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A field study of thermal comfort in low-income dwellings in England before and after energy efficient refurbishment

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ABSTRACT

This study investigates the effect of England's *Warm Front* energy efficient refurbishment scheme on winter thermal comfort in low-income dwellings. The analysis is based on an extensive survey of some 2500 dwellings selected from five major urban areas in England over the winters of 2001/02 and 2002/03. The surveys were carried out either before or after the introduction of retrofit insulation and energy efficient heating system. Self-reported thermal comfort (measured on a seven-point scale) and indoor temperature in the living room and in the main bedroom were recorded twice daily at 8 a.m. and 7 p.m. over 11 consecutive days. Results show that *Warm Front* was effective in increasing the mean indoor temperature from 17.1 °C to 19.0 °C leading to an increase in the proportion of households feeling thermally 'comfortable' or warmer from 36.4% to 78.7%. *Warm Front* also led to a slight increase in the whole house neutral temperature, i.e. the temperature at which most residents feel thermal neutrality, from 18.9 °C to 19.1 °C mainly from reduced clothing level associated with greater energy efficiency. Predicted Mean Vote, which is the standard thermal comfort model in ISO Standard 7730 predicted a higher neutral temperature of 20.4 °C compared to 18.9 °C found to be ideal among the average *Warm Front* households.

1. Introduction

About 2.3 million households in England are currently estimated to be in fuel poverty, and with increasing energy cost, this figure is likely to rise [1]. A household is classified as being fuel poor if a fuel bill in excess of 10% of income is required to maintain adequate domestic thermal comfort (living room: 21 °C, bedroom: 18 °C) in winter. Fuel poverty is caused by a combination of low income, high energy cost and energy inefficient dwelling; households living in fuel poverty generally experience poor quality of life and increased health risk from prolonged exposure to cold temperature [2].

Under the fuel poverty strategy set out by the UK government in 2001, England aims to eliminate fuel poverty by the year 2010 among the vulnerable households, i.e. families with older people or young children or with disabilities or with a long-term illnesses, the groups most susceptible to cold-related ill-health [3]. By recognizing poor energy efficiency in dwellings as one of the main causes of fuel poverty, the national strategy is based on the introduction of energy efficiency grants through a scheme titled *Warm Front* [4]. The scheme targets low-income households living in the private sector by providing funds for the installation of insulation, energy efficient heating system and draught proofing. *Warm Front* aims to reduce the burden of fuel cost which in turn is expected to encourage the householders to take up some of the cost savings benefit as improved thermal comfort. Evidence from a previous study has shown that *Warm Front* resulted in a 1.6 °C rise in the living room temperature and a 2.8 °C rise in the bedroom temperature [5]. These improvements are likely to have a positive impact on thermal comfort, well-being and health [6,7].

In 2001, a national evaluation of the health impact of *Warm Front* was initiated, a part of which entailed the collection of thermal comfort data from some 2500 dwellings. This study examines the impact of insulation and heating on field-surveyed domestic thermal comfort in low-income English dwellings in winter. The efficacy of the thermal comfort standard adopted in ASHRAE 55 [8] and ISO 7730 [9] in predicting domestic thermal comfort in winter is also examined.

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2. The *Warm Front* energy efficiency scheme

In year 2000, the *Warm Front* energy efficiency scheme was launched in England as the main component of the government's aim to tackle fuel poverty among the vulnerable households living in private tenure by providing grants for the installation of energy efficiency measures [4]. Eligibility for the grant is based on the receipt of a specific 'passport' benefit – used as a proxy indicator of fuel poverty – and having a household member in the vulnerable group classified as those aged below 16 or aged 60 or more or disabled or those suffering from a long-term illness.

By 2005 about 1.1 million households in England have benefited from this scheme. Until 2005, two grant schemes were available: the '*Warm Front*' with a maximum grant limit of £1500 for families with children under the age of 16 and the '*Warm Front Plus*' with a maximum grant limit of £2500 for households with a member aged 60 or over. Both grants offered cavity wall insulation, loft insulation and draught proofing but differed in that a gas central heating system was provided for the elderly group and gas wall heaters for the younger households. In 2005 the scheme was upgraded to include a gas central heating system for all of its recipients. This study is based on the scheme prior to the 2005 upgrade.

3. Thermal comfort standard

ASHRAE Standard 55 and ISO Standard 7730 are the most widely used thermal comfort standards in contemporary thermal comfort research. Both standards are essentially based on a 'heat-balance' model that takes into account the environmental factors of temperature, humidity and air speed and personal factors of clothing and metabolic rate to give a thermal comfort sensation described by the Predicted Mean Vote (PMV). PMV uses a seven-point index, ranging from -3 (cold) to 3 (hot), to measure the thermal comfort sensation most likely to be experienced by a group of people in a given environment under a steady state condition. The PMV model was developed by Fanger based on experiments undertaken in climate chambers [10].

ASHRAE Standard 55 also incorporates an optional standard known as the 'adaptive' model specifically designed to predict thermal comfort in naturally ventilated buildings. This model compensates for the limited effectiveness of the heat balance model in predicting the often wider comfort range observed in naturally ventilated buildings. The adaptive model uses the outdoor temperature as the key variable in predicting the comfort range [11–14].

The application of these standards, however, is limited to use in 'sedentary or near sedentary physical activity levels typical of office work' [8] since they were predominantly developed (heat balance model) and tested (adaptive model) against field measurements taken from office environments. The applicability of the heat balance model was indeed found to be 'inappropriate' when predicting the thermal comfort condition in air conditioned domestic environments in the US [15] and likewise when applying the adaptive model to naturally ventilated dwellings in California [16]. Little study has so far been undertaken in examining the effectiveness of the PMV model in heated dwellings in winter.

4. Potential impact of insulation and heating on thermal comfort

Warm Front aims to increase thermal comfort mainly by increasing the indoor temperature through the installation of insulation and energy efficient heating system. Insulation increases the mean indoor temperature by reducing the rate of heatloss through the building fabric while a central heating system increases the mean indoor temperature by improving the distribution of heat throughout the building and allowing higher demand temperatures. The cost savings from improved energy performance can in turn encourage the householders to take up some of the benefit by increasing the demand temperature, a process known as the 'take-back factor' or the 'rebound effect'.

Insulation and central heating also reduce the elements that can contribute to local thermal discomfort. Warmer external walls from insulation reduce discomfort arising from radiant temperature asymmetry and from localised downdraft caused when warm air touches cold surfaces [17]. By improving the uniformity of temperature distribution in a dwelling, gas central heating can also reduce the impact of 'thermal stress' associated with sudden changes in temperature when moving from room to room [18,19].

5. Methods

5.1. Warm Front survey

In 2001, the 'Health Impact Evaluation of *Warm Front*' study was commissioned to investigate the effect of *Warm Front* on resident health in England. The *Warm Front* study was designed to combine an empirical survey with statistical and epidemiological analysis to model the potential impact of improved energy efficiency on householders, mental and physical health and quality of life. The heart of the investigation involved documenting and quantifying changes in hypothesized elements such as energy efficiency [20], ventilation [21], indoor environmental conditions [5,22] and thermal comfort in a representative sample.

The study involved the collection of extensive household and property condition data from some 3500 dwellings selected from five major urban clusters around Birmingham, Liverpool, Manchester, Newcastle and Southampton to provide a good representation of the different household characteristic, housing types and climate conditions in England. The data was collected over two successive winters of 2001/02 and 2002/03 by a combination of surveying, interviewing and monitoring by trained surveyors. A sub-sample of 2519 dwellings was targeted for the thermal comfort study.

The basic survey design is based on cross-sectional comparisons between the pre- and post-improvement households measured in the same winter. Although statistically less efficient, this method is less open to bias than comparing the same dwellings before and after *Warm Front* in consecutive winters.

5.2. Comfort Vote

A self-reported thermal comfort diary was supplied to a designated occupant in each household, usually the head of household or spouse, who was instructed to record thermal comfort perception and the room temperature twice daily at 8 a.m. and 7 p.m. in the living room and in the main bedroom during 11 consecutive days. The selection of the hours is based on the assumption that dwellings are most likely to be occupied and heated at these times. The following information was also recorded in the comfort diaries: date of the diary delivery and collection, respondent gender, *Warm Front* intervention status, diary entry hour if it differed more than half an hour from the designated hours, living room temperature, bedroom temperature, occupant clothing and occupant activity level.

comfort – In response to the diary question 'In the middle of the room, the room felt' the respondents were asked to record their subjective thermal comfort based on a descriptive seven-point Comfort Vote (CV) index: 'much too cool' (-3), 'too cool' (-2), 'comfortably cool' (-1), 'comfortable' (0), 'comfortably warm' (1), 'too warm' (2) and 'much too warm' (3). Corresponding to