Figure 1. *Photograph of the study building*

Figure 2. *Floor plan of the study dwelling*

Figure 3. *Location of the installed thermometer*

Table 1. *Overview of the field measurements*

Building complex of the target measurements	It consists of twelve 19-story buildings, comprised of 16 housing units on each floor. The floor area of each housing unit is approximately 60 m^2.
Houses selected for analysis	A total of 21 houses, consisting of 4 houses with 2 occupants, 6 houses with 3 occupants, 7 houses with 4 occupants, and 4 houses with 6 occupants.
Measurement Period	i) Sept. 20, 2013 – Oct. 11, 2013 ii) Dec. 14, 2013 – Jan. 6, 2014 iii) Feb. 21, 2014 – Apr. 11, 2014

	iv)	Apr. 18, 2014 – May. 16, 2014
	v)	Jun. 26, 2014 – Jul. 24, 2014

A total of 21 dwellings that use air conditioners on almost a daily basis were selected for this analysis. The occupants in the other six dwellings did not use air conditioners as frequently as the former group, due to economic concerns or preferences for the use of natural ventilation or mechanical fans. In this analysis, the occupants of 12 dwellings installed an air conditioner in the living room, and those in nine other dwellings installed an air conditioner in the master bedroom.

RESULTS AND DISCUSSION

The air-conditioner on/off state was determined from the differences between the temperature at the air outlet, and the room temperature. An event was defined as the continuous period during which the air-conditioner unit was in use. By plotting a usage schedule (Figure 4), differing modes of behavior in different dwellings could be observed. For example, the occupants in one dwelling only used air conditioning for a short period of time around midnight (Figure 4a), while the occupants in another dwelling (Figure 4b) tended to use the air conditioner for a longer period, sometimes throughout the whole night.

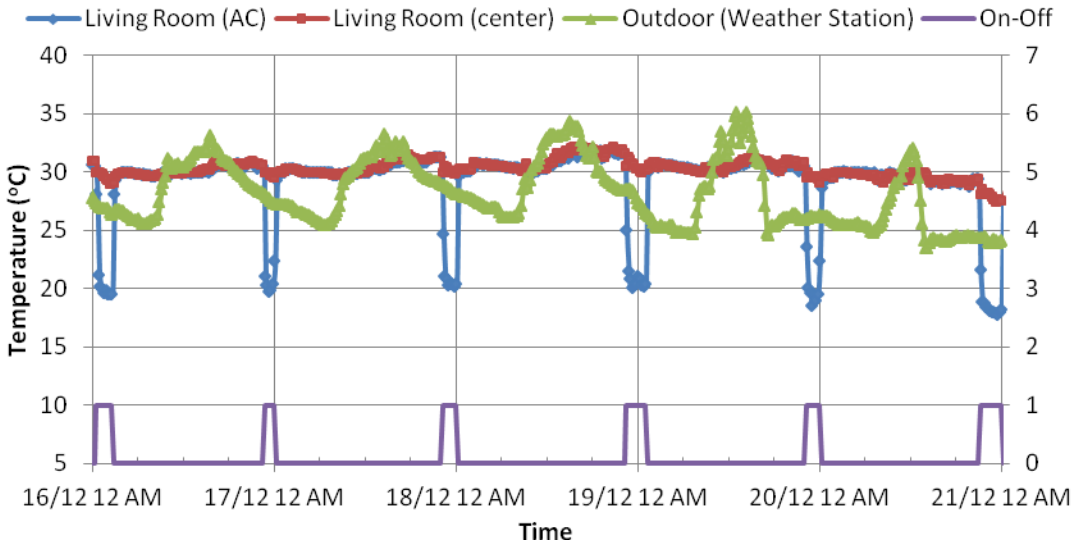

Figure 4a. *Five-day variation of room air temperature, and the behavior of air-conditioner usage from December 15 to 21 of 2013, in Dwelling #4*

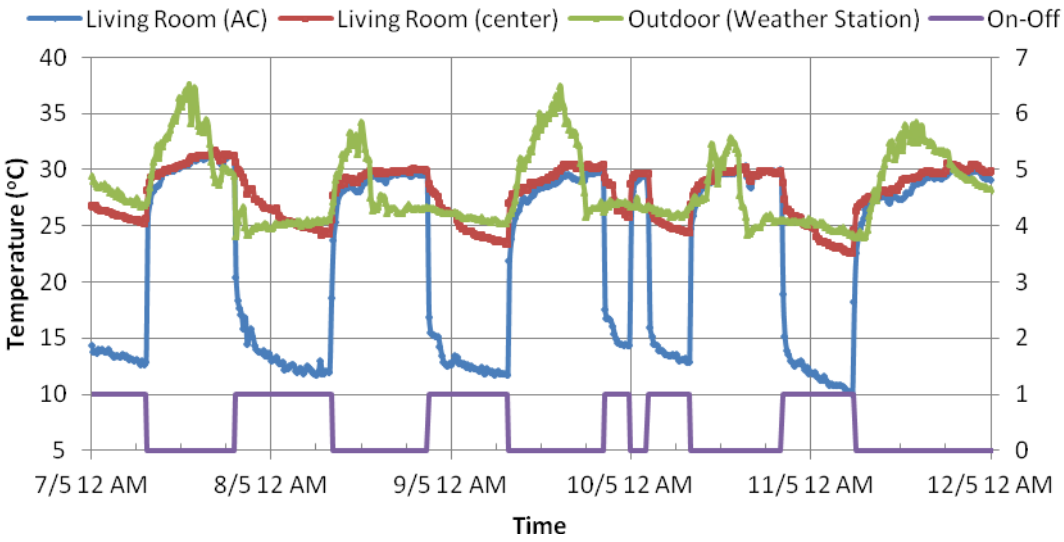

Figure 4b. *Five-day variation of room air temperature and the behavior of air-conditioner usage from May 7 to 12 of 2014, in Dwelling #2*

Start time

The percentage of time, during which air-conditioner use was initiated, was the highest during the night, particularly at 10 pm in both rooms and 1 am in the bedroom. The outdoor temperature at night was relatively low, averaging about 26°C. However, the heat stored in the dwellings throughout the day resulted in an average room temperature of 31°C. The lower percentage of air-conditioner usage in the daytime was due to the majority of occupants having left home for work or school. The trend observed with the bedroom air conditioning starting times differed little between weekdays and weekends. In the case of the living room, it was observed that the percentage of air-conditioner use in the afternoon during weekends was higher than that observed during weekdays. This is due to the fact that people tend to stay at home on the weekends. However, the percentage of air-conditioner initiation in between 7 pm and 10 pm was lower during the weekends compared to weekdays. This could be due to the tendency for occupants to go out at night during weekends.

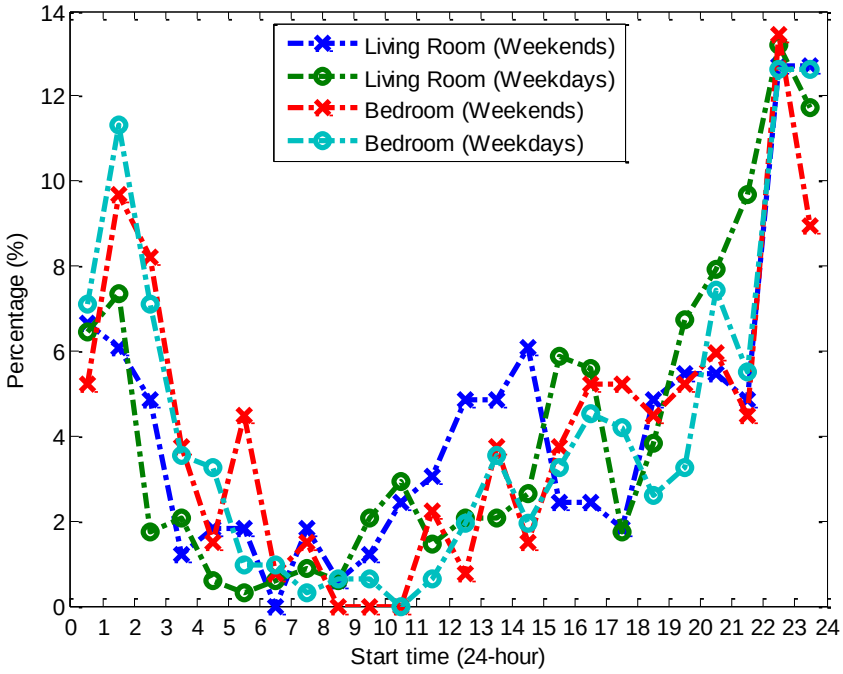

Figure 5. *Percentage of air conditioning start times over the course of a day.*

Duration of Air-Conditioner Usage

The duration of an event has some dependency on start times (Aerts 2014). For example, the air conditioner was more likely to be turned on for a longer period during sleeping hours compared to its use at other times, such as in the morning. For this reason, the duration of an event was divided into two time-based groups. The first group consisted of daytime hours, and the other consisted of nighttime hours.

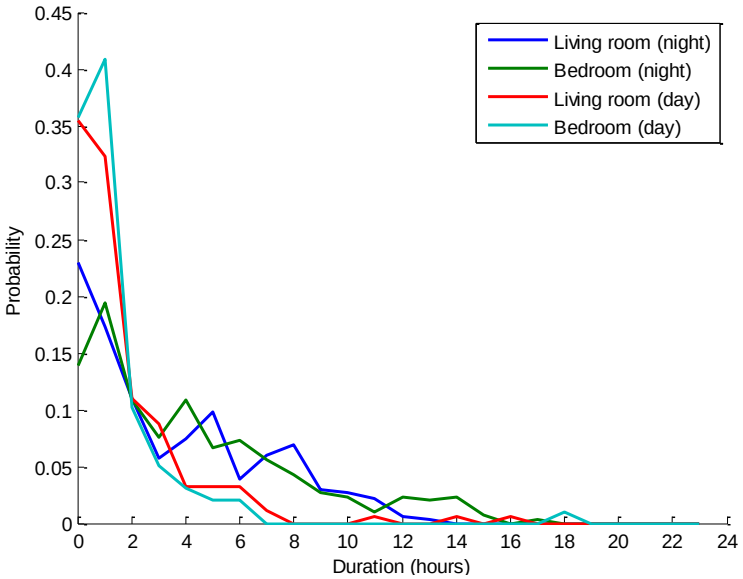

Figure 6. *Duration of air-conditioner usage over the course of a day*

Figure 6 shows that the duration of an event tended to be shorter during the daytime, regardless of room type. The longer duration of an event was more common at nighttime, also regardless of the room type. In the case of this housing area, some occupants preferred to sleep in the living room, given that the number of family members living in the house was greater than the number of available bedrooms. In some cases, the occupants left their bedroom doors opened, and used the air conditioner in the living room to cool the bedrooms as well. This would explain the minimal differences observed in the trends from both room locations.

Table 2. *Temperature before air-conditioner use in the living room*

Dwelling ID	Average (°C)	Std Dev (°C)	Kurtosis	Skewness	Maximum (°C)	Minimum (°C)
2	30.2	0.7	1.81	0.09	31.3	29.1
4	30.2	1.0	1.58	-0.19	31.6	28.5
5	28.7	0.8	2.98	0.04	30.6	26.8
8	29.8	0.9	2.52	0.29	32.4	28.2
16	31.2	1.4	2.30	0.70	34.3	29.4
18	27.1	1.9	1.70	0.02	30.7	24.2
19	28.2	1.6	2.92	-0.64	31.4	24.5
20	29.9	0.7	2.69	0.23	31.3	28.6
21	30.6	0.6	2.34	0.40	31.8	29.7
26	29.6	1.1	4.41	-1.12	31.9	26.3
27	29.2	0.9	2.58	0.16	31.2	27.2
37	30.5	0.5	2.34	-0.13	31.3	29.4
Average	29.6	1.0	2.5	0.0	31.7	27.7
Std Dev	1.1	0.4	0.7	0.5	1.0	1.9

Table 3. *Temperature before air-conditioner use in the master bedroom*

Dwelling ID	Average (°C)	Std Dev (°C)	Kurtosis	Skewness	Maximum (°C)	Minimum (°C)
1	29.32	0.6	2.55	-0.09	30.5	28
7	30.57	0.6	2.31	-0.08	31.7	29.4
11	30.18	0.8	2.90	-0.39	31.5	28
12	29.11	1.0	2.96	-0.15	31.3	26.6
14	29.32	1.6	5.85	-1.47	32.8	23.3
15	29.61	1.2	2.47	0.26	32.1	27.6
17	30.63	1.5	2.54	0.62	34	28.1
30	30.86	0.9	2.72	-0.15	33.2	28.7
33	29.9	0.6	2.34	-0.39	31.0	28.6
Average	29.9	1.0	3.0	-0.2	32.0	27.6
Std Dev	0.6	0.4	1.1	0.6	1.1	1.8

Tables 2 and 3 show room temperature statistics prior to air conditioning start times. These tables show that on average, the occupant would turn on the air-conditioner when the room temperature was at 30°C. Since there does not exist a precise temperature at which all occupants will initiate air-conditioner use, it was thought more useful to obtain the probability distribution of event occurrence as a function of room temperature. Figure 7 shows room temperatures measured prior to the initiation of air-conditioner use. The plot confirms that the probability of air-conditioner initiation increased as the temperature rose.

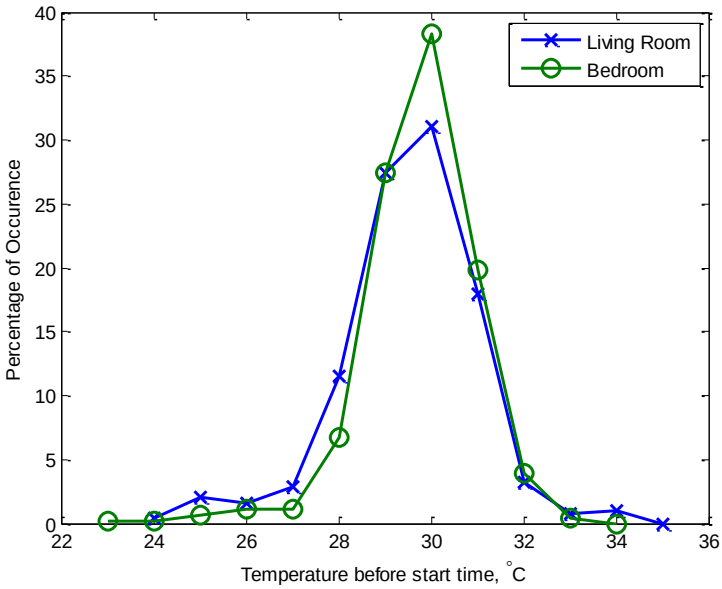

Figure 7. *Room temperatures prior to air-conditioner use*

CONCLUSION

Air-conditioner was used more frequently around midnight, when the occupants were sleeping. The results from this study will be used to develop a numerical model for the generation of air-conditioner usage schedules. These results vary stochastically each day due to the diverse behavior of building occupants and prevailing weather conditions in countries subjected to tropical climate.

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