SIMULATING OCCUPANT BEHAVIOUR AND ENERGY PERFORMANCE OF DWELLINGS: A SENSITIVITY ANALYSIS OF PRESENCE PATTERNS IN DIFFERENT DWELLING TYPES

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ABSTRACT

Influence of occupant behaviour on the energy performance of dwellings is an emerging research topic: Not only the amount of studies is insufficient, but also they provide contradictory results. The aim of this study is to reveal the sensitivity of dwelling energy performance to the presence of occupants in different dwelling types, assuming that presence is the precondition of behaviour. Sensitivity of dwelling energy performance to occupant presence is analysed using Monte Carlo method, which is one of the most commonly used methods to investigate the approximate distribution of possible results (energy performance) on the basis of probabilistic inputs (presence). For this study, the hourly inputs of presence are derived from a database of 319 dwellings in the Netherlands. 4 different types of Dutch reference dwellings are selected for the simulation model: Row house, Corner/Semi-detached, Free standing, and Flat. Steps of the methodology are as follows: (1) Pre-processing behaviour data (the maximum and minimum values of the input parameters); (2) Gathering samples from SimLab pre-processor; (3) Simulating each sample by a dynamic simulation program to collect output data. (The simulations are made with 'one at a time' approach. Each input is perturbed in turn while keeping all other inputs constant at their nominal value); (4) Combination of inputs and outputs in post-processor of SimLab to run Monte-Carlo analyses. Results of this study showed that presence varies at the weekends more than it does during the weekdays. Corner/semi-detached dwelling is the dwelling type that presence is the most consistent during the weekdays, and row house at the weekend. Flat is the dwelling type that demands the least heating energy, and corner/semi-detached is the most. Weekdays are more influential on the heating energy demand than the weekends. Corner/semi-detached dwelling energy performance is the most sensitive to presence on weekdays, row house at the weekend.

INTRODUCTION

A building consumes energy depending on its envelope characteristics, the systems installed for its services (heating and ventilation systems, electricity production and hot water), the site and climate it is located in and the behaviour of its occupants. Presence and occupant behaviour is an aspect of building energy performance that has been studied for the last two decades. In this paper, assuming that presence is the precondition to occupant behaviour in a building, the sensitivity of dwelling energy performance to the presence of occupants in different dwelling types is studied.

Sensitivity analysis, the study of how the variation in the output of a model can be qualitatively or quantitatively apportioned to different sources of variation, is conducted based on a mathematical model defined by a series of equations, input factors, parameters, and variables aimed to characterize the process being investigated. Input is subject to many sources of uncertainty including errors of measurement, absence of information and poor or partial understanding of the driving forces and mechanisms. This uncertainty imposes a limit on the confidence in the output of the model (e.g. Hamby et al, 1994; Helton et al, 2006)

One of the most common sensitivity analysis practice works is based on sampling (random, importance, Latin hypercube). In general, a sampling-based sensitivity analysis is one in which the model is executed repeatedly for combinations of values sampled from the distribution (assumed known) of the input factors. There are several examples of the application of sensitivity analysis in building thermal modelling (e.g. Spitler et al, 1989; Corson, 1992; Fülbringer and Roulet, 1999; McDonald, 2004; Harputlugil et al, 2009; Bedir et al, 2011). For sensitivity of energy simulation models, a set of input parameters and their values are defined and applied to a building model.

The simulated energy performance of the model is used as a base for comparison to determine how much the output (here measured in terms of heating energy demand in the heating season) changes due to particular increments of input values (here presence) (Corson, 1992). Consequently the results show which parameters can be classified as “sensitive” or “robust”. Sensitive parameters are the parameters that by a change in their value cause effective changes on outputs (in this case heating energy demand). Contrarily, change of robust parameters causes negligible changes on outputs.

The aim of this study is to find how sensitive or robust the dwelling energy performance is to occupant presence, and presence only. Accordingly, the analysis looks for the thresholds that energy performance of a dwelling becomes sensitive to presence. The sensitivity analysis is conducted on 4 different types of Dutch reference dwellings from year 2010: Row house, Corner/Semi-detached, Free standing, and Flat, considering that the sensitivity of dwelling energy performance could be different in different dwelling types.

METHOD

Monte Carlo method is used for the sensitivity analysis. It is one of the most commonly used methods to analyse the approximate distribution of possible results on the basis of probabilistic inputs (Lomas and Eppel, 2007; Hopfe et al, 2007). In this research, the inputs (parameters) include presence at home, thus the internal heat gain resulting from presence.

The steps of the analysis are as follows (Figure-1):

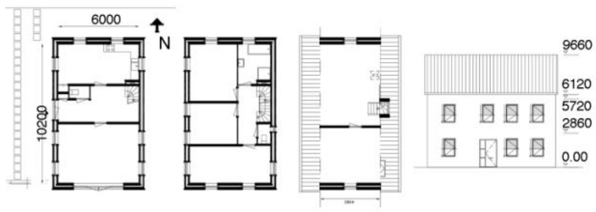
- Pre-processing survey data (see next section) in statistical analysis program (the maximum and minimum values of the input parameters are determined)
- Gathering random samples which are uniformly distributed from max and min values from SimLab pre-processor (SimLab)
- Simulating each sample by a dynamic simulation program to collect output data. The simulations are made with ‘one at a time’ approach. Each input is perturbed in turn while keeping all other inputs constant at their nominal value.
- Combination of inputs and outputs in post-processor of Sim-Lab to get Monte-Carlo
- Interpretation of the results

Data

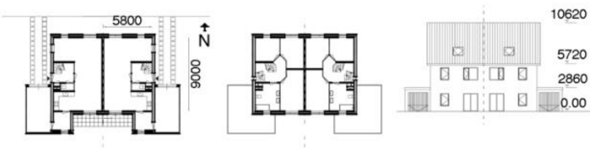
4 Dutch reference dwellings for row, corner/semi-detached, free standing, and flat (Referentie woning, 2010) are modelled using the simulation software. The characteristics of the

reference dwellings are explained below: Figure 1, the architectural drawings, and Table 1, the envelope properties.

Row house



freestanding house



Semi-detached house

flat

Figure 1: Plans and sections of the reference dwellings.

Characteristics of the reference dwelling	Row	Corner/semi-detached	Free standing	Flat
Width (m)	5,1	5,8	6,0	8,3
Depth (m)	8,9	9,0	10,2	11,9
Height (m)	2,6	2,6	2,6	2,6
Floor area (m^2)	45,4	52,2	61,2	98,8
Volume (m^3)	118,0	135,7	159,1	256,8
Rc façade (m^2K/W)	3,0	4,0	4,0	4,0
Rc roof (m^2K/W)	4,0	5,0	4,0	5,0
Rc ground floor (m^2K/W)	3,0	3,0	3,0	3,0
U window (W/m^2K)	1,8	1,7	1,7	1,7
U front door (W/m^2K)	2	2,0	2,0	2,0
EPC value (NEN5129)	0,78	0,80	0,80	0,80
Yearly energy use (MJ/m^2)	359	401	417	346

Table 1: Dimensions, envelope and energy use characteristics of the reference dwellings.

Data about presence is collected in two neighbourhoods that began to develop in 1996, in the Netherlands. The survey was conducted in Winter 2008, in 319 dwellings. Hourly presence patterns of these dwellings (based on the dwelling type) are converted to single daily presence values, and descriptive statistical analysis is applied to be able to obtain the maximum and minimum values of presence. These values are processed in SimLab pre-processor for gathering the generic presence patterns for 4 different dwelling types (see Pre-processing survey data step, in previous section).

Based on the 40 samples generated from pre-processor of SimLab, heating energy demand for each sample during the Dutch heating season (assumed as 01.October-01.April) is calculated with ‘one at a time’ approach (see previous section), using a dynamic building simulation program. Note that, semi-detached house is one of the two houses in the cluster, and the flat is one of the units that are located in one of the intermediary storeys of an apartment building.

The analysis of the results is conducted using the Monte Carlo statistical analysis method, in the post-processor of SimLab.

RESULTS AND DISCUSSION

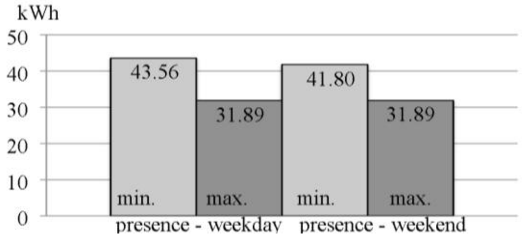
The presence inputs generated from the survey sample for each dwelling type show that presence during weekdays in corner/semi-detached dwelling does not vary a lot (R^2:0.78). Second most constant is the weekdays presence for flat type (R^2:0.66). Weekdays presence for row houses (R^2:0.59) and free standing (R^2:0.09) follow the flat type. At the weekends, the variance of presence for different dwelling types is as such: Row house (R^2:0.28), flat (R^2:0.20), corner/semi-detached (R^2:0.13), and free standing (R^2:0.03).

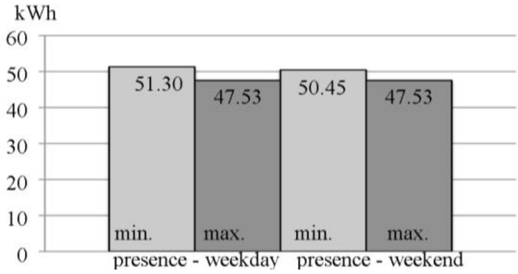
	Minimum presence sample (w/day)			**Minimum presence sample (w/end)**			**Maximum presence sample (same w/day & w/end)**		
	W/day (person)	**W/end (person)**	**Heating Energy Demand (kWh)**	**W/day (person)**	**W/end (person)**	**Heating Energy Demand (kWh)**	**W/day (person)**	**W/end (person)**	**Heating Energy Demand (kWh)**
Row	1	2	43.56	2	1	41.80	4	5	31.89
Corner/ semi-detached	1	1	61.81	1	1	61.81	4	5	49.54
Free standing	1	2	51.30	2	1	50.45	3	3	47.53
Flat	0	1	9.10	1	0	8.47	3	3	5.41

Table 2: Minimum and maximum presence values for the weekdays and the weekend and the heating energy demands.

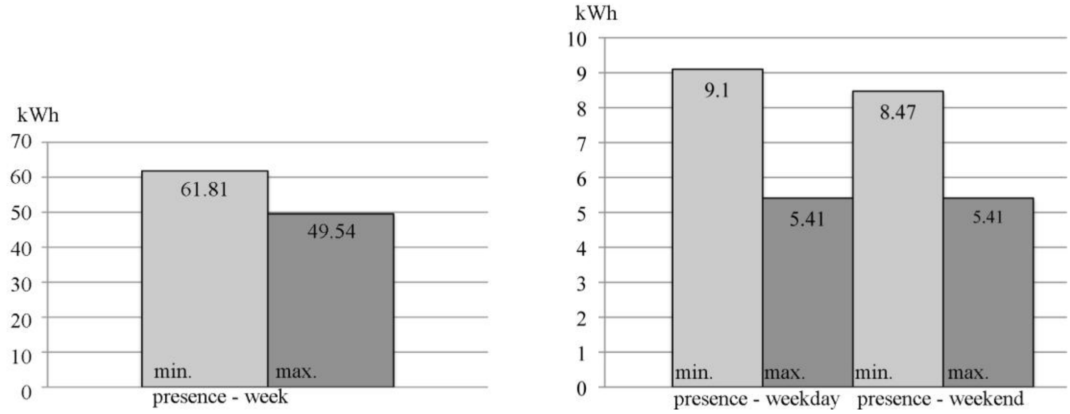
In addition, the samples of each dwelling type, with minimum and maximum presence for weekdays and weekends are compared (Table 2). The sample with minimum presence for weekday and the sample with minimum presence for weekend are considered separately for minimum presence samples. For the corner/semi-detached dwelling type, minimum presence for weekday and weekend is the same (1/1). Maximum presence for weekday and weekend are the same in all dwelling types. For flat, the minimum presence sample for weekday includes '0' person presence. The row and the corner/semi-detached dwelling have more presence than the flat and the free standing (4/5 to 3/3).

Presence has a negative influence on the heating energy demand of the dwelling, by means of the internal heat gain; and, flat is the least energy demanding dwelling type vs. corner/semi-detached dwelling type. Samples with minimum presence for weekend result in lower heating energy demand values than the ones with minimum presence for weekday. The minimum presence for weekday and weekend is the same for the row house and the free standing. The heating energy demand is higher in the latter, 15% for the minimum presence sample weekday (1/2), and 17% for the minimum presence sample weekend (2/1). The maximum presence values for weekday and weekend are the same for the row house and the semi-detached (4/5). The heating energy demand is 36% more in the latter. (Table 2 - Figure 2).





Row house *freestanding house*



Semi-detached house *flat*

Figure 2: The heating energy demand values for minimum and maximum presence in weekday and weekend for different dwelling types.

When the pear values for different type of dwellings for the weekday and weekend presence values are compared, it could be seen that the most sensitive dwelling type to presence is the corner/semi-detached for the weekdays. The flat, the row and the freestanding dwelling types follow the corner/semi-detached dwelling type, from the most to the least sensitive, for the weekdays. When a similar comparison is made for the weekend, the row house is the most sensitive to presence. The flat, the corner/semi-detached, and the freestanding dwelling types follow the row house (Figure 3).

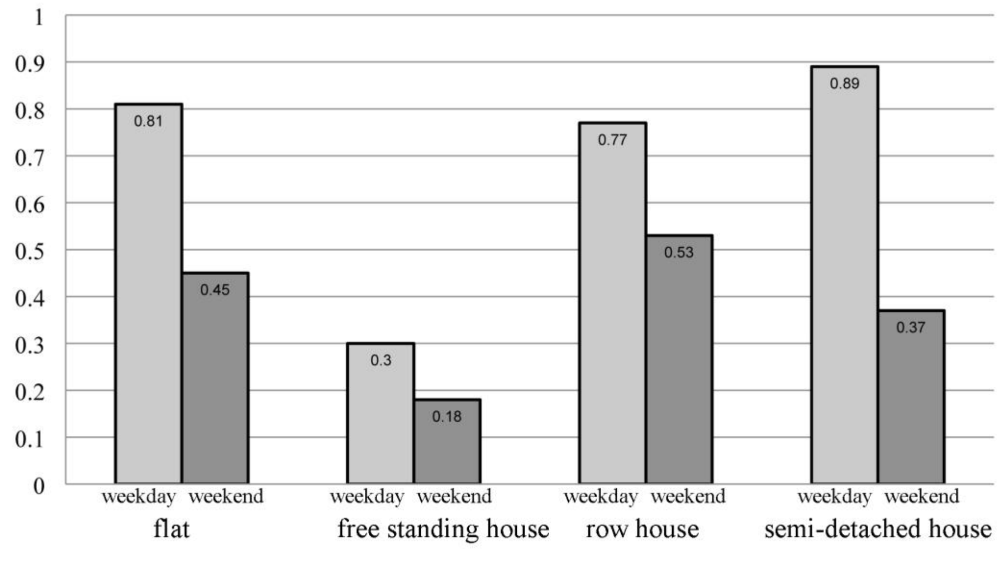


Figure 3: PEAR values for presence in weekday and weekend for different dwelling types.

CONCLUSION

In this paper, we focused on exploring the sensitivity of energy performance of a dwelling to presence, assuming that presence is the precondition of behaviour. Results of this study showed that weekdays are more influential on the heating energy demand than the weekends.

In addition, corner/semi-detached dwelling type is the most sensitive to presence in terms of the energy performance, during the weekdays, and row house is the most sensitive during the weekend.

Another result is that presence varies at the weekends more than it does during the weekdays. Also, corner/semi-detached dwelling is the dwelling type that presence is the most consistent during the weekdays, and row house at the weekend. Lastly, flat is the dwelling type that demands the least heating energy, and corner/semi-detached is the most.

This paper covers only presence, and it is necessary to include ventilation, and heating behaviour in further analysis. In order to reveal the interrelations among presence and different behavioural patterns, and their influence on the heating energy demand of dwellings, a further analysis is still under progress with 250 samples, and the factors of presence, ventilation, and thermostat settings.

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