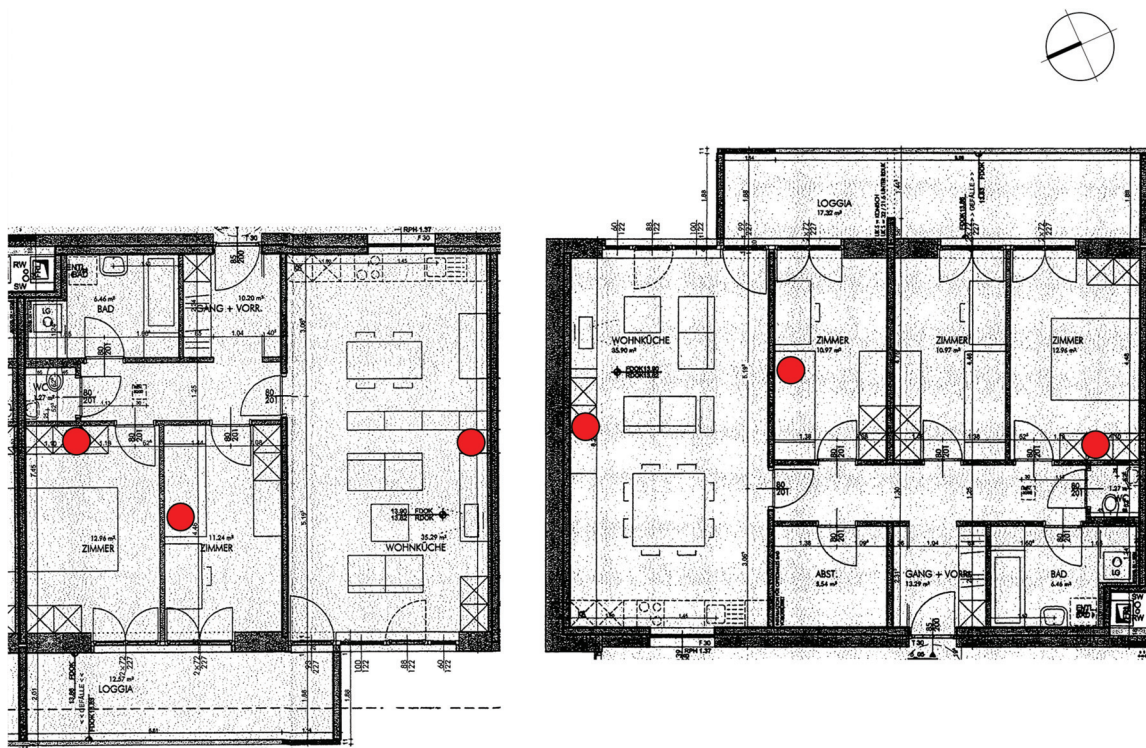

Figure 6 *Plans of apartments, W1 and W2 (left) and E1 and E2 (right), 5th floor shown. Data logger locations shown in red (Kaufmann 2007a, 2007b).*
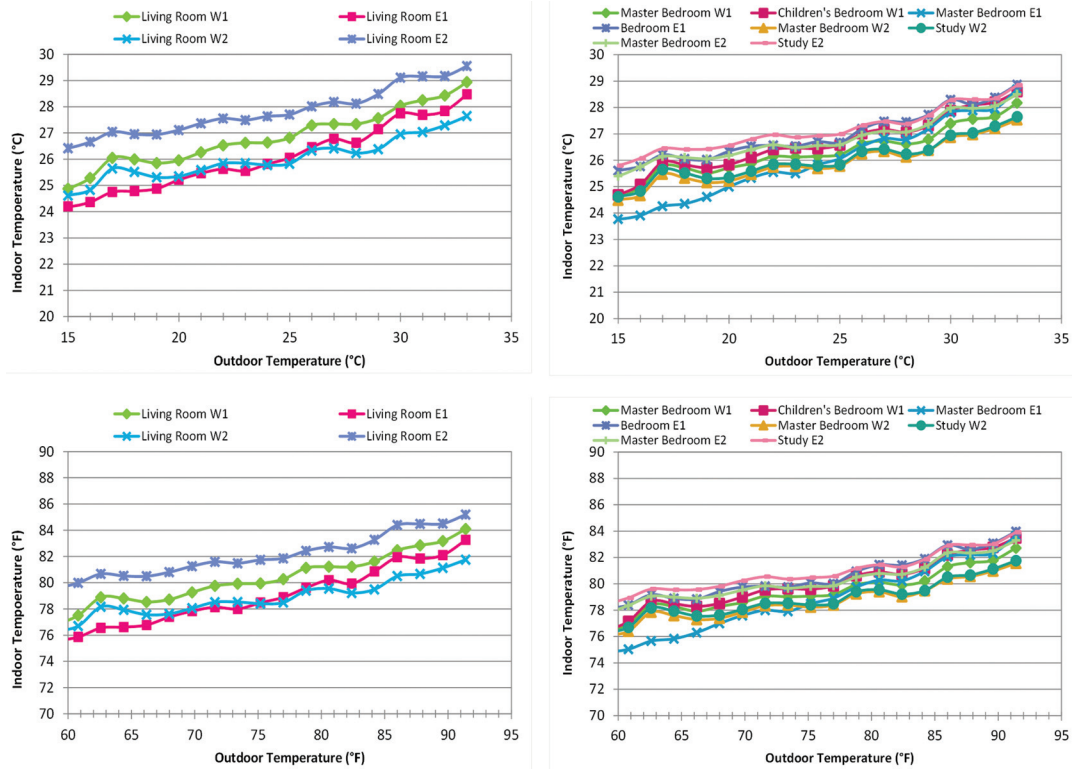
Figure 7 *Average indoor living room (left) and average bedrooms/study temperatures (right) from hourly measurements for 1 K intervals of outdoor temperature, 2010.*
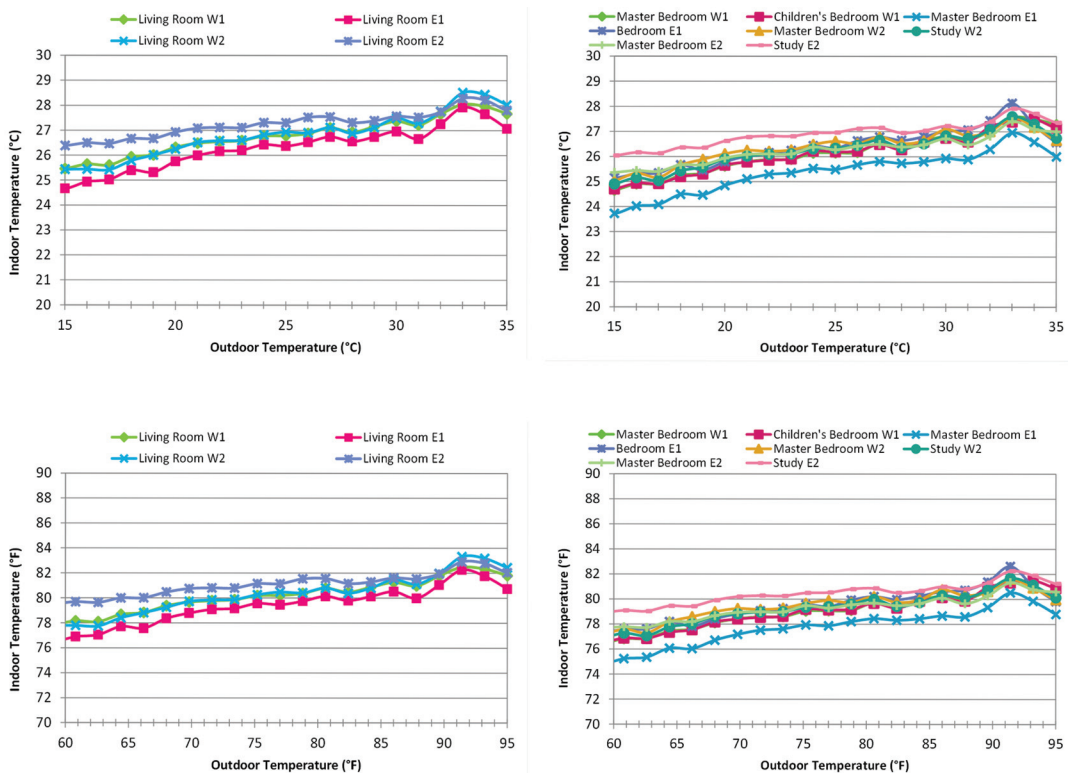

Figure 8 *Average indoor living room (left) and (right) average bedrooms/study temperatures from hourly measurements for 1 K (1.8°F) intervals of outdoor temperature, 2012.*
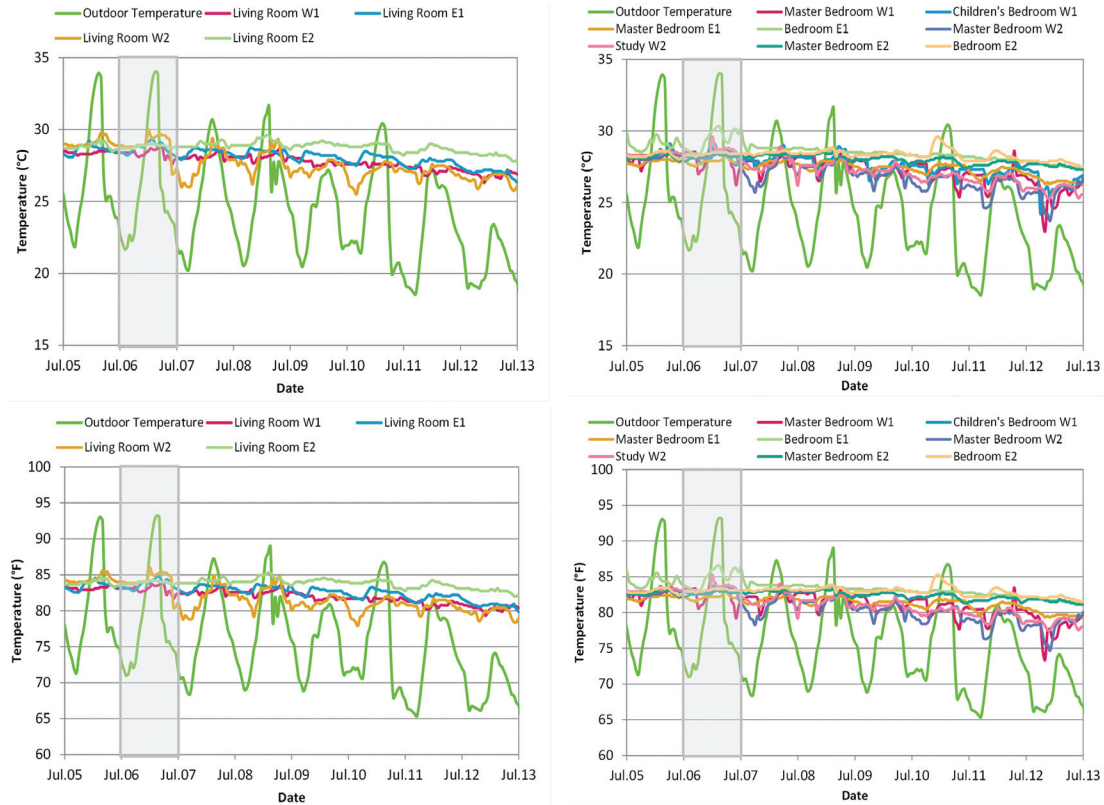
Figure 9 *Living room (left) and bedroom/study temperatures (right) in all apartments, July 5th to 13th, 2012.*
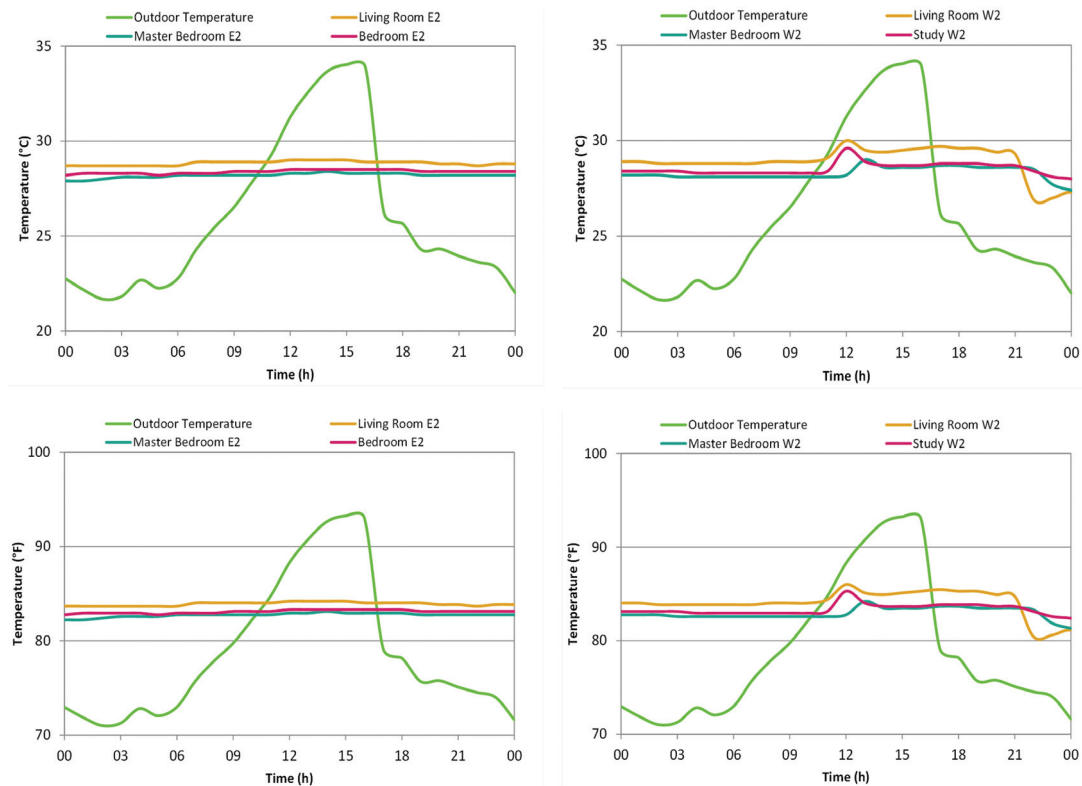

Figure 10 *Hourly values for all rooms in apartment E2 (left) and W2 (right) for July 6th, 2012.*

Figure 8 compares the indoor to outdoor temperatures in 2012. Similar to the living room temperatures, the living room temperatures in E2 are higher than the other apartments. The flatter slopes of both living room and bedroom/study graphs indicate that the rate of increase in indoor temperature is less than in 2010. Especially for temperatures between 26°C (79°F) and 30°C (86°F), the average indoor temperatures stabilize despite the rising outdoor temperatures. Living room temperatures are generally higher than in bedrooms.

2012 was the hottest of the three summers. The apartments show the same living room temperature patterns in Figure 8 (left) relative to the previous years. The hottest week is indicated in gray.

Figure 9 examines the heat wave from July 5th to 13th, 2012 in greater detail. W2 shows the greatest decrease in nightly temperature, however rises to the same daily temperature range as the other apartments which may be partially explained by open windows during the day with closed shading as described in Figure 4. E2 again shows the warmest temperatures, and especially shows continual constant indoor temperatures despite cooler outdoor temperatures on July 12th and 13th, reflecting that the occupants were on holiday.

The hourly indoor temperatures for July 6th, 2012 are compared in the two 6th floor apartments, E2 and W2, in Figure 10. None of the rooms in E2 reflect coupling to outdoor conditions indicating that the highly insulated and airtight envelope effectively decouples indoor from outdoor conditions, and that windows were not opened in this period.

The warmest to coolest rooms are the same in both apartments. However, increases in temperature at midday, and falling temperatures in the evening indicate that W2 has opened the windows. It is possible that the windows in the living room were fully open.

DISCUSSION

The measurement results show differences from the self-reported behavior. Following the adaptive comfort theory (Nicol and Humphres 2002), the occupants should be actively adjusting their environment to establish comfortable conditions. The homeowners received a "summer box", a unit to bypass the heat exchanger in the ventilation unit. Through experience, the homeowners have decided not to use the summer box, meaning that heat recovery always takes place within the apartment. The effect of the ground-source heat exchanger seems to have a larger effect than the heat recovery in the individual apartments in summer.

Measurements show that the homeowners leave windows closed at night during heat waves, causing indoor temperatures to rise up to 30°C (86°F). All homeowners were informed of the importance of opening windows at night, keeping windows closed during the day, and keeping exterior blinds closed during the day for maintaining cooler indoor summer temperatures. However, when interviewed, the homeowners gave reasons to keep windows tilted or closed at night such as outdoor noise (e.g., noise from rooftop fans

from the ventilation system, public transport, traffic, and people's voices), perceived security, and insects. It is also possible that windows were kept fully open with closed blinds to maintain darkness in bedrooms while cooling. The combination of the above factors potentially limited the effectiveness of night cooling. On the other hand, the temperatures in E1 are constantly lower than all other apartments in 2012, indicating that the combined actions of the occupants, shading from the balcony above, and ventilation system use maintained cooler temperatures, Figure 9.

The external blinds that were installed in E2 blocks most of the sunlight. The homeowners were dismayed by the need to close the blinds in summer for the majority of the day in order to maintain comfortable indoor temperatures as the interior becomes very dark during the day and no view to the outdoors is available.

CONCLUSIONS

The combined influence of the airtight and highly insulated envelope, thermal mass of the reinforced concrete structure, and the preconditioned air supply maintained stable indoor temperatures that were decoupled from outdoor conditions. User behavior to open and close windows and blinds was not necessarily influenced by outdoor climate conditions as a primary driving force, but rather other aspects such as access to daylight, night noise, and individual psychosocial factors (e.g., perceived safety), influenced behavior. Steady patterns of individual households were visible from year to year, even though behavior between households differed paralleling findings about window opening behavior by (Fabi, Andersen et al. 2012). More detailed investigations are necessary to determine detailed information about window opening behavior and shading use for longer periods, individual window opening monitoring, and ventilation system settings.

The measurement data reflects the actions taken by each household. However, the driving forces behind the reasons users decided to interact with windows and blinds cannot be obtained from the data; but rather requires further study into the factors about the context at physical, sociological, and psychological levels. IEA-ECBCS Annex 53, "Total Energy Use in Buildings—Analysis and Evaluation Methods" explores the contextual interaction of people and buildings. The possibility to categorize energy uses according to lifestyle and values for understanding users' actions and motivations are being explored in a dissertation which will also consider the influence of situational factors such as outdoor night noise, access to daylight, and temperature tolerance on summer cooling behavior.

ACKNOWLEDGMENTS

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