Development of Thermal Evaluation Tool for Detached Houses in Mongolia

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Abstract

During winter-time in Mongolia, the air pollution is so severe that it threatens the citizens' health. Ulaanbaatar is the capital city of Mongolia, and its population represents about half of the total population of Mongolia. The majority of people in the Ger area, approximately 50% of population of Ulaanbaatar, rely on direct coal burning to generate the required heat to maintain a comfortable environment in the cold season. The heavy reliance on coal leads to catastrophic air pollutant emissions including carbon dioxide, sulphur dioxide, nitrogen oxides and particulate matter, which leads to global warming, climate change and human health. As it is identified that building insulation retrofit is one of the best ways to reduce the reliance on coal consumption due to the improved heat retention and air tightness, a tool, named "FIXIT" has been developed to quickly quantify the impact from insulation retrofit. This paper presents how "FIXIT" was developed and is applied to help house owners to understand their building performance. Not only can "FIXIT" be applied for individual houses, it can also be used to estimate the reduction of air pollution from coal burning due to insulation retrofit. With "FIXIT", it is estimated that about 530 ktons of carbon emissions reduction can be targeted by applying building insulation retrofit, if around the 100,000 detached houses in Ulaanbaatar apply insulation retrofit. By highlighting the advantages on the building performance, "FIXIT" can encourage more house owners to improve their house insulation quality and thus contribute to the air quality, creating a cleaner and healthier environment and saving on fuel use.

Keywords: Detached Houses, Insulation, Thermal Tool, Building Energy Use, Fossil Fuel Reduction

1. Introduction

The aim of the paper is to provide insights for Mongolia on the implementation of an insulation retrofit scheme for the detached houses in the Ger area of Ulaanbaatar. By reducing the use of coal, this can lead to the improvement of the severe air pollution problem. The paper summarizes the findings from the investigations and describes the developed thermal tool, named "FIXIT". The paper presents the development of "FIXIT" and the correlation process and results in accordance with the findings of interview questionnaire surveys and on-site measurements carried out for the detached houses in Ger area of Ulaanbaatar. By using "FIXIT", the advantages of adopting building insulation retrofit on the existing detached houses, in terms of building energy performance and carbon dioxide emissions, are also estimated.

The geography of Mongolia covers various characteristics, with a desert in the southern part, while the western and northern part is mountainous. In general, according to the weather file extracted from the Energy Efficiency and Renewable Energy of the Department of Energy of the U.S. [1], the temperature in Mongolia fluctuates over a wide range throughout the year. It can be as cold as -32ºC in winter-time and as hot as 32ºC in summer-time. Figure 1 below illustrates the hourly temperature profile throughout a typical year in Mongolia.

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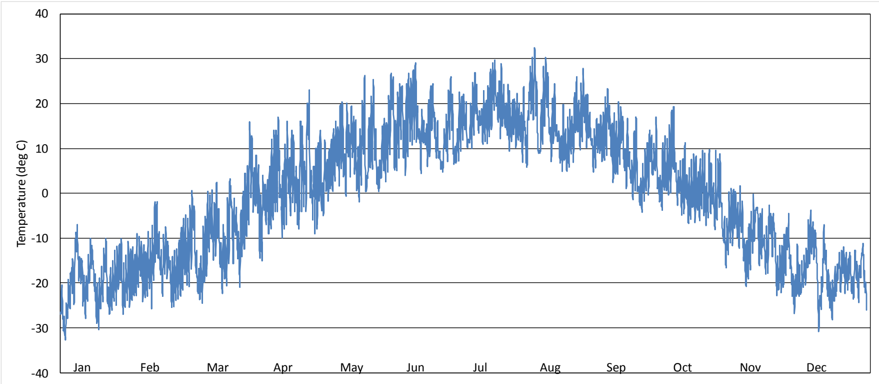

Figure 1 Hourly Temperature Profile throughout a Typical Year in Mongolia [1]

As there are more than 4000 hours (almost half a year) per year with a temperature lower than 0ºC and the heating degree days are more than 7000, the demand on heating systems to maintain a thermally comfortable indoor environment is high. As referred to in the World Bank's report [2], the primary source of heat to maintain the indoor temperature is burning coal in stoves, where the major consumed coal type is Nalaikh (fuel efficiency of about 14.7 MJ/kg), which accounts for around 76% of households using coal as primary heating source [3]. Relying heavily on coal not only leads to air pollution problem, but also affects the occupants' health, through inhaling the particulates generated during the coal burning process. Figure 2 indicates the air pollution problem in Mongolia during winter time.

In Ulaanbaatar, there are more than 100,000 detached houses in the Ger area, where more than 90% of the people rely heavily on direct coal burning to heat and maintain their living spaces at a comfortable level. The huge amount of pollution emissions, including carbon dioxide, sulphur dioxide, nitrogen oxides and particulate matter, is a major problem, contributing to global warming and climate change, and affecting human health. Further to reducing the occurrence of smog and carbon dioxide emissions, the use of coal (majority) and wood for heat generation could be alleviated by enhancing building design such as insulation system and heat generation system [4, 5, 6, 7].

Figure 2 Air Pollution Problems in Mongolia

M. Luvsan et al. presented the monthly average SO_2 levels, which is one of the major indicators of air pollution, for urban and steel industrial sites over the period of 1996-2009 in Mongolia [8]. It is observed that the SO_2 level in winter exceeds the WHO 24-hour mean limit, which is 20 $\mu g/m^3$, implying that the air pollution in Mongolia is so severe that would affect human health.

There have been a number of studies investigating the health impacts of air pollution, including, heart disease, decreased lung function, long-term mortality and respiratory illness such as asthma. In addition, many researchers also discuss about the other impacts due to air pollution, such as the environmental damage, visibility impairment and aesthetic damage [9, 10, 11].

Subsequently, a number of recommendations have been suggested to mitigate air pollution problems both directly and indirectly, including regulatory and policy implementation [12, 13], treatments on the pollution sources such as factory and power plants [14, 15] and promotions of energy-efficient building design strategies [16, 17]. These are all effective measures to deal with the air pollution problems at source, but they require a long-term implementation. To quickly reduce the carbon emission and thus the air pollution impacts, one of the most effective and long-lasting solutions is the improvement of building thermal insulation. Especially for Mongolia, where the temperature is extremely low during cold seasons, the impact of building increased insulation on the primary energy and CO_2 emissions and other pollutants associated with coal burning can be significant. The impact of increasing building insulation on the air pollution problem is investigated in this paper, providing a method for people to take into account the importance of building insulation when designing or retrofitting a building.

2. Methodology

In the study, interview questionnaire surveys and on-site measurements were conducted to establish a database of the current situation of the insulation performance of the detached houses in the study area. Subsequently, the energy modelling software, IESVE, was used to evaluate the impact of building construction on the energy consumption of individual houses. To ensure the accuracy of the model, correlations were conducted against the site surveys and on-site measurement data.

As there are a wide range of building configurations (such as the building geometry and building facade materials) that impact on building energy performance, the relationships among these factors with the building energy performance is complex. Therefore, Design of Experiment (DOE) was applied to identify the mathematical relationship between different factors.

By integrating DOE model and IESVE, "FIXIT" was developed to aid the insulation assessment by identifying the relationships of the input parameters such as the building geometry and insulation materials and thickness and the outputs including fuel consumption and carbon emissions. Figure 3 illustrates the simplified flow chart of "FIXIT".

Evaluating the building performance by using the simulation model alone is sophisticated, requiring the users to have strong engineering background on the building systems and construction materials. With "FIXIT", it enables non-expert users to determine building performance and to provide quick results without expert knowledge required.

The key features of "FIXIT" are:

1. Applicable for a variety of detached housing types in Ulaanbaatar;
2. Quick evaluation of building insulation performance;
3. Only simple information required from the building owner; and
4. User friendly and easy to evaluate the before/after insulation retrofit comparison.

Through the methodology used in the development of "FIXIT," a correlated regression model is built inside the tool and with the simple inputs such as the thermal transmittance (U-value) of the house façades and roof, floor area and number of house floors, the users can determine the possible improvement, including reduction of coal required to keep the house warm and reduction of carbon emission, by the implementation of better insulation. The energy savings of detached houses come from measures to the entire building envelope and to the service systems. This simplified approach took into account the local situation where it is simplified for the various local stakeholders to understand. The methodology including, questionnaire surveys, on-site measurements, IESVE and DOE modelling techniques, is outlined below.

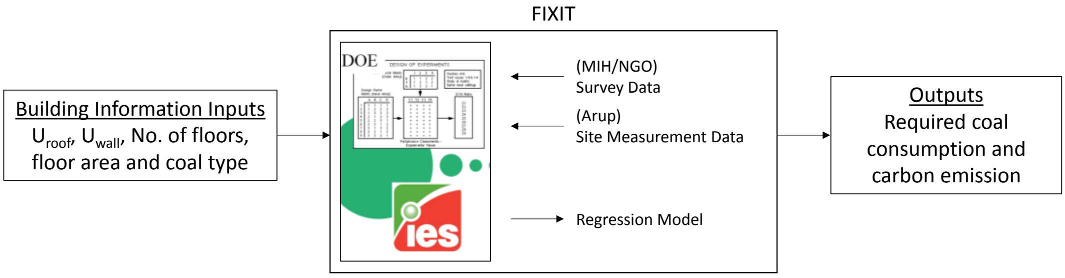

Figure 3 Simplified Flow Chart of "FIXIT"

2.1 Interview Questionnaire Surveys

124 interview questionnaire survey were conducted by MIH/Zagdkhorol NGO, covering 3 different Khoroos (Districts) in Ger area of Ulaanbaatar, including 1st and 9th Khoroos of Songinokhairkhan of and 16th Khoroo of Sukhbaatar, to establish a technical review on the existing situations of the buildings and to establish a database for the FIXIT tool development. Figure 4 below shows the standard types of the houses developments in Ger area, and they are in relatively high density districts. Most of the residential houses are low-rise building and are in their own land area, called "Khaasha," and so they have open area around the building. The questions covered by the surveys focused on the following information:

1. **Personal** – including house address, number of family members living in the house, employment details, average time staying at home and personal perception on the insulation performance of the house;
2. **House** – building size, no. of storey, construction details including construction materials of external walls, width of external wall, window type and floor and roof materials and the heating system; and
3. **Main consumption information** – fuel type for the heating system, coal type and average annual consumption of coal and wood (if any).

Figure 4 Range of Standard Types of Residential Buildings in Ger Area

2.2 On-site Measurements

In addition to the general understanding through the analysis of the interview questionnaire surveys, 21 houses in Ger area were visited and instantaneous on-site measurements were conducted. The on-site measurement of the visit covered the data collection of the followings:

1. External surface temperature of the building wall;
2. Internal surface temperature of the building wall;
3. Ceiling temperature;
4. Ambient temperature;
5. Indoor temperature; and
6. Building construction;

During the on-site measurements, a calibrated infra-red thermometer (Model: Testo 830-S1; Accuracy: ±1.5°C for 0.1°C – 400°C; ±2°C for -30°C – 0°C) was used to measure the surface temperature of the building envelopes, including the walls and roof. Considering the varied temperature distribution over the envelope surface, a measurement protocol was developed, where 9 different points on each surface were measured. Then, these points were averaged to represent the temperature of that surface.

Also, infrared imaging thermography (Model: Flir i5; Accuracy: ±2°C) was conducted to qualitatively identify the heat transfer distribution through the façade. In order words, it was aimed to identify the thermal bridging and leakage issues of the façade.

2.3 Integrated Environmental Solutions – Virtual Environment (IESVE)

This study used a dynamic simulation software, Integrated Environmental Solutions (Integrated Environmental Solutions Limited, 2015) - Virtual Environment (IESVE), which is an approved energy simulation software for LEED® Certification Programme. IESVE was used provide a detailed understanding of its energy performance.

IESVE uses first-principles models of heat transfer process which are driven by real weather data. The model uses 3-dimensional geometry of the house to be studied, together with the following data:

- Site location and local weather data;
- Layer-by-layer thermo-physical properties details of building elements including the wall, roof, floor and glazing;
- Sensible and latent gains from lights, equipment and occupants;
- Natural ventilation and infiltration;
- Plant operation profiles, efficiency and fuel characteristics; and
- Properties of house façades and roof.

With the calculations of solar impacts, indoor loads, system and building construction details, IESVE can evaluate the building performance in a variety of output aspects including:

- Internal load distribution;
- Thermal performance of the building, room, surface and glazing;
- Energy and/or fuel consumption details in hourly, monthly and annually basis; and
- Surface temperature and room temperature.

The IESVE model simulated the impact of the building thermal insulation performance on the building energy consumption.

The IESVE model used a typical layout of a detached house in Ulaanbaatar, as shown in Figure 5. Given that most of houses in the Ger area are low-rise buildings and have an open area surrounding and so any overshadowing effect would not have a significant impact to the heat transfer simulation. Also, the door was not modelled as it was not part of the heated living space. The model was then used to estimate the building energy performance under realistic conditions of weather data, building construction materials and internal loads.

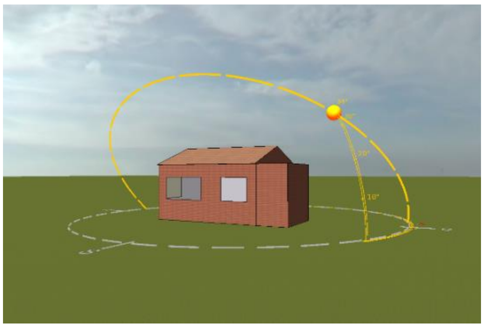


Figure 5 IESVE Geometry vs Real Household

2.4 Design of Experiment (DOE)

In this study, there are a number of variables affecting the building energy performance. The relationships between the input and output variables are complicated. Design of Experiment (DOE) is a statistical tool [18] and it was used in this study to identify the mathematical relationships among those variables.

DOE has been successfully adopted by many industries in the world, including electricity utilities [19], medical investigation [20, 21], chemical process [22, 23] and detection of any dysfunction of operating system [10]. The main capabilities of DOE are listed as follows [24]:

1. **Quantify multiple variables simultaneously** – a number of factors and responses can be investigated simultaneously in a single experiment.
2. **Identify parametric interactions** – the mathematical relationships between different variables can be identified and quantified.
3. **Identify significant variables** – the significance of all variables on the responses can be identified and ranked.
4. **Predict responses within design space** – performance at new points within the design space, i.e. within the input ranges of individual parameters, can be predicted.

In the DOE model, all the possible combinations of factor settings, which are also known as full-factorial, are considered. Considering the response “y” as the quantity of interest for the experimenter where “k” number of input factors would have impacts the output of “y”, the equation (1) shown below expresses the full predictive model describing how the process inputs jointly affect the quantity of interest and determining the optimization settings from the model. This equation also takes into account of the interactive relationships among the different input factors.

$$y = a_0 + \sum_{i=1}^{k} a_i x_i + \sum_{\substack{i.j=1 \\ i<j}}^{k} a_{ij} x_i x_j + \sum_{i=1}^{k} a_{ij} {x_i}^2 \qquad (1)$$

where
y is measured experimental parameter
a_0, a_i, a_j, a_{ij} are the coefficients to be calculated through the experimental simulations
x_i, x_j are the input factors that would affect the output of the experimental simulations

By evaluating this equation, the significance of impacts on the response “y” is illustrated by its magnitude of the coefficient “a” terms. The bigger the coefficient, the larger is the impact of that associated input factors on the response. Besides, the equation would also tell the directional relationship of the particular input parameters and the response. The positive value of the coefficient “a” refers to a direct proportional relationship with the response “y”, or vice versa.

Figure 6 below illustrates the calculation process using DOE model in this research. Design factors and ranges were first identified, which included the insulation performance of façades and roof, number of floors, floor area and average infiltration rate. Then, there are many experiment designs to choose from the DOE model [24]. In this research, full factorial design was chosen as the experiment design because it consists of a crossing of all levels of all the input factors, where the interactions of these factors can be quantified, and the results are more comprehensive by studying a wide range of different conditions. By executing the design experiment, a list of run order was generated which determined the settings of each experiments to be carried out. Then, based on the run order, simulations were carried out by IESVE models to generate the result, i.e. building heat requirement (MWh), which would be converted into required amount of coal and the equivalent carbon emissions. For each of the runs, the indoor air temperature was set to be 23°C and heat loads from people and lighting were included. By inputting the simulated results into DOE model, data analysis and diagnostics were then carried out by the application of ANOVA (Analysis of Variance) from which the parametric relationships among the design factors and the responses.

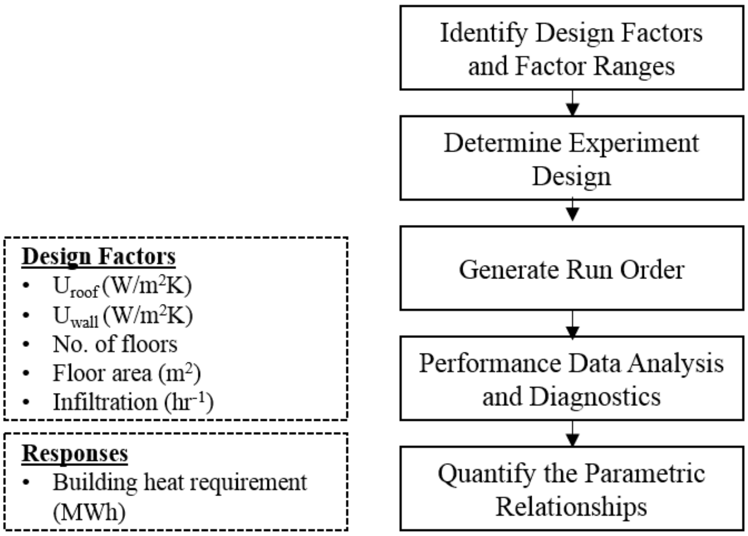

Figure 6 Calculation Process of DOE Model

2.5 Development of "FIXIT"

Figure 7 below illustrates the development process of "FIXIT". First of all, the study factors and the corresponding study range were identified, as summarized in Figure 7. This sets up a basis for the DOE study, which can identify the number of simulations required and the suggested input settings for each simulation. Then, based on the defined experiments and the suggested input settings, IESVE was adopted to evaluate the building performance results, which were fed in back to the DOE model to identify the mathematical relationships between different input parameters and the building energy performance. "FIXIT" was then constructed in both computer-based format and check sheet format.

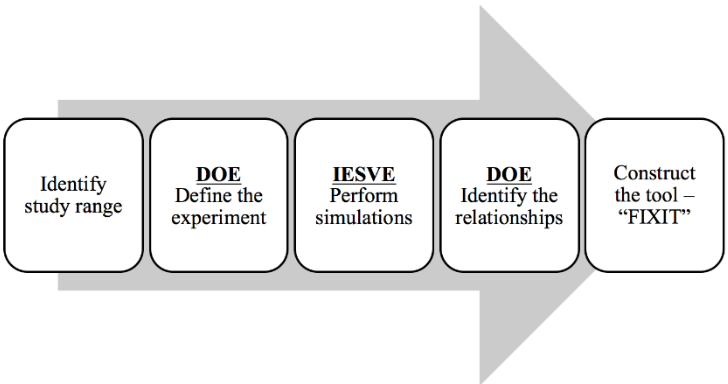

Figure 7 Development Process of "FIXIT"

Table 1 Studied Factors and the Corresponding Study Range

Factors	Parameters	Unit	Study Range
Vertical wall insulation performance	U-value	W/m^2K	0.15 (Insulated) – 2.20 (Non-insulated)
Roof insulation performance	U-value	W/m^2K	0.10 (Insulated) – 2.50 (Non-insulated)
Infiltration rate	Air Change per Hour	hr^{-1}	0.2 – 3

Building footprint	Area	m^2	12 – 150
Building height	No. of Stories		1 – 2

The tool development of “FIXIT” was based on the factors and study range as summarised in Table 1, where the rationale is shown in Figure 8 below. As stated by Ts. Enkhbayar [25], there are about 100 thousand detached houses in Ulaanbaatar. Based on the interview questionnaire surveys and on-site measurements, the collected data were then inter-connected with “FIXIT” for setting up a database. Subsequently, “FIXIT” can be used to evaluate the individual household insulation performance and thus to expend the tool to all the detached houses in Ger area of Ulaanbaatar. Eventually, by applying a conversion factor, which is about 333 kg/MWh according to USEIA [26], to the estimated reduction in required coal consumption, the reduction in air pollution of Mongolia due to insulation retrofit of the detached houses can be estimated.

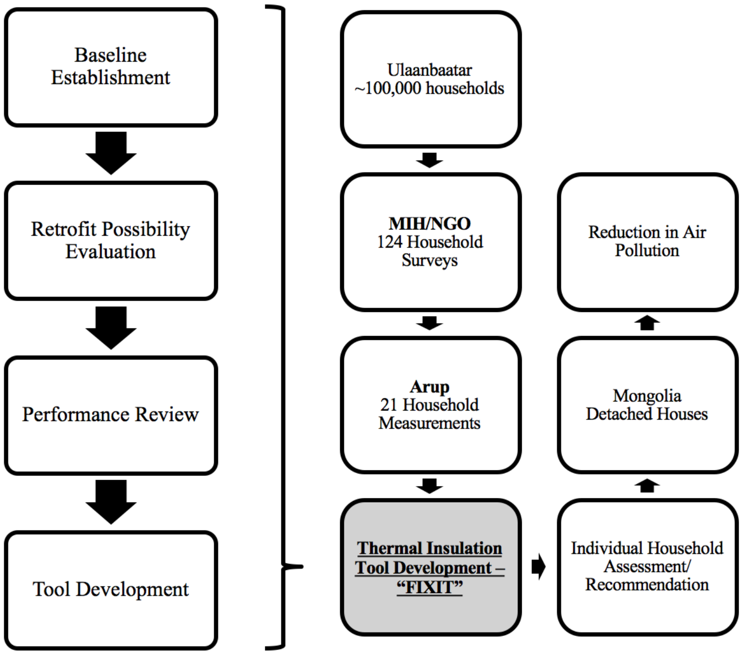

Figure 8 Development Concept of “FIXIT’

2.6 Correlation of “FIXIT”

The total coal consumption varies from one household to another depending on the floor area, building construction materials and thickness and air tightness. The building energy consumption results were extracted from the IESVE model and then converted to the equivalent required coal consumption to maintain a comfort indoor air temperature. This required coal consumption was then compared with the statistical results from the MIH/Zagdkhorol NGO site survey data.

To ensure the accuracy of the simulation model, correlations were conducted against the collected data from the 124 questionnaire surveys and the 21 on-site measurements in terms of thermal performance of the individual surfaces of the building envelope.

The IESVE model was built in accordance with the building information from the interview questionnaire surveys, including the building dimensions, building envelop construction details such as the materials and thickness and the annual coal consumption. Then, based on the temperature data collected from the on-site measurements, the thermal performance, i.e. thermal transmittance (U-value), in the IESVE model was modified in order to improve the accuracy of the model. For the simulated cases that have a considerate discrepancy between the actual measured and questionnaire results, the average infiltration rate, which is the only unknown factor of the model, was adjusted to make the simulated coal consumption required to maintain the measured room temperature to match the surveyed coal consumption data. The results ranged from 0.2 hr-1 to 3 hr-1, which were comparable to the ASHRAE’s [27] statistical findings of infiltration values for low-income houses, which range from 0.1 hr-1 to 3.5 hr-1.

Based on the on-site measurements during the house visits, correlations on the measured façade surface temperatures were conducted against the simulation model. As detailed information of the surface temperatures is not available to be extracted in IESVE model, the thermal transmittance (U-value) of the wall which is temperature-related was therefore chosen for correlation. With reference to the ASHRAE Handbook [27], the calculation of the thermal transmittance (U-value) is based on the equations below. In the IESVE model, the heat transfer through the individual wall was calculated. By then, based on the measured surface temperature of the particular wall, the thermal transmittance (U-value) can be calculated, which is compared with the thermal transmittance (U-value) of the wall used for simulation.

$$q = k \times \frac{A_C \times (t_{s1} - t_{s2})}{L} = U \times A_C \times (t_{s1} - t_{s2}) \qquad (2)$$

where U is the overall heat transfer coefficient; A_C is the wall area; t_{s1} and t_{s2} are the internal and external wall temperatures respectively; and q is the heat transfer through the wall.

3. Results and Discussions

3.1 Findings from Interview Questionnaire

From the interview questionnaire surveys conducted, it was found that 97% of the households rely on coal burning for heat generation during winter time. Depending on the household size, the annual coal consumption rate is different from one another, ranging from 1 ton to 5 tons, with slightly more than a half of the households consuming more than 4 tons of coal annually. The average annual coal consumption by the households using coal as the heating fuel was 3.3 tons.

The façade construction materials for the detached houses were also evaluated from the survey data. Table 2 below illustrates the summary table of household construction materials distribution and their thermal transmittances (U-values). The survey results reveal that about half of the detached houses are constructed by brick; about one-seventh of them are constructed by light block and timber respectively, which have the poorest thermal resistance, according to construction database in IESVE [28], among the other building construction materials. In other words, more than half of the households do not have a good insulation performance.

Table 2 Household Construction Material Distribution

Wall Construction Material	% Distribution	Conductivity (W/mK)
Light Block	13	0.60
Brick	48	0.62-0.84
Timber	12	0.17
Wooden Stave	15	0.12-0.14
Others	12	N/A

3.2 Findings from On-site Measurement

From the measurement results, it is found that even though insulation has been applied to some of the houses, the heat loss from the building facade is still high. Due to heat generation by coal burning, the average indoor air temperature of the visited houses was about 23°C and the internal wall surface temperature was about 20°C, implying that there was a continuous heat loss through the building envelopes. Besides, it was found that the surface temperature near the conjunction of building envelopes from the thermographic survey, illustrated in Figure 9, it was observed that the surface temperature along the internal wall-ceiling junction was approximately 3-5°C lower than that at the centre of the wall, implying that there is a significant increase in heat loss in this area. This is probably due to thermal bridging and not air leakage, as air would normally exfiltrate if there was air leakage at higher wall-ceiling details and would therefore not result in localised cooling on the internal surface areas. This thermal bridging would contribute to higher coal consumption in order to maintain a comfortable indoor environment.

Figure 9 Surface temperature measurement

3.3 Correlation Results

To verify the accuracy of the model, correlations against the surveyed coal consumption were conducted to compare (1) the surface temperatures of the building envelop; and (2) the estimated coal consumption which was converted from the energy consumption obtained from the IESVE model. In this correlation process, six real cases were randomly selected for the verification purpose. The construction details and the measured data of the selected buildings are summarised in Table 3 below. As some of the walls were not accessible to carry out the temperature measurements, the weight average of the external temperature was not necessarily lower than the external air temperature. The input thermal transmittance (U-value) of the building envelop in IESVE model was adjusted so that the difference between the simulated temperatures and the measured results was less than 10%.

Table 3 On-site Measurement Data for Model Validation

Case	Building Construction	Area (m^2)	To / Ti (°C)	To,wall / Ti,wall (°C)
1	Wood; foam; brick	56	-3 / 25.7	-2.7 / 19.5
2	Concrete block	42	-10 / 22.3	-15.9 / 22.4
3	Foam concrete	64	-12 / 18.8	0.5 / 20.0
4	Light block; foam	50	-16 / 21.3	-12.0 / 25.9
5	Brick; wood	42	-8 / 21.7	-4.3 / 23.0
6	Wood	66	-10 / 23.4	-6.3 / 24.8

With the tuned thermal transmittance (U-value) of the simulation model, the next correlation process was to compare the simulated and surveyed coal consumption. By adjusting the model including air infiltration and building operational profiles, the energy consumption of the selected buildings was simulated, which was converted to equivalent required coal consumption by using the estimated coal efficiency according to the coal type that the building user provided. The simulated and surveyed coal consumption data were compared and are summarized in Figure 10. The results showed that good accuracy can be achieved by the simulations, with the accuracy ranged from 83% to 98%.

Figure 10 Correlation Results of Coal Consumption between Simulation Model and Survey Data

Having validated the appropriateness and accuracy of the IESVE simulation models, the mathematical relationships among the input variables and the building energy performance were identified through the application of DOE model, as tabulated in Table 4 below. In the DOE model, the whole design matrix was set up to include three levels of parameters of each variable, which were lower bound setting (minimum value), higher bound setting (maximum value) and middle setting (medium value). Each of the variables was stretched to its possible extreme values. For example, the roof thermal transmittance (U-value) was set in the range between 0.1 W/m^{2}K and 2.5 W/m^{2}K. By doing so, this can result in a higher accuracy of the development of "FIXIT" in order to estimate the performance of a building with variables that fall within the examined parameter ranges. Taking the parameter of footprint as another example, this variable range was determined based on the minimum and maximum values from the 124 interview questionnaire surveys. By comparing the simulated and estimated results, a high accuracy of the estimation can be achieved, with the % error ranged from -2.4% to 5.7%.

Table 4 Design Matrix and the Results Comparison between the IESVE Simulation and DOE Prediction Model

Runs	Real Variables				Responses	
	Roof U-value (W/m^2K)	Wall U-value (W/m^2K)	Footprint (m^2)	Infiltration (ACH)	IESVE Simulated MWh	"FIXIT" Estimated MWh
1	0.1	0.150	12	0.2	0.3	0.3
2	2.5	0.150	12	0.2	2.6	2.6
3	0.1	2.200	12	0.2	5.5	5.5
4	2.5	2.200	12	0.2	7.8	7.8
5	0.1	0.150	150	0.2	0.3	0.0
6	2.5	0.150	150	0.2	20.8	22.0
7	0.1	2.200	150	0.2	25.0	25.3
8	2.5	2.200	150	0.2	48.4	47.2
9	0.1	0.150	12	3	3.4	3.4
10	2.5	0.150	12	3	6.0	6.0
11	0.1	2.200	12	3	8.6	8.6
12	2.5	2.200	12	3	11.1	11.1
13	0.1	0.150	150	3	47.9	47.8
14	2.5	0.150	150	3	78.4	77.6
15	0.1	2.200	150	3	72.9	73.0
16	2.5	2.200	150	3	102.1	102.9
17	1.3	1.175	81	1.6	26.9	27.6

3.4 Heat Loss Distribution

With the correlated model, the energy loss through the individual building envelops was studied by extracting the simulated data from the IESVE model and the heat loss distribution throughout the building envelopes was mapped out by calculating the portion of the individual building envelops over the whole building required energy consumption of each case. The findings are summarized in Figure 11 below. These are comparable to the heat loss evaluation results by different investigations in detached houses in the countries with similar weather conditions such as Finland and Canada [29, 30], implying that the retrofit solutions to improve the building energy consumption can be referenced to these countries. Nevertheless, the results reveal that the thermal performance of the roof and wall and the air tightness of a building contribute significantly to the total heat loss, where it is about three-quarters of the total heat loss. It demonstrates that when building insulation retrofit is applied, the building energy performance can be effectively improved.

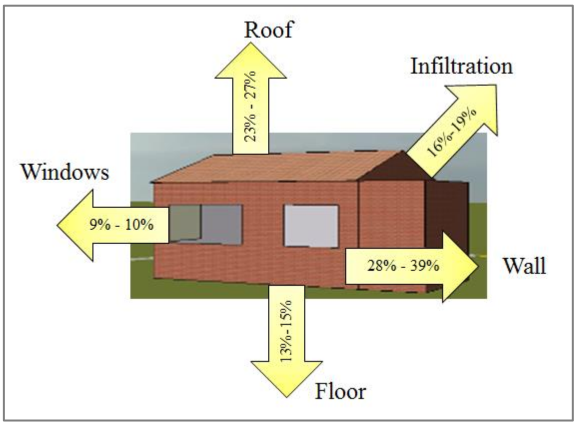

Figure 11 Heat Loss Distribution from the Building

4 Application of "FIXIT" – Case Study

The benefits from building insulation retrofit are well recognised by the industry, including:

1. Improved building energy performance due to reduced air leakage and improved insulation performance of the building envelope;
2. Improved thermal comfort due to the more even temperature distribution inside the house as the heat loss from the building envelope is reduced;
3. Reduced noise impact from the external environment
4. Reduced impact to the air pollution due to the reduction of energy consumption
5. Reduced impact to the health problem of citizens due to the reduction of air pollution

Based on the DOE model, which was set up according to Table 4, ANOVA was conducted and thus the relationships among different factors were evaluated. The graphical results can be found in Figure 12 below. Hold values of roof, wall, footprint and infiltration were set as 1.3 W/m^{2}K, 1.175 W/m^{2}K, 81 m^2 and 1.6 ACH respectively. These were the third parameters that were kept at their constant value when the data analysis was conducted. These results not only reveal the impact of the individual factor on the energy consumption, but also the combined effect by different combinations of two factors on the energy consumption. It is found that the impact by the infiltration and thermal transmittance (U-value) of wall is more significant for a house of same size. Therefore, to effectively improve the building insulation performance and the air pollution problem, building shall be retrofitted for its air tightness first, and then wall and roof would be the second retrofitting priority. One of them, as shown in (e) in Figure 12 below, from which it can be identified that the lower the thermal transmittance (U-value) of walls and infiltration, the lower the building energy is required to maintain the comfortable temperature within the building. For instance, as infiltration reduces from 2 to 1 (ACH) and the thermal transmittance (U-value) of wall improves from 1.8 to 0.6 (W/m^{2}K), the energy consumption can be reduced by approximately 30 MWh.

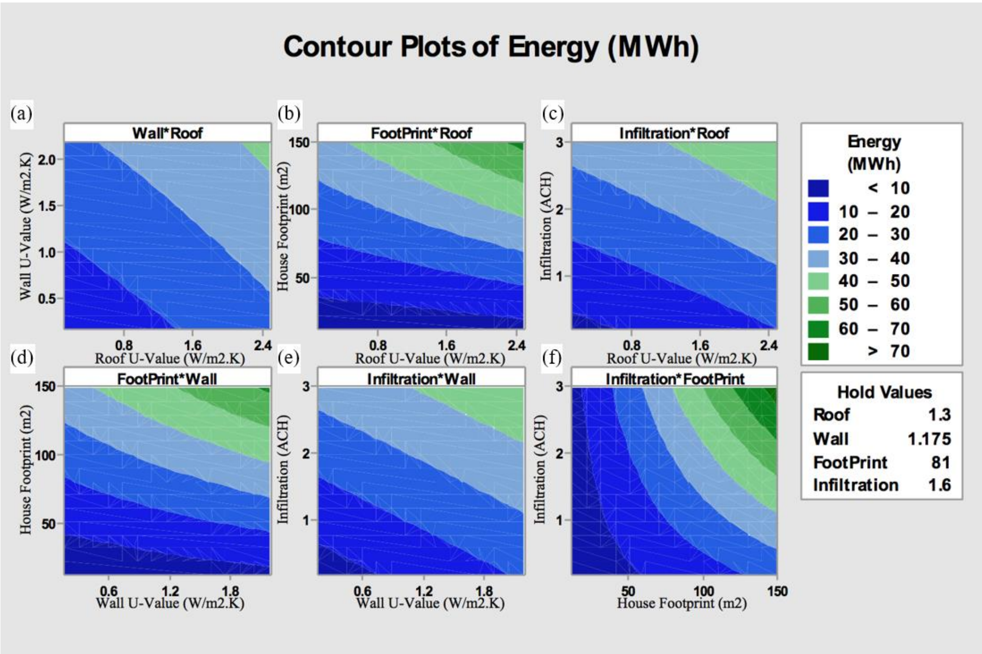

Figure 12 Contour Plots of Impact on Energy Performance by Infiltration and Wall Thermal Transmittance (U-value)

"FIXIT" can not only be applied to evaluate the impact of insulation retrofit on individual building energy performance, but it can also be used to estimate the effect of insulation retrofit on the total reduction in carbon emission for a city or even a country. "FIXIT" was applied to estimate the potential benefit by insulation retrofit for the detached houses in Ger area in Ulaanbaatar, Mongolia. On the basis of the established database with the MIH/Zagdkhorol NGO interview questionnaire survey and on-site measurements, the distribution of the household size to the population of detached houses in Ulaanbaatar is evaluated, as summarized in Table 5.

Table 5 Household Footprint Distribution

Footprint (m2)	Distribution (%)
12 – 29	7
30 - 49	43
50 - 69	30
70 - 150	20

Depending on the proportion of detached houses undertaking building insulation retrofit, the impact on the coal consumption and carbon emission is different. The more the detached houses carry out insulation retrofit, the larger is the reduction in the required coal consumption and carbon emissions. Assuming the thermal transmittance (U-value) of walls and roof is improved to 0.3 W/m^{2}K (this can be achieved by steel or wooden roof with 90 mm insulation materials and 13 mm plasterboard) and 0.4 W/m^{2}K (this can be achieved by brick wall with 70 mm insulation materials and 13 mm plasterboard) respectively and infiltration is improved to 0.5 ACH, the reduction in carbon emissions can be as large as 529.5 ktons when all the detached houses in Ger area of Ulaanbaatar undertake the insulation retrofit. Table 6 below summarizes the detailed findings.

Table 6 City-level Carbon Reduction Estimation

% Application	No. of Households	Coal Reduction (ktons)	Carbon Reduction (ktons)
25	25,000	96.8	132.4
50	50,000	193.7	264.8
75	75,000	290.5	397.1
100	100,000	387.3	529.5

5. Conclusion

In Mongolia, due to the severe winter conditions, the majority of the detached houses rely on direct burning of coal to generate the required heat to maintain thermal comfort. For most of the citizens, this is the most economical way to keep the environment warm during winter seasons. However, the drawback of direct coal burning is the severe air pollution, threatening the citizens’ health and damaging the environment, including contributing to climate change and global warming. In this study, heat loss and air leakage through the building envelope were studied. Based on the 124 interview questionnaire surveys and on-site measurements for 21 detached houses conducted, a database of the building façade thermal performance was established to compare with thermal simulations. Through the integration of IESVE energy simulation model and DOE statistical method, a tool, named “FIXIT”, has been developed for the quick evaluation of the energy performance of a building, based on a few items of building information, and for the non-expert user. “FIXIT” helps to compare the before and after energy performance, the required coal consumption, and the carbon emission reductions due to building insulation retrofit. By using “FIXIT”, the user can easily understand the benefit of building insulation retrofit, which encourages the house owners to adopt the insulation retrofit project, so that less coal consumption is required. By collectively undertaking the retrofit on all of the detached houses in Ger area of Ulaanbaatar, it was estimated that about 387.3 ktons of coal can be reduced, leading to reduction of about 530 ktons per year of carbon emissions.

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