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Definition of occupant behaviour patterns with respect to ventilation for apartments from the real estate market in Santiago de Chile

Felipe Encinas Pino*, André de Herde

Architecture et Climat, Université catholique de Louvain, Belgium

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ABSTRACT

A survey of perception of thermal comfort and occupant behaviour was carried out in Santiago de Chile from December 2009 to January 2010. The survey was applied in an apartment building of the private real estate market. This paper proposes a methodology based on the systematic application of multivariate statistical techniques (principal component analysis, multivariate logistic regression and cluster analysis) which were applied to the collected data of the survey.

The results of the statistical analyses show that daytime ventilation is not strongly correlated to the perception of thermal comfort in summer, probably since it is mainly oriented to hygienic purposes. On the contrary, both night ventilation and solar protection appear as very significant predictors for the same dependent variable. The objective of these models corresponds to the definition of occupant behaviour profiles which in combination with meteorological information can be used as input data in energy building simulations. Therefore, these results form a framework that can be implemented to make calculations of energy performance of dwellings more accurate, reliable and representative of the real estate market.

1. Introduction

It has been demonstrated that there is a strong relationship between occupant behaviour and thermal performance of dwellings. Indeed, according to Macdonald, Clarke, and Strachan (1999), some variables related to occupant behaviour constitute some of the main sources of uncertainty in the field of energy building simulations. In that sense, depending on the variability of aspects such as scheduled internal gains or natural ventilation (by means of manually operable windows), a wide range of variation in the energy consumption of dwellings may be expected.

Uncertainty and sensibility analyses frequently deal with this situation, since they can generate a great range of forecast values based on the distribution of the input variables. For example, in the case of the physical properties of building materials, uncertainty appears from variations between manufacturers, batches or even between products within a batch. However, this variability has been studied and may be obtained from references as Clarke, Yaneske, and Pinney (1999) or Lomas and Bowman (1987). On the contrary, Hyun, Park, and Augenbroe (2008) explain that unfortunately the widely varying occupant influences – especially related to operable windows – have not been directly measured or investigated.

At the same time, most of the building energy simulation programs are deterministic, rather than probabilistic and consequently their results frequently are not expressed in terms of probabilities. Additionally, a considerable difference between the standard values of ventilation used for simulations (e.g. for energy building certification) and the ventilation patterns in real occupied dwellings may be expected. Therefore, if the aim is to represent a wide range of cases (instead of a singular case study), it is absolutely necessary to characterize the occupant behaviour in terms of patterns or profiles to be used as input data in energy building simulations.

Due to the link between occupant behaviour and energy consumption, it is important to define this behaviour from the interaction with the control mechanisms of windows during daytime and night time, and also establishing the reasons for that specific behaviour, as is recommended by the IEA (1988). Andersen, Toftum, Andersen, and Olesen (2009) indicate that most of the energy building simulation programs provide possibilities of regulation of control systems (such as opening/closing windows), but there are no guidelines for how the simulated environment should be managed by the softwares. Consequently, according to the same authors, the definition of a set of standard behaviour patterns – based on the quantification of real inhabitants' behaviour – would significantly improve the validity of the outcomes of the simulations.

In this context, the obtained behaviour patterns represent a first approach in the process to obtain a more real thermal behaviour,

* Corresponding author at: Place de Levant, 1. B-1348 Louvain-la-Neuve, Belgium. Tel.: +32 10 47 91 52; fax: +32 10 47 21 50.
E-mail address: f.encinaspino@uclouvain.be (F. Encinas Pino).

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Table 1
Considered variables for the Principal Component Analysis (PCA).

Variables			Number of cases
Subject	Question	Name	
Perception of thermal comfort	Q6	Thermal sensation in the apartment during winter	88
	Q10	Thermal sensation in the apartment during summer	88
Ventilation	Q16	Daytime ventilation in winter	88
	Q20	Daytime ventilation in summer	88
	Q24	Night ventilation in summer	88
Strategies and systems	Q13	Presence of external solar protection	88
	Q27	Use of heating systems in winter	88

Source: Own elaboration.

since this information needs to be combined with meteorological data. Based on variables such as air temperature [°C], wind speed [m/s] and wind direction [°] is possible to establish accurate airflow patterns in terms of ventilation rates. These results can help to understand occupant behaviour as a function of the thermal performance of apartments (and depending on some variables such as orientation or windows area).

2. Methodology

Due to the importance of the occupant behaviour and ventilation on the thermal behaviour of apartments it is necessary to collect data about these aspects based on real and local sources. Nonetheless, due to the lack of references in the national state of art, a survey to obtain this information is required. As the scope of this study is applied to the architectural design and its implications for the thermal performance of apartments, the survey will be destined in a first approach to a specific pilot case study in Santiago de Chile.

The pilot case study corresponds to the *Edificio Don José*, located in the Santiago borough, city of Santiago. This is an apartment building, constructed in 1993–1994 and with 22 floors and 8 apartments per floor. The building is situated in an urban environment, near to the centre of the city.

The questionnaire survey has been built based on four variables, which correspond to the aspects to investigate. Each variable is disaggregated in several dimensions, indicators and items (questions). The main variables to measure the perception of thermal comfort and occupant behaviour proposed for this research are:

- *Control and segmentation*: In its demographical dimension, this variable allows to individualize the interview subject and its familiar environment.
- *Perception of thermal comfort (thermal sensation)*: in its two dimensions, "Perception of thermal comfort in winter" and "Perception of thermal comfort in summer", this variable tries to identify the way in which the specific occupants express satisfaction with the thermal environment. To define the categories of items referred to thermal sensation, the 7 point subjective scale of the European standard EN 15251 (2007) was considered.
- *Use of the dwelling with respect to thermal comfort*: in its two dimensions "Ventilation habits during winter and summer" and "Use of heating and cooling systems", this variable tries to characterize the apartment operation in terms of both natural daytime ventilation and night cooling and with respect to the use of heating and cooling systems.

After the definition of the variables, dimensions, indicators and items of the survey, a process of content validity by experts was proposed. This validity method is recommended by Hernández Sampieri, Fernández-Collado, and Baptista Lucio (2006) as a way to determine as the variables have been measured by their corresponding items. This type of content validity basically corresponds to the revision of the measurement tool of the study by a panel of experts, which in this case was integrated by 6 researchers of some important national and international universities, with a wide experience and knowledge about the thermal behaviour of dwellings in the Chilean context.

The survey questionnaire was finally integrated for 41 items. Most of the questions require just one answer option, while others accept more than one. The survey was carried out by means of interviews. Two interviewers were trained to address this activity along with the author of this study. The survey was applied to 91 randomly selected apartments in two summer months (December 2009 and January 2010), since the main objectives of the survey are related to natural ventilation and occupant behaviour during the cooling period.

The sample size corresponds to 91 cases over a population of 166 apartments. The margin of error and the confidence level are 6% and 90%, respectively. It is important to remember that the scope of the survey is related to the generation of an approach to the indoor environment and occupant behaviour in apartments of Santiago de Chile based on a pilot case study. Due to this, the survey frame was considered as appropriate. A most ambitious experience may be proposed as further research, with the aim of e.g. providing information for the definition of public policies. In that case, the population of the survey can be extended to several apartment buildings in Santiago de Chile.

2.1. Statistical methods

Factorial analysis is a multivariate analysis technique that it is used to reduce the dimensions of a large set of observed variables. The new obtained variables received the name of factors. According to Vivanco (1999), these factors are a lineal combination of variables. Also, the method allows the detection of subjacent dimensions that belongs to a correlation matrix. The factorial analysis can be used for exploratory purposes, in order to know the relations structure over a specific set of variables.

According to the procedure for extracting factors, it is possible to distinguish the "Factor Analysis" and the "Principal Component Analysis (PCA)". The difference between them is mainly to do with the way variance is dealt with. Since the objective of this study is to obtain a reduction of a large set of information contained in certain questions of the survey and perform further analysis with this information, the procedure of PCA was selected.

Table 1 presents all the variables that were considered to carry out the PCA. These questions were selected in order to represent the different aspects related to the perception of thermal comfort (both in winter and summer), natural ventilation and strategies and systems that affect the thermal behaviour of apartments.

In total, 88 cases were considered, due to the three cases that do not answer the question Q6 (related to the perception of thermal comfort in winter) and which were excluded in order to avoid miss-