Thermal Seasonal Variation and Occupants' Spatial Behaviour in Domestic Spaces

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Thermal comfort is essential for optimized performance of daily activities. Continuous variation in the thermal conditions of the environment influences humans' thermoregulation adaptive behaviour, in which people seek to find the most preferred places to move to. Detecting individuals' behaviour and correlated physical adaption measures can help in enhancing the built environment and minimizing energy consumption. Occupants' behaviour in buildings has been widely investigated, focusing largely on energy consumption, however fewer studies have examined the socio-economic aspects in domestic spaces. This study investigates the relationship between indoor thermal conditions of dwellings and occupants' adaptive behaviour in response to thermal seasonal variations. A field survey was conducted in a residential compound in Amman, Jordan, to detect occupants' spatial behaviour in 35 apartments in response to thermal seasonal changes. The results revealed that spatial behaviour was used as an effective adaptive thermoregulation technique, driven by socio-economic aspects. Seasonal thermal variation motivated occupants to move across their apartment seeking the most thermally preferred zones. The occupants' behaviour was based on achieving thermal satisfaction, and on their performed activity at the occupied zone. The developed model is based on family size and other family characteristics; and is proposed to optimize domestic spatial needs in apartment buildings.

Keywords: occupant behaviour, thermal comfort, adaptive behavior, thermal sensation, seasonal variation, thermoregulation, domestic space, adaptive behavior.

Introduction

Thermal comfort is a general term that describes a subjective physical sensation in which the mind expresses satisfaction with the surrounding thermal environment (Parsons, 2014). Thermal comfort has been considered as a 'socially determined notion', which is informed by changing time, place, and season, as well as cultural norms and expectations (Nicol & Roaf, 2017). Thermally comfortable environments are crucial for practicing daily life activities and optimizing task performance level. Building design guidelines and codes have been developed to maximize indoor comfort conditions in a non-mechanically air conditioned building (Givoni, 1998; Olgyay, 2015). However, local conditions and cultural differences can cause some limitations and lack of precision (Givoni, 1998; Olgyay, 2015). An established body of literature has investigated thermal comfort and occupants' behaviour, focusing largely on office buildings (Baker & Standeven, 1997; Meinke, Hawighorst, Wagner, Trojan, & Schweiker, 2017; Rijal, Humphreys, & Nicol, 2009; Zeiler, Vissers, Maaijen, & Boxem, 2014). Other studies have focused on thermal comfort in residential buildings (Bennet & O'Brien, 2017; Imagawa & Rijal, 2015; Nicol, 2017; Yu, Li, Yao, Wang, & Li, 2017). Earlier research also examined behavioural responses to cold thermal discomfort in dwellings (Gauthier & Shipworth, 2015) and adaptive thermal comfort in higher education buildings (Cha, Steemers, & Kim, 2017; Yao, Liu, & Li, 2010; Zaki, Damiati, Rijal, Hagishima, & Razak, 2017). However thermal seasonal variation and occupants' spatial behaviour was not largely explored in domestic buildings from a socio-economic perspective.

Various ways of responding to thermal discomfort were identified in the literature including mechanisms of psychological adaptation and behavioural responses (Gauthier & Shipworth, 2015). Normally, people measure their comfort by evaluating their thermal sensation of the built environment. Ambient temperature influences occupants' adaptive behaviour and place preference. However, the human body is also capable of modifying its core temperature when the ambient temperature is not adequate through a process known as "thermoregulation." This process is found to be subjective as it is mediated by environmental and personal parameters (Djongyang & Tchinda, 2010). Environmental parameters include outdoor climate and space properties (area, air conditioning availability, and building insulation); while personal parameters include age, gender, cultural preferences, technical practices in addition to past thermal experiences and expectations (Andersen, Toftum, Andersen, & Olesen, 2009; Schweiker, 2010). Recent research has highlighted considerable differences in thermal comfort evaluations of female and male participants in air-conditioned as well as mixed-mode buildings in Brazil (Maykot, Rupp, & Ghisi, 2018). Healey and Webster-Mannison adopted a qualitative thermal comfort research methodology to study office occupants' behaviour; they argued that cultural and contextual factors can facilitate, or limit thermal comfort-related adaptation behaviours (Healey & Webster-Mannison, 2012). The relationship between the spatial configuration of a modern house case, the building microclimate and thermal comfort was investigated in hot and humid climate (Du, Bokel, & van den Dobbelsteen, 2019). Du et al. (2019) studied a modern house with spatial configuration, close to local vernacular buildings, and a microclimate that has the potential to provide natural thermal comfort in summer.

A strong correlation is observed between thermal comfort and occupants' thermoregulation process. Occupants tend to control their indoor environments through adaptive responses to achieve thermal satisfaction and bring their bodies to a thermal steady state (Schultz, 2009). In addition, thermoregulation adaptation behaviours can help in maximizing human thermal tolerance to live in more extreme climates (Wenger, 1997). Detecting individuals' thermoregulation adaptation behaviours and correlated physical measures, such as energy use, can help in enhancing the built environment and optimising energy consumption (Li, Jiang, & Wei, 2007; C. Peng et al., 2012; Santin, Itard, & Visscher, 2009). Involving occupants in buildings' comfort process control is crucial as the impact of occupants' behaviour on energy consumption in buildings is evident (Zeiler et al., 2014). According to Delzendeh et al. (2017), collecting data about occupants' behaviour is essential to improve buildings' functionality and reduce energy consumption. This can be achieved by utilising the data in controlling lighting, Heating, Mechanical, Ventilation and Air Conditioning (HVAC), as well as other building functions (Delzendeh, Wu, Lee, & Zhou, 2017). Earlier research focused on the knowledge of occupants and their behaviour in relation to thermal comfort in green as well as conventional buildings (Brown & Cole, 2009). The relationship between prior knowledge, human interaction with buildings, using personal controls, and thermal comfort proved to be complex. Brown and Cole (2019) suggested that using new technologies and environmental systems in buildings to provide instant feedback can achieve a successful human-building interaction.

Nicol and Humphreys (1973) reported two approaches in evaluating thermal comfort and correlated adaptive behaviours: physical and non-physical (Nicol & Humphreys, 1973). The former can be conducted by measurements of environmental and personal physical factors. The non-physical approach is psychological and can be measured by human judgments and behaviours in thermal environments. The international thermal standards, such as ISO 7730 (2005) and the ASHRAE Standard 55-92 (ASHRAE, 1992), have utilised both approaches using Fanger PMV as well as Brager and De Dear (1998) adaptive theory in estimating thermal comfort and the adaptive behaviour. Post-occupancy strategies using simulations have been suggested, in which both adaptive occupancy pattern and natural ventilation are applied to improve thermal comfort (Rajasekar, Anupama, & Venkateswaran, 2014). Yet, some researchers argue that methods considering thermal comfort as a socio-cultural achievement instead of an engineering problem are more effective in exploring occupants' comfort and satisfaction (Healey & Webster-Mannison, 2012).

Earlier studies have focused on occupants' behavioural strategies towards thermal discomfort and environmental variation (Andersen et al., 2009; Indraganti & Rao, 2010; Nicol, 2001). However, detecting occupant's spatial behaviour was mostly investigated in behavioural simulation studies (Mahdavi, Mohammadi, Kabir, & Lambeva, 2008; Page, Robinson, Morel, & Scartezzini, 2008). In these studies, the occupant's responses were mainly related to adjusting clothing, natural ventilation, thermostat or changing location as tools to enhance energy consumption. Recent research has identified that existing space-use prediction models ignore the role of building users' space preferences; and developed a space preference model for group work in higher education buildings (Cha et al., 2017). Thermal comfort and behaviour of school children were studied in Australia; students preferred air-conditioned classrooms to maintain their comfort rather than adaptive options such as opening windows, using fans, blinds or clothing modifications (Kim & de Dear, 2018). However, adaptation behaviour that reflects occupants' thermal expectation and preference in domestic spaces where thermal seasonal variations can be extreme, such as the case in Jordan, is still under-researched.

Changes in seasonal thermal conditions influence human comfort satisfaction and can lead to significant variations in corresponding adaptive behaviours. Physical conditions of the house as well as occupants' psychological aspects have major impact on occupants' behaviours

(Sawashima & Matsubara, 2004). Thermal comfort and occupants' adaptive behaviour was studied in air-conditioned offices in Qatar during summer; occupants adapted through adjustments to their clothing and were less satisfired in cooler buildings (Indraganti & Boussaa, 2017). Earlier research described the individual contributions of thermoregulation adaptive behaviour to achieve thermal comfort including using building controls, utilising the spatial variation of rooms, changing posture and clothing, and metabolic rate (Baker & Standeven, 1997). Still, adaptive opportunities are not always available and economic aspects play a key role in prioritising these actions such as opening windows or using air conditioning. Indragantia et al. (2015) found that window-open behaviour is strongly connected to seasonal changes as a thermoregulation behaviour to cope with changes in temperature. By using logistic regression, they predicted that 50% open windows at 30 °C of indoor air temperature (Indraganti, Ooka, Rijal, & Brager, 2015). However, this behaviour is influenced by design and construction, operation and maintenance, environmental, sociocultural, attitudinal and behavioural factors (Indraganti et al., 2015).

Continuous changes between indoor thermal comfort and outdoor environment make it challenging to detect the adaptive behaviour of the occupants. Prior research attempted to develop equations to associate the chances of using controls in office buildings to the indoor and outdoor temperature, and to correlate the indoor thermal comfort to the outdoor temperature (Rijal et al., 2009). Other studies explored thermal comfort and occupants' satisfaction in high-rise residential buildings to identify occupants' preferences, focusing on window size and variations in temperature between summer and winter (Bennet & O'Brien, 2017). A large body of research investigated thermal comfort from a sustainability perspective focusing on energy efficiency (Muresan & Attia, 2017), heating performance (Ahn & Song, 2010), applying simulation studies (Nadarajan & Kirubakaran, 2017), and passive design techniques (Liping & Hien, 2007; Rincón, Carrobé, Martorell, & Medrano, 2019). Nonetheless, there is lack of research that examines the occupants' spatial behaviour in the domestic milieu as an adaptive thermoregulation behaviour in socio-economic terms. The aim of this study is to investigate thermal seasonal variations and occupants' spatial behaviour to design optimised domestic spaces in Jordan. The objectives are to analyze objective observations of residents' adaptive behaviour to the thermal environment; and to improve architects' understanding of occupants' needs in domestic spaces. Such inquiry is crucial to achieve an optimised spatial arrangement of the residential built environment. The occupant behaviour due to the thermal seasonal changes should be considered in the early phases of design (the program and schematic phase). Optimising the spatial needs of the residential apartments is a crucial need in developing countries for people on a low and middle income.

Method

This study employs self-report techniques to investigate the effect of thermal seasonal variations on occupants' spatial behaviour in residential buildings in Jordan. Participating residents were interviewed and asked to fill out a questionnaire that describes their socio-economic status. Then the participants were provided with a structured journal developed by the researchers. The journal had to be filled out in three seasons (hot summer, mild spring and autumn, plus cold winter) four times a day in three pre-scheduled days (two working days and a non-working day) each season.

Research sample

Occupants from thirty-five apartments from a residential compound in Amman, Jordan, participated in the study. Sample size selection depended on two factors: confidence level which sets as 95% and confidence interval which sets as 10. This influenced the sample size which should exceed 32 to match the requirements of the central limit theorem and the percentage that represents the accuracy of sampling procedure. Accordingly, the calculated size was equal to 35 apartments.

The selected residential compound, Al- Sahl Al-Akhdar Compound, has 8 buildings, each building consists of 4 floors with two apartments on each floor, a total of 64 apartments, see Figure 1 and Figure 2. The geographic location of the compound is "31°56'52"N 35°49'59"E". The selection of the 35 apartments was based on a stratified sampling technique, whereas the investigated sample was divided into three different subcategories "strata" then a random selection was applied within each stratum. In order to select the sample, the compound was divided into eight main buildings categorized alphabetically. The apartments were categorized numerically (1, 2, 3, 4, and 5) based on their rotation in the site and their location (level) in the building, see Figure 3. Each floor was given a numeric value; floor 1, floor 2, floor 3, and floor 4. Then, the selected apartments were randomly chosen from each subcategory. The selected apartments were identical in their area and typical in their architectural design and spatial configuration. The total area of each apartment is 175m^2, divided into a living room, guest and dining room, three bedrooms, two bathrooms and a kitchen with a small veranda, see Figure 4.

Figure 1

A. The Main Entrance of the Compound

B. The Back Entrance of the Compound, (South-East Elevation)

C. The Top View of the Compound Building Roof

D. The North West Elevation

Figure 2

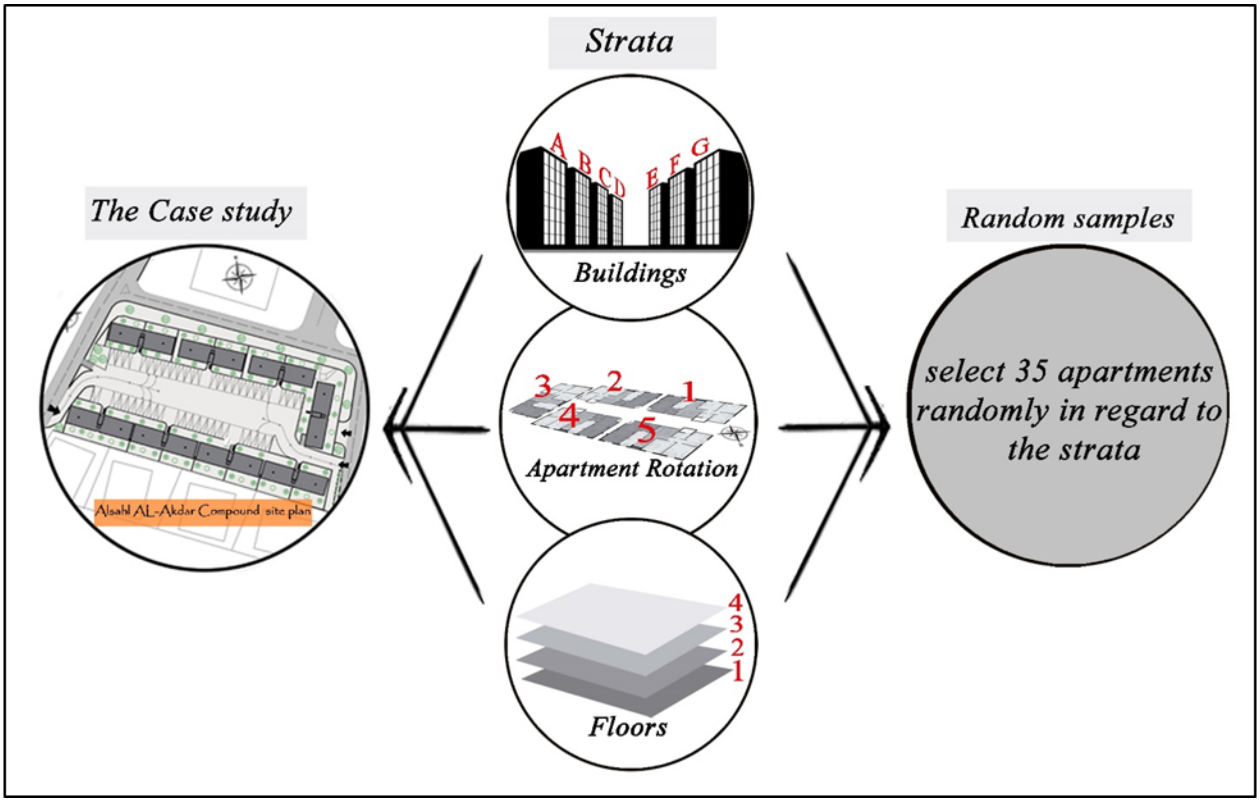

Figure 3

The spaces in each apartment were divided into four zones: Private, Semi-private, Public and Outdoor. The Private zone includes the bedrooms; the bathrooms and the kitchen. The Semi-private zone includes the living room and in some cases the kitchen-diner. Some owners have modified the design by integrating the kitchen with the living room as one open space. The Public zone includes the guestroom and dining room, see Figure 4.

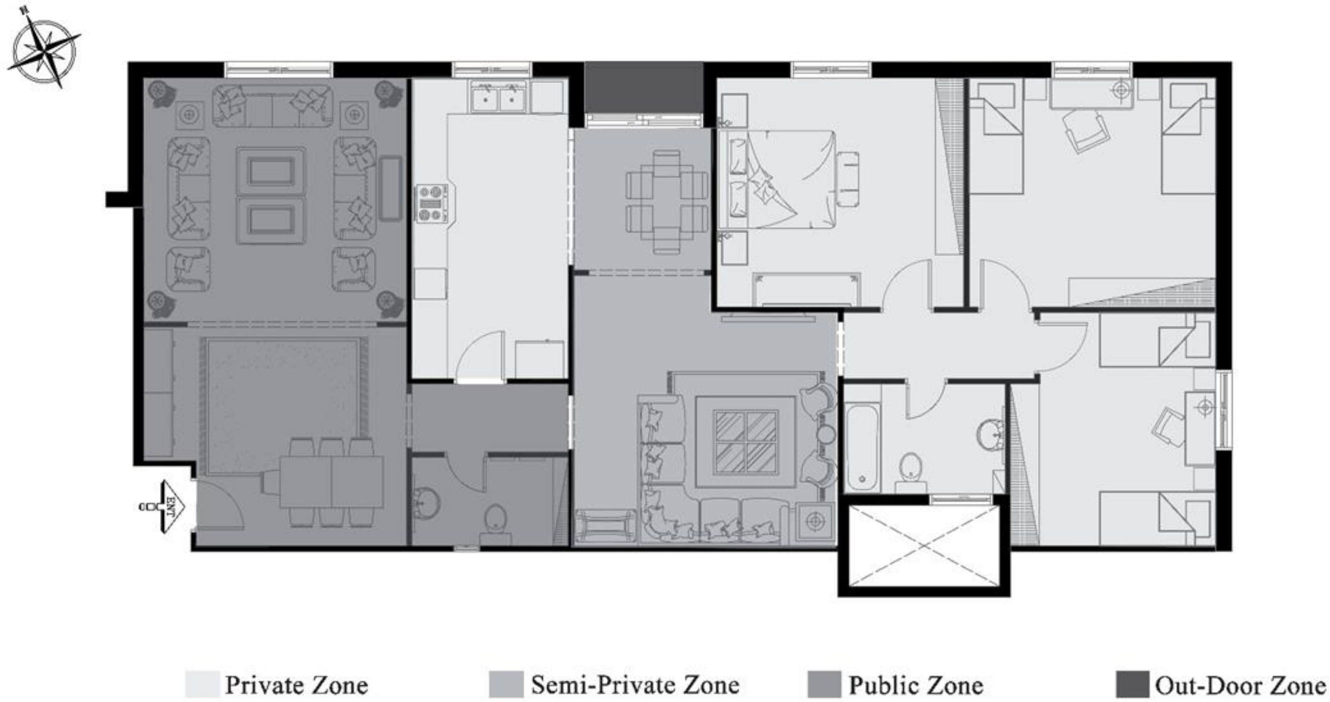

Figure 4.

According to the Climate Data Organization (CDO), Amman has a Mediterranean climate with an annual average temperature of 16.6 °C and a rainfall average of 350 mm. August is the hottest month with an average of 24.5 °C. January has the lowest average temperature of the year with an average of 7.3 °C. During the year , the average temperatures vary by 17.2 °C (Nicol & Roaf, 2017), see Table 1.

Table 1

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Avg. Temperature (°C)	7.3	8.4	10.8	15.2	19.9	22.5	24.3	24.5	22.8	19.7	14.4	9.4
Min. Temperature (°C)	3.1	3.8	5.6	8.7	12.6	15.3	17.4	17.6	15.6	12.9	8.9	4.8
Max. Temperature (°C)	11.6	13	16	21.8	27.2	29.7	31.2	31.5	30.1	26.5	19.9	14
Rainfall (mm)	80	74	64	17	5	0	0	0	0	7	34	69

Data collection methods

The following methods were used to collect data for this research study:

(1) Questionnaire: used to collect basic information about the residents and the main variables affecting indoor thermal comfort adaptive behaviours. The questionnaire had three parts: general personal information; apartment ventilation and heating systems report; and self-reported thermal sensation evaluation scale during the respective season.

(2) Daily Journal: used to trace the occupants' behaviour through the day in the apartments in various seasonal changing conditions. Using a daily journal was found to be the most appropriate technique that attained acceptance from all participants. It is an easy technique that did not require specific training or involved complex technicalities. The journal contained the following questions:

-Where are you now? to track the participants' location by reporting the zone they are occupying through that particular period.

-What are you doing? to report their performed activity at the zone; (watching TV, studying, eating, gathering, sitting, sleeping, cooking or cleaning). These examples were the most reported activities in this study.

-Rate your thermal feeling on the provided scale; to evaluate their thermal sensation evaluation in the zone on ASHRAE 55 7-point scale.

-What have you done to adjust the thermal situation? to address their adaptive behaviors (open or window/door, turn-on/off Air Conditioning (AC), take-off/put on clothes, turn on/off heater, or turn-on fan). These examples of adjustment behaviors were based on the literature review and the occupants' most reported behaviors in the study.

Each zone in the apartment was given a numeric value, as well as the reported activity and the adjustment behaviors in order to ease completing the journal and track the occupants' behaviour.

(3) Thermometer instrument: TS - C01 Wireless Digital Thermometer" used to measure the out-door temperature at each time of the scheduled survey dates.

Procedure

The survey was conducted through four stages in four different seasons: summer, autumn, winter and spring. The four stages of the survey were:

(1) An initial interview: Each apartment's head of household was interviewed to fill out a questionnaire about his/her family's personal information (family size, occupants' age and gender, family income, etc.).

(2) Filling out a self-reported journal: Each family was provided with a journal. The journal had to be filled out in three days (two working days and a non-working day) each season, four times a day in prescheduled days. The selected dates were based on Jordan Meteorological Department (JMD) data of 2016 which helped in addressing the annual maximum, minimum and moderate air temperatures of Amman. Accordingly, the selected dates in the summer were: 24th, 26th, and 27th of June 2016. Although August was recorded as the warmest month according to CDO, these three dates were selected according to the residents' availability before going away on holiday, for example. In winter, the selected dates were 8th, 9th and 13th of January 2017. Autumn and spring were combined together and considered as a mild season. For the mild seasons, the selected dates were 6th, 7th and 10th of October 2016 and 2nd, 3rd and 7th of April 2017. The process of selecting the dates started by suggesting a number of dates for each season by the researcher. The final selected dates were those dates found consensus among the residents who participated on the study.

(3) The participants were asked to complete the journal on the scheduled dates from 12.00 to 20.00 hours on a two-hour frequency. The reported data in the journal had to include the family mobility pattern across the four designated areas in the apartment throughout that period. Each family had to record their performed activity at the zone, their thermal sensation evaluation in the respective zone on ASHRAE 55 scale and their correlated adjustment behaviours.

(4) Measuring outdoor temperature; the temperature varies across the day, therefore, the researcher recorded the outside temperature using a thermometer on the four selected times on the scheduled days.

Analysis and results

The research applied a multinomial logistic regression technique to model the relationship between independent variables and occupants' behaviour. The multinomial regression test was used to model the relationship between research categorical variables. It nominated one of the response categories as a baseline or reference. The regression test results indicated whether the association between the occupation selection and each investigated term was significant, as well as the probabilities of choosing one zone over another by comparing the outcomes of the influencing factor. The Zone Occupation Ratio (ZOR) represents the rate/percentage of users in a zone to the total amount of users in other available zones.

Calculating ZOR for the four zones reveals variations across the three seasons, see Table 2. The outdoor and private zones have their highest ZOR in the summer with 10% and 41% respectively. The public zone was mostly occupied in the mild season with a 12% value. Finally, the semi-private zone has its maximum ZOR value in the winter with 67%.

Table 2

	Out-Door	Private	Public	Semi-Private
Summer	10%	41%	6%	43%
Mild	8%	32%	12%	48%
Winter	0%	30%	3%	67%

To test if there is a significant difference in the ZOR among the four designated zones across the three seasons, ANOVA test was conducted. The results of the test demonstrated a significant difference within the zones and across the seasons, with P value 0.025 and F value 3.731. The assumptions of normality and homoscedasticity related to (ANOVA) was verified and checked for the validity of the ANOVA results.

Factor analyses of occupants' spatial behaviour: a cross seasonal variation

In discussing the relationship between seasonal variations and occupants' spatial behaviour, a Chi-square test was applied to assess the best fit between zone occupation selection and seasonal thermal variation. The test was also used to determine the existence of a relationship between the spatial behaviour and the seasonal changes. The results of the test showed that both zone occupation selection and seasonal variations are significantly associated (P-Value is equal or less than 0.05). Regression analysis was then applied to test independent and confounding variables' effect on the zone occupational ratio across all seasons, see Table 3.

Table 3

Variables	P-Value	R-sq.
Adjustments Behaviour	0.647	50.06%
Gender	0.460	40.15%
Family Income	0.180	31.50%
Children's Age Average	0.004	72.33%
Family Size	0.677	30.05%
Ac Number	0.045	71.12%
Heaters Number	0.847	30.01%
Ac Location	0.174	37.53%
Thermal Sensation	0.000	51.01%
Occupation Activity	0.000	69.53%
Mother Education	0.011	61.78%
Outdoor Temperature	0.007	53.21%
Occupation Time	0.000	64.2%

The regression analysis revealed that the most influencing variables on occupants' spatial behaviour were their thermal satisfaction and performed activity. Occupants' age, outdoor temperature, mother educational level and the number of AC units in the apartment have a significant effect on the occupants' spatial behaviour, see Table 3.

Further analysis on the influencing variables was carried out. The results showed that the summer season has the highest ZOR for both private and outdoor zones. In this season, the private zone was occupied 41% and the outdoor zone 15 % of the total occupation time. On the other hand, the public zone was mostly occupied in the mild seasons, ZOR 51%. In the winter, the semi-private zone was the most occupied zone with ZOR 70%. The outdoor zone was entirely abandoned in the winter and the public zone was rarely occupied, see Figure 5. These dynamic changeable occupation patterns across the three seasons indicate how occupants act spatially to adapt to the seasonal thermal variations.

Occupant's thermal sensation had an effect on their spatial behaviour and zone occupation. The occupants felt slightly warm and slightly cool in the zones with the highest ZOR, see Figure 6. On the other hand, the occupants rarely sensed neutral, cool and hot condition in their occupied zones, see Table 4.

Table 4

Variable	Mean	SE Mean	StDev	Sum	Min	Median	Max
Summer Thermal Sensation	0.58	0.11	1.28	82.00	-1.00	1.00	3.00
Mild Thermal Sensation	0.41	0.07	0.83	58.00	-1.00	0.00	2.00
Winter Thermal Sensation	0.27	0.09	1.09	38.00	-2.00	1.00	2.00

Age also affected occupants' spatial behaviour in terms of the amount of time they spent in their apartment. Family members with an average age of 10 to 15 years old tended to spend more time at their home in the semi-private area and subsequently their ZOR was the highest. On the other hand, occupants older than 20 years old had the lowest ZOR as they spent less time at their homes, see Figure 7.

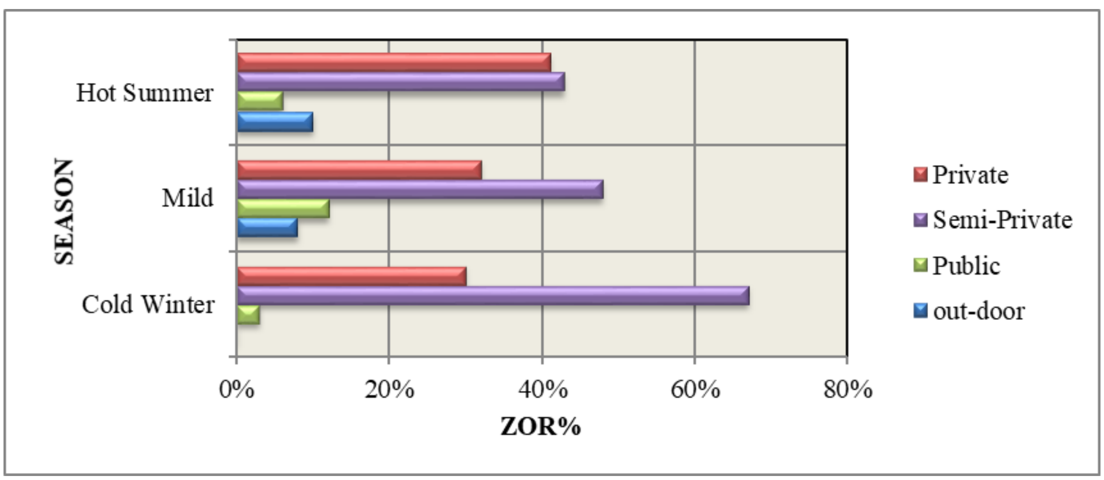

Figure 5

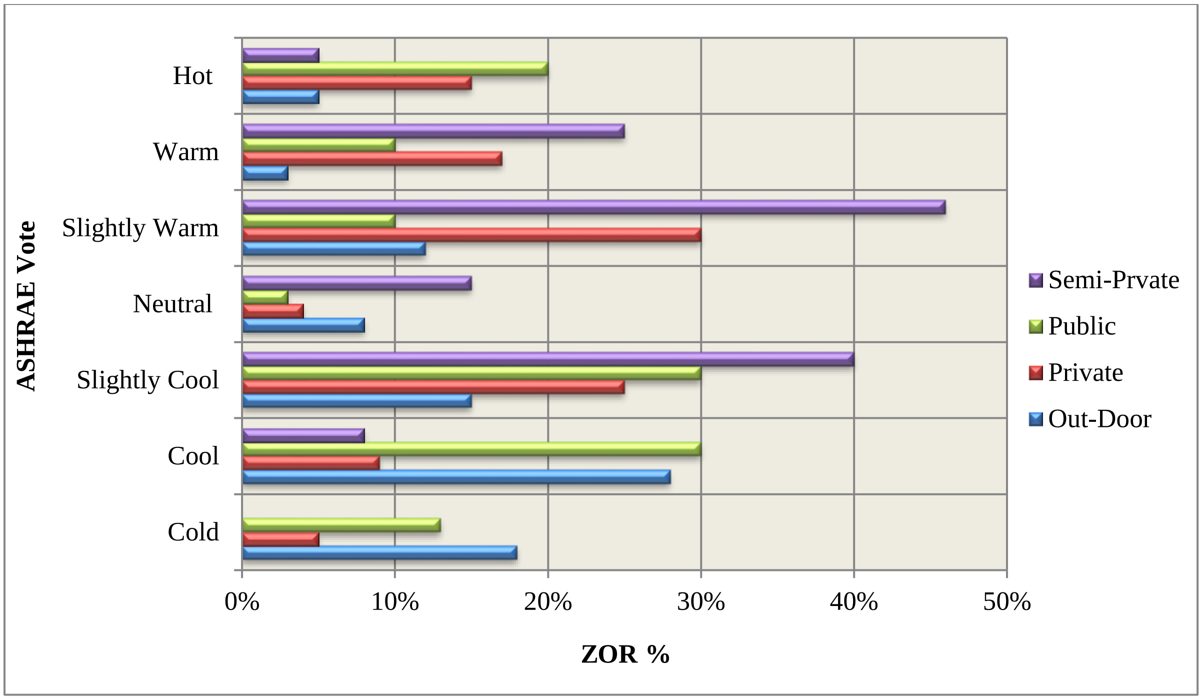

Figure 6

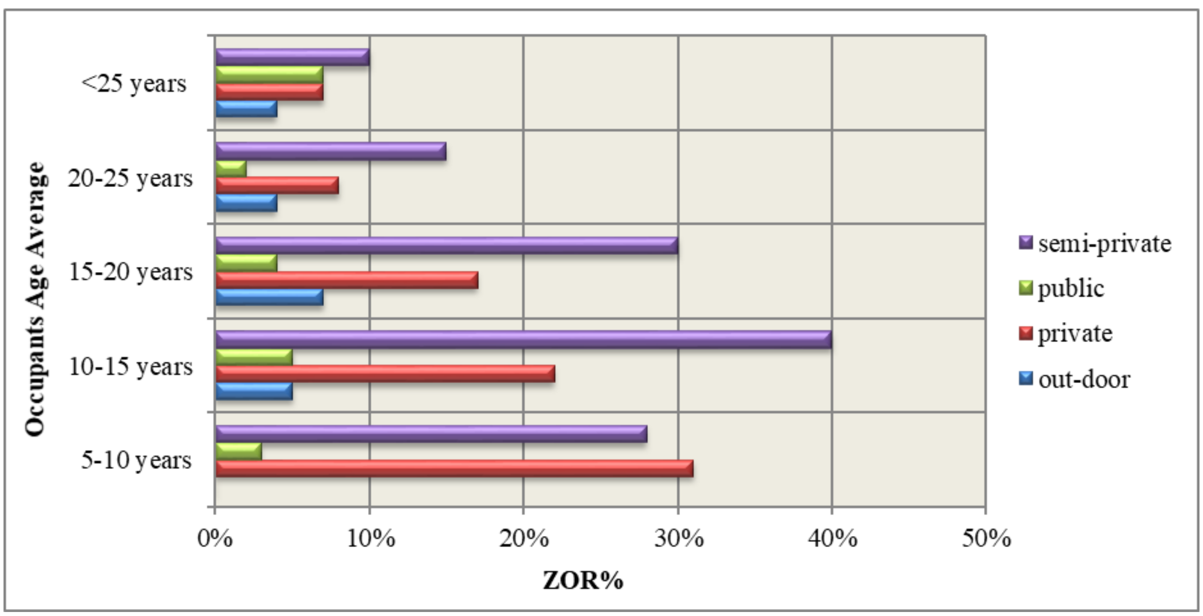

Figure 7

The mother's educational level and her work status affected the family zone occupation selection and spatial behaviour. Mothers with university degree families tended to use semi-private and private spaces more often. On the other hand, mothers with non-university degree families preferred to occupy outdoor space more, see Figure 8. It appeared that the mother's educational level seems to formulate her perception of the zones' function and occupation, which in return affected her family's spatial behaviour and occupation selection.

ZOR was found to be affected by time and performed activity. Zones under this criterion can be divided as morning, daily and night zones. For example, the private zone occupation highest value was in the morning; it decreased throughout the day then increased again at night. On the other hand, ZOR of the semi-private zones increased throughout the day and decreased at night as the occupants spent most of the day in the semi-private zone watching TV, dining and socializing. The ZOR of outdoor and public zones generally increased during the day and reached the peak point in the evening, see Figure 9.

Thermal controllability has a significant impact on determining occupied space preferences. The analysis revealed that preferred spaces for occupants are those that provided them with the ability to control their thermal situations, represented by the availability of AC units. The ZOR in public, semi-private and in private zones showed a tendency to increment when AC units are installed in the zones. However, the lack of AC units encouraged occupants to occupy outdoor zones in the mild and hot summer seasons, see Figure 10.

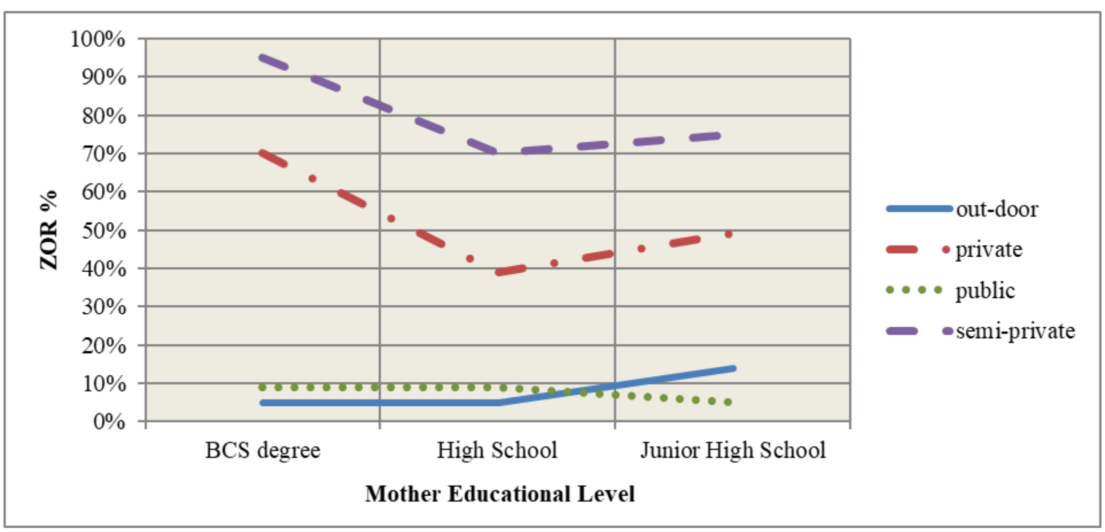

Figure 8

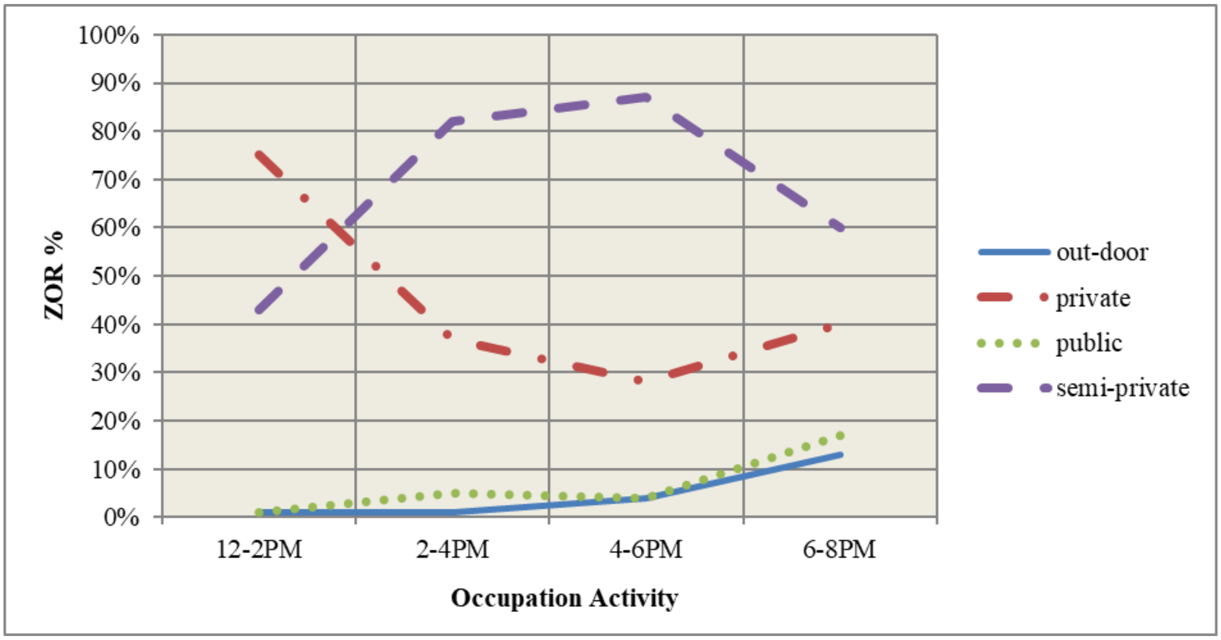

Figure 9

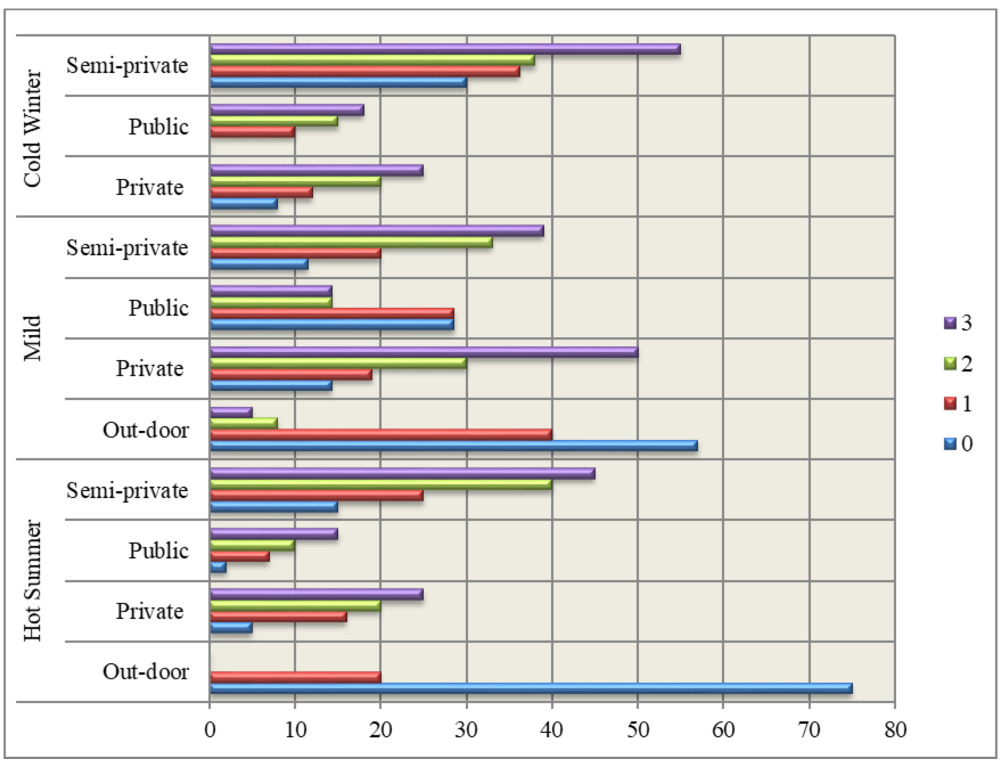

Figure 10

Thermo-occupation models

Applying the stepwise selection on the variables resulted in selecting the most influencing variables on the regression models. The multi-nominal regression aims to estimate the conditional probability function, but the conceptual problem here is that the Probability of zone occupation (P) must be between 0 and 1, which may not be applied to the data. The best solution for this problem is to convert it into a linear regression as the linear functions are unbounded.

So in order to unbound the range of P, we should switch to the logistic (or logit). Logit (p / 1−p) is a linear function, which assumed that Y = 1 when $p \geq 0.5$ and Y = 0 when $p < 0.5$. This means guessing 1 whenever $\beta 0 + x \cdot \beta$ is non-negative, and 0 otherwise, which is a linear classification as the decision boundary separating the two predicted classes is the solution of $\beta 0 + x \cdot \beta = 0$. (C. J. Peng, Lee, & Ingersoll, 2002)

The multi-nominal regression test produced three models; the exponential beta coefficient represents the change in the odds of the selected zone (private, public, or semi-private) in comparison to the reference event outdoor zone, associated with a one unit change of the corresponding independent variable.

- $P\,(Y1) = P(\text{ Private}) = \left(\frac{exp^{\,(\beta 0+\ \beta 1(A)+\beta 2(B)+\beta 3(C)+\beta 4(D)+B6(F)+\ldots\beta pXp)}}{1+exp^{\,(Y1+Y2+Y3)}}\right)\ ,-\infty < \mathrm{x} < \infty$
- $P\,(Y2) = P(\text{ Public}) = \left(\frac{exp^{\,(\beta 0+\ \beta 1(A)+\beta 2(B)+\beta 3(C)+\beta 4(D)+B6(F)+\ldots\beta pXp)}}{1+exp^{\,(Y1+Y2+Y3)}}\right) .-\infty < \mathrm{x} < \infty$
- $P\,(Y3) = P(\text{ Semi} - \text{private}) = \left(\frac{exp^{\,(\beta 0+\ \beta 1(A)+\beta 2(B)+\beta 3(C)+\beta 4(D)+B6(F)+\ldots\beta pXp)}}{1+exp^{\,(Y1+Y2+Y3)}}\right), -\infty < \mathrm{x} < \infty$

where:

- P (Y) is the probability of zone occupation
- X1, X2,….X*p* is the independent variables, A= X1, B= X2, C= X3,(*p*= number of independent variables included in the model)
- βo is the intercept, β1, β2… β*p* are the coefficients (effect) of independent variables

The applicability of the thermo-occupation models

To test the applicability of the three-thermo models, two families (8- member family and 4-member family) were chosen as case studies. The aim was to calculate the probabilities of using each zone in the four seasons by each family member.

(1) Family 1: a large family that consists of 8 members, the mother has a BSc degree, the income is 1000JD, they have 6 children: 1 male and 5 females, there are AC units in all zones, and 2 heaters were located in semi-private and private zones.

(2) Family 2: a nuclear family that consists of 4 members, the mother has a high school degree, the income is 650JD, they have 2 children: both are male, one AC unit was located in the semi-private zone, and 3 heaters were located in semi-private and private zones.

For the two families, the probabilities of occupying the three zones in the thermo-models varied from one season to another for the same family, indicating that thermal variation affects the occupants' spatial behaviour, see Table 5 and Table 6. In addition, the ZOR tends to increase with the number of family members. The probability of occupying the three zones for Family 1 is higher than the probability of occupying the same zones for Family 2. Other factors including the mother educational level, family income, occupants' gender, the number of AC units and their location in the apartment, were influencing factors as discussed previously.

Table 5

ZONE	***Y = LOGIT(p/1-p)***	***P = exp(Y1)/(1+exp(Y1+Y2+Y3))***
Private	**34%**	
Summer	0.39201	0.341236
Mild	0.50387	0.381624
Winter	0.3092	0.3141172
Public	**27%**	
Summer	0.70664	0277469
Mild	0.75543	0.388426
Winter	0.60629	0.205750
Semi-private	**40%**	
Summer	0.2846	0.395082
Mild	0.25578	0.365137
Winter	0.40016	0.430374

Table 6

ZONE	***Y = LOGIT(p/1-p)***	***P = exp(Y1)/(1+exp(Y1+Y2+Y3))***
Private	**29%**	
Summer	0.50284	0.28649
Mild	0.60974	0.318813
Winter	0.45003	0.271753
Public	**17.5%**	
Summer	0.9064	0.194081
Mild	0.85215	0.183832
Winter	0.70568	0.158785
Semi-private	**36%**	
Summer	0.37293	0.358161
Mild	0.30857	0.335835
Winter	0.43495	0.381077

The thermo-occupation models have presented the probability of occupying the three zones "Private, Public, and Semi-private" which can be an effective tool in demonstrating the actual percentage use of each zone, see Figure 11.

From the logit models, it was found that both Private and Public zones are more occupied in both mild and summer seasons rather than in the winter. The odds of choosing the private zone in summer were 1.2 times greater than choosing the private zone in winter, also the odds of choosing the zone in mild season were 2.2 more than choosing the zone in winter. In addition, the odds of choosing the public zone in summer were 3.4 times the odds of choosing the public zone in winter. The odds of choosing the public zone in mild seasons were 1.4 times more than choosing the public zone in winter. However, the Semi-private zone was more occupied in the winter season. The odds of choosing the semi-private zone in summer were 4 times less than the odds of choosing the semi-private zone in winter, while the odds of choosing the semi-private zone in mild season were 1.7 times less than choosing the semi-private zone in winter.

A multinomial logistic regression was used to predict a categorical nominal outcome or dependent variable with more than two levels, based on a combination of qualitative and quantitative independent variables or predictors. The outcome of the dependent variables in the study consist of the categories A, B, and C (Zones). The independent variables are family size, occupants age, gender, mother's education, and family income. The multinomial logistic regression does not assume normality, linearity, and homoscedasticity. A main assumption on fitting the model is multicollnearity, which was checked in the analysis for the validity of the fitted multinomial logistic regression model. Normality and homoscedasticity assumptions was verified and checked for the validity of the results.

To apply and validate the model in a real situation, two schematic prototypical apartment layouts were designed for large family size (8 members) and for nuclear family size (4 members). The two layouts were given to the residents of the apartments with similar or close family size and the participants were asked to evaluate their satisfaction with the suggested layout, see Figure 12 and Figure 13. In total, 25 apartments out of 35 expressed their satisfaction with the suggested layouts, 6 apartments were neutral in their response, while 4 apartments expressed a negative evaluation.

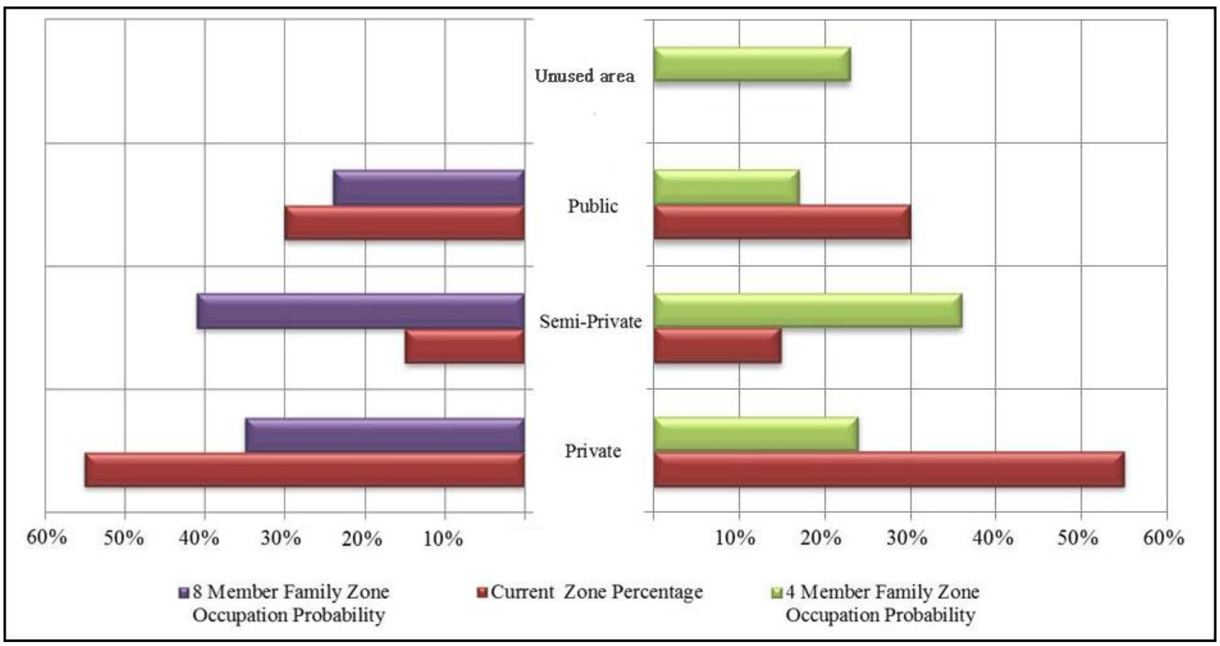

Figure 11

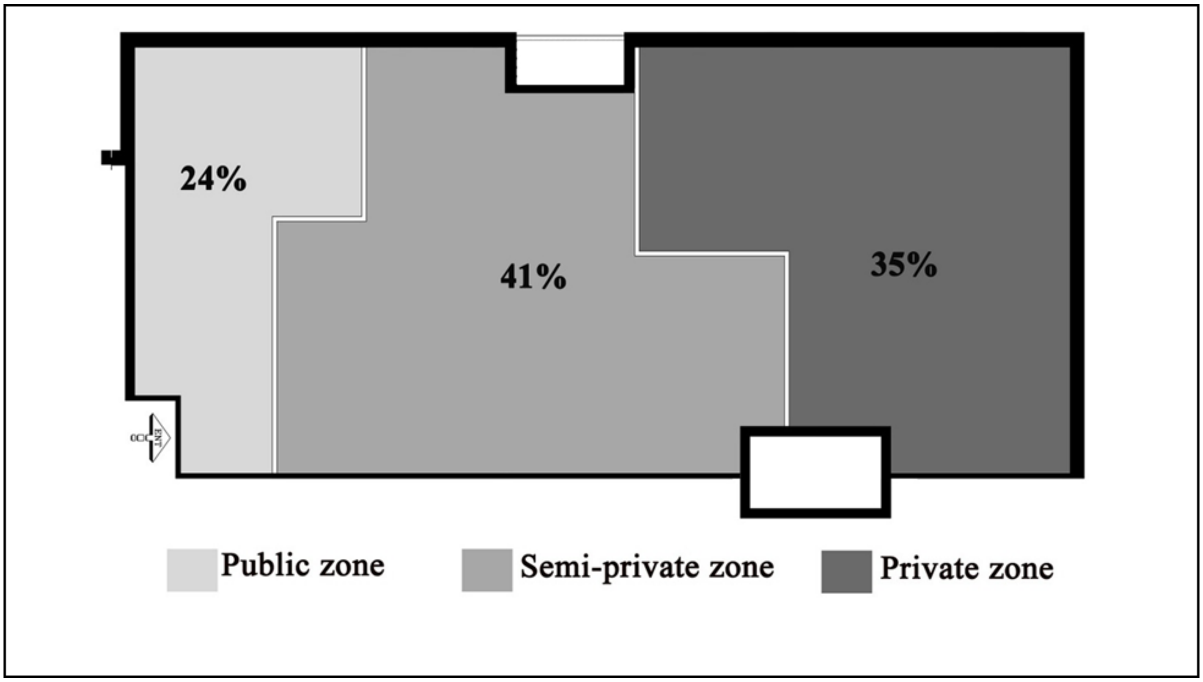

Figure 12

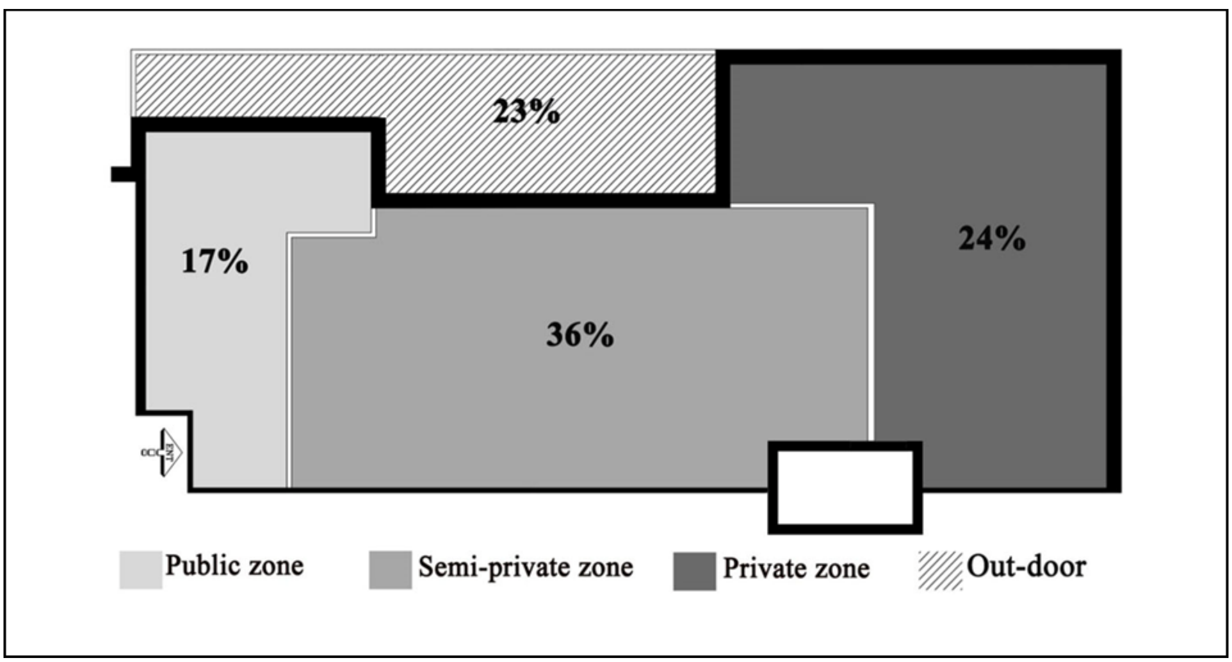

Figure 13

Discussion

The occupants' spatial behaviour was highly correlated with physical and psychological factors. The categorical detected variables from the survey required using the multi-nominal statistical technique to model the relationship between independent variables and the spatial occupation behaviour. Applying statistical regression technique to analyze the main effects of the investigated variables on the spatial behaviour across the three seasons demonstrated that some of the variables had no impact on the occupants' spatial behaviour. For example, the location of the AC unit, heater number, family size, family income, and adjustment behaviours. However, some of these variables affected the occupants' spatial behaviour in certain seasons and were neutral in their effect in others.

In general, the results show that the residents' ZOR was not consistent; it was influenced by the season's thermal variations and moderated by other impacted factors such as gender and controllability. For example, people showed more frequent occupation of outdoor spaces in summer, however they spent more time in the semi-private zone, for example the living room, in winter. In the absence of AC units, outdoor spaces were considered as breathing spaces where people in summer sought to restore their thermal comfort, thus using them more frequently. However, warming a central space in the apartment where the family gathers, which is driven by economic aspects, highlights the importance of the living room as a destination for all family members. These findings are in agreement with recent research which draws attention to the significance of providing varied spatial configuration with different thermal environments to meet the diverse needs of participants throughout thermal seasonal changes (Du et al., 2019). Public spaces represented by the guest room and the attached dining room were barely used across the three seasons. These spaces are significant in the Jordanian culture and are normally used for hosting guests, thus they should be always available. However, as these guest rooms are rarely used, efficient use of space should be considered.

Adjustment endeavors affected the spatial behaviour in winter and mild seasons regardless of the gender aspect. This is in agreement with Humphreys and Nicol's findings (Humphreys & Nicol, 1998). For occupants in general, searching for the best physical setting to restore their thermal comfort is a goal by itself through thermal variations. Toftum (Toftum, 2002) supported this argument by justifying the contrasting findings of field studies about the factors influencing adaptation behaviour driven by seasonal thermal changes. This study builds on a body of research that attempts to advance our understandings of the thermal relationship between buildings and people (Nicol & Roaf, 2017); and consider occupants' expectations and adaptive behaviour (Brown & Cole, 2009; Indraganti & Boussaa, 2017; Kim & de Dear, 2018; Nicol, 2017). We contribute by shedding light on the socio-economic aspects of occupants' spatial behaviour in response to thermal seasonal variations. In addition, this study develops the literature which investigates spatial configuration and adaptive thermal comfort (Du et al., 2019; Yu et al., 2017) by providing further understandings to knowledge of residential buildings (Muresan & Attia, 2017; Nadarajan & Kirubakaran, 2017; Rincón et al., 2019) in places such as Amman in Jordan.

Across the three seasons the time of occupation and performed activities were strongly correlated with ZOR, hence this reflects a spatio-temporal lifestyle routine. Each zone was time-correlated with certain preformed activities. For instance, the private zone had a high ZOR in the morning and at night, as the occupants were performing sleeping activity during those periods. Watching TV and eating at noon increased the semi-private ZOR at that period. Previous research supports these findings, Yun and others (2009), for example emphasized the significance of taking time into consideration to predict occupants' behavior more accurately.

Additionally, indoor thermal sensation and the outdoor temperatures were highly correlated. As a result of inadequate thermal insulation, the apartment buildings can have uncomfortable thermal situations especially in the cold months. As presented in Table 2, residents reported high preference in occupying the semi-private zone in winter. According to Sawashima & Matsubara (2004), when houses are thermally uncomfortable, residents experiencing cold weather prefer to heat the living room only, and the time they stay there increases as a thermoregulation behaviour. The statistics revealed that zone occupation percentage increased when the occupants had the ability to control and modify the occupied zone's thermal conditions, see Figure 10. De Dear et al. (1998) argued that people tend to have wider tolerance of indoor thermal variations and spend more time in places that provide more control.

From the results of thermo-occupational models, it is evident that there is a variation in occupation behaviour. The odds of choosing a place over another varied due to several physical and psychological factors, such as seasonal changes, gender, age, family size, mother educational level, availability of AC units, thermal sensation, and economic status. By applying multi-nominal analysis on these factors, the results show that each factor affects the odds of occupying the zone and the overall probability of the zone occupation. According to Frank et l. (2000), seasonal variations and the correlated changes in the environmental factors stimulate humans' seasonal modifications to their thermal physical setting. In addition, the zones' occupations odds increased when the family size increased. These results confirmed the findings of Feng et al. (2015).

The mother's educational level and her working status also affected the odds of occupying the zones. The results showed that mothers with BSc degrees used private and semi-private zones most of the time with minimal usage of outdoor spaces. However, mothers with junior level of education used semi-private and private zones less frequently in comparison to outdoor spaces, see Figure 8. Women with high educational level usually work and prefer to use private and semi-private zones as they spend most of their time outside the apartment. On the other hand, less educated women spend most of their time at home, thus the probability of using outdoor spaces increases. This result is in agreement with previous research (Hobfoll, 2004) which argues that the physiological and psychological variables, such as gender, culture, and level of knowledge affect the perception of the individual and their performed behaviours in the environment.

Gender was an influential variable in deciding the occupied zone across seasons. Such a result was expected due to the physical nature of females, as females prefer to feel warmer (Van Ooijen, van Marken Lichtenbelt, & Westerterp, 2001) and are more sensitive to temperature variations than males (Burse, 1979). Also, females have higher capability of adaptation to their environment in seasonal variations and more efficiently than males (Indraganti & Rao, 2010). This is also in line with recent research which highlighted the noticeable differences in the evaluation of thermal comfort between and female and male participants (Maykot et al., 2018).

The analysis showed that the availability of AC units and heating appliances would reflect positively on the odds of occupying the zone as discussed earlier. Earlier research (Williams, 1997) supported the previous concept and argue that occupants prefer to choose a space that provides them with a higher level of control.

Testing the applicability of the thermo-occupational models on two families showed a variation in the zone occupation probability of each model with seasonal variation for the same family. These results highlight the seasonal variation effect on the occupants' spatial behaviour. On the other hand, family size in the nominal test was the most influencing variable on zones' occupation odds. This was evident in the variation of zone occupation probability between the 8-member family and the 4-member family whereas more family members increased the probability of occupying the zones. Such data can help in determining the zone proportion of the apartment spaces through the design process, and minimizing wasted areas.

Conclusion

This research examined thermal seasonal variations and occupants' spatial behavior patterns in apartment buildings in Amman as a thermoregulation adaptation behavior. These patterns were found to be strongly affected by thermal seasonal variations influenced by personal factors such as age, gender, education level and thermal controllability over the occupied spaces. A large body of research on occupants' behavior paid immense attention to energy consumption in dwellings. However, this study contributes by providing insights into people's adaptive spatial behavior in relation to seasonal thermal variations. In addition, it proposes a way to optimize spatial design of residential apartments in response to families' diverse characteristics, needs and sizes. The results of this research have the potential to perform as a framework for economic and affordable residential design. To apply this procedure in practice, design guidelines should be prepared for architects, engineers and builders.

Furthermore, this research provides insights into occupants' behavior as a thermoregulatory behavior. Such understandings help in improving the ways people utilise and occupy their residential spaces across the year. This research sheds light on the significance of optimal spatial design to reduce the cost of building and operating domestic spaces.

This study has some limitations that are related to data sampling and cultural aspects in various places in Jordan. This study focused solely on apartments in one area of Jordan. Occupants of other residential types, such as detached houses, may develop different thermoregulation spatial patterns. Similarly, occupants of residential buildings in other parts of Jordan may exhibit behaviours that differ from those reported here. Cultural background as well as social norms and understandings of proxemics' constructs: privacy, territoriality and personal space may also affect people's spatial behavior. The self-reporting may involve a degree of subjectivity and also a lack of accuracy, and therefore the results presented should be viewed with this caveat in mind.

Future research could investigate other residential building types and a qualitative data analysis approach can be adopted to provide a deeper understanding of adaptation behavior in transitional spaces. Spatial behavior theories can be applied as an analytical framework to make sense of the qualitative data. Cultural aspects should also be taken into consideration when examining the various patterns of thermoregulation spatial behaviour. Motion sensors and cam recorders could be used to provide more accurate information about space usability, subject to gaining appropriate ethical approvals. This may help to address some of the uncertainties relating to self-reporting.

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