BEHAVE 2016
4th European Conference on Behaviour and Energy Efficiency
Coimbra, 8-9 September 2016

UNDERSTANDING TENANTS' BEHAVIOURAL ENERGY CONSUMPTION IN A MULTI-UNIT RESIDENTIAL BUILDING IN DOWNTOWN TORONTO, CANADA

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Keywords: Multi-Unit Residential Building **(**MURB), energy consumption, tenant behaviours.

Abstract

Toronto's population of Multi-Unit Residential Buildings (MURBs) are responsible for emitting over 2.6M tonnes of eCO_2 annually. While most research on MURBs aims to understand the relationship between physical building characteristics and energy consumption, little attention is given to the impact of tenants' behaviours on energy consumption. The aim of this pilot study is to ascertain energy behaviours that have the most significant impact on energy consumption in a Toronto MURB where tenants do not pay their own bills. Of all behaviours investigated, average hours spent at home, hours TV, oven and microwave are used per day were found to have a significant impact. While results are not generalizable, a similar methodology may be applied to the wider population of Toronto MURBs, and may be used to inform tailored tenant engagement

programs to encourage more environmentally-friendly behaviours.

1. INTRODUCTION

Multi Unit Residential Buildings (MURBs) comprise over 50% of the City of Toronto's residential building stock [1]; and house over one-third of the city's population [2]. Most MURBs were constructed during the post-war construction boom of the 1960s and 70s; when energy-efficiency was not as grave a concern as it has increasingly become [3], and are responsible for emitting over 2.6M tonnes of eCO_2 annually [3]. There is correspondingly a growing body of research aiming to explain major determinants of energy consumption in MURBs, both Canada-wide and focusing on the Greater Toronto Area. Most studies focus on the entire building as a single unit of analysis, aiming to establish a relationship between building characteristics and energy consumption. In [4], relationships are found between two characteristics (building vintage and height) and energy consumption. Building vintage is also found to affect energy consumption in [5], as well as floor area.

Similar studies, focusing exclusively on Toronto MURBs are presented in [1,3]. A survey was conducted on a sample of over 100 Toronto MURBs aiming to establish a relationship between various building characteristics (including height, vintage, gross floor area, number of suites, ownership type, wall-to-window ratio and efficiency of the heating system) and energy use. Unlike preceding studies, no significant correlation was found between building vintage and energy use. On the other hand, wall-to-window ratio and thermal conductance (u-values) of the windows were found to correlate with heating and cooling loads. Heating system efficiency also weakly correlated with energy use. Despite the large sample size and the large number of building characteristic variables explored; it is maintained that *"correlations between energy use components and single building characteristics were lower than expected"* [1]. This suggests that data that exhibiting energy consumption at a finer level of granularity may better explain determinants of energy use in Toronto MURBs.

2. ENERGY BEHAVIOURS AND ENERGY BEHAVIOUR SURVEYS

On the other hand, occupant behaviour is believed to influence energy use to the same degree as building characteristics [6-9]. It is contended in [10] that differences in occupant behaviour can cause variations of up to 300% in energy consumption. Departing from the position that *"buildings don't use energy, people do,"* [11], there is a large body of research arguing for the need to both understand and take into account the ways in which occupants interact with buildings; and the ways in which occupants' behaviours influence energy use [11-12] Surveys of self-reported energy behaviours are useful tools in studies of this nature, allowing an intimate understanding of how occupants use energy in their households. We review some studies in which surveys of self-reported behaviour are used in the remainder of this section.

A survey of 600 households was conducted in Sweden in [9]; to find both energy-efficient and inefficient behaviours. Energy-efficient behaviours were found with respect to heating, using an iron, laundry activities, cooking activities and washing dishes. However, results of this same survey revealed many more energy inefficient behaviours such as using energy inefficient light-bulbs, leaving lights switched on in vacant rooms, keeping indoor temperatures high at night and using the washing machine 4 times per week, amongst others. The study in [13] aimed at establishing the main determinants of electricity use in the Netherlands, focusing on lighting and appliance use. Data was collected using self-completion surveys from a sample of 323 households and analysed with a view to multiple regression. Three regression models were constructed to predict determinants of electricity use. The first model tested direct determinants of electricity use (i.e. number of lighting and appliances, and duration of use), explaining up to 37% of variance in electricity consumption. The second regression model tested what the authors describe as indirect determinants of electricity use (i.e. household characteristics and presence at home), and succeeded in explaining 42% of total electricity consumption. The final model, combining parameters of both the first and second models, explained up to 58% of variance in electricity use.

In the Canadian context, the most comprehensive energy use survey is the Survey of Household Energy Use (SHEU 2011) [14]; a national survey conducted by Natural Resources Canada and Statistics Canada. This provides detailed information on types of appliances in Canadian households and details of their use. However, SHEU does not include demographic data or data investigating social aspects related to households, whereas previous studies (e.g. [6, 13]) emphasise the importance of demographic and socio-cultural aspects of households in explaining some variation in energy use. To gain a closer understanding of energy use Toronto MURBs, SHEU data could not be relied upon based on this limitation. To date, the only known work examining impacts of occupant behaviour specifically in the context of Toronto MURBs is the survey data described in [2]; which the work presented in this paper builds upon. A deep examination of occupant behaviour in MURBs on a suite-by-suite basis may help to draw a more illustrative picture of energy consumption beyond what is currently known about Toronto MURBs. The aim of this paper is to therefore extrapolate energy behaviours that have the most significant impact on electrical energy use in a Toronto MURB; as a pilot study.

3. METHODOLOGY

This study falls under the umbrella of a municipal initiative in Toronto known as the 'Tower Renewal Program.' One of the major components of this initiative is reducing energy consumption in MURBs constructed between 1945-1984, of eight or more stories [2]. This paper presents a segment of a multi-stage study focusing on a MURB located in downtown Toronto. The MURB is owned and managed by a not-for-profit organization, providing affordable rental housing for newcomers to Canada, people living with disabilities or those in need of affordable housing. The MURB is 11 storeys high and consists of 136 sub-metered suites; 134 of which are bachelor suites (single occupancy, $21.4m^2$). The MURB recently underwent sustainable retrofitting to allow for geothermal and solar thermal domestic hot water heating and sub-metering. Heating is provided centrally with a fan coil unit installed in every suite, only giving tenants control over **fan speed, not temperature.** There is no provision for air conditioning in summer. Tenants do not pay their own electricity bills, which are included in the monthly rent. Finally, there is a low turnover of tenants; at the time this data-analysis was conducted, over 62% of tenants had lived in the MURB for 7 years or more.

3.1. Survey

In a preceding research stage, a survey was administered by members of the same research team to collect data about occupants' behaviours related to energy consumption [2]. This survey consisted of 51 questions related both to household characteristics and energy behaviour. Household characteristics and energy behaviours are shown in Appendix A and B respectively. A total of 48 usable responses were retained from 136 households; corresponding to a response rate of 35%. Descriptive statistics are provided in [2].

3.2. Electrical energy consumption data and weather normalization

In addition to sub-metering, energy consumption data was collected through use of data-loggers installed to monitor energy consumption in the suites of all survey participants [15], meaning that energy consumption data for every month between October 2010-December 2013 was available. The Princeton Scorekeeping Method (PRISM) [16] was applied to the data to provide a weather-normalized estimate of energy consumption for each suite (normalized annual consumption); which was the main energy consumption variable used in the analysis. Normalized annual consumption (NAC); a continuous variable, was checked for normality of distribution, kurtosis, skewedness and outliers. A Kolomogrov-Smirnov test indicated that the distribution was not normal, yet any outliers were found accurate and consistent with the data. Since outliers were found accurate, the NAC variable was transformed to a normal distribution curve using base 10 logarithm to permit application of parametric tests [17]. Means and standard deviations for both NAC and (log) NAC are shown in Appendix B. Normalized values for heating and cooling loads were also generated, which were used to understand heating and cooling behaviours. Inferential statistical analyses were performed using SPSS (www.spss.com) to find relationships between some household characteristics and energy behaviours (survey data) collected in [2] and energy consumption.

4. RESULTS AND DISCUSSION

4.1. Household characteristics and energy consumption

Statistical tests were performed to find a relationship between each of the six household characteristics shown in Appendix A and energy consumption ((log)NAC). Two significant relationships were revealed (table 1). A one-way ANOVA revealed a relationship between age-group and energy consumption. A Post-hoc analysis using a Tukey test showed a significant difference between those in the 31-40 category and participants in the 60+ age category; with lower consumption associated with the 31-40 age category. This result aligns with findings in [6, 18] which also confirm a relationship between energy consumption and age. However, both these studies describe this as a linear relationship; as age increases so does energy consumption [6, 18]. The results of this research did not confirm linearity of the relationship; a Spearman's correlation[i] performed between the two variables ((log)NAC and age group) did not retain significant results.

A highly significant relationship between total household income and energy consumption was also found, based on a one-way ANOVA. This is similar to findings from [19], which indicates that an increase in income leads to an increase in consumption. On the other hand, it is argued in [20] that increased consumption leads to adoption of energy saving behaviours, meaning lower consumption. Nevertheless, [19-20] both describe linear relationships (correlations) between total household income and energy consumption. However, in this study, a linear relationship could not be described. Rather, a Tukey test revealed significant differences between the following income groups:

- The lowest income group ($0-$14,999) and the second income group ($15,000-$29,999).
- The lowest income group ($0-$14,999) and the third income group ($30,000-$49,999).

Based on the means (table 1) we can conclude that income groups 2 and 3 are using less energy than those in the lowest income group.

Table 1: Showing significant relationships found between household characteristic variables and energy consumption.

(Energy variable)*(Household characteristic variable)	Statistics (ANOVA – F-Statistic).	Means and standard deviations
(log)NAC*Age group	F(3, 44) = 3.265*	18-30 (M = 3.23, SD = 0.14).
		31-40 (M = 3.07, SD = 0.18).
		46-60 (M = 3.14, SD = 0.17).
		60+ (M = 3.25, SD = 0.17).
(log)NAC * Total household income	F(3, 44) = 4.509*	$0-$14,999 (M = 3.25, SD = 0.21).
		$15, 000 - $29,999 (M = 3.09, SD = 0.18).
		$30,000 - $49,000 (M = 3.05, SD = 0.078).
		$50,000+ (M = 3.24, SD = 0.11).
Notes*<0.05, **<0.01, ***< 0.0001 and n.s. not statistically significant.		

4.2. Tenant behaviours and energy consumption

Hours spent at home, television and cable box ownership and use

In this section, the relationship between tenant behaviour variables (Appendix B) and energy

[i] Spearman's correlations were used instead of Pearson's correlations when one of the variables was not normally distributed.

consumption is explored. A Spearman's correlation performed between average hours spent at home and energy consumption ((log)NAC) indicated a highly significant moderate positive correlation (table 2). A strong, positive correlation was also found between average hours TV is on per day and (log) NAC. This aligns with the literature as, out of all appliances on the market, the television has been defined as the only appliance that consumes increasing amounts of energy as the years progress [13]. However, type of TV owned did not appear to have a significant impact on energy consumption based on results of a one-way ANOVA (table 4). This comes despite the fact that plasma TVs have been found to consume over twice the amount of energy needed to power LCD screens, and over three times the power needed for tube (CRT) televisions [21]. Nevertheless, only 9 respondents in the sample reported owning a plasma TV, which may explain the insignificant result.

On the other hand, no cable box variables (cable box ownership and average hours cable box is on per day) had a significant impact on energy used; based on a Spearman's correlation (table 2) and one-way ANOVA (table 3). Finally, statistical tests were performed between occupant behaviour variables (Appendix A) and variables concerned with television ownership and use, to better understand the degree of association between time spent at home average hours TV is on per day. A significant positive yet weak correlation was found between these two variables (table 2).

Table 2: Results of correlation analyses performed in this section. Only significant results are shown.

(Variable 1)*(Variable 2)	Correlation co-efficient	Strength direction
Avg. hours spent at home * (log)NAC	Spearman's rho (r_s)= 0.482**	Moderate, positive
Avg. hours TV is on per day * (log)NAC	Spearman's rho (r_s)= 0.574**	Strong, positive
Avg. hours spent at home * Avg. hours TV is on.	Spearman's rho (r_s) = 0.317*	Moderate, positive
Avg. hours oven is used per day *(log)NAC	Spearman's rho (r_s) = 0.302*	Moderate, positive
Avg. minutes microwave is used per day * (log)NAC	Spearman's rho (r_s) = 0.302*	Moderate, positive
Avg. hours lights are left on per day* (log)NAC	Spearman's rho (r_s) = 0.309*	Moderate, positive
Setting at which fan for heating is set during winter months * (log)NAC	Spearman's rho (r_s) = 0.381*	Moderate, positive
Notes*<0.05, **<0.01, ***< 0.0001.		

Computer ownership and internet subscription.

An independent samples t-test performed to find whether ownership of a computer is associated with energy consumption did not retain a significant result (table 3). Similarly there was no significant correlation between average hours computer is used per day and energy consumption. Finally, type of computer owned was not found to significantly affect energy consumption based on the results of a one-way ANOVA (table 3), despite the fact that laptop computers are known to use a fraction of the energy used by desktop computers [22]. Nevertheless, it is maintained in [22] that increased widespread of laptop computers has caused an upsurge in energy consumption; which may explain why here is no difference in the energy consumed by those who own a desktop and those who own a laptop. On the other hand, this insignificant result may be explained by small sample size, as more than half the sample do not own a computer.

Cooking and lighting

Occupants were asked to provide information on their cooking patterns; particularly the duration of in-suite stove, oven and microwave use. Moderate, positive correlations were found between energy consumption and average hours oven is used per day as well as average minutes microwave is used per day (table 3). This is a notable result, as cooking in the residential sector is known to consume large amounts of energy (7MJ/kg food product according to [23]). Moreover, most tenants are newcomers to Canada, originating from countries where it is common practice to cook two to three meals per day, instead of cooking and storing food for later consumption.

With regards to lighting variables shown in Appendix B, only the average duration during which the lights were left on per day was found to have a significant relationship with energy consumption based on a moderate positive correlation (table 2). On the other hand, type of light bulbs installed (whether CFL or incandescent) and the number of light bulbs installed did not retain any significant result.

Heating and cooling

In countries where there is a strong heating requirement, heating tends to have the most significant impact on energy consumption [6-8]. However, in this particular MURB, tenants only have control over fan speed for heating and no control over temperature, which is controlled by the management office and kept constant across all suites.

Four variables concerned with heating and cooling are shown in Appendix B. Spearman's correlations and one-way ANOVAs were performed to determine whether a relationship exists between the categorical variables '*setting at which the fan for heating is set during winter months*' and '*setting at which the fan for cooling is set during summer months*' and energy consumption. However, none of these tests retained significant results, meaning that there is no relationship between energy consumption and fan settings for heating and/or cooling (for results of one-way ANOVAs please see table 3). The same tests were repeated; replacing ((log)NAC with the annual heating load (for winter months) and annual cooling load (for summer months). A highly significant, moderate correlation was found between (log) annual heating load and '*setting at which the fan for heating is set during winter months*' (table 2). This was also confirmed using a one-way ANOVA testing the relationship between the same two variables. However, no significant relationships were ascertained between the annual cooling load and '*setting at which the fan for cooling is set during summer months*'. This makes sense, seeing as Canada's heating season, lasting for eight months per year, is much longer than the cooling season. On the other hand, this result may also be interpreted as an indication that the cooling system in place is poor, as no matter how high the fan setting for cooling is; it is having little impact on internal comfort conditions. This interpretation was confirmed subsequently using an independent samples t-test, examining the relationship between ownership of a personal fan for summer months and ((log)NAC). A significant difference was found between those who own and use a personal fan during summer months to provide for cooling and those who do not (table 3). On the other hand, a t-test performed to ascertain whether there is a significant difference in energy consumption between those who own a personal heater to provide additional heating during winter months and those who do not retained non-significant results. This suggests that, while the existing system provides adequate heating during winter, cooling requirements needed during summer months are not satisfactory.

Table 3: Results of one-way ANOVAs and t-tests performed in this section.

(Variable 1)*(Variable 2)	**Statistics (ANOVA – F-Statistic).**	**Means and standard deviations**
(log)NAC * Type of TV owned	F(3, 44) = 0.478 n.s.	Tube (M = 3.17, SD = 0.21)
		LCD / LED (M = 3.19, SD = 0.17).
		Plasma (M = 3.15, SD = 0.17).
		No TV owned (M = 3.10, SD = 0.19).
(log) NAC * Whether cable box is switched on or off when not in use.	F(2, 45) = 2.448 n.s.	On (M = 3.21, SD = 0.09).
		Off (M = 3.22, SD = 0.20).
		No cable box owned (M = 3.10, SD = 0.17).
(log)NAC * Type of computer owned	F(3, 44) = 1.303 n.s.	Desktop (M = 3.27, SD = 0.24).
		Laptop (M = 3.12, SD = 0.122).
		Both (M = 3.25, SD = 0.03).
		No computer owned (M = 3.19, SD = 0.14).
(log)NAC * Setting at which fan for heating is set during winter months.	F(2, 45) = 1.977 n.s.	High (M=3.24, SD = 0.18).
		Medium (M = 3.13, SD = 0.20).
		Low or off (M = 3.12, SD = 0.18).
(log)NAC * Setting at which fan for cooling is set during summer months.	F(2, 45) = 3.179 n.s.	High (M=3.358, SD = 0.61).
		Medium (M = 3.21, SD = 0.20).
		Low or off (M = 3.16, SD = 0.18).
(log)Annual heating load * Setting at which fan for heating is set during winter months.	*F*(2, 45) = 4.479*	High (M = 344.37, SD = 460.75).
		Medium (M = -40.50, SD = 147.36).
		Low or off (M = 143.67, SD = 369.29).

Table 3 (continued): Results of one-way ANOVAs and t-tests performed in this section.

(Variable 1)*(Variable 2)	Statistic (t-test, t-statistic)	Means and standard deviations
(log)NAC * Whether a computer is owned	t(df) – 0.431, n.s.	Yes (M=3.15, SD = 0.21).
		No (M = 3.19, SD = 0.14).
(log) NAC*Personal fan owned	t(46) = 2.358*	Yes (M = 3.26, SD = 0.23).
		No (M = 3.13, SD = 0.15).
(log)NAC*Personal heater owned	t(46) = 0.274 n.s.	Yes (M = 3.19, SD = 0.20).
		No (M = 3.16, SD = 0.18).
Notes*<0.05, **<0.01, ***< 0.0001 and n.s. not statistically significant.		

5. CONCLUSIONS

Analysing the survey data using inferential statistics allows us to observe the direct cause-and-effect relationship between behaviour and energy consumption. While the survey data provides a snapshot of the behaviours that have the most significant impact on energy consumption, it does not paint a complete picture; explaining underlying reasons for particular significances or behaviours. For example, while the number of hours cooking appliances (oven and microwave) correlate significantly with energy use; cooking patterns in this MURB are affected by cultural practices resulting in this particular behavioural pattern. It is therefore not possible to generalize these results beyond this MURB, as both tenant characteristics and the single occupancy arrangement are unique to this building and not representative of the population of households residing in Toronto MURBs.

One limitation of this work is the reliance on surveys of self-reported behaviour, which depend to a great extent on the respondent’s honesty. Even if the participant is making a genuine effort to provide truthful responses about their consumption, it is unlikely that they will be able to introspectively assess consumption and behaviour accurately; in fact most tenants are likely to over or underestimate the frequency or durations of use of electrical appliances. This limitation is further compounded by the fact that tenants do not pay their own energy bills; meaning that tenants receive no feedback about their actual energy use. By paying a flat rate for all utilities compounded (electricity, water and gas), direct and/or financial implications of energy behaviours are not felt, reducing any potential impetus to reduce energy use. Moreover, the fact that tenants do not pay for their actual consumption may be causing a principal / agent issue. Tenants are unlikely to modify their energy behaviours when they do not feel the effects of rising energy costs. Equally, there is little motivation on the building owner’s part to invest in improving or retrofitting building features, or investing in energy-efficient appliances. Instead, periodically introducing increases in rent is considered a faster and easier response to rising energy costs for the owner.

While striking a balance between building owners’ and tenants’ interests remains a long-term challenge, one way to affect reduction in energy use is by introducing tailored tenant engagement programs such as the one described in [15]. This was conducted by members of the same team as a continuation of this pilot study; giving direct feedback in real-time about energy use and providing energy conservation tips designed to improve behaviours previously identified as energy inefficient. The ability to foster a deeper understanding of energy consumption through the methodology applied in this pilot study serves as a starting point toward the wider applicability of the methodology on the wider population of MURBs in Toronto, particularly those accommodating more representative samples of Canadian households consisting of at least two or more people.

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APPENDIX A: Household characteristics explored in the survey.

VARIABLE	CATEGORY
Gender	(1) Male (2) Female
Age group	(1) 18-30 (2) 31-40 (3) 46-60 (4) 60+
Country of origin	(1) Canada or USA (2) Europe (3) South/Central America or Carribean (4) South Asia (5) East Asia (6) Southeast Asia (7) West Asia or Middle East (8) Africa (9) Australia, New Zealand or South Pacific (10) Other (11) Info. Withheld.
No. of years spent living in Toronto MURB at time of survey administration	(1) 0-1 year (2) 2-4 years (3) 5-7 years (4) 7+ years

No. of people living in household	(1) 1 person (2) 2 persons
Total household income.	(1) $0-$14,999 (2)$15,000-$29,000 (3) $30,000-$49,000 (4)$50,000 (5) Info withheld.

APPENDIX B: Tenant behaviour variables explored in the survey.

VARIABLE	DEFINITION	MEAN	SD	n
Energy	Normalized annual consumption (NAC)(kWh) (continuous, non-normally distributed).	1595.11	845.86	48
	(log)Normalized annual consumption (log)NAC (kWh) (continuous, normally distributed).	3.16	0.18	48
	Annual heating load (kWh) (continuous, non-normally distributed).	143.67	369.29	48
	Annual cooling load (kWh) (continuous, normally distributed.	16.83	162.83	48
Time spent at home	Avg. hours spent at home (continuous, non-normally distributed).	11.90	3.459	48
Television and cable box variables				
TV type	Type of TV owned (categorical): (1) Tube (2) LCD / LED (3) Plasma (4)No TV owned	2.38	1.178	48
TV daily usage	Avg. hours TV is on per day (continuous, non-normally distributed).	3.33	3.45	48
Cable box ownership and use	Whether cable box is switched on or off when not in use (categorical): (1) On (2) Off (3) No cable box.	2.33	0.724	48
Cable box daily usage	Avg. hours cable box is on per day (continuous, non-normally distributed).	5.13	8.76	48
Computer and internet subscription variables				
Computer owned	Whether a computer is owned (categorical): (1) Yes (2) No.	1.38	0.49	48

APPENDIX B: (Continued).

VARIABLE	DEFINITION	MEAN	SD	n
Computer type	Type of computer owned (categorical): (1) Desktop (2) Laptop (3) Both (4) Neither	2.38	0.70	48
Computer daily usage	Average hours computer is used per day (continuous, non-normally distributed).	1.77	2.56	48
Internet daily usage	Average hours internet is used per day (continuous, non-normally distributed).	1.48	2.31	48
Cooking variables				
Stove usage	Avg. hours stove is used per day (continuous, non-normally distributed).	0.83	0.81	48
Oven usage	(Avg. hours oven is used per day (continuous, non-normally distributed).	0.42	0.62	48

Microwave usage	Avg. mins microwave is used per day (continuous, non-normally distributed.	0.42	0.62	48
Lighting variables				
CFL bulbs	No. of CFL bulbs in the unit (continuous, non-normally distributed).	2.40	1.72	48
Incandescent bulbs	No. of incandescent bulbs in the unit (continuous, non-normally distributed).	1.60	1.50	48
Total light bulbs	Total no. of bulbs in the unit (CFL + incandescent) (continuous, non-normally distributed).	4.00	1.46	48
Unused light off	No. of lights switched off when not in use (continuous, non-normally distributed).	1.38	0.79	48
Lights on more than 3 hours	No. of lights which are left on for more than 3 hours per day (continuous, non-normally distributed).	1.82	0.94	48
Lights daily usage	Average hours lights are left on per day (continuous, non-normally distributed).	5.25	4.11	48
Heating and cooling variables.				
Fan setting for heating.	Setting at which fan for heating is set during winter (categorical) (1) High (2) Medium (3) Low or off.	2.10	0.86	48
Fan setting for cooling.	Setting at which fan for cooling is set during summer (categorical): (1) High (2) Medium (3) Low or off.	2.50	0.59	48
Personal heater owned.	Whether a personal heater is owned for use during winter months (categorical): (1) Yes (2) No	1.94	0.25	48
Personal fan owned.	Whether a personal fan is owned for use during summer months (categorical): (1) Yes (2) No	1.73	0.50	48