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The Effect of an Energy Refurbishment Scheme on Adequate Warmth in Low-income Dwellings

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Abstract: Many fuel poverty support programs have been implemented in the world. Energy-efficient retrofitting in low-income households is a main aspect of support programs in the context of energy saving, reduction of greenhouse gas emissions, and improvement of the thermal comfort and health of residents. This study analyzed the effects of an energy efficiency program for fuel poverty in Korea on the thermal comfort of residents. A total of 330 households were investigated wherein energy retrofits had been conducted. Indoor temperatures in the main bedroom and in the living room were recorded twice. The results showed that the average indoor air temperature in the surveyed households was 15.1 ± 3.7 °C, indicating that 95.2% of main bedrooms and 80.0% of living rooms did not meet the recommendations of the World Health Organization regarding temperature. These results indicated that the surveyed households did not use energy for heating their rooms, and an energy-saving effect due to the retrofits was difficult to expect. Accordingly, retrofit building or energy policies addressing fuel poverty are shown to be ineffective in the context of energy saving and thermal comfort in Korea. This article highlights issues that need to be analyzed to evaluate how effective the welfare program is. The results of this study alert policymaker to the need to improve the welfare policy; the methods proposed in this article will help them in their decisions.

Keywords: fuel poverty; energy efficiency programs; thermal comfort; field measurements

1. Introduction

Fuel poverty was initially identified as a serious social problem for elderly people in the UK in the 1970s, when household income levels were low, fuel prices were high because of the oil crisis, and housing conditions were inadequate for certain population segments [1,2]. Fuel poverty differs from income poverty in that it is influenced by various factors, such as fuel prices, income levels, and characteristics of housing [3]. Accordingly, the definition of fuel poverty is important in policy-making and in determining the scale and nature of the problem [4]. The most widely recognized definition of fuel poverty has been proposed by Brenda Boardman. Fuel poverty describes a household wherein fuel expenditure on energy services, particularly warmth, exceeds 10% of the total income [5]. This designation of 10% was based on the 1988 Family Expenditure Survey for UK households. At that time, the bottom 30% of low-income households spent a mean of 10% on fuel [6]. Thus, according to this definition of fuel poverty, a household may have a sufficient energy supply, but not for adequate warmth. This description of fuel poverty is suitable in developed countries, where energy supply problems have mostly been solved at the local level and where the climate is cold. More than 124 million people within the European Union are considered to live in circumstances of fuel poverty [7].

Nevertheless, access to energy has different meanings in many countries around the world. Thus, it is important to distinguish between the terms energy poverty and fuel poverty [8]. Studies conducted in developing countries relate energy poverty to a lack of access to energy [9]. These studies are often based on rural settlements, which lack infrastructure [10].

Policies to address fuel poverty can be classified as subsidy programs and energy efficiency programs. Subsidy programs are intended to support heating expenditures. Energy efficiency programs are intended to strengthen thermal insulation and to improve the performance of heating systems in low-income households. The long-term solution for fuel poverty is to improve energy efficiency in low-income households. Income support policies, in contrast, help households get out of income poverty, but rarely of fuel poverty [11]. Most EU countries have adopted energy efficiency policies as a strategy to address fuel poverty. Indeed, EU countries have their own definition of fuel poverty and have implemented energy efficiency programs [12]. England implemented the Warm Front scheme to mitigate fuel poverty via highly efficient heating equipment and insulation measures [13]. The UK adopted the 10% threshold of Boardman to define the official parameters of this scheme in 2001 [6]. More recently, the Low-Income/High-Costs (LIHC) fuel poverty indicator was introduced in 2012 to establish a new definition of fuel poverty. Unlike the previous definition, the new indicator is a relative measure, with thresholds that change on an annual basis. These dynamic thresholds make it difficult to identify and monitor the problem consistently at the local level. The LIHC indicator considers not only the number of fuel poverty cases, but also how severe each case of fuel poverty is [14,15]. The primary energy efficiency support scheme of the government of Ireland for Irish households in fuel poverty is the Better Energy Warmer Homes Scheme (BEWH) [16]. In order to measure fuel poverty, three self-reported indicators are used based on the statements of householders, including that householders are unable to adequately heat their home, that they are unable to pay scheduled utility bills, and that they have inadequate heating facilities [2,17]. The Weatherization Assistance Program (WAP) of the United States Department of Energy (DOE) provides energy efficiency services to reduce energy bills for low-income households [18]. The DOE has partnerships with state and local government agencies to implement fuel poverty policies [19]. The DOE provides grants to grantees, such as states, and subsequently, the grantees provide grants to sub-grantees, such as local weatherization agencies to conduct business intended to maintain thermal comfort at the local level [20].

Recently, health and comfort were added to energy efficiency as discrete goals of the fuel poverty program. In a 2017 report on cutting the costs of keeping warm, the UK established the vision of the fuel poverty program as cutting bills and increasing comfort and wellbeing [21]. In a report on its strategy to combat energy poverty in 2016, Ireland also set goals to reduce energy bills and to improve the health and wellbeing of the participants [16]. The US WAP aims to increase the energy efficiency of dwellings owned or occupied by low-income persons, reduce their total residential energy expenditures, and improve their health and safety [18,20].

As a result, the goals of the fuel poverty program can be summarized as reducing energy bills, providing solutions to residents' health problems, and improving indoor thermal comfort. The impacts of the fuel poverty program on energy efficiency and health problems of residents in low-income households have been reported in many cases. According to research on more than 30,000 households eligible for participation in WAP in the state of Michigan, it was estimated that WAP reduced energy consumption by 10–20% among participating households [22]. Following the Warm Front measures in the UK, the number of people affected by anxiety or depression declined from 30% to about 15%. Also, mold exposure in homes was reduced from 12% to 8% following the Warm Front scheme [23]. A report examining the health, mental health, and housing conditions in the UK using the 2007 Adult Psychiatric Morbidity Survey (APMS) indicated that subjects with a common mental disorder were more likely to have experienced circumstances of fuel poverty [24]. Liddell et al. reviewed a study on the health impacts of fuel poverty, which was a large-scale research conducted across 10 years. Although the physical health effects of fuel poverty on adults was quite small, caregivers recognized significant impacts on the respiratory health of children due to living in fuel poverty [25]. Policymakers are paying increasing attention to indoor living environments as a consequence of a growing body of evidence linking buildings—especially housing—to human health [26].

Regardless, there are few studies on the effects of fuel poverty programs on thermal comfort [27]. Guidelines established by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) 55 [28] and the International Organization for Standardization (ISO) 7730 [29] propose indicators for human thermal comfort and define set-point temperatures in cooling and heating conditions, but these indicators have not been officially adopted in fuel poverty policies. Many reports for fuel poverty use World Health Organization (WHO) indicators to analyze the effects before and after specific projects. The WHO recommends a minimum temperature of 21 °C in the main living room of a residence and 18 °C in other rooms to avoid negative health impacts during winter [30]. Following the Warm Front initiative, 222 out of 888 households were identified as still being cold, defined as homes in which the average bedroom temperature fell below 16 °C or the average living room temperature fell below 18 °C during the measurement period [31]. Findings from a national household survey in Ireland report that the living room temperatures of 29.4% households in fuel poverty fell below 18 °C or less, compared with only 10.8% of other households not experiencing fuel poverty during the measurement period [32]. These results suggest that the goal of providing a comfortable indoor environment for the health and wellbeing of residents is not achieved with the existing fuel poverty schemes.

Operating as a case study in Korea, this paper analyzes indoor thermal environments following energy efficiency measures for fuel poverty in Korea by field measurement. Based on the analysis, this study aimed to determine whether the fuel poverty policy is effectively reflected in the households and dwellings and to suggest alternative solutions to the problem. Thus, by revealing the shortcomings of the fuel poverty programs, this study may contribute to refining the fuel poverty programs. The remainder of this paper is structured as follows: Section 2 introduces the outline of fuel poverty programs in Korea and the measurement methodology, Section 3 describes data analysis and results, Section 4 presents a discussion, and finally Section 5 presents the conclusions of this study.

2. Methods

The method applied in this paper consisted of the following steps (Figure 1): Review of Korea's fuel poverty statistics and policies; Introduction of the residential energy retrofit program for low-income households; Field measurement for house conditions after the energy retrofit building program; Assessment of the thermal environment according to measurement data; Assessment of the effectiveness of the program and recommendation for improvement of the method.

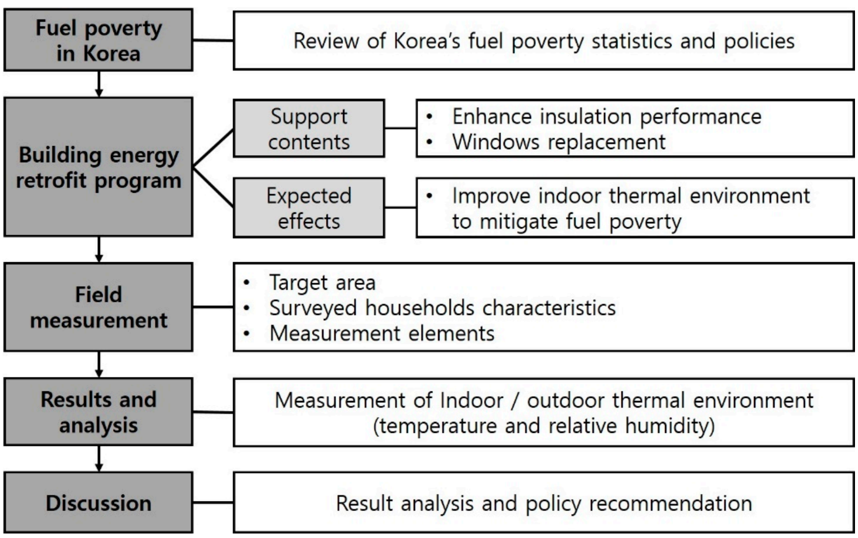

Figure 1. Flowchart of the applied methodology.

2.1. Fuel Poverty Programs in Korea

The definition of fuel poverty is not clear in Korea. The rate of fuel poverty in Korea was estimated at 6.9% in 2010 by using the definition of fuel poverty proposed by Brenda Boardman [5]. The rate was estimated at 9.7% when fuel costs within a portion of the population experiencing an incrementally higher level of basic living expenses were used as the baseline of fuel poverty [33]. Also, more than 614,000 households spent more than 20% of their disposal income on fuel in 2013, and the rate has been increasing year by year (Table 1) [34].

Table 1. Number of households with an excessive energy cost burden.

Energy Spending as % of Disposable Income	2010	2011	2012	2013
10% and more	1,646,353	1,630,908	1,748,064	1,780,824
20% and more	606,763	596,180	556,742	614,249

The 1st income decile in Korea spent on average as much as 21% of their disposable income on fuel for heating and cooking during 2010–2013 according to the Household Income and Expenditure Survey of Statistics Korea (Table 2), while the percentage decreased to 8.5% for the 2nd income decile and to 1.7% for the 10th income decile in the same period. Fuel costs have decreased for high-income households in percentage of disposable income; however, the costs for the low-income households have gradually increased.

Table 2. Monthly energy bill and its share in disposable income, by income decile.

	Fuel Cost/Disposable Income			
	2010	**2011**	**2012**	**2013**
1st decile	19.6%	20.6%	21.1%	21.0%
2nd decile	8.1%	8.2%	8.3%	8.5%
10th decile	1.8%	1.8%	1.7%	1.7%

Source: Household Income and Expenditure Survey, Statistics Korea.

The analysis results of the Welfare Needs Survey, conducted by the Korea Institute for Health and Social Affairs, found that the near-poor and the poor (those living on 120% or less of the national minimum) were more likely to be unable to keep the indoor temperature at a reasonable level or pay energy bills as they fell due. As many as 13.3% of households in receipt of National Basic Living Security benefits found themselves unable to keep their indoor temperature at a reasonable level. About 9.8% of the 120% or less of the poverty threshold group said they could not keep the home adequately heated [35].

High oil prices since the early 2000s and greenhouse gas mitigation policies have led to growing energy costs in Korea. Rising energy costs affect energy consumption conditions in low-income households, causing insufficiencies in existing energy consumption structures. Recognizing the problem, the Korean government formalized an Energy and Welfare Statement, and the Energy Act was legislated in 2006. Also, the Korea Energy Foundation was established to effectively implement the Energy Welfare program in 2006. In addition, the government has operated many programs aimed toward fuel poverty reduction, such as subsidies for energy bills, improving energy efficiency in housing, and energy rate discounts. By the end of 2013, 11 energy welfare programs were in operation in Korea as follows:

- Provision and energy efficiency program:
    - Residential energy efficiency for low-income households

- Electricity efficiency (high-efficiency lighting)
- New renewable energy facilities for National Rental Housing
- Provision of new renewable energy for welfare facilities
- Safety checks on general-use electrical installations
- Improving the gas system for low-income and near-poor households.

• Energy bill discount program:

- Utility (electricity, gas, and district heating) bill discount.

• Energy cost assistant program:

- Heating energy (kerosene) assistance for low-income households
- Coal briquette assistance for low-income households.

The purpose of the residential energy efficiency (retrofit) program for low-income households is to improve the thermal performance and airtightness of households in fuel poverty, as well as to reduce heat loss, lower energy bills, and improve the thermal comfort and health of residents [35]. This program involves the strengthening of insulation in walls and/or the replacement of old windows, doors, and boilers. A maximum of 1.5 million KRW (1,500 USD) subsidy is assigned to each low-income household.

The achievements of projects for improving energy efficiency for the low-income households during 2007–2016 in Korea are shown in Table 3. At the beginning of 2007, about 10 billion KRW (10 million USD) was supported and it increased to about 48.9 billion KRW (48.9 million USD) in 2016. About 435,000 households, or 363 billion KRW (363 million USD), were supported until 2016.

Table 3. Number of households benefited by the residential energy efficiency program for low-income households.

	2007	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Number of benefited households	16,501	80,130	68,331	43,336	21,428	29,628	63,508	42,158	40,707	29,468
Budget, KRW million (USD million)	10,000 (10.00)	28,500 (28.50)	28,500 (28.50)	29,200 (29.20)	19,450 (19.45)	29,580 (29.58)	41,080 (41.08)	67,110 (67.11)	61,270 (61.27)	48,900 (48.90)

Source: Korea Energy Foundation.

As for insulation materials in walls, heat-reflective insulation materials, extrusion heat insulation materials, and calcium carbonate insulation materials are used. Window replacement is classified into two types, i.e., double-glazed windows with a heat transmission coefficient of 2.03 $W/m^2{\cdot}K$ and an airtightness of 0.91 h^{-1} and quadruple-glazed windows with a heat transmission coefficient of 1.262 $W/m^2{\cdot}K$ and an airtightness of 0.83 h^{-1}. In addition, as of 2018, a series of retrofit initiatives such as roofing work and boiler replacement will be carried out as elements of retrofitting schemes to reduce fuel poverty in Korea. Fuel poverty retrofit plans are determined within the support costs and depending on the housing conditions of each household. However, because support costs are limited to 1.5 million KRW (1500 USD) per household, energy efficiency retrofits are not sufficient to fully improve the indoor thermal environments of low-income houses in Korea.

2.2. Field Measurements

Field measurements were carried out from January to February (the winter season) in 2016 to analyze indoor thermal environments following subsidized retrofitting due to energy efficiency programs for households with fuel poverty in Korea. Of the total 40,707 households in which the energy efficiency program was conducted in 2015, 330 households and 504 rooms were investigated in this study. The target area of the survey was divided into four regions including the northern, eastern, central, and southern regions of the Gyeonggi Province in Korea (Figure 2). Gyeonggi Province is the most populous province in Korea. Its population is about 13,256 million, and 2% of if was the recipient of the National Basic Living Security benefits in 2017. Accordingly, there are many low-income households in Gyeonggi Province. The analyzed areas are located at a longitude of 36.9–38.3° N and a latitude of 126.3–127.8° E.

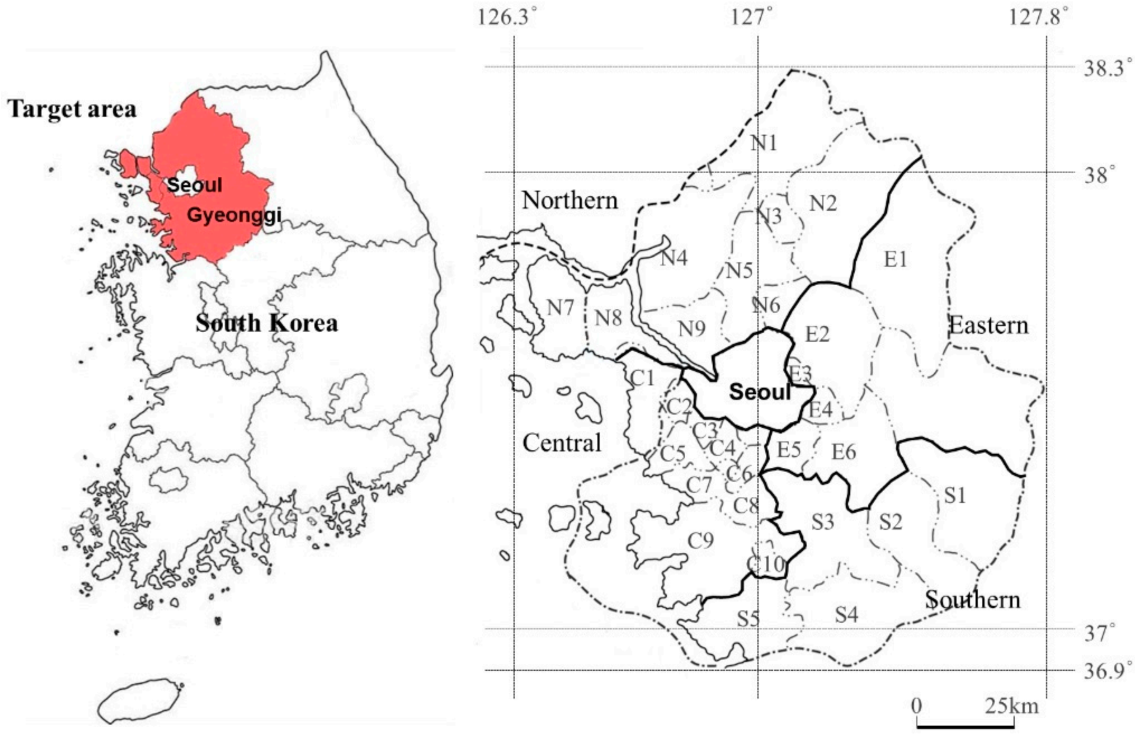

Figure 2. Surveyed area.

Figure 3 shows the number of surveyed households in the target area presented in Figure 2. Field measurements were accomplished to investigate thermal environments in households with fuel poverty following retrofitting for energy efficiency, and the temperature and relative humidity of 504 rooms in 330 households were measured using a temperature and humidity data logger (Testo 175 H1). The specifications of the data logger are shown in Table 4. The measurements were repeated three times for one room at intervals of 20 min by an inspector. The measurement point was 1.1 m from the floor in the center of the room. Also, the outdoor temperature and humidity were measured simultaneously.

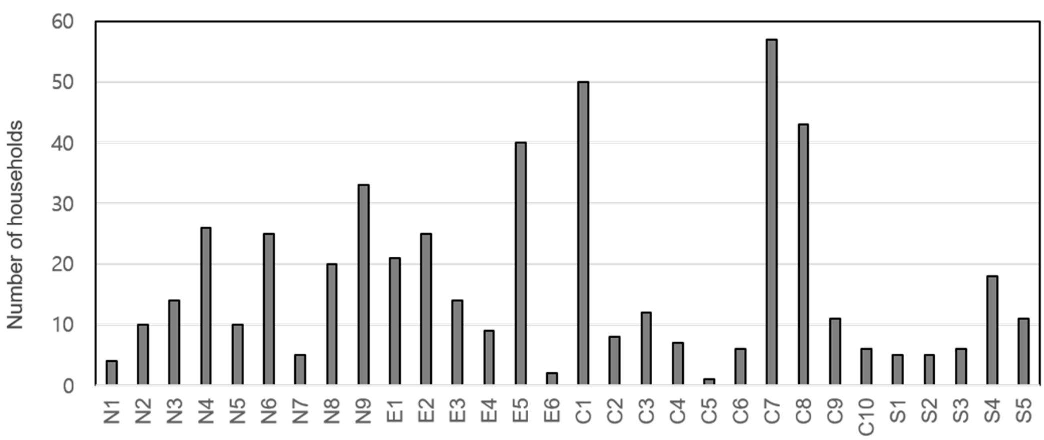

Figure 3. Number of surveyed households in the target area in Figure 2.

Table 4. Specifications of temperature and humidity data logger.

Instrument	Specification	
	Temperature	Relative Humidity
Testo 175 H1	Measurement range of −20 to + 55 °C, accuracy of ± 0.4 °C, resolution is 0.1 °C.	Measurement range of 0 to 100%RH, accuracy of ± 2%RH, resolution is 0.1%RH.

The analyzed households generally consisted of one or two bedrooms, together with a kitchen and boiler room. Most of the analyzed houses had combined structures of concrete and masonry walls, with one or more windows facing the outside. All households were equipped with radiant floor heating using gas or oil boilers.

To retrofit for energy efficiency, 128 households received both the reinforcement of insulation in walls and the replacement of windows, wall insulation was strengthened in 154 households, and windows were replaced in 48 households (Figure 4).

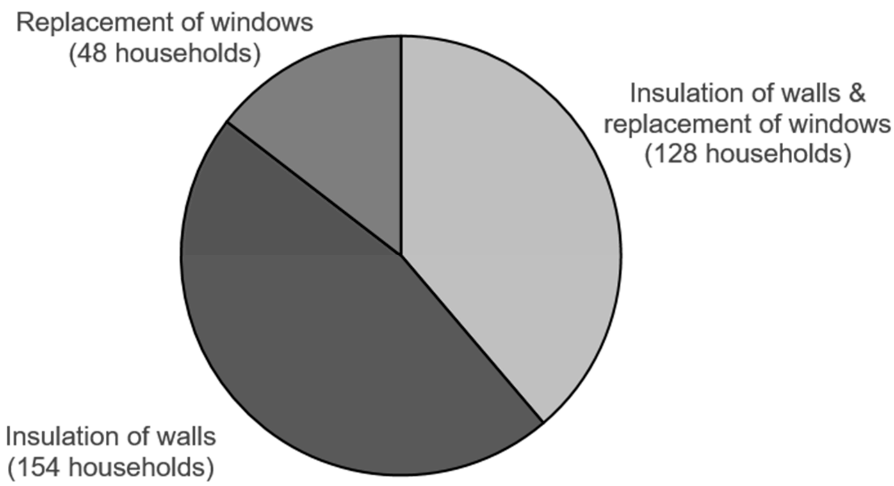

Figure 4. Types of retrofitting for energy efficiency.

Figure 5 shows the age distribution of the residents in households with fuel poverty. Most of the residents in our sample were aged people in their 70s (83 people), with 65 people in their 50s and 59 people in their 60s. The portion of people over the age of 60 years was 61.8%.

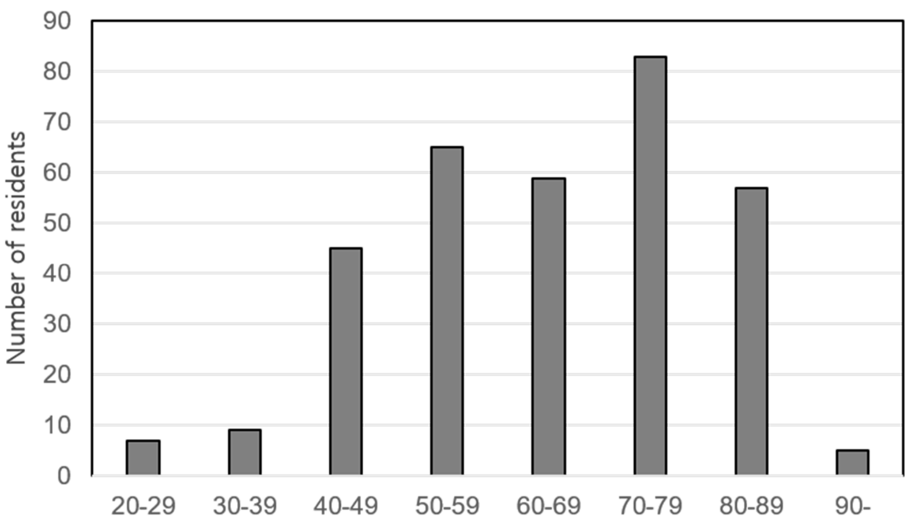

Figure 5. Age distribution of residents (years).

3. Results

3.1. Thermal Environments of Analyzed Households

Figure 6 shows the distribution of outdoor and indoor temperatures during the survey period. Outdoor temperatures ranged from −15.6 °C to 20.9 °C during the filed measurement periods, and the average outdoor temperature was 1.9 ± 6.4 °C. Indoor temperatures of the analyzed households ranged from 3.9 °C to 26.4 °C, and the average room temperature was 15.1 ± 3.7 °C. In other words, the indoor average temperature was 13 degrees higher than the outdoor average temperature. Even though the surveyed households were supported by the retrofitting program for energy efficiency, the room temperatures did not satisfy the WHO recommendations for an adequate standard of warmth (i.e., 21 °C in the main living room and 18 °C in other occupied rooms). About 95.2% of main living rooms did not meet the WHO standards, and 80.0% of other occupied rooms were under the 18 °C WHO threshold for adequate warmth (Figures 6 and 7).

During the investigation period, the average outside relative humidity was 33.3 ± 14.6%, and the average indoor relative humidity was 48.9 ± 15.9%. That is, the average indoor relative humidity was 15.6% higher than the average outdoor relative humidity (Figures 7 and 8). Though the residents did not use humidifiers indoors, the indoor relative humidity was high as a consequence of the low indoor temperature.

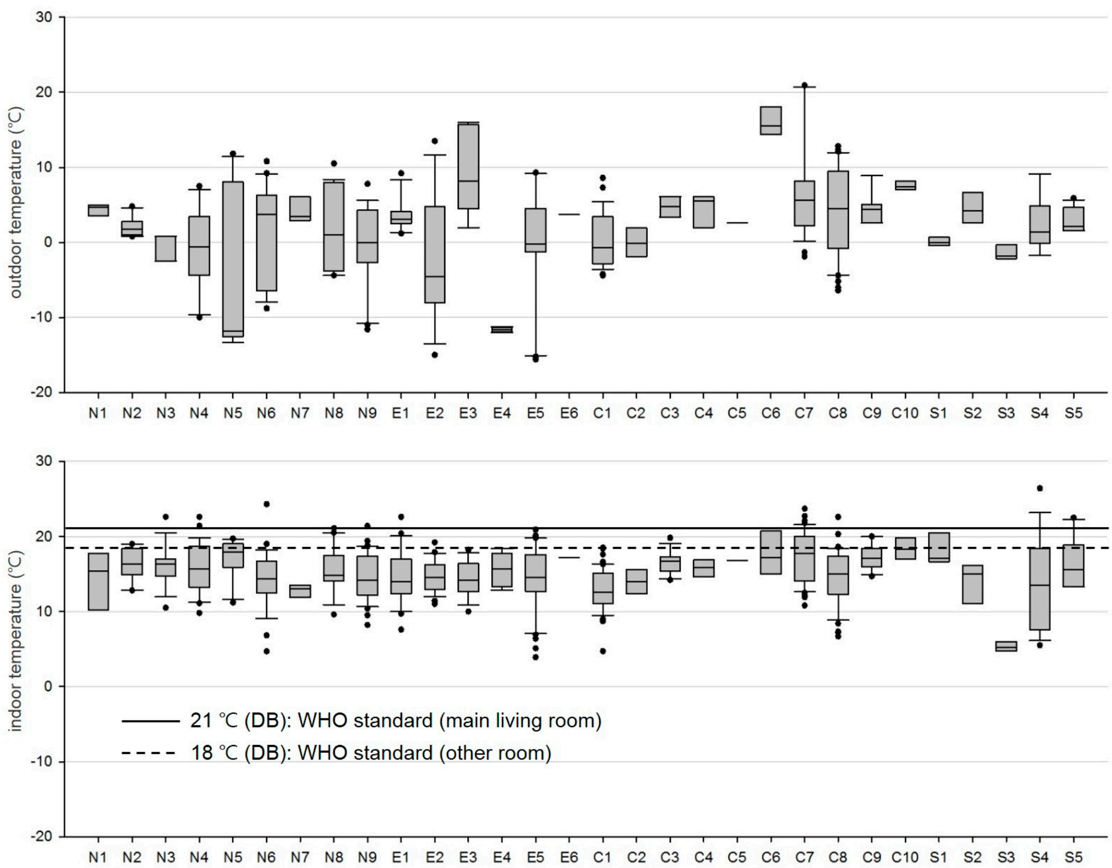

Figure 6. Distribution of outdoor and indoor temperatures.

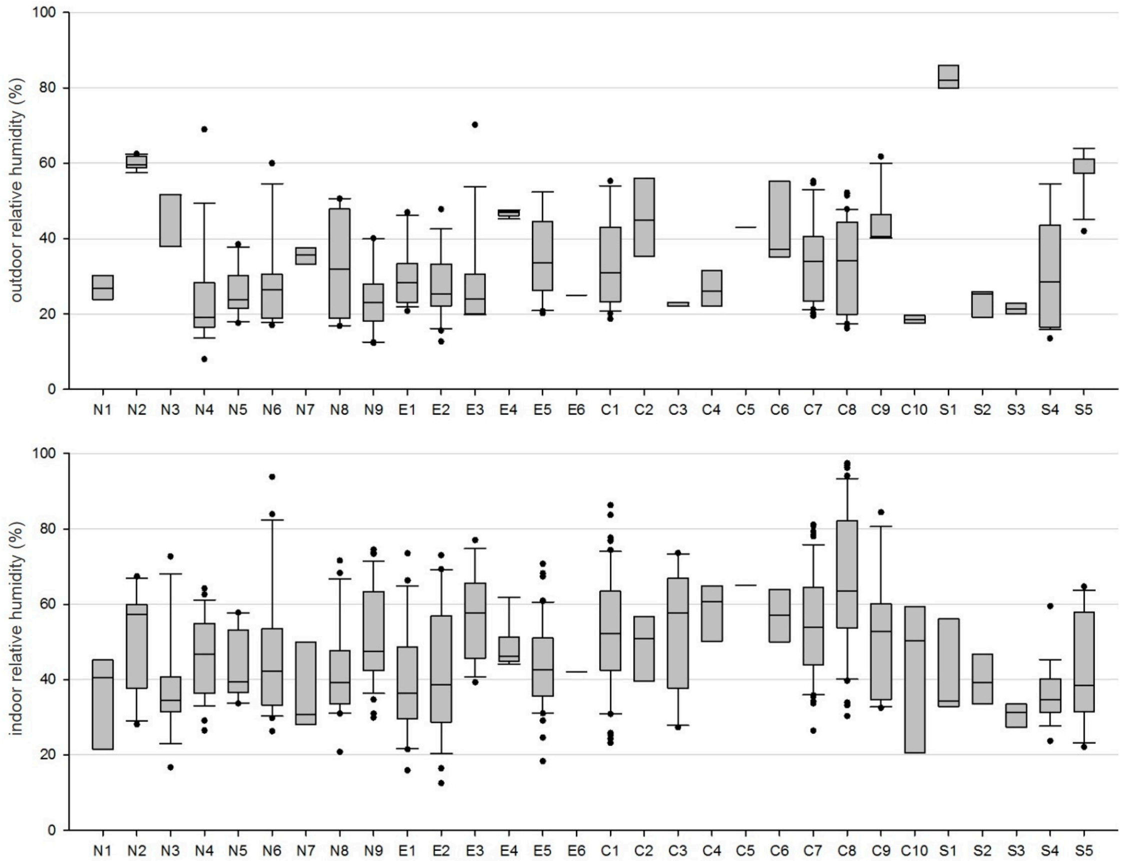

Figure 7. Distribution of outdoor and indoor relative humidity.

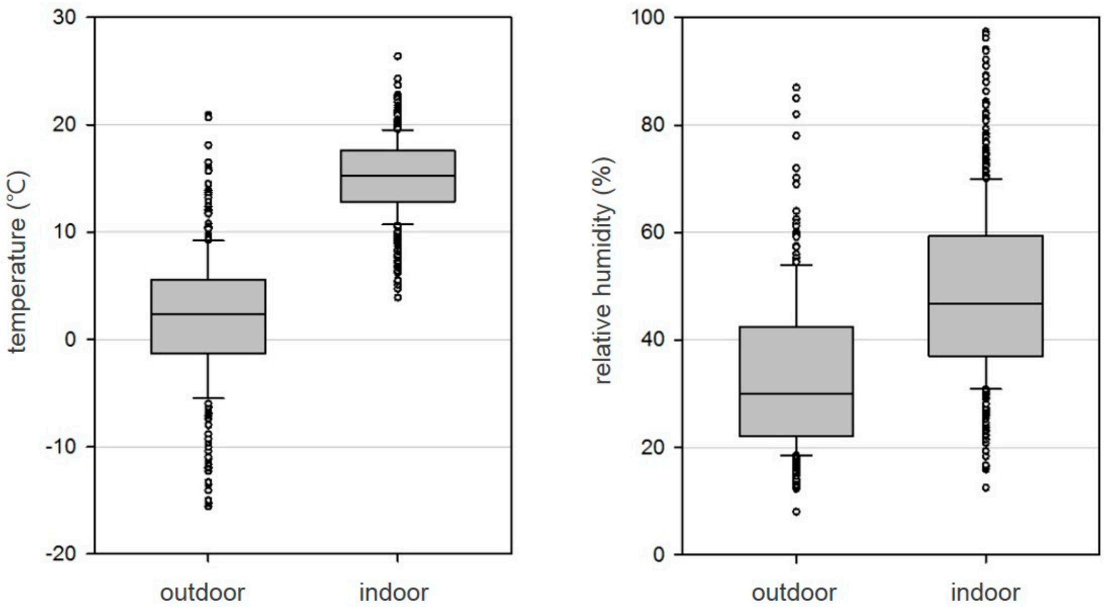

Figure 8. Distribution of outdoor/indoor temperatures and relative humidity.

3.2. Relationship between Outdoor and Indoor Temperatures

There was no significant correlation between outdoor temperatures and humidity and room temperatures and humidity (Figure 9). On the basis of these findings, it can be said that low-income households do not adjust indoor temperatures and humidity regardless of external environment changes. Room temperatures in about 48% of the households surveyed were lower than 15 °C. Moreover, room temperatures in 8% of the households surveyed were lower than 10 °C (Figure 9).

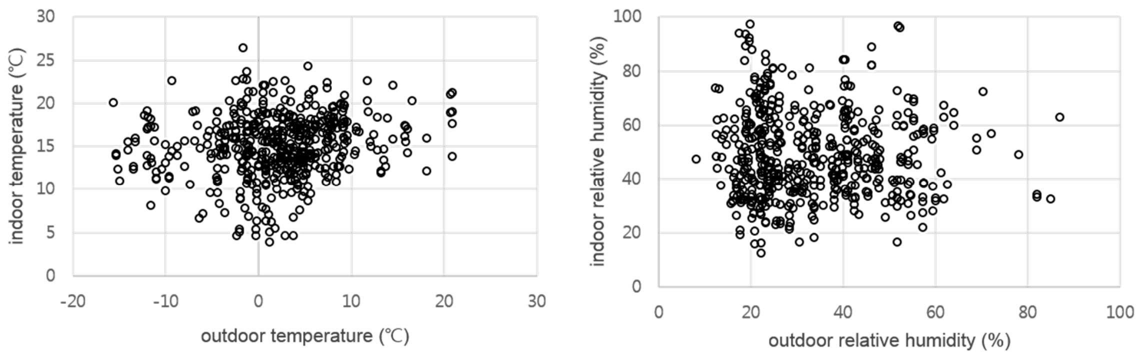

Figure 9. Relationship between outdoor or indoor temperatures and relative humidity.

3.3. Thermal Comfort of Residents

The term thermal comfort is defined by the ASHRAE as that "condition of mind that expresses satisfaction with the thermal environment" [28]. In this study, the ASHRAE comfort zone was used as an index for evaluating the thermal environment of the surveyed households. Herein, air velocity was within 0.2 m/s, and activity levels and amount of clothing worn by residents were 1.0–1.3 met and 0.5–1.0 clo, respectively. The mean radiant temperature to calculate the operative temperature was often replaced by air temperature because of the complexity of the measurement [36,37]. Moreover, the operative temperature can be substituted with air temperature when air speed is less than 0.2 m/s [28]. The measured results were examined according to ASHRAE standards for thermal comfort, and only about 5.6% (28 rooms) of people were comfortable in the analyzed rooms. This result suggests that 94.4% of people in the surveyed households lived in circumstances in which they were thermally uncomfortable, even following energy efficiency retrofitting (Figure 10).

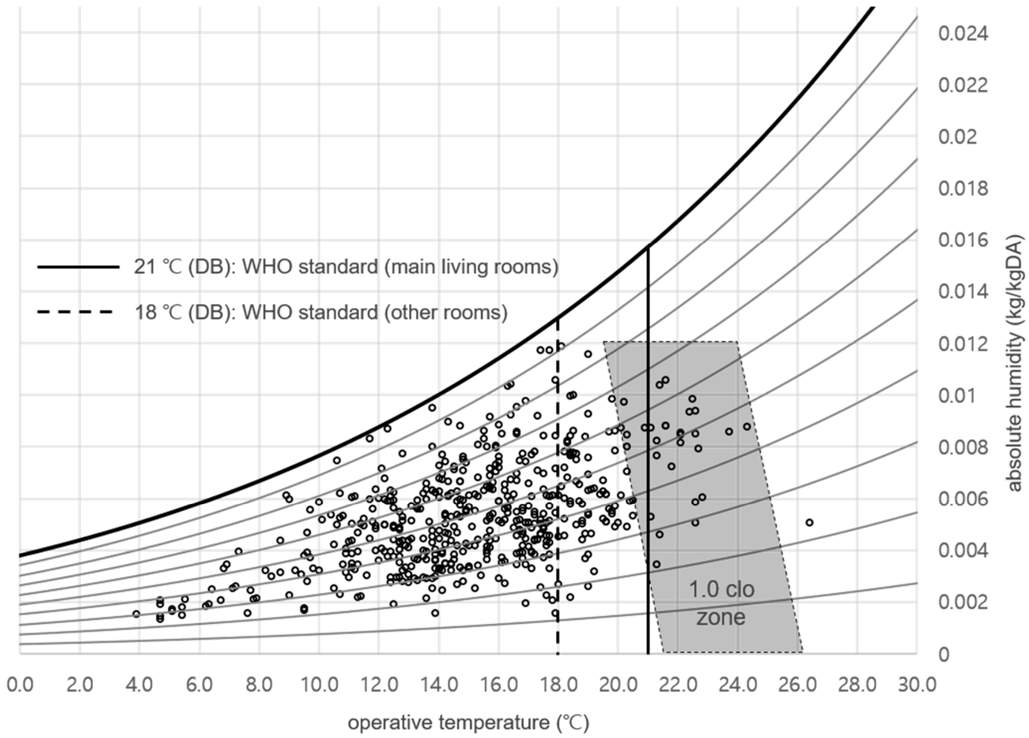

Figure 10. Psychometric chart of American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and World Health Organization (WHO) standards for thermal comfort.

4. Discussion

Residents of low-income households have been shown to live in inadequate thermal environments in comparison to the general population. During winter, the average indoor temperature is 23.9 ± 1.6 °C, and the indoor relative humidity is 31.6 ± 7.7% in a sample of general households in Korea [38]. The indoor temperature of the low-income households surveyed in this study was 15.1 ± 3.7 °C, and the indoor relative humidity was 48.9 ± 15.9%. Temperatures in the low-income households surveyed in this study were about 8.8 °C lower than temperatures in ordinary households in Korea in winter. These results indicate that the surveyed households did not use energy for heating their room, and an energy saving effect derived from building retrofit is difficult to expect. This is because the low-income group tends to prioritize cost savings over thermal comfort. Accordingly, the low-income group is less willing to pay for indoor thermal comfort than the group of ordinary people [39]. Similarly, a survey of 38 low-income households in two cities in Cyprus found that 89% of the monitored low-income households did not meet the WHO recommendations for room temperatures of 18 °C and 21 °C for warmth in winter. The low-income group in that research, however, reported a good level of satisfaction despite uncomfortable thermal conditions. The majority of the low-income households were heated by auxiliary mobile heaters, such as stoves, and the residents reported wearing additional heavy clothes—methods of thermal adaptation—during periods in which average room temperatures were below the standard for comfort [40]. This phenomenon was similarly observed in this study. Most of the residents of low-income households surveyed in this study were either unheated or sub-heated.

As a result of this study, subsidized retrofitting to increase the thermal performance of low-income households should raise the thermal performance to the level of passive house [41] to maintain comfortable thermal environments for residents. Districted central heating systems seem to be a strategy to guarantee thermal comfort for low-income groups in winter. Utility bill for district heating should be discounted or supported. In China, in places equipped with districted central heating systems, indoor temperatures are maintained close to 20 °C in winter [42]. In any case, rising costs are inevitable.

In the case of Korea, cost support for retrofitting for energy efficiency is limited to 1500 USD or less per household. With only this amount of support, it is impossible to sufficiently improve the thermal performance at the household level, thereby ensuring the comfort of residents. In addition, it is necessary to devise ways to properly evaluate the effects of the support programs for low-income households with fuel poverty considering the actual usage status thereof. The results of this study are helpful if post-evaluation of the energy welfare program is not carried out properly.

This study emphasizes that the effect of the residential energy efficiency program for fuel poverty has not been properly analyzed and evaluated. This paper is a reminder that an improved policy, which is mentioned above, is needed to include post-evaluation factors in welfare programs.

5. Conclusions

In the context of thermal comfort, the effects of retrofitting programs for fuel poverty in Korea were analyzed. Indoor thermal environments in a total of 330 households (to which energy efficiency retrofits were applied) were evaluated. The results showed that the average indoor air temperature of the surveyed households was 15.1 ± 3.7 °C. These results mean that 95.2% of the main living rooms and 80.0% of other occupied rooms of surveyed households did not meet the WHO temperature recommendations for warmth. Also, 94.4% of the surveyed rooms were at temperatures outside of the ASHRAE comfort zone. This is because the surveyed households did not use energy for heating their room, and the energy saving effect due to building retrofit was difficult to achieve. Therefore, the ongoing building retrofitting or energy policies addressing fuel poverty appears to be less efficient in the context of thermal comfort, and, thus, no energy savings may occur. An alternative to cost-effective policies should be developed to improve the thermal comfort of residents through building retrofitting in situations where budgets are limited.

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Conflicts of Interest: The authors declare no conflict of interest.

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