Building and Environment 82 (2014) 388–399

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

Determinants of ventilation behavior in naturally ventilated dwellings: Identification and quantification of relationships

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ARTICLE INFO

Article history:
Received 8 July 2014
Received in revised form
10 September 2014
Accepted 13 September 2014
Available online 20 September 2014

Keywords:
Occupant behavior
Ventilation
Window opening
Vent opening
Household characteristics
Residences

ABSTRACT

Background: Ventilation in dwellings is essential for well-being and health. However, insight in determinants of ventilation behavior is still limited.
Aim: Identifying determinants of ventilation behavior and quantifying relationships. Secondly, identifying households characteristics associated with low ventilation activity.
Methods: In a cross sectional study, ordinal and binary logistic regression analyses were performed, in a large population based survey, to identify determinants of window and vent opening behavior in the main living areas during the heating season in naturally ventilated dwellings. Relationships were quantified.
Results: Window opening behavior was associated (although not always consistently between models) positively with household size, negatively with disposable income (living- and bedroom), and with ethnicity (association different in direction between room types). Furthermore, window opening behavior was positively associated with 'respondent or partner does not have a paid income' (living room only), presence of females and age of the oldest occupant (bedroom only). In addition, significant associations were found between dwelling characteristics and window opening behavior, including the presence of vents (strong negative association, both room types), type of dwelling (association different in direction between room types), and the overall heat transfer coefficient by transmission. A smaller number of household and dwelling characteristics was found associated with vent opening behavior.
Conclusion: Window and vent opening behavior was associated with a range of both household and dwelling characteristics. More research is needed to confirm associations.

1. Introduction

People spend a large percentage of their time indoors [1–3]. Because of the effects on health and the large numbers exposed, indoor air quality is widely recognized as an important public health issue. The indoor air may be polluted by a broad range of components originating from both indoor and outdoor sources [4–10]. Ventilation can affect these exposures in several ways. First, ventilation can dilute the concentration of air pollutants originating from indoor sources. Second, ventilation can indirectly improve air quality by limiting the growth of micro-organisms that thrive under conditions of high humidity by removal of indoor dampness [11,12]. In a recent study was found that increasing air exchange rates decreased concentrations of bacteria and the total inflammatory potential of microbial factors in airborne inhalable dust samples [13]. Thus, inadequate ventilation may, through affecting indoor air quality in several ways, impose a health risk on those exposed.

The associations between ventilation, indoor environmental quality (IEQ) and adverse health effects have been a subject of study for many years. Several reviews investigating effects of ventilation rate directly, reported that the ventilation rate is associated with perceived air quality, (respiratory) allergies, productivity at work [11,14], inflammation, (respiratory) infections, short-term sick leave [14,15], sick building syndrome symptoms and asthma [11,14,15]. The association between the onset and severity of asthma and

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http://dx.doi.org/10.1016/j.buildenv.2014.09.008
0360-1323/

environmental exposures from indoor sources, such as tobacco smoke, pet–derived allergens and house dust mite, has been reported in reviews as well [16,17]. Furthermore, dampness and mold in residential dwellings have been associated with respiratory infection and bronchitis, but the causality of these associations has not yet been confirmed [18].

Although for some health endpoints previously associated with ventilation there is still limited evidence [15], it is commonly recognized that ventilation aids in achieving acceptable indoor air quality, which is seen as an essential determinant for health and well-being [19]. The influence of occupant's behavior on ventilation can be large [20–23]. For instance, results of a Japanese study showed that 87% of the total air change rate in eight dwellings was attributed to the opening of window and doors by occupants [23]. Occupant behavior is expected to become increasingly important, since homes are becoming better insulated to reduce energy costs, and may thereby become more airtight [16].

Current insights on driving forces for window opening behavior are mainly based on studies investigating instantaneous responses in ventilation behavior to meteorological factors and building characteristics [22,24]. Besides, only few studies were performed in residences [25,26]. While such studies do provide insight in factors affecting fluctuations in ventilation behavior, they provide no insight in differences between households living in similar residences under comparable meteorological outdoor conditions. Thus, insight in which factors may determine 'typical ventilation behavior' on an 'average day' is still limited. A study that did investigate determinants of typical ventilation behavior focused on the relationships between building characteristics and ventilation behavior [27]. A demographic characteristic that was included was income, which showed to be negatively correlated to ventilation behavior. Moreover, to our knowledge, population subgroups who generally tend to ventilate less (or more) than other population groups have not yet been identified. Therefore, the aim of this study is to identify which household characteristics (e.g. disposable income of household) are associated with typical ventilation behavior (window opening behavior, vent opening behavior) in residences and to what extent, taking into account some important dwelling characteristics (e.g. type of dwelling). In addition, attention will be given to the identification of households that according to their characteristics may tend to show relatively low (or relatively high) ventilation activity.

2. Methods

2.1. Study population

In this cross-sectional study, existing data was analyzed from the 2006 Netherlands Housing Research survey (In Dutch: Woon Onderzoek Nederland (WoON)). Details on the design of this survey and data collection procedures have been previously described in more detail in a report of ABF research [28] and are therefore only briefly described here. WoON is performed every three years in the Netherlands with the aim to collect data on housing conditions. The WoON survey is a joint collaboration between Statistics Netherlands (in Dutch: Central Bureau voor de Statistiek (CBS)) and the Ministry of the Interior and Kingdom Relations (BZK). A subset of the approximately 64,000 respondents of the WoON 2006 survey (the 'Housing market module'), also participated in an additional survey on energy related behavior (the 'Energy module'), which included detailed questions on ventilation behavior in individual households. A total number of 4724 respondents completed the Energy module survey, of which the majority of respondents were residents of naturally ventilated dwellings ($N = 4534$).

2.2. Data acquisition

The Energy module questionnaire contained a broad range of questions, including questions on household composition, year of birth of each occupant, and ventilation behavior of households during the heating season (October–April). Respondents could choose how to complete the questionnaire: by telephone, face-to-face or online. In addition to the survey, dwelling characteristics were collected by an independent observer. The WoON 2006 Energy module database, provided by BZK, also contained information on gender for each occupant. Additional information on household characteristics available from the WoON 2006 Housing market module, which was provided by Data Archiving and Networked Services (DANS) (version 1.2, 20th of July 2007), was linked with the Energy module database (our study population) on respondent number, including information on disposable income, sources of income, ethnicity, education, ownership status of the dwelling and type of dwelling. DGMR consulting engineers used the data on dwelling characteristics to calculate the energy label of each dwelling. With information on the latter, the overall heat transfer coefficient by transmission was calculated, which is a measure of the level of thermal insulation of the dwelling. The method used for the calculation is described elsewhere [29].

2.3. Ventilation behavior

The survey included separate questions on the ventilation duration by means of window, doors and vents, in order to collect data on ventilation behavior of households during the heating season. The survey started with: 'The following questions relate to the way you ventilate your dwelling during the heating season (October until April)'. 'Window opening behavior' was assessed by the questions: 'How long do you ventilate by opening a window or a door?' for the living room, the bedrooms, the kitchen, and the bathroom. 'Vent opening behavior' was assessed by the questions: 'How long do you ventilate by opening vents?' for the same four room types. Respondents could give a self-reported estimate for typical number of hours per week or indicate if they ventilated the specific rooms permanently. Obviously, vent opening behavior could not be analyzed for respondents reporting that vents were absent in the relevant rooms. In the analyses the focus was on the main living areas: living room and bedroom, as occupants are assumed to spend the majority of their time in these areas.

2.4. Independent variables

The database included data on a broad range of both household characteristics and dwelling characteristics. Characteristics of the household included in the analyses comprised the following continuous variables: 'Age of the oldest occupant in the household' and 'disposable income of the household'. Dichotomous variables included in the analyses were: 'Presence of females' (older than eighteen years, Y/N), presence of children between the age groups zero to three (Y/N), four to eleven (Y/N) and twelve to seventeen (Y/N), 'ownership status of the dwelling' (home-owner or tenant), and 'respondent or partner does not have a paid income' (Y/N). A person had a paid income if the income source was a salary, profit from own company or when having a freelance income source. Categorical variables included in the analyses were: 'Number of people in the household' (one, two, three or more than three persons),'ethnicity of the household' (native, non-western non-native, western non-native, or mixed), and 'educational level of the household'. The latter was determined by the highest achieved educational level between the respondent