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Improving energy efficiency in Vietnamese tube houses

A survey of sustainable challenges and potentials

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Abstract

Purpose – Refurbishing houses is considered a key measure to improve the energy efficiency of the built environment. However, little is known about the implementation and outcome of housing renovation for energy upgrades in the Vietnamese practice. The purpose of this paper is to investigate the energy performance of the current housing stock in Vietnam and the potential to reduce energy use in households.
Design/methodology/approach – The paper is based on a survey with 153 respondents in three major climatic regions of Vietnam. The survey focusses on building characteristics, environmental performance, energy performance and refurbishment activities. Data collected from the survey were statistically analysed to give insight into the current performance of the housing stock and its energy saving potential.
Findings – This paper concludes that building design and construction, particularly the building envelope, have a significant influence on the occupants' comfort. However, the energy consumption in houses is not statistically associated with building design and indoor environment. It is suggested that financial status and occupants' behaviour currently have a strong influence on the household energy use. The survey also showed that refurbishment improves the housing performance, especially if improving the indoor environment was one of the drivers.
Originality/value – There are very few studies on energy use in households in Vietnam, especially with regards to actual energy consumption. This paper brings insights into the actual energy consumption and reveals the "performance gap" in Vietnamese housing stock.

Keywords Refurbishment, Sustainable, Energy efficiency, Vietnam

Paper type Research paper

1. Introduction

Vietnam has made a lot of significant developments in both economic and social fields since the introduction of the economic reform in 1986. The energy sector, which accounts for one-fourth of the national foreign earnings, certainly plays an important role. In order to continue contributing to the sustainable development of Vietnam, the energy sector has to tackle the problems of ensuring adequate energy supply and minimise energy-related environment impacts. According to the summarised overview of primary energy demand-supply balance for the period of 1997–2025, both policy makers and planners

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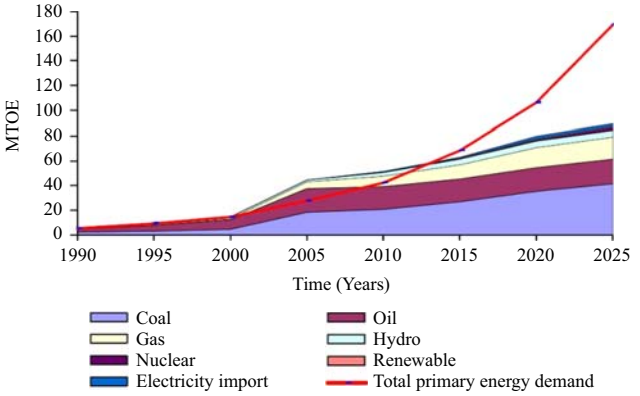
The authors would like to sincerely thank to Dr Clarine van Oel for her enthusiastic support in conducting and presenting statistical analysis in this paper. This study was financially supported by the Ministry of Education and Training of Vietnam (Grant No. 2844/QĐ-BGDĐT: 5 August 2015).

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agree that the energy demand will soon outweigh and double the domestic supply by 2025, see Figure 1 (Do and Sharma, 2011).

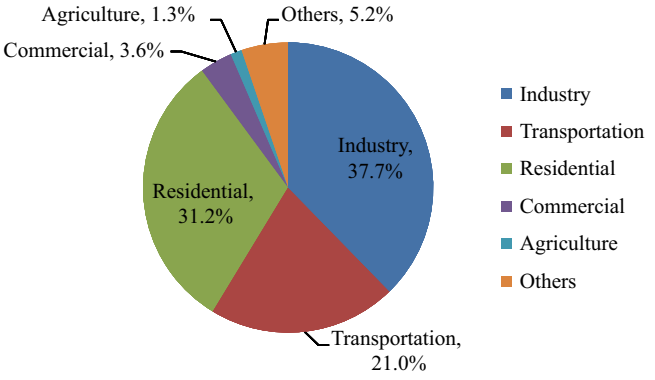
Accounting for more than 31 per cent of the total energy consumption in 2012, the residential sector has been addressed as one of the most important sectors that can potentially reduce the total energy consumption in Vietnam, see Figure 2 (IEA, 2012). Various organisations are aware of the importance of saving energy in buildings. Within the framework of the National Energy Efficiency Program for the 2006–2015 period, the Vietnamese Government issued the National Technical Regulation on Energy Efficiency Buildings (NTREEB) which applies both to new buildings and to renovation of existing buildings (MOC, 2017). In addition, the Vietnam Green Building Council was established in 2007 to raise awareness and build capacity for the development of green buildings in Vietnam. The NTREEB only applies to large-scale buildings but not to small houses, although the small houses account for almost 99 per cent of the housing stock (GSO, 2010).

Energy use of households in Vietnam, especially energy consumption of single dwellings, is also rarely investigated. Previous studies focussed on the relationship between



Source: Do and Sharma (2011)

Figure 1.
Primary energy demand and supply balance



Source: IEA (2012)

Figure 2.
Vietnam final total energy consumption by sector in 2012

building parameters and indoor environment (Nguyen *et al.*, 2011; Ly *et al.*, 2010a) and simulated energy consumption (Vu, 2017). Nguyen *et al.* (2011) utilised in-situ measurements and building simulations to investigate the design strategies in Vietnamese vernacular dwellings and the thermal performance. Ly *et al.* (2010a) conducted a housing survey in 4 different cities of Vietnam to examine the climate responsive design of the Vietnamese housing stock. Although there were 350 participants in that survey the results did not take into account the energy consumption. Several architects have claimed their design to be sustainable or "green". Nevertheless, no post-occupancy monitoring was conducted to verify the actual energy performance of the renovated houses. Vu (2017), for example, presented a case study that aims to achieve a zero energy home standard in Vietnam, but the project was just a single specific example.

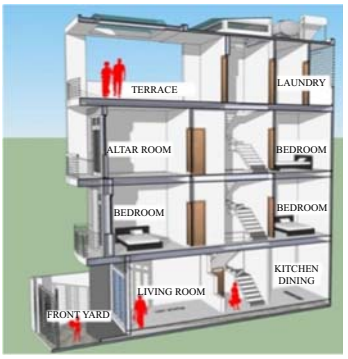
Refurbishing houses is considered a key measure in improving energy efficiency in the built environment. The newly constructed buildings have more potential to achieve higher energy performance than f refurbished projects which are limited by fixed factors in existing sites. However, the importance of the existing building should not be ignored due to the fact the number of existing buildings far outweigh the number of new building added to the market annually. Moreover, in Vietnam, most of the people own their private homes, which also means they are also the main beneficiary of the refurbished project and lower energy consumption can be one of the main priorities.

Many studies have investigated the energy upgrade potential through housing renovation. Refurbishment plans have proven to reduce the energy use of houses by at least 20 per cent (Burgett *et al.*, 2013). Zavadskas *et al.* (2008) proposed a model that helps to choose between various retrofitting options. The model was based on a multivariable approach and aimed to select the optimum solution for each project and for each of the housing components. Loussos *et al.* (2015) has even included the embodied energy in the total energy reduction of a facade after refurbishment. The improvement in energy systems can also improve energy efficiency in the built environment (Jansen, 2013). Since residential buildings account for a large part of the total building stock, housing refurbishment for energy upgrade is expected to contribute substantially to the final energy performance of the building sector. Due to the lack of energy efficiency studies, there is a urgent need for a study that explores the current energy use and potential for energy upgrade in the housing stock of Vietnam.

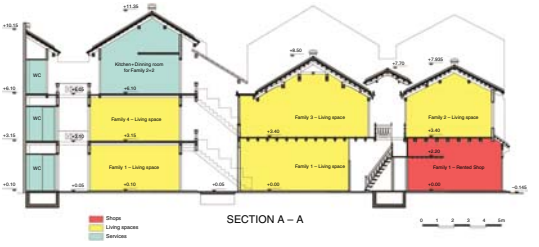
This paper aims to investigate the current context of housing refurbishment activities in Vietnam with a special focus on energy consumption. Furthermore, the study intends to figure out the challenges for implementation and the potential improvements of energy efficient retrofitting. Accounting for more than 70 per cent of the current housing stock, tube houses or attached row houses are the main target of this research. Figure 3 illustrates plans of a typical new tube house and a traditional tubehouse.

2. Literature

The first part of the study investigated status of the current housing stock in Vietnam. Most available data of housing are extracted from the national population and housing census which was conducted in 2009 (GSO, 2010). Data from the census are only used to analyse the housing age and typology. The well-known economic reform in Vietnam in 1986 is an important milestone because only after this event, Vietnamese people was able to own or trade their homes. The big change in housing policy has led to a booming in the housing stock. As a results, majority of the current houses were built after 1986 (GSO, 2010). Among the housing typology, private housing was accounted for 99 per cent and attached row houses alone was accounted for more than 70 per cent (GSO, 2010).



New tube house



Traditional tube house

Source: Nguyen *et al.* (2016)

Figure 3.
Layout of a typical new tube house a traditional tube house in Vietnam

Housing characteristics and housing performance were investigated by a few scholars. Previous studies mainly looked at the climatic design features of the traditional dwellings and the analyses was based on few case studies (Phe and Nishimura, 1991; Nguyen *et al.*, 2011; Le *et al.*, 2013; Ly *et al.*, 2010b). Ly *et al.* (2010a) conducted a housing survey in four cities in Vietnam and received 350 responses. This survey investigated the condition of the houses such as total floor area, construction material and housing performance which included thermal performance, energy use, water conservation and other criteria. Although the survey covered a broad range of topics, the analysis was mostly descriptive and the results only presented a good overview of the houses but no robust analysis was conducted to give an insight in to the performance of the houses.

The latter part of this study explores the refurbishment potential for sustainability and energy efficiency in Vietnam houses. Refurbishment is considered as one of the key elements in making the built environment sustainable as the existing buildings often account for most parts of the housing stocks. Moreover, old buildings often are less energy efficient since they are not fitted with the latest construction technology.

The implementation of sustainable refurbishment often involves different participants including government (central and local), private sectors (developers, consultants, contractors), knowledge institutions (universities, research institutes) and occupants. Government policy is identified as a major driver for sustainable retrofit in many countries. Swan *et al.* (2013) found that adoption of sustainable retrofit in UK social housing was strongly driven by government-funded programmes. As a result, low technology solutions were mainly used in UK social housing projects. In Malaysia, the main barrier for sustainable construction was identified as the government's lack of incentive programmes and the slow progress in revising regulation (Abidin *et al.*, 2013). The Green Deal, a major new energy policy in UK, was found to raise the awareness of the home owners towards energy efficiency renovation (Pettifor *et al.*, 2015).

The very first legislation for energy efficiency buildings in Vietnam was the NTREEB issued in 2013 and updated in 2017 (MOC, 2017). It provides mandatory technical standards in design, construction or retrofit of buildings with a gross floor area of 2,500 m^2 or larger of the following types: offices, hotels, hospitals, schools, commercials, services and residential. The requirements of this regulation apply to four main subjects: building envelope, ventilation and air-conditioning systems, lighting systems and other electrical equipment (electric motors, water heating system and so on). It is important to note that for refurbishing projects, the mandatory requirements apply to the corresponding systems

to be retrofitted. Private housing, which has a total floor area which rarely exceed 300 m^2, is not within the scope of this regulation. However, the available regulation for larger scale apartment buildings is an important basis to develop a suitable regulation for the small scale residential units.

The private sector, including developers and contractors, are mostly commercial organisations, hence depend significantly on the government incentive programmes, as mentioned above. Low cost technology was preferred by the providers because cutting-edge technology was often perceived as less effective (Swan *et al.*, 2013). Abidin *et al.* (2013) also claimed that one of the challenges is the high cost of importing green technology.

Occupants, or home owners in case of private housing, also play important roles in sustainable housing refurbishment. A survey study in Sweden pointed out that 70 to 90 per cent of the people did not have the intention of applying energy efficiency measures in their houses over the next ten years, mostly because they were satisfied with their current homes regarding physical condition, thermal performance and aesthetics (Nair *et al.*, 2010). Energy efficiency policy, the Green Deal in UK for example, can potentially motivate home owners to adopt a more sustainable approach when they are thinking about how to improve their homes (Pettifor *et al.*, 2015). However, actual financial benefit was seen as a common challenge for home owners when energy efficiency measures are considered (Pettifor *et al.*, 2015; Nair *et al.*, 2010). Other barriers to the energy efficiency intervention were also defined as aesthetic tastes and effect on lifestyle (Crosbie and Baker, 2010).

Actual energy savings also depend largely on user behaviour. Nguyen and Aiello (2013) studied different projects in Europe and the USA and found that unaware behaviour can add up to one-third of a building designed energy performance. Post occupancy evaluation (POE) also showed effect of inhabitants' behaviour over building performance. Gill *et al.* (2010) performed an POE in a site of UK EcoHomes with an "excellent" rating and found out energy efficiency behaviour can explain 51 and 37 per cent of the variance in heat and electricity usage between dwellings.

Energy efficiency refurbishment is still a new concept and is not popular in the Vietnamese housing stock. Therefore, this study aims at investigating the potential for energy upgrading in the existing houses, mainly focussing on the user/home owner's perspective.

3. Methodology

This research includes a survey on housing, energy consumption and refurbishment. The set-up of the survey is based on the results of the interviews conducted in 2016 (Nguyen *et al.*, 2016) and several studies on housing in Vietnam (Ly *et al.*, 2010a; Nguyen *et al.*, 2011). The survey is an online questionnaire in Vietnamese created with Google Form and was sent to Vietnamese respondents through e-mail in March and April of 2016. Respondents were asked to answer 38 questions which were divided into five parts: general information, housing information, housing environment, energy consumption and housing refurbishment. Housing information was recorded mainly through multiple choice questions. A summary of the questions and answers is shown in Tables I–III. Likert-type scale and semantic differential scale questions were asked to acquire users' perception of the indoor environment, energy bills and refurbishment priority, corresponding to the results shown in Figures 4, 16 and 17. The first ten participants were from the network of the first author. Some were also asked to provide additional evidence, such as energy bills or photos, to support their answers. Doubts or uncertainties were discussed in the first few cases to make sure the questions were clear and understood correctly. Each of the respondents was then asked to spread the questionnaire to the people in their contact list. This procedure was repeated again and again until the survey no longer accepted respondents, which was after two months. In total, 153 households

Houses' characteristics/ performance	Red/Bad	Yellow/Neutral	Green/Good
Orientation	West, South West	North, North East, North west	South, South East, East
External wall	Single wall without insulation	Double wall without insulation	Double wall with insulation
Roof	Roof without insulation		Roof with insulation
Windows	Single glazed		Double glazed
Courtyard existence	No		Yes
Solar control	Curtain or none	Double layer of windows No shading device	Double layer of window Shading device
Use of energy efficiency equipment	No		Yes
Use of solar collectors	No		Yes
Use of air-conditioners	Frequently		Infrequently, not in use
Number of cases	46	39	68

Table I. Summary of houses categories/ colour coding

House colour	Red	Yellow	Green	Total
Total	46	39	68	153
Respondents' age				
< 25	8	9	7	24
25–40	35	29	54	118
> 40	3	1	7	11
Number of occupants				
1–2	9	14	3	8
3	13	7	23	28
4	8	6	16	43
5	6	5	15	30
> 5	9	14	3	17
Tenure status				
Privately own	30	25	63	118
Non- privately own	16	14	5	35
Climatic region				
North	34	32	61	127
Centre and South	12	7	7	26

Table II. Characteristics of the study population

participated in this survey. Although the selection of the respondents were random, the first ten surveys were sent out to the people in the network of the authors so they are more or less involved in the built environment field and well-aware of technical aspects. The follow-up respondents are randomly selected but was also in the network of the previous ones so they are more likely to be well-educated and know what the questions were about. Moreover, in all the questions, there are always an option "Others or I don't know". Therefore, the responses are reliable and can be used for analysis. Data were inspected for outliners but no value was found to be excludable. The results of the survey were analysed by SPSS software, version 24.0.

Data collection

From the collected data, the following information was selected for analysis.

Housing typology	Apartment	(%)	Attached	(%)	Detached	(%)	Semi- detached	(%)	Total	(%)
Total	43	28	95	62.1	13	8.5	2	1.3	153	100.0
Region										
North	35	22.9	84	54.9	8	5.2	0	0.0	127	83.0
Centre and South	8	5.2	11	7.2	5	3.3	8	5.2	26	17
Building age										
0–10	22	14.4	46	30.1	6	3.9	1	0.7	75	49.0
10–20	13	8.5	34	22.2	4	2.6	1	0.7	52	34.0
> 20	7	4.6	13	8.5	3	2.0	0	0.0	23	15.0
Function										
Mixed-use	7	4.6	14	9.2	1	0.7	0	0.0	22	14.4
Residential	36	23.5	81	52.9	12	7.8	2	1.3	131	85.6
Orientation										
East, South, South East	17	11.1	33	21.6	8	5.3	1	0.7	59	38.6
North, North East, North West	9	5.9	26	17	2	1.4	0	0.0	37	24.3
West, South West	10	6.6	29	19	1	0.7	0	0.0	40	26.1
No. of floor										
1	43	28.1	4	2.6	3	2.0	0	0.0	32	20.9
2	0	0.0	13	8.5	3	2.0	1	0.7	18	11.8
3	0	0.0	35	22.9	4	2.6	1	0.7	44	28.8
4	0	0.0	29	19.0	2	1.3	0	0.0	31	20.3
5	0	0.0	14	9.2	1	0.7	0	0.0	28	18.3
Floor area										
< 40	10	6.5	11	7.2	0	0.0	0	0.0	21	13.7
40–80	13	8.5	16	10.5	0	0.0	0	0.0	29	19.0
80–120	17	11.1	23	15.0	2	1.3	0	0.0	42	27.5
120–200	1	0.7	19	12.4	6	3.9	0	0.0	26	17.0
> 200	1	0.7	22	14.4	3	2.0	2	1.3	28	18.3
Structure										
Load-bearing wall	7	4.6	24	15.7	2	1.3	0	0.0	33	21.6
Reinforced concrete	27	17.6	60	39.2	7	4.6	1	0.7	95	62.1
Steel structure	1	0.7	0	0.0	0	0.0	0	0.0	1	0.7
Wooden structure	0	0.0	0	0.0	1	0.7	0	0.0	1	0.7
External wall										
Brick wall 100–150 mm, no insulation	13	8.5	35	22.9	3	2.0	1	0.7	52	34.0
Brick wall 100–150 mm, with insulation	1	0.7	7	4.6	0	0.0	1	0.7	9	5.9
Brick wall 200–250 mm, no insulation	10	6.5	35	22.9	5	3.3	0	0.0	50	32.7
Brick wall 200–250 mm, with insulation	0	0.0	2	1.3	1	0.7	0	0.0	3	2.0
Other	19	12.4	16	10.5	4	2.6	0	0.0	39	25.5
Roof										
Reinforced concrete, with insulation	16	10.5	45	29.4	6	3.9	0	0.0	67	43.8

Table III.
Housing characteristics of the survey in 2016 among Vietnamese inhabitants

(*continued*)

Housing typology	Apartment	(%)	Attached	(%)	Detached	(%)	Semi- detached	(%)	Total	(%)
Reinforced concrete, without insulation	8	5.2	21	13.7	0	0.0	0	0.0	29	19.0
Steel frame with tiling, with insulation	2	1.3	13	8.5	5	3.3	1	0.7	21	13.7
Steel frame with tiling, without insulation	2	1.3	7	4.6	1	0.7	0	0.0	10	6.5
Ventilation										
Side window	40	26.1	47	30.7	13	8.5	1	0.7	101	66.0
Inner courtyard	1	0.7	12	7.8	0	0.0	1	0.7	14	9.2
Light well	2	1.3	36	23.5	0	0.0	0	0.0	38	24.8
Solar control										
Shading devices	13	8.5	44	28.8	8	5.2	0	0.0	65	42.5
Double layer of windows	5	3.3	17	11.1	2	1.3	1	0.7	25	16.3
Curtain	20	13.1	25	16.3	3	2.0	1	0.7	49	32.0
Other	5	3.3	9	5.9	0	0.0	0	0.0	14	9.2
Energy source										
Electricity only	22	14.4	29	19.0	2	1.3	0	0.0	53	34.6
Electricity and gas	21	13.7	66	43.1	11	7.2	2	1.3	100	65.4
No. of air-conditioners										
0	4	2.6	11	7.2	1	0.7	0	0.0	16	10.5
1	17	11.1	23	15.0	3	2.0	0	0.0	43	28.1
2	10	6.5	34	22.2	2	1.3	0	0.0	46	30.1
3	9	5.9	17	11.1	3	2.0	1	0.7	30	19.6
4	2	1.3	5	3.3	2	1.3	0	0.0	9	5.9
5	1	0.7	5	3.3	2	1.3	1	0.7	9	5.9
No. of electric water heaters (for bathroom)										
0	5	3.3	5	3.3	1	0.7	0	0.0	11	7.2
1	25	16.3	37	24.2	5	3.3	0	0.0	67	43.8
2	13	8.5	30	19.6	3	2.0	0	0.0	46	30.1
3	0	0.0	16	10.5	2	1.3	1	0.7	19	12.4
4	0	0.0	3	2.0	1	0.7	0	0.0	4	2.6
5	0	0.0	4	2.6	1	0.7	1	0.7	6	3.9
Solar hot water (solar collectors)	3	2.0	26	17.0	4	2.6	1	0.7	34	22.2
Energy efficiency equipment	18	11.8	46	30.1	7	4.6	1	0.7	72	47.1

Table III.

Building design and construction information was recorded by asking multiple choice questions that specify the housing design and construction. For example, one can indicate if the house has a west orientation, double layer external walls with insulation, an integrated inner courtyard, shading devices, solar collectors and energy-efficient electrical appliances.

For energy consumption data, occupants were asked minimum and maximum monthly electrical consumption (in kWh) and average monthly gas consumption, if applicable. Data on gas use can be given on an average monthly basis since in Vietnam gas is mostly used for cooking purposes. Gas is converted into kWh using the conversion rate of 1 kg gas = 13.6 kWh (Hahn, 2010) and then summed with electrical use to generate the monthly and annual total energy consumption. Total energy use is divided by the number of occupants to provide an energy use index.

The Indoor environment was assessed by three factors: daylight, thermal environment and natural ventilation. People were asked to indicate their perceived comfort level of the

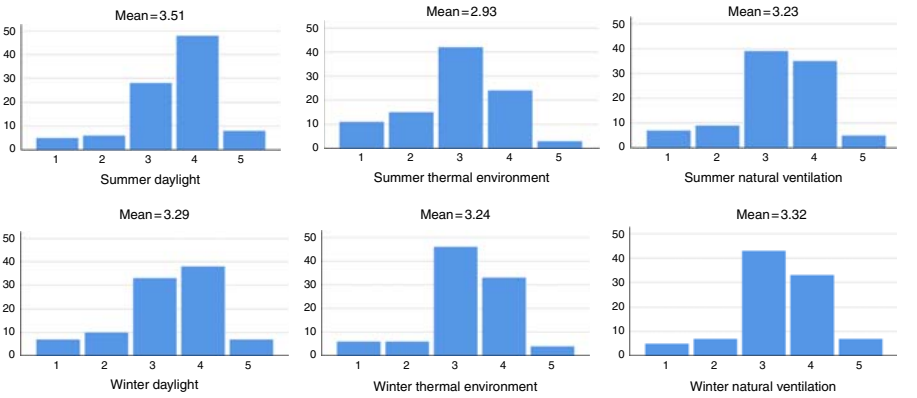


Figure 4.
Frequency of indoor environment self-assessment (1 = very bad, 5 = very good)

living spaces. A five-point scale from 1 to 5 was used in which 1 is very unsatisfactory and 5 very satisfactory. The questions had to be answered separately for Summer (May to July) and Winter (November to January) conditions, even though there is no actual Winter in the southern half of the country.

Descriptive analysis

Descriptive statistic such as frequency, percentages, range, were used to summarise the characteristics of the occupants and their homes.

Statistical analysis

The buildings consume a different amount of energy. The statistical analysis aims to relate different factors with housing energy consumption. Energy performance data were associated with different user-related factors. The investigated factors are: occupant perception of energy saving, use of electrical equipment and renewable energy sources.

Categorising housing

There are many factors that have an effect on the performance of houses. Therefore, the buildings were classified into two main groups by using nine criteria: orientation, external walls, windows, roof, courtyard presence, thermal control devices, use of solar collectors, energy-efficient appliances and air-conditioners. In each criterion, the answers were divided into three main groups: poor, unsatisfactory, inefficient or "red"; good, satisfactory, efficient or "green"; and neutral or "yellow", see Table I. The classification was based on widely accepted literature of bioclimatic and energy-efficient design (Almusaed, 2011; Nguyen, 2013, 2017).

For example, the southeast orientation houses which benefit from the prevailing cool wind in Summer are given one point in "green" category and an single external wall without insulation is considered as 1 "red" point.

Based on the multi-criteria classification method (Roulet *et al.*, 2006), the houses will be categorised as follows:

- a building is "green" if more than 50 per cent of criteria is marked as green;
- a building is "red" if more than 50 per cent of criteria is marked as red; and
- otherwise, the building is "yellow" or not sorted.

This method assumes that all the criteria have the same weight. Although this is debateable, we chose to keep it this way in order to make the analysis easier.

4. Descriptive analysis

Respondents

Among 153 responses recorded, see Table I, there are 142 persons (93 per cent) under the age of 40 and only 11 persons (7 per cent) are 40 or older. Most respondents are aged between 25 and 39, which accounts for 77 per cent (118 persons) of the respondents.

At first, the survey aimed to categorised the responses according to the climatic region where they live, in order to compare the differences in housing and performance. However, 83 per cent (127 people) are located in the Northern part and only 17 per cent lives in the other regions of the country, Central and South.

The number of people in a family ranges from one to seven and the most common composition is a four-person family (28 per cent). Three and five person families accounted for 18 and 20 per cent, respectively, while two-person and six-person families accounted for 12 per cent each. Single persons and big family compositions (more than six occupants) presented less than 10 per cent of the total, see Table II.

The traditional Vietnamese custom is to look for a stable home for the whole family. It is therefore no surprise that 118 persons (77 per cent) stated that they were living in privately owned houses. About 15 per cent of the families were living in a private rental unit and the rest shared rent or otherwise. The fact that majority of the houses are privately owned emphasises the roles of the home owners in the course of energy upgrade of the housing stock. Government policy and incentive programmes are therefore recommended to target directly at the citizens.

Building characteristics

Typology. Tube houses or attached row houses are the main target of this research. They account for 62 per cent of the houses in this survey. About 28 per cent of the houses are apartments and the remaining 10 per cent are detached and semi-detached houses. Among the 95 tube houses, 78 houses (82 per cent) are at least three-storey high, and 77 houses (81 per cent) have a plot size of 60 square meter or lower. Courtyard are presented in 12 houses (13 per cent of the row houses). Densely populated cities have made the contemporary houses narrower and higher which leave less room for daylighting and natural ventilation. Traditional tube houses in Hanoi, Vietnam are mostly one to two storey high and are often bigger and include inner courtyards (Nguyen *et al.*, 2016).

Building age. Most of the houses were built in the last 30 years (95.4 per cent), which means after the Economic reform of 1986. Almost half of the houses (49 per cent) was built in the most recent ten years, about one third (34 per cent) was built in the earlier ten-year period and 12.5 per cent of the houses were constructed in the period from 1986 to 1995. Compared with the national census conducted by the General Statistics Office in 2009, the housing ages in this survey have a similar pattern as the census although the timeline is slightly different. The survey confirms that the houses in Vietnam are mainly built in the last 30 years and this suggests that the potential refurbishment (of houses built in the period between 1986 and 2005) accounts for approximately half of the total housing stock.

Building function. In total, 85 per cent of the houses are used solely for residential purposes and the others have a mix-use type, combining living spaces with offices, commercial activities or workshops. While residential houses are often only partly occupied, office and commercial places are normally fully occupied with more people and devices during the day. Therefore, the energy consumption between these two groups might differ substantially. In some of the analyses regarding energy consumption, mix-used houses are therefore excluded.

Building orientation. People were asked about the main orientation of their house. There were eight options to select from: North, East, South, West and four in between orientations. The orientations do not differ much because many houses are row houses and apartments where the orientation is fixed.

Building construction. Frame: there are two main construction types: reinforced concrete (62 per cent) and load-bearing masonry (21 per cent).

Walls: external walls are all built from clay brick with one layer (100–150 mm) or two layers (200–250 mm), each accounting for half of the houses. In total, 90 per cent of the walls are built without any insulation layer.

Roof: there are two main types of roof constructions: reinforced concrete or a frame (steel or wood) with tiling. Concrete is still the most popular material for roofs, accounting for 75 per cent of the houses. In terms of insulation, 70 per cent of the roofs are constructed with an insulation layer to prevent direct solar gain from the top. The occupants (or architects) appreciated the benefit of roof insulation.

Windows: 82 per cent of the transparent windows are single glazed, while 18 per cent is double glazed. Popular window frames are wood and aluminium (88 per cent) which can be explained by their economic price. In total, 36 times the wooden shutter was mentioned to block direct sunlight and protect the house from overheating.

Discussion: Ly's *et al.* (2010a) investigation also found that the reinforced concrete frames and brick external walls are dominant. However, in Ly's paper, the majority of the houses were roofed with corrugated iron, while in this study, flat concrete roof is the most popular. This is explained by the difference in location where the surveys were taken and hence in the difference in climate and construction practice.

There was lack of energy efficiency factors in the building envelope variation. For example, no green roof or green facade were recorded in the answers Thermal insulation was mostly applicable to roof construction. However, contemporary tube houses are often three to five storey high and living spaces are mostly located at street level, hence, the insulation effect of the roof does not contribute much to the energy performance of the houses. Moreover, simplicity in the choices for building envelope is also due to the lack of new technology in the market and sustainable design approach. Ly (2012) found that less than 20 per cent of the attached row houses in Vietnam at that time were designed by architects. Instead, they were built upon builder's experiences and owner's personal taste. This fact raises a need for educating home owners in a way that they should either consult a qualified architecture firm or they can acquire sustainable knowledge which should be made widely available.

Solar and ventilation control. The main source for natural daylight and ventilation is a side window (82 per cent). A small light-well was mentioned 43 times and inner courtyards were recorded in 14 answers (9 per cent).

Solar control is a popular concept since almost all the houses use one of the following: shading devices, double window layers (transparent and opaque) and curtains.

Building performance

Indoor environment. Respondents were asked to assess their homes' indoor environment on a five-point scale from 1 to 5, where 1 is very bad, 2 is bad, 3 is neutral, 4 is good and 5 is very good. In general, many occupants expressed their satisfaction with the indoor environment regarding daylight, natural ventilation and thermal comfort both in Summer (May to July) and Winter (November to January). However, the average Summer thermal comfort is less than neutral and 40 persons (26 per cent) indicated that the thermal environment in their house is bad or very bad (Figure 4).

Ly *et al.* (2010a, b) also investigated the indoor environment of the Vietnamese houses. Ly also found that the occupant satisfaction with the thermal performance and natural ventilation of their houses. Also in both cases, more people had overheating problems rather than cold issues.

Energy consumption

In Vietnam, there are two main energy sources: electricity and gas. The gas is often only used for cooking purposes but not for heating or domestic hot water. In many houses, people replaced cooking on gas by cooking on electricity. In this survey, 35 per cent of the families used only electricity, 65 per cent used both electricity and gas.

The most energy-consuming equipment are the air-conditioner and the water heater (for kitchen and bathroom). According to the responses, 90 per cent of the families use the air-conditioner and 93 per cent of the people have water heaters. The respondents were mainly located in the Northern part of the country where there are two distinct seasons, hot Summer and cold Winter. Therefore, the air-conditioners are mainly turned on in the Summer (more often at night than during the day).

In terms of energy-efficient equipment, the solar collector was mentioned in 22 per cent of the answers and 47 per cent of the respondents use equipment with energy efficient labels. Compared to Ly's results in 2010, where only 3 per cent of the surveyed houses installed either solar collectors or photovoltaic cells or energy efficiency equipment.

5. Energy performance indicator

The paper investigates the relationship between energy consumption and residential building characteristics. Energy consumption was measured in kWh where gas consumption is also converted into kWh using the exchange rate of 1 kg gas = 13.6 kWh (Hahn, 2010). Houses with additional functions, other than residential, are excluded from this part. However, absolute monthly energy consumptions are not comparable since the houses were different in size as well as number of occupants. This part identifies an energy performance index that will be used to compare houses' performance.

The energy consumption from survey data were the maximum and minimum monthly energy bills. Correlation between the maximum and minimum electricity consumption was examined and a linear relationship between them was found, see Figure 5. The "goodness of fit value", $R^2 = 0.752$ and the significance is $p < 0.001$. The regression line is then given by: max monthly energy $= (204 \pm 68) \cdot 10^3 + (1.56 \pm 0.13) \times$ minimum monthly energy. Because of the direct relationship between the maximum and minimum monthly energy, the analysis is continued with only the maximum monthly energy.

Non-building related aspects

Furthermore, the energy performance possibly depends on non-building related aspects such as the floor area and the number of occupants. It is found that there is a linear relationship between the maximum monthly energy use and the number of occupants.

The regression equation is as follows: max monthly electricity $= (84 \pm 125) \cdot 10^3 + (200 \pm 30) \cdot 10^3 \times$ number of occupants.

The coefficient of determination, $R^2 = 0.563$ and the correlation is significant with $p < 0.001$.

There is also a correlation between energy use and the total floor area, see Figure 6.

The floor area and the number of occupants have a relationship with the energy consumption. Among them, the number of occupants is the one with the strongest correlation. The next part investigates if the floor area depends on the number of occupants. If that is the case, the effect of the floor area is determined by the number of occupants,

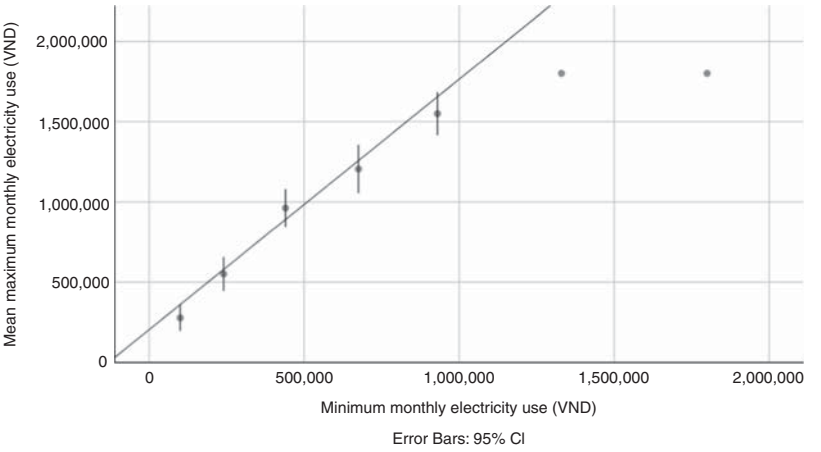


Figure 5.
Maximum and minimum monthly energy use in households

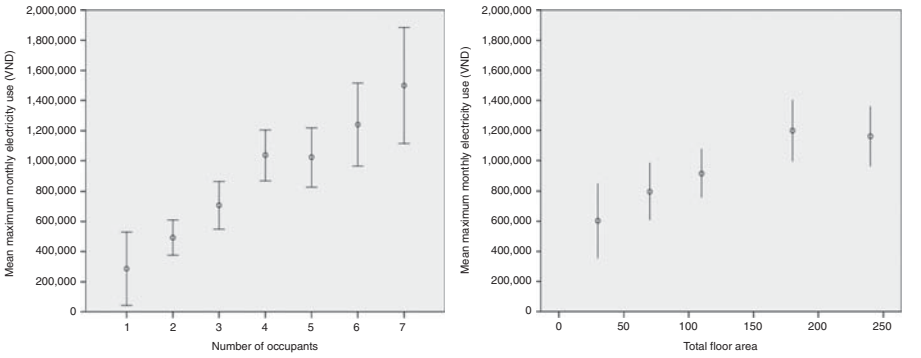


Figure 6.
Relationship between maximum monthly energy consumption and number of occupants, total floor area

making the maximum monthly energy demand per occupant the main parameter when investigating the effect of the building on the energy demand.

Figure 7 shows the relationship between the number of occupants and the total floor area. According to the regression analysis, the $R^2 = 0.378$. Considering the data and the graphs, the correlation is not extremely good, but good enough to assume that the main influence on the energy demand is the number of occupants. The aspect of total floor area is the secondary parameter.

6. Results and discussion

Correlation between energy consumption and overall building characteristics

The energy consumption and the indoor environment of the houses were associated with each of the building characteristics to see which factors have more effect on the overall performance of the houses. The Spearman correlation method was used to examine the relationship between building performance and building characteristic, see Table IV.

The building envelope, specifically the external walls and roof, have a considerable impact on the perceived comfort of the occupants at 0.05 and 0.1 level of significance, respectively. Orientation and solar control devices also have some correlation, though minor, with the indoor environment of the houses. On the other hand, energy consumption does not show any correlation with the building design and construction but has a weak

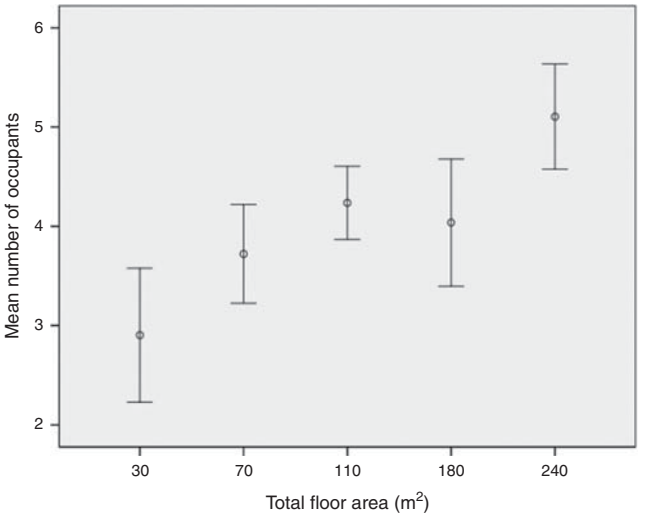


Figure 7.
Scatterplot graph showing the relationship between the number of occupants and the total floor area

	Indoor environmental comfort		Energy consumption per person	
	Correlation coefficient	Significance value (p)	Correlation coefficient	Significance value (p)
Orientation	−0.105	(0.234)	−0.096	(0.281)
External walls	0.251**	(0.004)	−0.096	(0.277)
Windows configuration	−0.098	(0.267)	0.084	(0.346)
Roof detail	0.223*	(0.011)	0.094	(0.289)
Courtyard	0.082	(0.354)	0.084	(0.341)
Solar control	0.153	(0.081)	0.027	(0.762)
Use of energy efficiency equipment	–	–	−0.147	(0.096)
Use of solar collectors	–	–	0.133	(0.133)
Indoor environment	–	–	−0.096	(0.277)

Notes: *,**Significant at 0.05 and 0.01 levels, respectively

Table IV.
Correlation between indoor environment and maximum monthly energy consumption with building characteristics

correlation with the use of energy efficiency equipment and solar collectors. The indoor environment also does not show any statistical correlation with the final energy use of a household in this analysis.

Relation between energy consumption and facade insulation

External walls and roof construction did not show any statistical relation to the energy performance of the houses. In many cases, the houses with better insulation even consumed more energy than ones with insulated facade, see Figures 8 and 9. According to the responses, the majority of the houses had similar facade details, including brick walls without insulation, single glazing windows and concrete roof with insulation. Such practice might have been widely accepted among the builders as well as home owners.

Discussion: for external walls, the question of whether or not insulation helps reduce energy consumption is still debatable. Common practice did not record often the existence of insulation. Traditional architecture also mostly appreciated lightweight facade, without

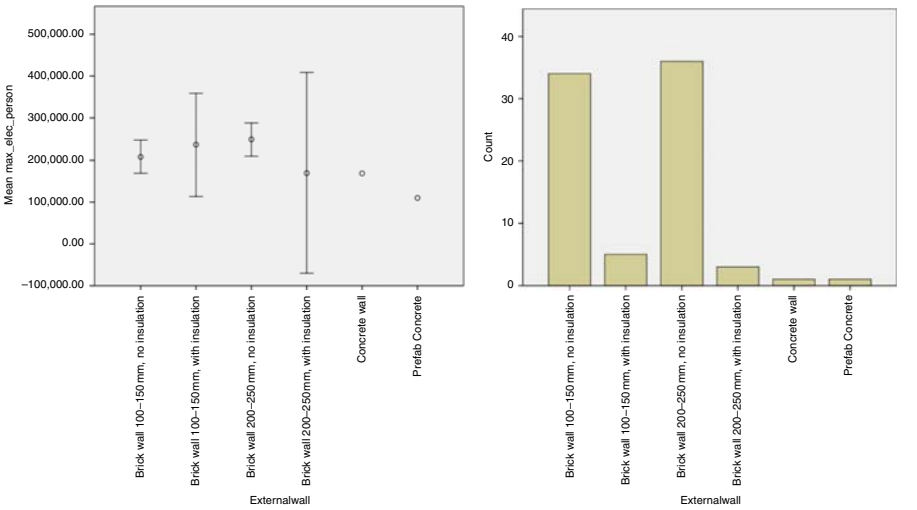


Figure 8.
Energy use of different external walls types

Notes: Left: scatterplot graph of external walls type and mean of maximum monthly energy consumption per person (kWh). Right: number of cases with different types of external walls

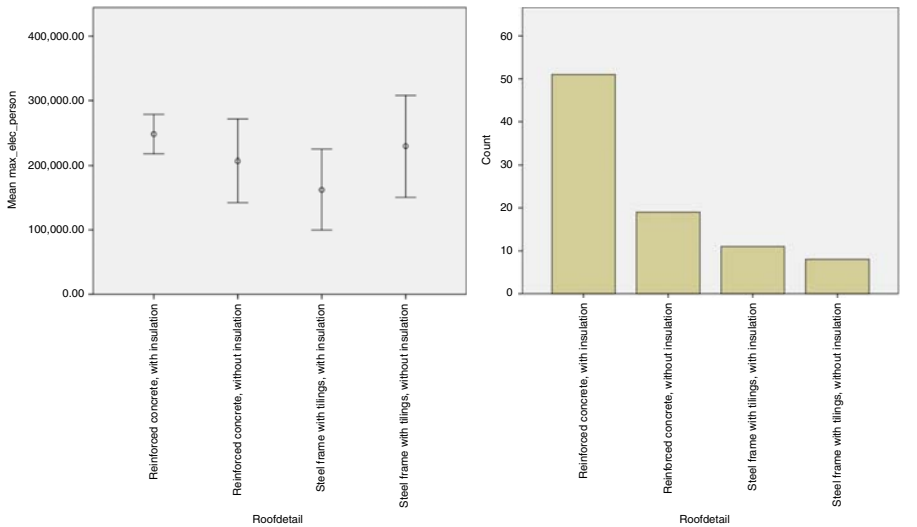


Figure 9.
Energy use of different roof types

Notes: Left: scatterplot graph of roof type and mean of maximum monthly energy consumption per person (kWh). Right: number of cases with different types of roof

insulation in order to get rid of unwanted heat as fast as possible (Nguyen *et al.*, 2011). However, the national technical regulation of energy efficient buildings required large-scale buildings to have a high performance facade, with certain level of insulation (MOC, 2017). The current regulation mostly applies to offices and commercial buildings which are air-conditioned most of the occupied period. High performance facades in this case play a role in preventing the "cold loss". In residential buildings, the use of air-conditioners is subject to

the behaviour of the occupants. A high performance facade might accumulate unwanted heat and create overheating problem but at the same time benefit a frequent air-conditioner user. Therefore, it is suggested that more comprehensive research should be conducted to quantify actual outcome of high performance facade before putting them into regulation for private housing in Vietnam.

For the concrete roofs, the maximum monthly energy consumption per person is higher for roofs with insulation than for roofs without insulation. For the steel frame roofs, the effect of insulation is positive, therefore steel roofs with insulation will have a lower energy demand. Concrete flat roofs are most popular and mainly applied for houses higher than three stories. In this case, the roofs normally cover unoccupied spaces such as an altar room or storage. On the other hand, simple steel-frame structure roofs are generally applied to lower dwellings with one or two stories and the roofs are normally directly above the living spaces. That might explain the difference in the efficiency of insulation in the roof detail.

According to the analysis, insulation leads to a higher energy demand. It might be because of the low number of houses with insulation compared to the uninsulated ones. Moreover, the lack of correlation between building characteristics and energy performance might also be due to the difference between the predicted and the actual energy consumption, or "performance gap", which was discussed in many researches (IEA, 2013; Ortiz *et al.*, 2017). Among the causes for such a performance gap, occupant behaviour is defined as a heavily influential factor (Demanuele *et al.*, 2010). On the other hand, Kurvers *et al.* (2013) indicated that housing design that ignores climate conditions might lead to a greater performance gap compared to the climate-oriented ones. Therefore, further studies are recommended to investigate the cause for the "performance gap" in Vietnam and how to minimise it.

Relation between energy consumption, indoor comfort and the use of electrical equipment

Electric appliances are often ignored in the prediction of electrical consumption, as suggested by Majcen (2016). This phenomenon might lead to greater variation in the performance gap in Vietnam where electrical equipment uses most of the energy. Therefore, although no statistically significant effect is found when the buildings are divided in three groups (green, orange and red), the high significance with low p-value suggests to further investigate the relationship between the energy consumption and the amount of electrical equipment. Table V and Figure 10 illustrate the regression analysis and scatter plot of energy consumption in relation with the number of air-conditioners and water-heaters.

According to the regression analysis, one more air-conditioner and one more electric boiler increases the monthly energy consumption by 61 kWh and 83 kWh, respectively. If the equipment is considered separately, 114 kWh would be consumed monthly for each of air-conditioner unit and 138 kWh for an additional water boiler, see Figure 8. Note that the mean household's monthly energy consumption is 514 kWh. On average, 244 kWh of electrical energy was consumed for other things (lighting, washing machine, TV, fridge and so on). Although it seems obvious that an increased use of electrical equipment leads to

Table V.
Regression analysis showing relationship between monthly energy consumption (kWh) and number of air-conditioners and electrical water-heaters

Model 1	Unstandardised coefficients *B*	SE	Standardised coefficients *β*	*t*	Sig.
(Constant)	244	35		6.9	0.000
Number of air-conditioners	61	21	0.307	2.8	0.005
Electricity water heater	83	25	0.354	3.2	0.001

a larger use of energy, it warrants further investigation to find out how to reduce energy in houses.

Discussion: in general, 90 per cent of the houses have air-conditioners to improve their indoor environment (see Table VI). Notably, all the houses which claimed to thermally perform very well (5 points) have at least one conditioner. None of them were only naturally ventilated. Similar observations apply to houses which score 4 points (good) in thermal performance. Only one out of 42 houses that score good on indoor environment does not use any air-conditioner.

Most air-conditioned houses own one to three AC units (78 per cent of the total number of cases and 87 per cent of the air-conditioned ones). Among this group, three quarters of the respondents rated their houses as having a neutral or good thermal performance. Well-performing houses are usually not good "enough" to keep the houses air-conditioner free. This means that either houses can perform generally good but not in some extreme weather period or people prefer using active mechanical ventilation in any thermal condition.

Houses that perform badly in terms of thermal comfort in Summer are less likely to have air-conditioners in their homes. For instance, 24 per cent of the "very bad" and 31 per cent of

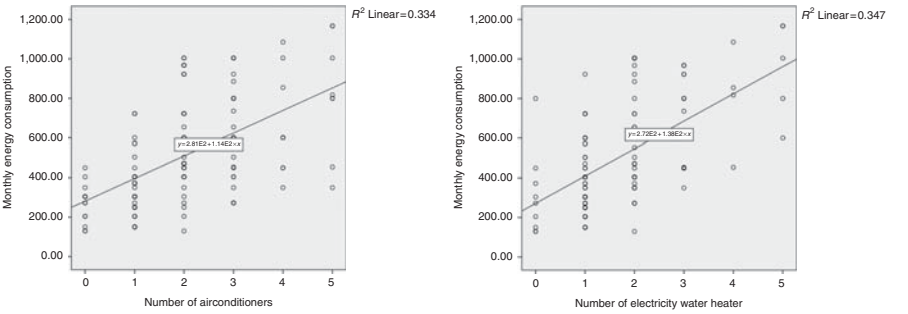


Figure 10.
Scatter plot showing relationship between maximum monthly energy consumption (kWh) and number of air-conditioners and electrical water-heaters

	Number of air-conditioners			
	0	1–2	3–5	Total
Summer thermal comfort				
Very bad (1)				
Count	5	8	8	21
% within Summer thermal comfort	23.8	38.1	38.1	100.0
Bad (2)				
Count	6	11	2	19
% within Summer thermal comfort	31.6	57.9	10.5	100.0
Neutral (3)				
Count	4	44	18	66
% within Summer thermal comfort	6.1	66.7	27.3	100.0
Good (4)				
Count	1	23	18	42
% within Summer thermal comfort	2.4	54.7	42.8	100.0
Very good (5)				
Count	0	3	2	5
% within Summer thermal comfort	0.0	60	40.0	100.0
Total				
Count	16	89	48	153
% within Summer thermal comfort	10.5	58.2	31.4	100.0

Table VI.
Crosstab table of number of air-conditioners and self-assessment of thermal comfort in Summer

the "bad" indoor comfort houses do not have any air-conditioners, see Table VI. To further test the hypothesis that houses without air-conditioner do not have a good comfort, such houses were further investigated.

Houses that do not use air-conditioner and consume less energy are typically poorly designed in terms of providing good indoor environment and do not take energy efficiency into consideration. Out of 16 houses, 50 per cent were built in the last ten years, and more than 30 per cent were built in the previous decade. In all, 13 people responded to the external wall question, which were all single walls without insulation. Ten out of 14 known roof details did not report a thermal insulation layer. In 13 houses, daylight and natural ventilation comes from windows only. Rates of using a solar hot water system and energy efficiency equipment are both only 25 per cent. In general, ten houses were graded as "red" and only two houses were "green". They also have not been refurbished recently because they are not permanent houses, the budget is limited or simply because the houses were newly built.

Other aspects

The lack of correlation between building performance and building characteristics suggests that there are more reasons for the energy use in houses beside building configurations. In this case, household income could be a responsible factor since people with a lower income might live in poorly designed houses and are more likely to be unable to afford air-conditioners and high energy bills. However, income data is privacy-sensitive and was not acquired in this survey. Instead, the use of electrical equipment and consumed energy are correlated with intermediate factors that somehow refer to income. These factors are housing typology, tenure status and total floor area. In Vietnam, higher income people tend to possess larger privately owned houses and not apartments (Sanghoon *et al.*, 2013).

Figure 11 shows the number of air-conditioners by tenure status and total floor area of the houses. Among 120 private owned houses, only two of them do not have any air-conditioning units while 45 per cent of the rented homes (13 out of 29) was air-conditioner free. Regarding sizes of the houses, smaller residential units are more likely to have less air-conditioners. However, such a correlation does not directly address household income as a driver for the use of electrical equipment, but it also suggests that most rooms still require or are desired to have mechanical ventilation. For this reason, a further investigation on the income of the people as well as a more detailed examination of the case studies is recommended.

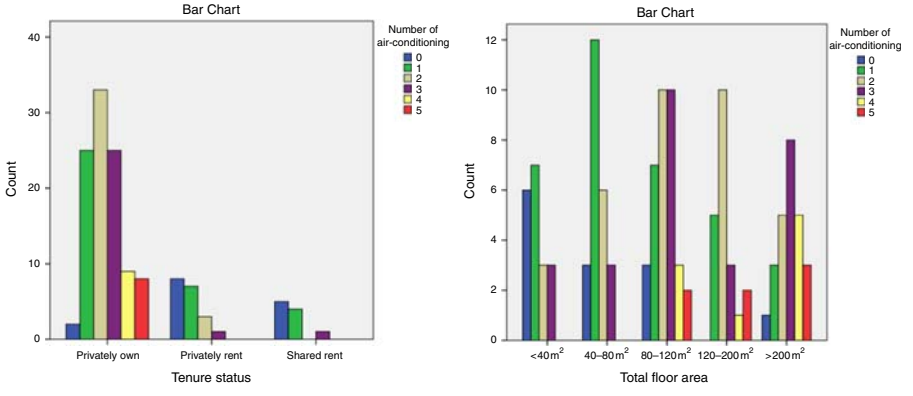


Figure 11. Characteristics of air-conditioner-free houses

7. Refurbishment

Refurbishment is a complicated process and the motivations for housing renovation are also complex and usually there is more than one reason for refurbishment. Different reasons led to different levels of intervention ranging from minor repair (redecorating, repairing parts or service) to intensive renovation (expanding space, adding or removing building components to improve the indoor environment, etc.) (see Figure 12).

Older houses are more likely to be in need of refurbishment. About two-third of the houses that are over 20 years old have been refurbished in the last ten years, see Figure 13. This fact also applies when the cases were broken down into separate refurbishment reasons. Recently built houses within the last decade are more likely to be redecorated or repaired. On the other hand, more than 20 year-old houses often have a more complex refurbishment with different activities.

Refurbishment in the last ten years has led to changes in housing performance in terms of indoor environment and energy consumption. Figure 14 illustrates the effects that were indicated by the respondents. In general, the indoor climate was improved, especially with regards to the thermal environment. The energy performance also shows improvement, though minor. This result suggests that housing refurbishment might potentially improve the indoor environment as well as the energy performance even if they are not the main drivers for renovation activities.

Refurbishment in general improves the building performance. Table VII shows the changes in accordance with the refurbishment action. Only changes in thermal and energy performance are shown with respect to four different refurbishment options: redecorate, repair, expand spaces and improve indoor environment. The results show that the improvement rates are the same regardless of the measures involved. For instance,

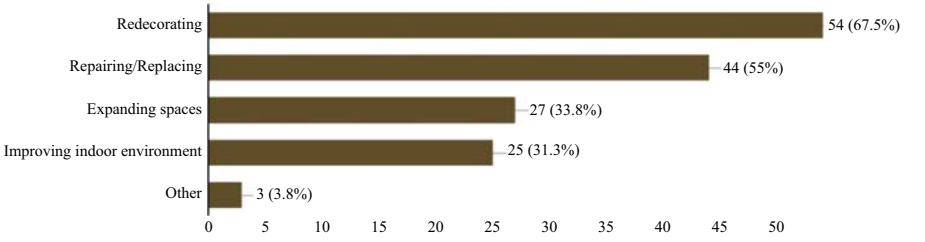


Figure 12.
Reasons for refurbishing houses according to the respondents

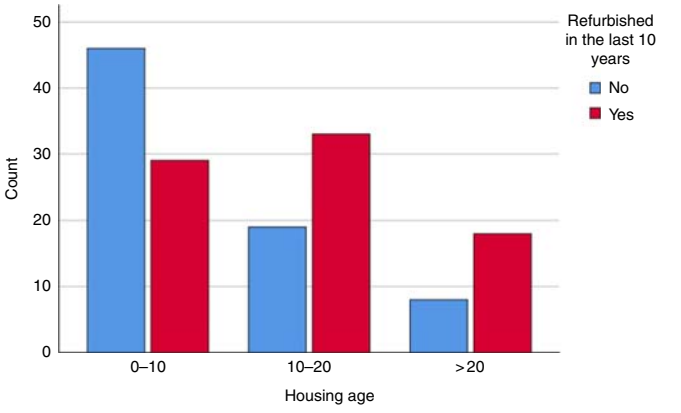


Figure 13.
Houses that are being refurbished in the last ten years and their ages

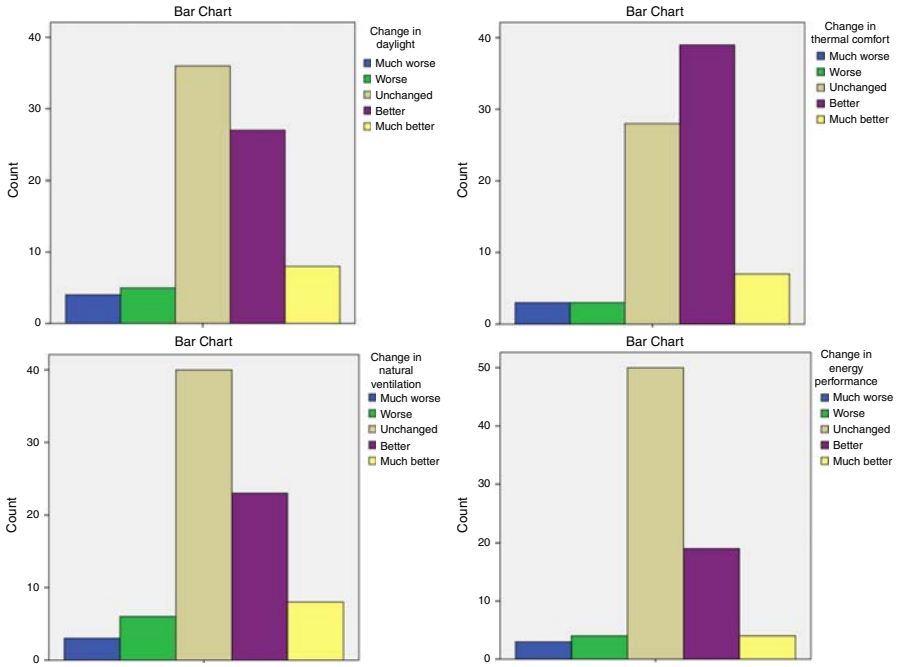


Figure 14.
Change in housing performance after refurbishment

	Repair damaged parts		Redecorate interior		Expand living spaces		Improve indoor environment	
Change in energy performance								
Much worse	0	0%	3	6%	2	7%	0	0%
Worse	1	2%	4	7%	2	7%	0	0%
Unchanged	29	66%	34	63%	14	52%	15	60%
Better	13	30%	12	22%	8	30%	8	32%
Much better	1	2%	1	2%	1	4%	2	8%
Change in thermal performance								
Much worse	0	0%	3	6%	2	7%	0	0%
Worse	1	2%	3	6%	1	4%	0	0%
Unchanged	17	39%	16	30%	3	11%	2	8%
Better	23	52%	29	54%	20	74%	19	76%
Much better	3	7%	3	6%	1	4%	4	16%
Total	44	100%	54	100%	27	100%	25	100%

Table VII.
Refurbishment content and change in housing performance

the building performance remained unchanged or improved for at least 86 per cent of the cases. A minor notice here: repairing damaged parts and improving indoor environment are less likely to make the current situation worse (less than 2 per cent of the cases, whereas these rates in the redecorating and expanding sections ranged from 11 to 14 per cent).

On the other hand, refurbishment activities generally show higher improvement rates in thermal performance than in energy performance. Regarding thermal performance, each measure shows "better" and "much better" results for 59 to 92 per cent of the cases.

These rates only vary from 24 to 40 per cent with regards to energy performance. Such differences can partly be explained by the occupant behaviour and the use of electrical equipment.

Improving the indoor environment is shown to be the most successful measure in improving the building performance compared to others. However, it is the least favourable reason for refurbishment with only 25 cases, only comparable with expanding living spaces with 27 cases. This fact is probably due to the complexity and high cost of an extensive refurbishment which is required by "improving indoor environment" and "expanding living spaces". Nevertheless, refurbishment decisions are often made with a combination of intentions and, together with the improvements shown above, we can expect a favourable result in energy and indoor environment of housing refurbishment in Vietnam in the near future.

Among the 75 of the houses that were not refurbished recently, 64 per cent of the respondent were satisfied with their homes and did not have the need to improve their current homes. In all, 12 per cent of them wanted to renovate the houses but did not have sufficient funding. The rest 24 per cent of the homes were rented properties so the occupants did not want to or were not allowed to refurbish their houses, see Figure 15.

Occupants perceived energy bills in most cases as not expensive nor cheap. In total, 64 per cent of the respondents stated that the bills were reasonable for them (Figure 16). That explains why energy efficiency is not the high priority when refurbishment measures are considered. Respondents gave high priority to economic factors (mean rank = 2.73) and indoor environment (mean rank = 2.69) (Figure 17). Improving indoor environment was also the on top of the wish lists of the occupants when they were asked about what they want to improve in their current homes, see Figure 17. Although improving the indoor environment can potential reduce the heating and cooling loads, hence reduce energy use in home, the term "energy efficiency" is not yet widely discussed or fully understood among the home owners in Vietnam and it was not given a high credit. Therefore, Vietnamese people are still applying energy efficiency refurbishment measure quite passively. Energy saving results from the refurbishment process will be limited. It is recommended that information campaign announcing benefits of the energy efficiency design measures should be implemented to raise the awareness of the people.

8. Conclusion

This paper presents results of a housing survey in Vietnam, focussing on building characteristics, energy performance and refurbishment activities. There are few studies on the

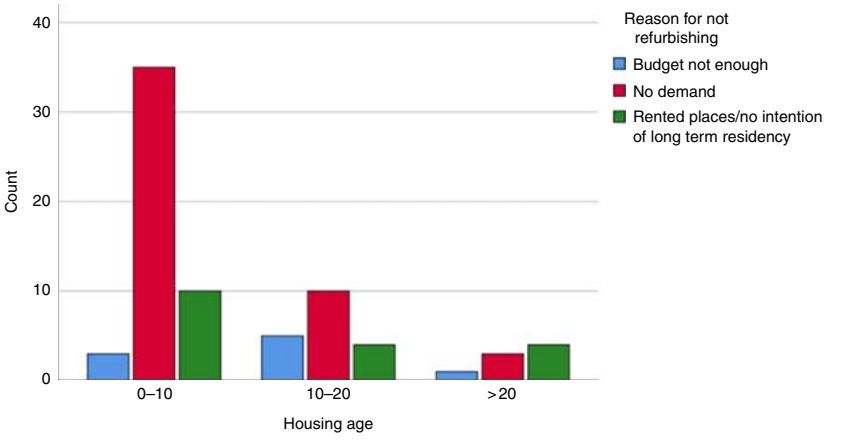
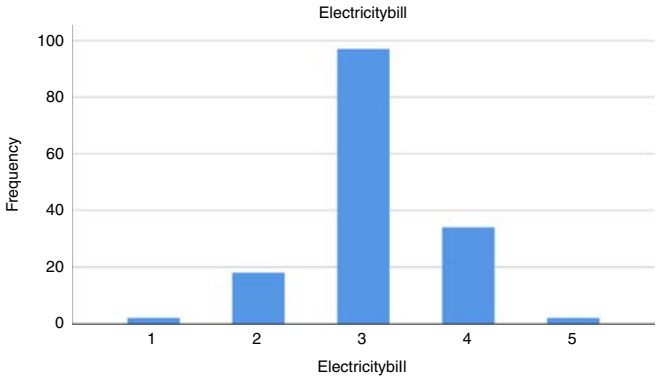


Figure 15.
Reasons for not refurbishing houses



Notes: 1: cheap; 3: neutral; 5: expensive

Figure 16.
Occupants perception of energy bills

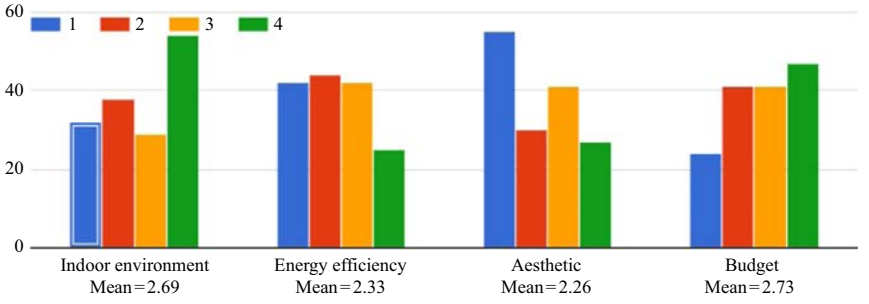


Figure 17.
Ranking of different criteria in refurbishment decision

energy use of households in Vietnam, especially actual energy consumption. Previous studies focussed on the relationship between building parameters and indoor environment (Nguyen *et al.*, 2011; Ly *et al.*, 2010a) and simulated energy consumption (Vu, 2017). This research is not an exhaustive survey of energy performance, building characteristics and refurbishment activities in Vietnam. The respondents and the houses and were not completely randomly selected. This study mainly aims to explore the problems and potentials in the current energy context of Vietnamese houses in order to set up the foundation for future work. The following results are therefore only qualitative and not quantitative.

First, it reveals some insights into the current housing stock of Vietnam. The most popular housing typology in Vietnam is the privately owned, attached, terraced house, which is called the "tube house". The majority of the residential units studied were built in the last 30 years. Houses in Vietnam have a lot in common in construction practice: reinforced concrete frame, brick masonry wall without insulation and single glazed windows combined with wooden shutters.

Building design and construction have a strong relationship with the occupants' comfort levels. Better designed houses usually result in more comfortable living experiences. Among different parameters, the building envelope, including external walls and roofs, was found to have the greatest influence on the indoor environment of the houses. This result fully agrees with the work conducted by Nguyen (2013) and partly agrees with Ly's *et al.* (2010a) paper where orientation was the main responsible parameter for thermal performance of houses, apart from the building envelope and shading options. Refurbishment activities were also

likely to have positive effect on thermal performance of living spaces. The majority of houses that are more than 20 years old were recently refurbished and they often included improving indoor environment as a goal along with other reasons.

This paper investigates the actual energy consumption and reveals the "performance gap" in Vietnamese housing stock. Energy use is strongly associated with the use of electrical appliances, particularly air-conditioners. This research also suggests that occupant behaviour depends on the financial status of the occupants. There are people who live in poorly designed houses with bad indoor comfort but they consume less energy because they cannot afford energy-consuming equipment. Houses that perform well thermally still depend on air-conditioners to ensure indoor comfort. Therefore, both innovation design strategies and more detailed legal regulations should be developed in order to aim for better energy performance or zero energy housing stock in Vietnam.

Housing renovation is initially found to enhance building performance. Improvements in the indoor environment are more likely to be reported than a reduction in energy use. Improvements in building performance were found regardless of the renovation actions. However, preliminary results indicate that focussing on improving housing microclimate generally leads to more satisfactory housing performance in Vietnam although such intentions usually require other refurbishment drivers such as expanding living spaces, repairing damaged parts or redecoration. Although budget plays an important role in refurbishment decision making and energy is at the bottom of the priority list, the high desire of improving indoor environment suggests potential energy saving through housing refurbishment.

Results from this survey should be studied quantitatively in the future to better assess the benefit of the different intervention measures on the indoor comfort and energy demand. Building simulation is a good method to investigate variations of building design and facade types. Other components such as greenery systems, which are more difficult to simulate, should be studied through physical experiments.

References

Abidin, N.Z., Yusof, N. and Othman, A.A.E. (2013), "Enablers and challenges of a sustainable housing industry in Malaysia", *Construction Innovation*, Vol. 13 No. 1, pp. 10-25, available at: https://doi.org/10.1108/14714171311296039

Almusaed, A. (2011), *Biophilic and Bioclimatic Architecture*, Springer, London.

Burgett, J.M., Chini, A.R. and Oppenheim, P. (2013), "Specifying residential retrofit packages for 30% reductions in energy consumption in hot–humid climate zones", *Energy Efficiency*, Vol. 6 No. 3, pp. 523-543, doi: 10.1007/s12053-012-9190-6.

Crosbie, T. and Baker, K. (2010), "Energy-efficiency interventions in housing: learning from inhabitants", *Building Research & Information*, Vol. 38 No. 1, pp. 70-79.

Demanuele, C., Tweddell, T. and Davies, M. (2010), "Bridging the gap between predicted and actual energy performance in schools", World Renewable EnergyCongress XI, Abu Dhabi, pp. 25-30.

Do, T.M. and Sharma, D. (2011), "Vietnam's energy sector: a review of current energy policies and strategies", *Energy Policy*, Vol. 39 No. 10, pp. 5700-5777, available at: https://doi.org/10.1016/j.enpol.2011.08.010

Gill, M.Z., Tierney, M.J., Pegg, I.M. and Allan, N. (2010), "Low-energy-dwellings: the contribution of behaviours to actual performance", *Building Research & Information*, Vol. 38 No. 5, pp. 491-508.

GSO (2010), *The 2009 Population and Housing Census of Viet Nam*, General Statistics Office of Vietnam, Hanoi.

Hahn, E. (2010), "LPG conversions: gas kg, litres, MJ, kWh & m³", available at: www.elgas.com.au/blog/389-lpg-conversions-kg-litres-mj-kwh-and-m3 (accessed 18 April 2017).

IEA (2012), "Statistics extracted from IEA website at the address", available at: www.iea.org/statistics/statisticssearch/report/?year=2012&country=VIETNAM&product=Balances (accessed October 2018).

IEA (2013), *EBC Annex 53 Total Energy Use in Buildings: Analysis & Evaluation Methods*, International Energy Agency, AECOM Ltd.

Jansen, S.C. (2013), "Exergy in the built environment: the added value of exergy in the assessment and development of energy systems for the built environment", PhD dissertation, Delft University of Technology, Delft.

Kurvers, S.R., Raue, A.K., van den Ham, E.R., Leyten, J.L. and Juricic, S.M.M. (2013), "Robust climate design combines energy efficiency with occupant health and comfort", *ASHARE IAQ 2013 Proceedings: Environmental Health in Low Energy Buildings*, pp. 85-92.

Le, T.H.N., Park, J. and Cho, M. (2013), "Lesson from Vietnamese urban street houses for contemporary high-rise housing", *Open House International*, Vol. 38 No. 2, pp. 31-46.

Loussos, P., Konstantinou, T., van den Dobbelsteen, A. and Bokel, R. (2015), "Integrating life cycle energy into the design of façade refurbishment for a post-war residential building in The Netherlands", *Buildings*, Vol. 5 No. 2, pp. 622-649.

Ly, T.P. (2012), "A critical regionalist approach to housing design in Vietnam: socio-environmental organisation of living spaces in pre- and post-reform houses", PhD dissertation, Queensland University of Technology, Brisbane.

Ly, T.P., Birkeland, J. and Demirbilek, N. (2010a), "Towards sustainable housing for Vietnam. In transitions to sustainability", *Sustainability Engineering and Science Conference, NZSSES, Faculty of Engineering, The University of Auckland, Auckland, 30 November–3 December*.

Ly, T.P., Birkeland, J. and Demirbilek, N. (2010b), "Applying environmentally responsive characteristics of vernacular architecture to sustainable housing in Vietnam", *Second International Conference, Sustainable Architecture & Urban Development, CSAAR Press, Amman*, pp. 287-306.

Majcen, D. (2016), *Predicting Energy Consumption and Savings in the Housing Stock: A Performance Gap Analysis in the Netherlands*, Delft University of Technology, Delft.

MOC (2017), *QC 09:2017/BXD: National Technical Regulation of Energy Efficiency Buildings*, Ministry of Construction, Hanoi.

Nair, G., Gustavsson, L. and Mahapatra, K. (2010), "Owners perception on the adoption of building envelope energy efficiency measures in Swedish detached houses", *Applied Energy*, Vol. 87 No. 7, pp. 2411-2419, doi: 10.1016/j.apenergy.2010.02.004.

Nguyen, A.T. (2013), "Sustainable housing in Vietnam: climate responsive design strategies to optimize thermal comfort", PhD dissertation, University of Leige, Leige.

Nguyen, A.T. and Aiello, M. (2013), "Energy intelligent buildings based on user activity: a survey", *Energy and Buildings*, Vol. 56, pp. 244-257, available at: https://dx.doi.org/10.1016/j.enbuild.2012.09.005

Nguyen, A.T., Tran, Q.B., Tran, D.Q. and Reiter, S. (2011), "An investigation on climate responsive design strategies of vernacular housing in Vietnam", *Building and Environment*, Vol. 46 No. 10, pp. 2088-2106, available at: https://doi.org/10.1016/j.buildenv.2011.04.019

Nguyen, P.A., Bokel, R. and van den Dobbelsteen, A. (2016), "Towards a sustainable plan for new tube houses in Vietnam", *17th International Planning History Society Conference, Vol. 2, Delft*, pp. 211-222.

Nguyen, P.A. (2017), "Refurbishing houses to improve energy efficiency – potential in Vietnam", *Passive Low Energy Architecture Conference (PLEA) 2017: Design to Thrive, Vol. 3, Edinburgh*, pp. 4204-4211.

Ortiz, M.A., Kurvers, S.R. and Bluyssen, P.M. (2017), "A review of comfort, health, and energy use: understanding daily energy use and wellbeing for the development of a new approach to study comfort", *Energy and Buildings*, Vol. 152, pp. 323-335, available at: https://doi.org/10.1016/j.enbuild.2017.07.060

Pettifor, H., Wilson, C. and Chryssochoidis, G. (2015), "The appeal of the green deal: empirical evidence for the influence of energy efficiency policy on renovating home owners", *Energy Policy*, Vol. 79, pp. 161-176, available at: https://dx.doi.org/10.1016/j.enpol.2015.01.015

Phe, H.H. and Nishimura, Y. (1991), "Housing in central Hanoi", *Habitat International*, Vol. 15 Nos 1-2, pp. 101-126.

Roulet, C.-A., Flourentzou, F., Foradini, F., Bluyssen, P., Cox, C. and Aizlewood, C. (2006), "Multi-criteria analysis methodology of health, comfort and energy efficiency in buildings", *Building Research & Information*, Vol. 34 No. 5, pp. 475-482, available at: https://doi.org/10.1080/09613210600822402

Sanghoon, J., Huynh, D. and Rowe, P.G. (2013), "The pattern of foreign property investment in Vietnam: the apartment market in Ho Chi Minh City", *Habitat International*, Vol. 39, pp. 105-113, available at: https://doi.org/10.1016/j.habitatint.2012.11.003

Swan, W., Ruddock, L., Smith, L. and Fitton, R. (2013), "Adoption of sustainable retrofit in UK social housing", *Structural Survey*, Vol. 31 No. 3, pp. 181-193, available at: https://doi.org/10.1108/SS-12-2012-0039

Vu, T.T. (2017), "Which green factors for the small-scale buildings in Vietnam?", Green Architecture for Sustainable Communities Symposium, Hanoi.

Zavadskas, E.K., Kaklauskas, A., Tupenaite, L. and Mickaityte, A. (2008), "Decision –making model for sustainable building refurbishment. Energy efficiency aspect", *Environmental Engineering Conference*, pp. 894-901.

Further reading

Vietnam Green Building Database and Network (E4G), available at: http://e4g.org/cong-trinh/ (accessed 20 May 2017).

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