Housing Refurbishment for Energy Efficiency and Comfort
Toward sustainable hosuing in Vietnam

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Housing Refurbishment for Energy Efficiency and Comfort

Toward sustainable housing in Vietnam

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Housing Refurbishment for Energy Efficiency and Comfort

Toward sustainable housing inVietnam

Dissertation

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at Delft University of Technology
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chair of the Board for Doctorates
to be defended publicly on
Friday, 19 February 2021 at 12:30 o'clock

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Summary

Vietnam has made a lot of significant developments in both economic and social fields since the transition from a centrally planned to the market-oriented economy in 1986. Along with the growth of the country, the energy sector, which accounts for one-fourth of the national foreign earnings, 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 minimising energy-related environment impacts.

In building sector, a newly constructed building has more potential to achieve better energy performance than a refurbished project, which is limited by unchangeable factors on the existing site. However, the importance of the existing building should not be ignored due to the fact that the number of existing buildings is outweigh the number of possible new buildings added to the market annually. Although refurbishment activities are being carried out regularly in Vietnam, little effort was recognised to improve the energy performance of the building. One of the reasons is that the contemporary construction methods in Vietnam are still quite simple and do not integrate energy efficiency measures.

Sustainable and energy-efficient housing was not just recently recognised and concerned in Vietnam. However, there is still lack of research in this specific field. This research aims to develop a design strategy for housing refurbishment projects in Vietnam, in order to achieve better energy performance. The approach should be systematic and holistic, addressing all relevant issues in the current housing stock of Vietnam. It is expected to be used to help architects in decision making in the early design stage and to help state agencies to set guidelines and regulations for future housing of Vietnam. This led to the main research question to be answer in this thesis.

What are the design strategies for energy efficiency in Vietnam housing and how should they be integrated in an existing house as well as in a new built house?

In order to answer the research question, the thesis is divided into 3 main parts.

Part I

Part I introduced background information on the Vietnam housing stock and energy efficiency design measures. Chapter 2 gives an overview of the housing stock. History of housing development, housing typologies and housing characteristics are introduced. A number of green dwellings are presented in Chapter 3. Chapter 4 discusses energy efficiency approaches where potential design measures are examined on their applicability on Vietnam houses. Chapter 5 presents the potential of solar energy by reviewing latest legislation, studies and practices.

Part II

Part II investigates energy upgrade potentials and challenges of housing refurbishment in Vietnam Chapter 6 presents outcome of a housing survey. The survey investigated 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.

Housing renovation is initially found to enhance building performance. Improvements to the indoor environment are more likely to be reported than a reduction in energy use. Improvements in building performance were found regardless of renovation actions. However, preliminary results indicate that focusing on improving the microclimate generally leads to a more satisfactory performance in Vietnamese housing. Although the budget plays an important role in refurbishment decision making and energy is at the bottom of the priority list, the strong desire of improving indoor environment suggests potential energy savings through housing refurbishment.

After identified potential measures for refurbishing, it is important to validate their actual benefit in term of comfort and energy use. The first study is a housing performance simulation for different types of facades, presented in chapter 7. The second one is a real life experiment in Vietnam where the effect of a green façade on energy demand and comfort inside is investigated, as in chapter 8. The simulation results showed that applying the Vietnamese technical regulation can save up to 9% of energy for heating and cooling. More interestingly, a highly insulated facade that followed the Dutch standard led to much more favourable results of 21% reduction in air-conditioner energy consumption. The second study compared the performance of a green façade on a real house with to the performance of a similar room, which has a bare façade and, on a different period, an aluminium shading device.

The indoor temperature of the green façade room and the bare façade room were compared. Results showed that there is a potential reduction of up to 1°C in indoor temperature by applying a green façade. In terms of energy consumption, the green façade of this case could save up to 35% of the cooling demand during the day, if the air-conditioners were used for 5 consecutive hours.

Part III

This final part explored the application of potential design measures by investigating outputs of an international design workshop (GASC), being held in Vietnam in 2019. Students from Delft University of Technology and two other Vietnamese universities worked together to propose integrated solutions for energy-efficient refurbishment of existing tube houses in Hanoi. From the workshop, a new strategy was developed, which was adopted from the Dutch New Stepped Strategy. The new strategy consists of three steps: 'Reduce', 'Reuse' and 'Produce', preceded by 'Research'. This design approach is presented in section 9.3.3.

The workshop outcomes also suggest that design measures should be applied and combined in three main groups to amplify the effect of each. Firstly, greenery and sun-shading should be considered together in protecting the house from direct solar gain. Secondly, a courtyard, greenery and solar chimney work well together in ventilating houses, providing cooling and filtering air from fine dust. Combining the solutions creates synergy in functionality and sustainability. Finally, solar thermal, PV cells or the combined version, PVT, along with rain water collection help to make the best use of renewable resources for the users' needs. And they can all be collected from the building's roof.

As important as the existing housing stock should be, this final part also discusses the future sustainable tube house model for Vietnam. Future sustainable housing should both inherits the traditional values and meets the demand of urban developments in the coming future. Beside energy efficiency, other important sustainable aspects are circular economy, urban densification, and social interaction. A new approach to a residential neighbourhood as well as housing design are proposed as an effort to contribute to a more sustainable cities in Vietnam.

To sum up the above findings, there are several approaches to boost the development of the energy efficient housing in Vietnam. First, it is important to raise the awareness of the people as they are the investors, users as well as the main beneficiary of the private housing projects. Since there is currently no mandatory requirements that the houses need to meet, users' perspective on sustainability and energy efficiency is important in both design phase and operational phase of the houses. Next, housing design process should follow a structured strategy for the target of energy efficiency. Law makers, architects, contractors and house owners should all use this approach to coordinate their actions. A three-stepped strategy is proposed in this research. The three steps are ‘Reduce’, ‘Reuse’, and ‘Produce’. Among those steps, potential design measures are sun shading, green façade, courtyard, natural ventilation, solar thermal and photovoltaics. Finally, energy efficient design should also be considered in urban scale. A future tube house needs to be energy efficient and follow the above strategy. Besides, it also needs to meet the demand of other sustainability factors, including circular economy, urban densification, and social interaction.

This thesis is mainly composed of a collection of the author’s published papers.

Samenvatting

Sinds Vietnam in 1986 de transitie maakte van een centraal geplande naar marktgeoriënteerde economie Vietnam heeft het land veel significante ontwikkelingen ondergaan, zowel economisch als sociaal. Samen met de groei van het land is de energiesector, die een vierde van de nationale inkomsten voor buitenlandse verdiensten behelst, een steeds belangrijker rol gaan spelen. Om te blijven bijdragen aan de duurzame ontwikkeling van Vietnam moet de energiesector de problemen van leveringszekerheid en de energiegerelateerde milieueffecten oplossen.

In de bouwsector heeft nieuwbouw een grotere potentie om een goede energieprestatie te bereiken dan een gerenoveerd project, dat beperkt wordt door onveranderbare factoren op de bestaande plek. Echter, het belang van bestaande gebouwen kan niet ontkend worden, omdat het aantal bestaande gebouwen de jaarlijkse aanwas van nieuwe gebouwen ver overtreft. Hoewel renovatiewerkzaamheden regelmatig plaatsvinden in Vietnam wordt er weinig moeite gestoken in de verbetering van de energieprestatie van een gebouw. Een van de redenen is dat hedendaagse bouwmethoden in Vietnam nog steeds vrij simpel zijn en energie-efficiëntiemaatregelen niet meenemen.

Duurzame en energie-efficiënte huisvesting is niet recent herkend en serieus genomen in Vietnam, maar er is nog steeds gebrek aan onderzoek op dit specifieke vlak. Het voorliggende promotieonderzoek heeft tot doel een ontwerpstrategie te ontwikkelen voor woningrenovatieprojecten in Vietnam, teneinde een betere energieprestatie te bereiken. De aanpak moet systematisch en holistisch zijn, waarbij alle relevante aspecten voor de huisvesting in Vietnam worden geadresseerd. De verwachting is dat architecten daarmee worden geholpen in hun besluitvorming in de vroege ontwerpfasen en dat staatsdiensten er richtlijnen en regelgeving voor toekomstige woningbouw in Vietnam kan opstellen.

Dit leidde tot de hoofdvraag die in dit proefschrift wordt beantwoord:

Wat zijn de ontwerpstrategieën voor energie-efficiëntie in Vietnamese woningbouw en hoe zouden deze geïntegreerd moeten worden in een bestaand huis en in een nieuwbouwhuis?

Om deze vraag te beantwoorden is het proefschrift onderverdeeld in 3 hoofddelen.

Deel I

Deel I introduceert achtergrondinformatie van de Vietnamese woningvoorraad en energie-efficiëntiemaatregelen. Hoofdstuk 2 geeft een overzicht van de woningvoorraad. De geschiedenis van de ontwikkeling van woningbouw, woningtypologieën en huisvestingskarakteristieken worden geïntroduceerd. Een aantal duurzame woningen worden gepresenteerd in hoofdstuk 3. Hoofdstuk 4 behandelt energie-efficiëntiebenaderingen waarmee potentiele ontwerpmaatregelen worden beoordeeld op hun toepasbaarheid in Vietnamese huizen. Hoofdstuk 5 presenteert de potentie van zonne-energie door een bespreking van de laatste wetgeving, studies en praktijkvoorbeelden.

Deel II

Deel II onderzoekt energieverbeteropties en -uitdagingen van woningrenovatie in Vietnam. Hoofdstuk 6 presenteert de uitkomsten van een woningbouwenquête. De enquête onderzoekt het werkelijke energiegebruik van Vietnamese woningen en onthult het ‘prestatiegat’. Energiegebruik is sterk verbonden aan het gebruik van elektrische apparaten, vooral airconditioners. Uit dit onderzoek lijkt het dat gebruikersgedrag afhankelijk is van de financiële status van de gebruikers.

Woningrenovatie wordt aanvankelijk gekozen om de gebouwprestatie te verbeteren. Verbeteringen aan het binnenmilieu worden eerder gerapporteerd dan een vermindering van het energiegebruik. Verbeteringen van de gebouwprestatie worden gevonden onafhankelijk van renovatiemaatregelen. Voorlopige resultaten geven echter aan dat aandacht voor de verbetering van het microklimaat in Vietnamese woningen in het algemeen tot een meer bevredigende prestatie leidt. Hoewel het budget een belangrijke rol speelt in de besluitvorming omtrent renovaties en energie onderaan de prioriteitenlijst staat, lijkt de sterke wens om het binnenmilieu te verbeteren toch potentiële energiebesparingen door woningrenovatie mogelijk te maken.

Na het identificeren van potentiële maatregelen voor renovatie is het belangrijk om hun werkelijke voordeel voor comfort en energiegebruik te valideren. De eerste studie gepresenteerd in hoofdstuk 7 is een woningprestatiesimulatie voor verschillende geveltypes. De tweede is een real-life experiment in Vietnam dat het effect van een groene gevel op de energievraag en het comfort binnen onderzoekt, wat in hoofdstuk 8 wordt besproken.

De simulatieresultaten tonen aan dat het toepassen van de Vietnamese technische regelgeving tot 9% energie voor koeling en verwarming kan besparen. Interessanter nog: een goed geïsoleerde gevel die de Nederlandse bouwnorm volgt, leidt tot een nog gunstiger resultaat: 21% besparing in energi voor airconditioning. De tweede studie vergelijkt de prestatie van een groene gevel aan een echt huis met de prestatie van een vergelijkbare kamer die een kale gevel heeft en, in een andere periode, een aluminium zonwering. De binnentemperatuur van de groene gevel wordt vergeleken met de kale gevel. Resultaten laten zien dat er een potentiele binnentemperatuurvermindering van 1°C mogelijk is door het toepassen van een groene gevel. Wat betreft energiegebruik kan de groene gevel tot 35% besparen op de koelenergie gedurende de dag, als de airconditioning 5 achtereenvolgende uren wordt gebruikt.

Deel III

Het laatste deel verkent de toepassing van potentiele ontwerpmaatregelen door uitkomsten te bestuderen van een internationale ontwerpworkshop (GASC), gehouden in Vietnam in 2019. Studenten van de Technische Universiteit Delft en twee Vietnamese universiteiten werkten samen om integrale oplossingen voor te stellen voor de energie-efficiënte renovatie van bestaande 'tube houses' in Hanoi. Vanuit de workshop werd een nieuwe strategie ontwikkeld, die gebruik maakte van de Nederlandse 'Nieuwe Stappenstrategie'. De nieuwe strategie bestaat uit drie stappen: 'Reduce' (verminder), 'Reuse' (hergebruik) en 'Produce' (produceer), voorafgegaan door 'Research' (onderzoek). Deze ontwerpbenadering wordt gepresenteerd in paragraaf 9.3.3.

De workshopuitkomsten suggereren dat ontwerpmaatregelen zouden moeten worden toegepast en gecombineerd in drie hoofdgroepen om elk afzonderlijk effect te versterken. Allereerst zouden groen en zonwering samen overwogen moeten worden om het huis te beschermen tegen directe zoninstraling. Ten tweede werken een binnentuin, groen en zonneschoorsteen goed samen voor het ventileren van huizen, waarmee koeling wordt verschaft en fijnstof wordt gefilterd uit verse lucht. Door deze oplossingen te combineren wordt synergie in functionaliteit en duurzaamheid gecreëerd. Ten slotte helpen zonnecollectoren, PV-panelen of de gecombineerde versie, PVT, samen met regenwateropvang om voor de gebruikersbehoefte het best hernieuwbare bronnen te benutten. En deze kunnen allemaal worden gewonnen op het dak van het gebouw.

Hoe belangrijk de bestaande gebouwvoorraad ook is, dit laatste deel behandelt ook de toekomstige duurzame ‘tube house’ woning voor Vietnam. Duurzame toekomstige woningbouw zou zowel de traditionele waarden moeten overnemen en in de behoeften van stedelijke ontwikkelingen in de nabije toekomst moeten voorzien. Naast energie-efficiëntie zijn andere belangrijke aspecten: de circulaire economie, stedelijke verdichting en sociale interactie. Een nieuwe aanpak van een woonwijk en het woningontwerp wordt voorgesteld als een poging om bij te dragen aan duurzamere steden in Vietnam.

Om bovenstaande bevindingen samen te vatten: er zijn verscheidene benaderingen om de ontwikkeling van energie-efficiënte woningbouw in Vietnam te stimuleren. Ten eerste is het belangrijk om het bewustzijn van mensen te verhogen, omdat zij de investeerders, gebruikers en voornaamste bevoordeelden zijn van private woningbouwprojecten. Aangezien er momenteel geen verplichte eisen zijn waar de huizen aan moeten voldoen, is het gebruikersperspectief op duurzaamheid en energie-efficiëntie belangrijk in zowel de ontwerpfase als de exploitatiefase van de huizen. Vervolgens zou het woningontwerpproces een gestructureerde strategie moeten volgen om het doel van energie-efficiëntie te bereiken. Wetgevers, architecten, aannemers en huisbezitters zouden deze aanpak allemaal moeten gebruiken om hun activiteiten te coördineren. Een driestappenstrategie wordt in dit promotieonderzoek voorgesteld. De drie stappen zijn ‘Reduce’, ‘Reuse’ en ‘Produce’. Vallend onder deze stappen zijn zonwering, groene gevels, een binnentuin, natuurlijke ventilatie, zonnecollectoren en zonnepanelen. Ten slotte zou energie-efficiënt ontwerpen ook moeten worden beschouwd op de stedelijke schaal. Een toekomstige ‘tube house’ moet energie-efficiënt zijn en kan daarvoor het best de genoemde aanpak volgen. Bovendien moet het ook andere duurzaamheidsfactoren beantwoorden, zoals circulaire economie, stedelijke verdichting en sociale interactie.

Dit proefschrift is vooral samengesteld op basis van een verzameling door de auteur gepubliceerde wetenschappelijke artikelen.

Terms and Definitions

Circularity – an economic system aimed at eliminating waste and the continual use of resources. Circular systems employ reuse, sharing, repair, refurbishment, remanufacturing and recycling to create a closed-loop system, minimising the use of resource inputs and the creation of waste, pollution and carbon emissions. [1]

Energy efficient buildings - buildings that are designed to provide a significant reduction of the energy need for heating and cooling, independently of the energy and of the equipment that will be chosen to heat or cool the building.

Green building - a building that is environmentally responsible and resource-efficient throughout its life-cycle: from planning to design, construction, operation, maintenance, renovation, and demolition. [2]

Indoor environmental quality (IEQ) - the quality of a building's environment in relation to the health and wellbeing of those who occupy space within it. IEQ is determined by many factors, including lighting, air quality, and damp conditions [3].

Sustainability - focuses on meeting the needs of the present without compromising the ability of future generations to meet their needs. The concept of sustainability is composed of three pillars: economic, environmental, and social—also known informally as profits, planet, and people. [4]

Tube houses - attached row houses characterized by its physical tube form, which means that its length is much longer than its width. It is the current main dwelling type in Vietnam.

Zero Energy Building (ZEB) - a building with zero net energy consumption, meaning the total amount of energy used by the building on an annual basis is equal to the amount of renewable energy created on the site. [5]

Source

[1] M. Geissdoerfer et al. (2017). “The Circular Economy – A new sustainability paradigm?”. *Journal of Cleaner Production.* 143: 757–768. doi:10.1016/j.jclepro.2016.12.048.

[2] Green Building - US EPA. www.epa.gov.

[3] Centers for Disease Control and Prevention. www.cdc.gov.

[4] United Nations General Assembly (1987). Report of the World Commission on Environment and Development: Our Common Future. Transmitted to the General Assembly as an Annex to document A/42/427 – Development and International Co-operation: Environment.

[5] A Common Definition for Zero Energy Buildings. US Department of Energy. September 2015.

1 Introduction

1.1 Background

Vietnam has made a lot of significant developments in both economic and social fields since the transition from a centrally planned to a market-oriented economy in 1986. Along with the growth of the country, the energy sector, which accounts for one-fourth of the national foreign earnings, 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 minimising energy-related environment impacts. According to the overview of the primary energy demand-supply for the period of 1997-2025, both policy makers and planners agree that the energy demand will soon outweigh and double the domestic supply by 2025 (Minh Do & Sharma, 2011), see Figure 1.1.

Accounting for more than 31% 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 (IEA, 2012), see Figure 1.2. In order to tackle the issue of energy shortage in the future, the Vietnamese government has initiated several actions, including the National Energy Efficiency Program for the period 2006-2015 (Prime Minister of Vietnam, 2006). In this program, one of the key projects is to establish a legal framework for energy efficiency in construction management, industrial production and electrical equipment.

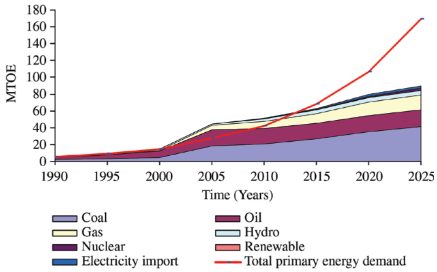

FIG. 1.1 Primary energy demand and supply balance in Vietnam

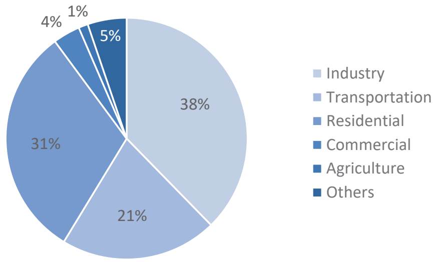

FIG. 1.2 Vietnam final total energy consumption by sector in 2012

1.2 Problem statement

In the housing sector, a newly constructed building might have more potential to achieve a better energy performance than a refurbished project, which is limited by unchangeable factors, such as orientation, on the existing site. However, the importance of the existing building should be emphasized due to the fact that the number of existing buildings far outweighs the number of possible new buildings added to the market annually. Although refurbishment activities are being carried out regularly in Vietnam, little effort is recognised to improve the energy performance of the building.

The housing sector in Vietnam only took off with the introduction of the economic reform, also known as 'Doi moi' ,in 1986. Since then, the numbers of residential units have increased at an enormous rate. However, in the early years after 'Doi moi', the majority of housing had been constructed by the people themselves and often without permission (JICA, 1999). This spontaneous development has led to a booming of building construction but also brought issues of housing quality and poor living conditions. Until 2010, 98.5% of the total existing housing units across the country were small private houses and many of them are the self-built houses from the early stages after the 'Doi moi' (GSO,2010).

Little effort is recognised to improve the energy performance of existing buildings in Vietnam. There are a few possible reasons. In Vietnam, the topic of sustainability and energy efficiency of buildings caught the attention of the Vietnamese government and other related parties. But only in 2010, the Vietnam Green Building Council established its own voluntary green building certificated called LOTUS. In 2013, the Ministry of Construction issued the national technical regulation on energy-efficient buildings and then updated it in 2017, in order to guide practice construction experts to achieve energy saving in the building sector (MOC, 2017). This is an important legal basis for the development of a sustainable and an energy-efficient building stock. However, until recently, there were only 103 buildings in the whole country that had been certified as green buildings, including 27 LOTUS-certified and 76 LEED-certified ones. The main reason is that the initial investment for a green building project is often higher than an ordinary one. Besides, the current technical regulation only applies to buildings that have a total floor area greater than 2500 square metres, including commercial buildings, hotels, schools, apartments, hospitals. It does not apply to the majority of private housing in Vietnam.

Regulation is not the only challenge for energy-efficient houses in Vietnam. Many researchers have conducted housing studies in Vietnam. However, very few studies investigated energy efficiency in housing design, contrary to the large amount of research in European countries such as the Netherlands. In a study published in 2003 (Huong & Soebarto, 2003), the authors claimed that there is consensus on the need to provide thermal comfort for users in Vietnam, but the problems addressed were too general and on a small scale. More research to investigate the housing sector in Vietnam was funded by the Japanese government. These studies were focused on the historical and conservational aspects, especially for heritage cities of Vietnam (Mizuno et al., 2000; Phe & Nishimura, 1991). On the other hand, Nguyen (2011) paid attention to the environmental design aspects of traditional dwellings. In his work, he stated that some climate design strategies employed in traditional houses proved to function quite well to help achieve human comfort. However, he also stated that under extreme conditions, these strategies alone are not good enough, and these strategies were not tested yet in the new urban context that might be much less favourable. Generally, there is still a lack of research on sustainable and energy-efficient houses in Vietnam.

The common practice of self-built houses and the lack of awareness of the occupants poses a bigger challenge for the development of energy-efficient homes in Vietnam, even when there is regulation for small dwellings. The best motivation for designing an energy efficient house is that the owners have a real need for such houses. Therefore, education on sustainable and energy-efficient design of new and refurbished tube houses for young architects is an important part of the way forward for a reduction in the Vietnam energy demand for housing. The poor living conditions in the existing tube houses are also taken into account.

1.3 Objectives

This research aims to develop a design strategy for housing refurbishment projects in Vietnam, in order to achieve better energy performance and good indoor environment quality. The design strategy should be systematic and holistic, addressing all relevant issues in the current housing stock of Vietnam. The design strategy is expected to be used to help architects and architecture students in decision making in the early design stage and to help state agencies to set guidelines and regulations for future housing of Vietnam.

It is worth to note that there are some examples of well-designed houses in Vietnam. Bioclimatic design measures can be learned from traditional architecture. Experienced architects and even builders can design houses that provide good indoor environment quality and also be energy efficient. But their approach often based on their own expertise or preferences. However, there is still lack of a holistic design strategy approach that integrate both local and traditional knowledge and lesson learned from other contexts. Therefore, one of the missions of this research is to investigate how to combine existing well-known measures, and how a design measures learned from other region, which might not be novelty, can fit into the current context of Vietnam and its expected results on housing performance.

1.4 Scope of the research

This research aims at housing refurbishment in order to achieve human comfort as well as energy efficiency in Vietnam. In spite of the common hot period of the year, Vietnam has quite a number of different sub-climate regions that may have certain effects on the results. This study focuses on northern Vietnam which has a subtropical humid climate, with cold winter months as a distinctive feature, see Figure 1.3. Moreover, local cultures and construction techniques also vary over the country.

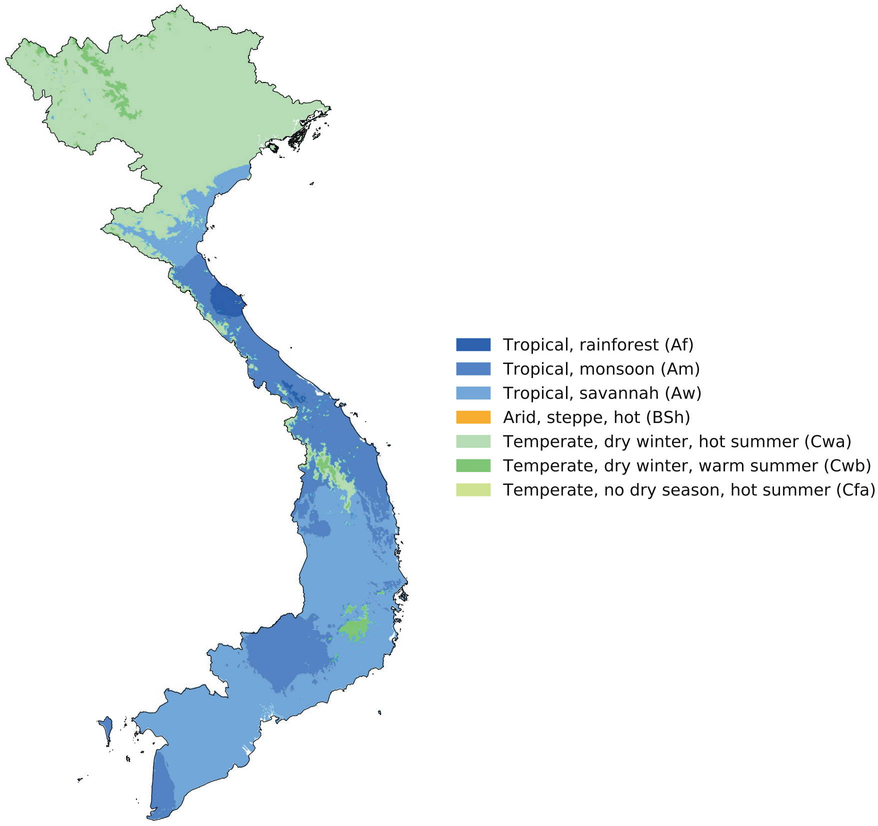

FIG. 1.3 Koppen-Geiger climate classification map for Vietnam (Beck et al., 2018)

Although all housing typologies should be investigated, statistics indicate that the majority of the existing housing stock refers to attached houses (or tube houses) which are responsible for a large share of energy consumption. In these houses, the owners are investors and beneficiaries at the same time. Moreover, recent studies also indicate that tube houses will still be the preferred housing typology in the future, because of their value and affordability (Seo & Kwon, 2017). Consequently, this research deals with this type of housing. A typical tube house in Vietnam is presented in Figure 1.4.

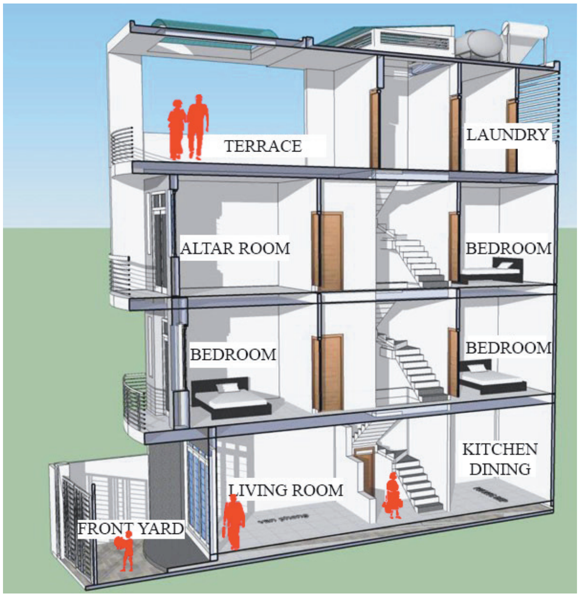

FIG. 1.4 A typical tube house in Vietnam

Refurbishment is a complicated process, which involves technical, social and financial matters. Intervention levels vary from simple minor repairs to complete reconstruction. Taking into consideration the Vietnamese context, certain intervention levels might be applied, depending on the particular case. This study focuses on the housing stock in Vietnam, so refurbishment measures proposed need to comply with the Vietnamese National Building code and other local construction regulations. Computer simulation software, measurement equipment used to generate data in this research are subject to the availability thereof and the best fitting possible tools are chosen.

1.5 Research questions

The main research question that follows from the problem statement and the objectives is:

What are the design strategies for energy efficiency in Vietnamese housing and how should these design strategies be integrated in an existing house as well as in a newly built house?

The following sub-questions are formulated in order to answer several aspects of the main research question:

1. What is the current practice and what are the drivers of energy-efficient refurbishment in Vietnam?
2. How do energy-efficient design measures affect the energy consumption of tube houses in Vietnam?
3. How can energy-efficient design strategies be integrated in tube house refurbishment projects in Vietnam?
4. How can energy-efficient design strategies be applied in new housing projects in Vietnam and what is their contribution to the overall sustainability of the housing stock?

1.6 Methodology

1.6.1 Research approach

Figure 1.5 shows the four stages of the research. The first stage of this research provides an introduction to Vietnamese housing and reviews different design approaches for energy efficiency. At this stage, it is important to acknowledge what the existing design strategies are and which ones are best suited for application in the Vietnamese context. The second stage features empirical research. This empirical research aims at investigating the current refurbishment practice in Vietnam and the potential for energy-efficient refurbishment through cases studies and a housing survey. In the third stage, potential energy savings are measured using computer simulation and physical experiments. In the last stage, a design workshop was held in Vietnam with the aim of integrating the design measures in real buildings.

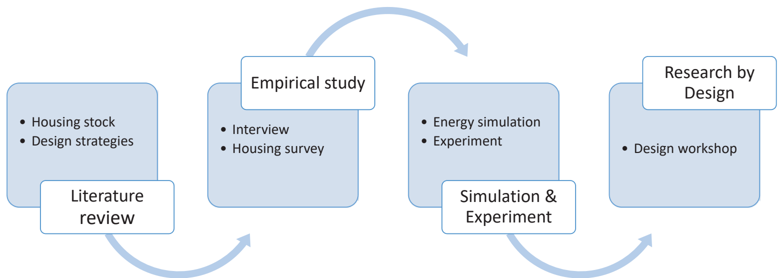

FIG. 1.5 Research approach

1.6.2 Research methods

Stage 1: Literature study

A literature review is conducted to give an overview of the current housing stock practice in Vietnam and to emphasize on the importance of the urban attached houses (tube houses). Previous studies on design strategies are also reviewed to define potential energy efficient design measures

Stage 2: Empirical study

Surveys
House s owners in Vietnam were asked to take part in a housing survey. The housing survey consisted of an interview and a questionnaire. The information from the survey is used to understand the users' desires as well as the adverse factors for housing refurbishment.

Stage 3: Experimental study

Simulation
An energy simulation of different façade refurbishment options for a tube house in Vietnam is conducted to examine potential energy savings by using Design Builder software.

Experiment
An experiment on an existing tube house in Hanoi, Vietnam, was conducted to investigate the effect of a vertical green façade on the thermal performance and energy performance.

Stage 4: Research by design

Design measures should be integrated together in a housing project. An international design workshop in Hanoi, Vietnam, was held to test a holistic design approach for energy efficient tube houses, including existing and new dwellings.

1.7 Outline of the thesis

Figure 1.6 shows the outline of this thesis. It includes eleven chapters that aim to answer the research questions, in order to identify a design strategy for tube houses in Vietnam.

The thesis starts with a background part (Part I), including chapter 2, 3, 4 and 5. Chapter 2 gives an overview of the housing stock through a literature study. History of housing development, housing typologies and housing characteristics are introduced. A number of green dwellings are reviewed in chapter 3. Chapter 4 discusses energy efficiency approaches from several points of view. Potential design measures are discussed on their applicability on Vietnam houses. Chapter 5 presents the potential of solar energy by reviewing the latest legislation, studies and practices.

Part II consists of chapters 6 to 8. Chapter 6 discusses the potential and challenges of housing refurbishment for energy efficiency in Vietnam. Results from an interview and housing survey are presented in this chapter. A statistical analysis was used to investigate housing characteristics, user behaviour and the thermal and energy performance of the houses. Refurbishment histories and users' opinions on housing refurbishment are also highlighted to assess the potential for energy upgrade in existing buildings.

The energy upgrade potential is investigated in the next two chapters. Chapter 7 presents the results from an energy simulation while chapter 8 conducts a physical experiment. Each chapter investigated a specific tube house in the urban area of Vietnam. Different scenarios were compared to investigate the optimum façade design solution for energy savings.

Part III presents results from the international design workshop. Chapter 9 analyses how design measures were applied in the student design workshop. The results were also used to evaluate the overall effectiveness of each measures and to propose an integrated design approach for energy efficiency. Chapter 10 evaluates the education of sustainable design during the design workshop.

Chapter 11, discusses a new approach to future tube houses in Vietnam with energy efficiency as a key element. Other sustainable factors are also mentioned and discussed through an example of a new residential neighbourhood.

Chapter 12 concludes the energy-efficient design strategy, with implications and recommendations for future research work.

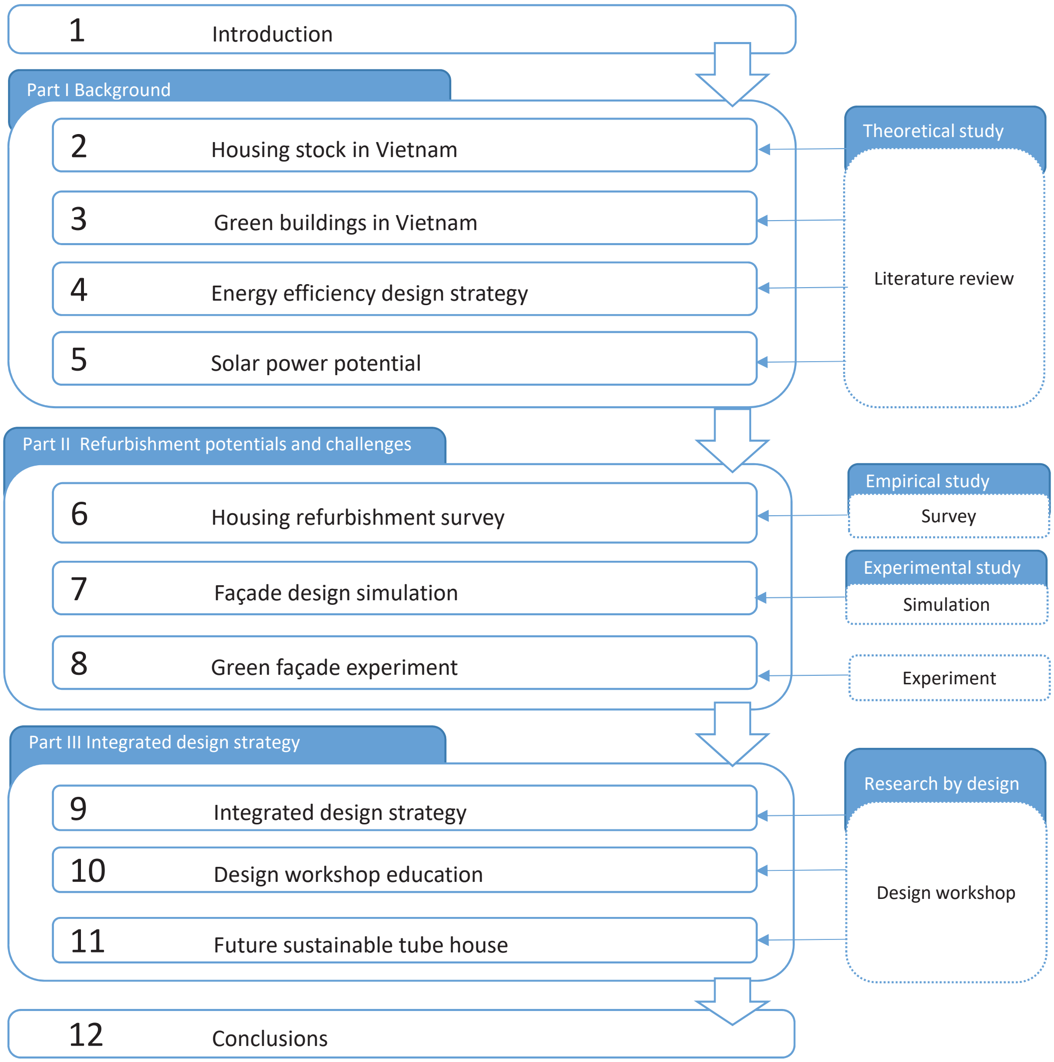

FIG. 1.6 Research structure and methods

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PART 1

Background Information

Part I introduces background information on the Vietnam housing stock and energy efficiency design measures.

Chapter two introduces the Vietnamese housing stock in Hanoi from a historical perspective. It presents the tube house type in more detail and reports the results of 12 interviews on refurbishing dwellings. This chapter is published in the proceeding of the International Planning History Society 2016 (IPHS) conference in Delft.

Chapter three presents the state of the art of energy efficient, green and sustainable dwellings in Vietnam. The best performing dwellings are shown to have a combination of active and passive energy efficiency measures.

Chapter four introduces the tube house again. This chapter also discusses the active and passive design measures, including those found in chapter 3, in more detail. The potential design measures are examined on their efficiency and their applicability on Vietnamese houses. This chapter was presented at the Passive Low Energy Architecture (PLEA) 2017 conference in Edinburgh.

Chapter five presents the potential of solar energy by reviewing latest legislation, studies and practices.

2 Housing in Vietnam

This chapter is reproduced from a conference paper titled ‘Toward a sustainable plan for housing in Vietnam’, published in the proceeding of the International Planning History Society 2016 (IPHS) conference in Delft.

2.1 Introduction

Vietnam, a small country in Southeast Asia, has undergone a lot of changes in its history, which includes different wars against Eastern and Western invaders as well as the development of a socialist society. Governments in different periods had their own significant impact on the whole country both economic as well as social aspects. Architecture and urban planning are not an exception. In Vietnam, the histories of cities can easily be seen in their urban patterns, landscapes and housing typologies. Traditional Vietnamese architecture has been influenced by Chinese architecture which can clearly be seen from the pagodas, temples and the traditional tube houses in the ancient quarters. In the colonial period (1858 -1945), Vietnam adopted the French urban planning system and many French style buildings. After the colonial wars, many old apartment blocks were built, inspired by the Soviet Union in the early years of the Communist Era. Most recently, the economic reform in 1986 called ‘Doi moi’ has had a huge impact on Vietnamese society. The rapid economic growth and privatisation of the market has resulted in the appearance and significant development of the ‘new tube house’ which soon became the most dominant housing type in Vietnam. The spontaneous development of this housing type helped to solve the housing shortage in the context of urbanization and modernization. In time, each housing typology evolved and adapted to societal changes aiming to meet the demand of housing quality and quantity.

Hanoi, the capital city of Vietnam, has a long history and is therefore very rich in architectural styles and typologies which are reflected in its urban pattern. There are various areas within the city that have distinctive characters. However, for new tube houses, there is no clear boundary in the urban scale as they are scattered all over the city and adapted differently in their contexts. Because of their dominance, regardless of their advantages and disadvantages, the new tube houses will continue to play a significant role in the near future. This chapter investigates how the traditional urban tube houses in Hanoi transformed into the new tube house.

The housing stock also needs to face the challenge of becoming sustainable, provide a healthy living environment and reduce its energy consumption. The responsibility lies not only in new buildings but also in the existing houses. Nevertheless, little is known whether this new urban housing typology, the new tube houses, offers adequate living conditions for the occupants and can adapt to climate change.

2.2 Methodology

The urban planning does have a considerable influence on housing typology, characteristic and performance. On the other hand, as a dominant feature of the urban fabric, a change in housing type can have impact on the city level. Therefore, understanding the current condition of the housing stock, requirements of a sustainable home can help in forming a sustainable plan of a city. This study investigates the energy upgrade potential of contemporary new tube houses in Vietnam through refurbishment activities and hence the sustainable development of the city.

The first part of this study explores how houses have transformed through time and adapted to societal and economic changes in different historical periods. New tube houses are compared to the traditional ones to see how this specific typology has evolved.

The second part focused on how the new tube houses performed in terms of indoor environment, energy performance and the potential to improve such performance through renovation. This part includes an interview. The interview has 3 main parts. The first section focuses on the household’s composition and housing character. In the second part, respondents were asked about their living experiences including indoor environment and energy consumption. The final section questioned the interviewees about their attitude and their refurbishment needs for sustainable housing. This interview did not intend to generalise the result for the whole tube house type but to provide general ideas to discuss and to support the implementation of the follow-up questionnaire.

Due to this reason, there were no more than 12 interviewees that took part in this survey. The respondents were chosen in such a way that they maximise the variety in location, housing age and occupants' background.

2.3 Housing in the Hanoi urban areas

Hanoi, the capital city of Vietnam consists of seven different architectural areas, see figure Figure 2.1: (I) Imperial citadel; (II) Old quarter; (III) French quarter; (IV) Neighbourhood built before 1986; (V) Private housing built after 1986; (VI) New urban areas built recently and (VII) less urbanized areas (To, 2008). Most of the areas are residential areas except for the Imperial citadel (I). It can easily be noted that Hanoi has expanded its urban city boundary considerably over time.

FIG. 2.1 Different areas in Hanoi

Until the late 19th century, the city of Hanoi was still ruled by the feudal empire. The city consisted of two main parts: the imperial citadel for the royal family and the old quarter for the citizens. The old quarter served as residential area as well as a place for the people to do business, trade the goods by the banks of the Red river. The old quarter streets were also known as the “36 streets of Hanoi” which represented 36 different administrative units called “Phuong”. The main streets were designed on the east-west axis that connects the citadel and the river bank in order to promote trade. The urban pattern of the Old quarter has not changed much since the late 19th century as illustrated in Figure 2.2.

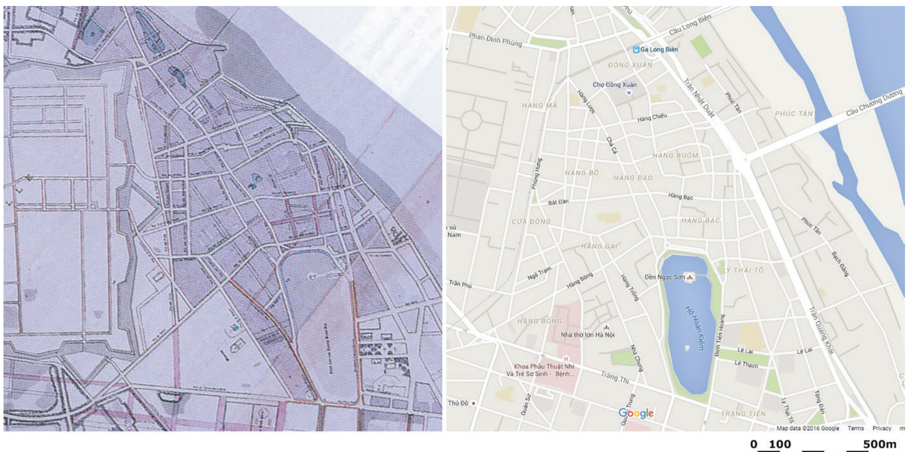

FIG. 2.2 Plan of the Old quarter in 1987 (left) and 2016 (right)

The housing type was the traditional tube house. The character of a traditional tube house included: very small front (2-4 meter) and a depth varying from 20 to 50-60 meter, in general 2 storeys high. Inner courtyards were employed to enhance daylight and natural ventilation and were used for outdoor activities. The front areas on the ground floor were used as shops. There are different explanations for the extremely narrow front of the traditional tube house. One of which is that it was the result of a division of inheritances. Another hypothesis proposed that the houses had initially been developed from the market stalls a long time before the streets came into existence (Phe & Nishimura, 1991). Narrow width was due to the act of the feudal government that taxed the households by their houses’ front width (To, 2008). As the settlement increased in population, the houses extended inwards and formed the tube-like houses. The urban pattern of the Old quarter can still be recognised, nowadays.

However, although most of the houses still retain their tube shape, not many of them are in their original form but have transformed into the new tube houses. Figure 2.3 below illustrates a traditional tube house in old quarter of Hanoi which retains parts of its in original form (the front two-storey blocks). The rear three-storey parts were renovated in 2003.

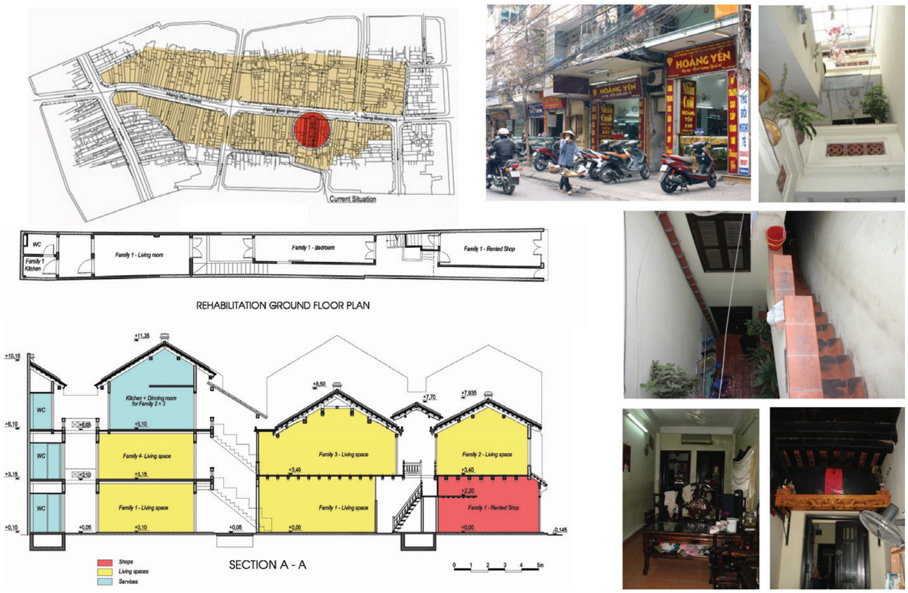

FIG. 2.3 Traditional tube house. Number 47 Hang Bac Street, Hanoi

The French came into Vietnam in the late 19th century and they have had a huge impact on the Vietnamese society, including its urban form and architecture. During the French colonial years, the extension of Hanoi was well planned and built. French colonial buildings have various styles and were constructed at a large scale. The French colonial quarter brings to the city a unique landscape in Asia and great opportunities for developing tourism and business (Parenteau et al., 1995). In the period of 60 years (1885-1945), two areas of the French quarter were built adjacent to the Old quarter. The first area is located to the west of the Old quarter which includes the area of the imperial citadel and its surrounding and the second area is located to the South of the Old quarter. The first urban plan of Hanoi was designed in 1900 by Henri Vildieu, then in 1924 by Ernest Hebrard, in 1934 by Louis-Georges Pineau and for the last time in 1943 by Henri Ceruttti (Tran, 2012).

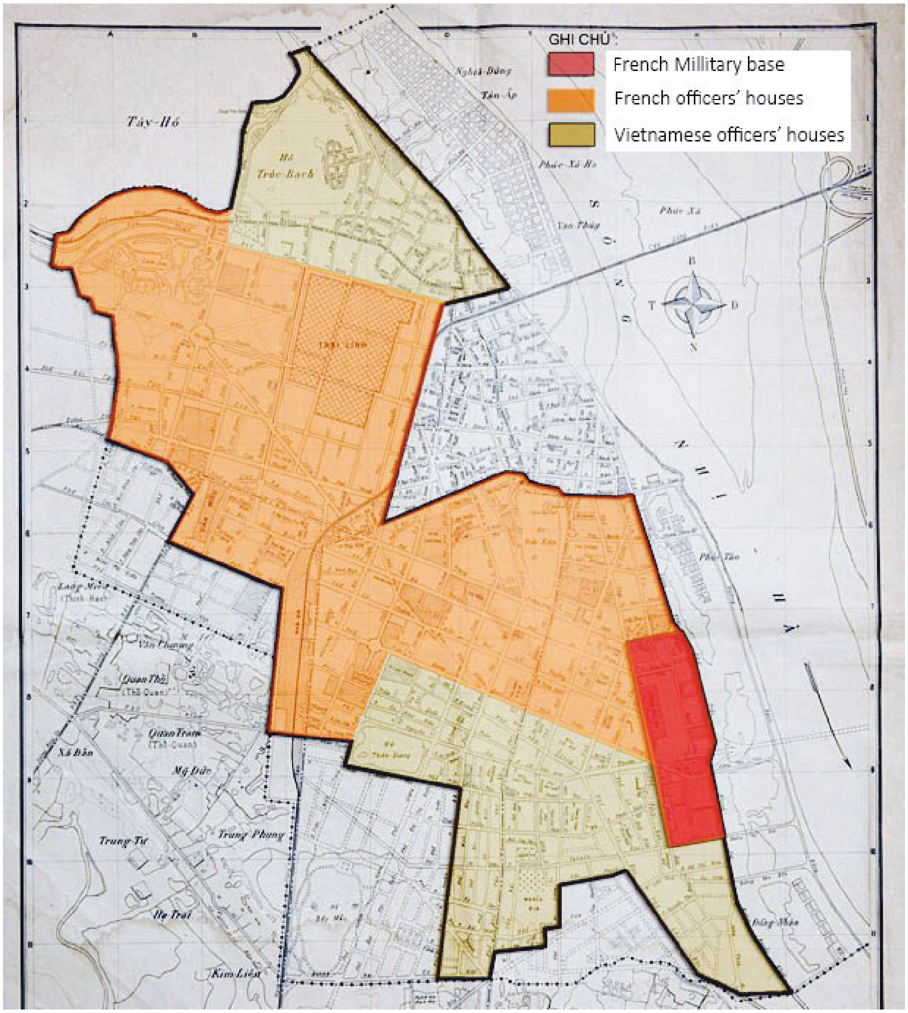

FIG. 2.4 Plan of the French quarter

With the intention of transforming Hanoi into the centre of the Indochina peninsula, the French architects aimed to plan the city in a complete western style with a checker pattern wide streets and French style buildings. There were three main building types: the public office buildings for the French government, the villas for the French officers and the street houses for the Vietnamese officers as shown in Figure 2.4 (Tran, 2012).

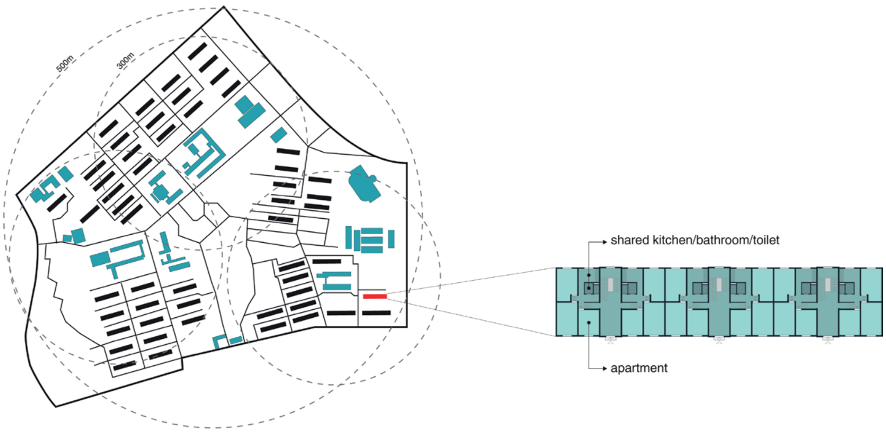

FIG. 2.5 Apartment blocks in Kim Lien area, Hanoi

After the French colonial period, the Vietnamese socialist government was established. In the 31-year period from 1954 to 1985, housing policy did not allow privately owned houses in the North, including Hanoi. Houses were built by the government and distributed to the state employees in the cities with extremely low rent (Mizuno et al., 2000). These state housing consisted mainly of 3 to 5-storey apartment blocks with communal kitchens and toilets. The government maintained a monopoly on urban planning and housing design in order to provide citizens with equal living conditions and avoid social differences (Gough & Tran, 2009).

However, these apartment blocks were claimed to be poorly maintained and provided little comfort and inadequate living conditions for the occupants (Mizuno et al., 2000). Nowadays, these blocks still exist and have lots of problems such as illegal expansion, low living condition, lack of public spaces and so on (Luong, 2007). Figure 2.5 illustrates the planning and current condition of the old apartment blocks in Kim Lien area, Hanoi.

Most recently, the economic reform “Doi Moi” in 1986 has made considerable impact on the social and economic development of the cities. The privatisation of the market allowed people to do business, and especially buy and sell houses. People from the countryside migrated to the big cities to look for job opportunities and better social services. Big cities became more densely populated and a lot of pressure was put on the demand for quantitative and qualitative good housing. In order to adapt to the population boom, the number of available houses increased. The new tube house appeared and soon became the most dominant housing typology in Vietnam, accounting for about 75% of the total housing stock. Therefore, despite its advantages and disadvantages, this housing typology will continue to play significant role in the next few decades (Nguyen, 2013).

A report of the national census and housing survey in 2009 indicated that there was a huge improvement in the housing supply due to the higher construction rate. However, the requirement of the housing demand in big cities was not yet met. As a result, it was more important to provide enough housing rather than providing better living condition in terms of indoor environment, health and safety (Ly et al., 2010). On the other hand, the energy sector in Vietnam has to ensure an adequate energy supply and minimise energy-related environmental impact. According to the overview of the primary energy demand and supply balance for the 1997-2025 period, both policy makers and planners agree that energy demand will soon outweigh and even double the domestic supply by 2025 (Minh Do & Sharma, 2011). Accounting for more than 31% of 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 (IEA, 2012). In 2013, the Ministry of Construction has issued the National technical regulation on energy efficient buildings (QC:09/2013/BXD) as an effort to improve the energy performance of the building sector (MOC, 2013). However, this regulation does not apply to small scale residential houses, such as the new tube houses. Hence, this chapter aims to investigate the characteristics of row house, the most important housing typology, in terms of its environmental and energy performance. In order to support this contemporary housing type in its adaptation to reach a lower energy demand and an increased sustainability of the housing sector.

2.4 Traditional tube houses and new tube houses

The traditional tube houses have been studied by many researchers because of its historical value. Researchers investigated their history, urban planning, architecture, conservation methods, living experience of occupants and so on. On the contrary, the new tube houses did not attract attention of academic scholars until recently, when the question of sustainability arose. Features of the traditional tube house and the new tube house were compared as shown in Table 2.1 (To, 2008).

TABLE 2.1 Comparison of the traditional tube houses and the new tube houses

	Type Identity	Traditional tube house	New tube house
1	Construction period	16-19 Centuries	From late 1980s
2	Settlement pattern	Attached	Attached
3	Average plot size	3.5m x35m	4.5m x 20m
4	Tube-form layout	Yes	Yes
5	Tube-form façade	No	Yes
6	Front shop	Mostly yes	Mostly yes
7	Inner courtyard	Yes	Yes/No
8	Number of storey	1-2	3-5
9	Building materials	Ceramic roof tiles, wood beams, brick walls, plaster	Reinforced concrete bearing frame, brick walls, plaster
10	Number of households	Mostly multiple	Mostly single
11	Number of residents	Ca. 10	Ca. 3-7
12	Ownership	Multiple/single	Mostly single
13	Privacy	Little	Yes
14	Financing	Difficult	Convenient
15	Construction permit	Restricted	More freely

A new tube house layout is presented in Figure 2.6. Compared to the traditional tube house, the new tube house has better privacy and is more convenient for financing and privatisation. However, the new tube house is not as sustainable as the traditional one. As the attached houses are generally designed by owners and builders but not by architects, many times the owners and builders do not even follow urban regulations creating chaotic street façades and urban landscapes.

It is also noted that, due to the location and historical value in the Old quarter, construction, demolition or refurbishment process of the traditional tube houses is far more complex than that of the new tube houses.

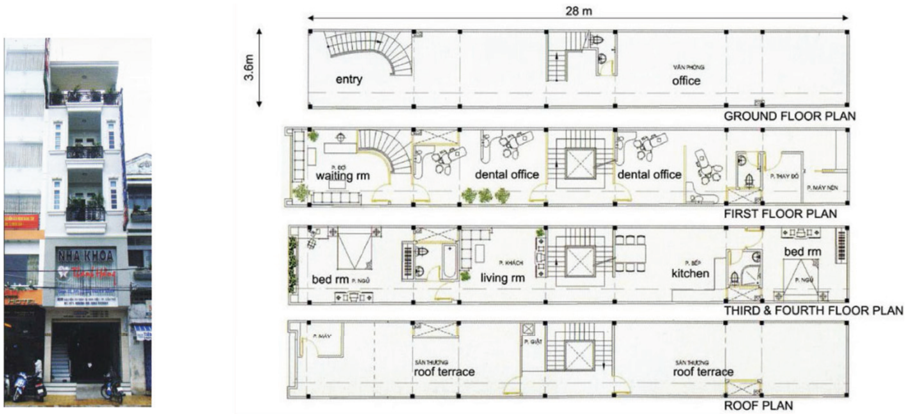

FIG. 2.6 A tube house in Nguyen An Ninh street, Can Tho city (south of Vietnam)

2.5 Interviewees' responses and discussion

2.5.1 Housing characters

Results presented in this paper are taken from twelve interviews of people who are currently living in their own attached row house in Hanoi (except for interviewee 8 who lives in a shared rented house of college students). Among the twelve interviewees, four people's house were built 20-30 years ago, which is the first 10 years after the economic reform, four houses were built in the next 10-year period, and four were built within the last ten years. The broad range and equal distribution of housing age increased the responses' variety. The number of occupants living in each house ranges from one person to five persons (typical Vietnamese household composition of three generations living together in one house).

The average number of floors is four while according to the construction law, the maximum number of floors of a tube house is five. Vietnamese people tend to make the most of the land by building on the whole plot and maximise the number of floors. There are some common characters of the houses in terms of construction. The houses were all built with a reinforced concrete frame, as were the floor slabs and flat roofs. External walls are brick walls, thickness ranging from 110-200 millimetres, no insulation and the transparent windows are single glazed. Among the twelve responses, none of them indicated the existence of an inner courtyard. Only two houses, built the last five years, were recorded to have a light-well (interviewee 3 & 9). Recently built houses seem to be built with more consideration of the indoor environment.

2.5.2 Indoor environment

Interviewees were asked about their living experiences and how they assess the indoor environment of the houses for the three aspects: daylighting, thermal comfort and natural ventilation (see Table 2.2). It is remarked that most of the interviewees were quite satisfied and highly rated their housing performance in terms of daylighting and natural ventilation. It is even more surprising since inner courtyards were not reported to be inside those houses. Nine out of twelve interviewees' responses rate the daylighting as 'good' or 'very good'. No bad experience was recorded and half of the responses indicate that natural ventilation is good. Only one interviewee reported bad natural ventilation in his house. However, since occupant's perception is very complicated and is difficult to measure, certain conclusion on the indoor environment quality of these houses requires more in-depth research. Initial attempts were made to try to understand this phenomenon. One of the explanations is that the houses have two openable façades to enhance daylighting and natural ventilation (interviewee 1,2,3,4,5,8 & 10). It is also important to note the role of urban planning and the surrounding areas. Many house are located in urban areas where streets are at least as wide as 11 metres (interviewee 1,2,3,4,5,9,10) and there are cases that houses are not obstructed for 50 metres (interview 6 & 11). Interviewee 7, whose house located in a small alley with only one openable façade, claimed indoor natural ventilation as bad.

It is more complicated when it comes to the thermal comfort aspect. Interviewees did not rate the thermal performance of their house as good as that of daylighting and natural ventilation. One third of the respondents said their houses were bad in maintaining its indoor temperature. Only two people gave a positive reply.

TABLE 2.2 Summary of indoor environment assessment and housing characteristics

Int. No.	Daylight	Thermal	Natural Ventilation	Orien-tation	Surrounding	Ext. Wall (mm)	Window
1	Very good	**Bad**	Neutral	SW (-)	Wide street, 2 façade	110 (-)	Single glazed glass (-)
2	Good	Good	Good	NE	Wide street	220	2 layers, wood & glass
3	Very good	**Very bad**	Very good	NW	Wide street, adjacent houses not yet built (-)	110	Single glazed glass
4	Very good	Neutral	Neutral	NW	Wide street, 2 façade	220	Single glazed glass
5	Good	Good	Good	SW (-)	Wide street	220 (+)	Wooden (+)
6	Good	Neutral	Neutral	SE (+)	Wide street	110	Single glazed glass
7	Neutral	Neutral	**Bad**	NE	Small alley (-)	220	2 layers, wood & glass
8	Good	**Bad**	Good	W (-)	Wide street	220	2 layers, wood & glass
9	Good	**Bad**	Good	SW (-)	Wide street, adjacent houses not yet built (-)	220	Single glazed glass
10	Neutral	Good	Neutral	SW (-)	Wide street, shaded all the time (+)	220	Single glazed glass
11	Good	Neutral	Good	SE (+)	Wide street	220	Single glazed glass
12	Neutral	Good	Neutral	SW (-)	Small alley, more shade (+)	110	Single glazed glass

(-): Housing characteristic that has a negative influence on the indoor environment
(+): Housing characteristic that has a positive influence on the indoor environment

According to the interviewees 1,8,9, the reason behind the poor performance is due to the orientation of the houses (West and South West). Interviewee 3 claimed thermal environment in his house is very bad and explained that because the adjacent houses were not built, his house is more exposed to the sun in summer while external walls are only 110 millimetres thick in order to maximize inner living spaces. Interview 4 noted that the thermal performance varied between different zones in the houses. The rooms which are located on the top floors are much hotter in summer and provide little comfort while the rooms which are closer to the ground are cooler and are regarded as better living spaces. On the other hand, interviewee 10, whose house also has the main façade face on the South West, rated his house as ‘good’ in terms of offering thermal comfort. He stressed that the good outcome is thanks to the shading provided by the urban trees and the big apartment blocks located on the other side of the street during the hottest hours.

In general, it is noted that house orientation and the exposed area to the sun are the two most important factors for the thermal performance of the houses.

2.5.3 Energy consumption

Electricity is the primary energy as recorded in all 12 houses while half of the people still used gas as fuel for cooking. Respondents also claimed that they had changed or they wanted to switch from using gas to electricity for cooking because of safety reasons. The main equipment that consumes a large amount of energy are the air-conditioner and the electrical water heater which appear in all twelve interviewees' houses. There are three houses that have a solar hot water system and that system was claimed to successfully provide hot water over the majority of the year and only during a short time in winter, an auxiliary electrical water heater is needed. All the responses indicate a careful use of electricity to save energy but eight of the interviewees still think they have to spend too much money on energy. Interviewee 1,3,4 noted that they have spent a lot more energy than usual for air-conditioning to keep the indoor temperature stable because of their small babies. It is important to remark that energy consumption also largely depends on the lifestyle, special needs of each household. Monthly energy use per capita ranges from 120 kWh to 250 kWh.

2.5.4 Housing refurbishment

Apart from the four interviewees who just recently built their houses, only three persons had their houses refurbished in the last 10 years, the rest did not renovated houses or just had small maintenance or redecoration. Details of three refurbishments cases were summarised in Table 2.3 where the owners shared the same reason that their family were expecting new member(s) (marriage or having babies) so they needed extra space and better living conditions. Interviewee 1 stated shading devices were added to the house south west façade as an effort to prevent overheating in summer. Interviewee 5 installed a new solar hot water system in his house during an intensive refurbishment in 2015. Both of the above refurbishment cases claimed to work well. Interviewee 12 also had a major refurbishment in 2010 when adding a whole new floor on top of the old house. As this led to more rooms, he was also happy with the better thermal performance of the house but he claimed that the daylight was worse. From theses 12 cases, the main reason for intensive renovation was to expand living spaces. This fact raised the possibility to upgrade energy performance through refurbishment activities.

When asked about priority in the refurbishment decisions, respondents indicated that the most important factor was to improve the indoor environment. Half of the responses put that factor on top and four others chose it to be the second priority. While other categories varied among the responses, energy consumption did not attract people's attention, ten people said it was their least priority when considering a refurbishment decision. In general, although energy efficiency is not one the priorities of the occupants, there is still a chance that houses can reduce a considerable amount of energy consumption because improving the indoor environment is still the most important refurbishment need.

TABLE 2.3 Summary of major refurbishment activities in last 10 years

Int.no.	Year	Reason	Major work	Effects	Cost (Euro)
1	2014	Moving in vacant space Need better environment for baby	Add shading device Add facilities (air-conditioner, electric water boiler) Add extra spaces (toilet & storage)	Better thermal performance Less glare issue from SW windows	4,000
5	2015	Repair major damage	Add solar hot water system Re-equip service system (electric and plumbing network) Add air-conditioner Repair damage in floor and walls	Saving energy for water heater Eliminate leakage in floor and walls	15,000
12	2010	Need more spaces for new family member (marriage)	Add a whole new floor	More living spaces Better thermal performance Less daylight	N/A

2.6 Conclusion

The history of Vietnam had a lot of effect on urban planning and architecture in cities of Vietnam and in Hanoi in particular. Urban areas and their housing types reflect the character and ideology of the various periods. Urban houses themselves have their own distinctive character in the different historical periods and adapt, again, to the contemporary challenges. Most recently, the economic reform of 1986 started the introduction of the 'new tube houses' which then became the most dominant housing type in the whole country, accounting for about 75% of the total housing stock. Therefore, the existing 'new tube houses' have an important role in planning more sustainable housing and energy preservation. A recent survey, conducted in March 2016 in Hanoi, investigated the new tube houses' character and their potential for energy upgrade. The results indicate that the thermal performance of a third of the existing houses is unsatisfactory and people state that they spend a lot of energy on cooling and heating the spaces. Although the Vietnamese occupants do not include the energy upgrade in their refurbishment priority list, there are still chances to reduce the environmental impact of the current housing stock. The most important factor for a refurbishment plan is an improvement in the indoor environmental quality which, with a little incentive, could be combined with measures that also reduce the energy demand. A follow-up questionnaire on a larger scale is planned to get more insights.

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3 Green buildings in Vietnam

3.1 Introduction

The terms of green building and energy efficient building are often interchangeable though they are not the same in Vietnam. Energy efficient buildings are designed to provide a significant reduction of the energy need for heating and cooling, independently of the energy and of the equipment that will be chosen to heat or cool the building. Green buildings are environmentally responsible and resource-efficient throughout its life-cycle: from planning to design, construction, operation, maintenance, renovation, and demolition (USEPA).

In Vietnam, most of so-called energy efficiency (EE) buildings are public ones because the recent National Technical regulation on Energy Efficiency only applies to buildings with more than 2500 square metre of total floor area. Small scale sustainable houses are often known as 'Green Home' or 'Passive house' which are claimed by the architects but not accordingly to any standards. The energy performance of those houses is usually not verified if they are efficient or not. This chapter introduces some of 'green houses' in Vietnam.

There are five houses being introduced in this chapter. The first 4 houses were listed as either 'green building' or 'energy efficient building' in the website of the Vietnam green building database and network (E4G.org). Two of those were designed by Vo Trong Nghia Architect, one of the most well-known Vietnamese contemporary architect, who focused on using greenery in buildings. The other two examples were designed by other architects who tried to use bioclimatic design measures to improve the indoor environment of the houses. The last one, Bi Eco Suite, is the first tube house that was certified with LOTUS, a green building rating system developed by Vietnam Green Building Council.

3.2 Green houses in Vietnam

3.2.1 Le Binh House

Le Binh house is a refurbished project located in Hanoi, designed by Vo Trong Nghia Architects and finished in 2013 (see Figure 3.1). 15-year-old existing house, located in the city center, suffered from dim, dark, wet and mouldy environment, which are typical conditions for many of the older houses in Hanoi. The house was secured and closed by security bars and shutters, making balconies unused space. To remedy this situation, the house is renovated to live with green and abundant light.

The house was renovated for a family of 7 occupants in 3 generation. Passive design strategies were employed to improve indoor environment, protect the house from overheating and provide daylight efficiently. Highlighted measure in this project was a green façade of plantation that helps block direct solar radiation from the South West. This green building skin not only improves indoor but also outdoor environment which has become worse than ever due to the extensive use of concrete (Vo Trong Nghia, n.d.).

The house is located in a densely populated area in Hanoi with the main orientation of South West. Compared to the existing house, refurbished design maximized glazing areas on all façades to acquire daylight into most part of the house. Two closed staircase were replaced by one open stair case and an additional void to improve daylight and airflow (see Figure 3.2). Internal screen was also removed to enhance daylight for the ground floor. Refurbished plan also prioritized the light-well over the bedrooms on the above floor, providing more daylight and view to the green building skin.

The house is characterized by green facade named ‘Greenfall’, a pleasant green waterfall which attracts both from interior and from exterior, providing leafy-scape to the streets (see Figure 3.1). Old security fences were removed and replaced with galvanized steel trellis, attached to existing balcony, on which climbers grow. From the interior, every room can enjoy the view of green and get fresh air through it.

FIG. 3.1 Le Binh House before (left) and after (right) refurbishment

FIG. 3.2 Living area in existing building (left) and In refurbished house (right)

The concrete roof was also refurbished into a new green roof covered with grass and trees which help improve the roof thermal insulation and provide evaporative cooling effect on the roof, see Figure 3.3. A solar thermal system was also installed on the roof to provide hot water all year around.

Most of the doors and windows are glazed to enhance daylight. Moreover, all of them were added rubber seal to avoid air leakage, hence reduce heating load in the winter.

FIG. 3.3 Green envelope of the project

3.2.2 The Mesh house

The Mesh house is another refurbishment project in Hanoi, see Figure 3.4. When the owner bought this house, the frame and the masonry part have been done. The architects were hired to design a new solution to improve and optimise the indoor environment of the house.

The Mesh house have two façade which makes it less urgent to employ daylight like other tube house. However, the two main orientation of the house was South West and North West so it is important to prevent overheating in the summer afternoon caused by high solar radiation (E4G, n.d.).

Because of the unfavourable orientation of the West, the architects proposed a new solution for the building envelope: a double skin façade with a ventilated cavity in between. In addition to the normal masonry wall, the building skin was added another fibre cement mesh layer on the external surface so direct solar radiation into the house was reduced significantly. This outer layer is offset 6 centimetre from the brick wall and is designed like a mesh, so the air cavity is ventilated and hence cool the whole façade. Furthermore, rainwater is collected in an underground water tank and used to spray mist into the cavity to enhance evaporative cooling effect. Staircase was brought outside and an additional void was added to improve natural ventilation. Cross ventilation was achieved because windows existed on both side of the bedrooms, see Figure 3.4.

FIG. 3.4 The Mesh house- external view

The house is located in Hanoi, so both heating and cooling is required. Doors and windows were double layer type which bring more flexibility in use, see Figure 3.5. The inner layer is glazing and the outer layer is wooden shutter. Operation of the system is described below:

- day: shutter closed, glazing opened
- Summer night: shutter opened and glazing opened
- Winter day: shutter opened and glazing closed
- Winter night: shutter closed and glazing closed

FIG. 3.5 The Mesh house: internal view of living space

3.2.3 Stacking green house

Stacking Green house is a new built project designed by Vo Trong Nghia Architects in Ho Chi Minh city in 2011. This designed was granted many Awards including Building of the year 2012 on Archdaily, 2013; World Architecture Festival, House category Winner, 2012; Green Good Design, 2012; International Architecture Award, 2012; AK House Awards, Top 15, 2011 (Vo Trong Nghia, n.d.). The house was located in the Southern part of the country which is constantly hot during the year. Therefore, design requirement was mainly to prevent overheating, enhance natural ventilation, hence reduce the cooling load.

The house, designed for a couple in their thirties and their mother, is a typical tube house constructed on the plot 4m wide and 20m deep. The front and back facades are composed of layers of concrete planters cantilevered from two sidewalls, see Figure 3.6, Figure 3.7. To water plants, the automatic irrigation pipes inside the planters were installed. Rainwater is collected in the tank and pumped up for this irrigation system.

This green facade and roof garden protect its inhabitants from direct sunlight, street noise and pollution. According to the post-occupancy measurement of the indoor environment, wind flows throughout in the house thanks to the porous façades and 2 skylights. This result was already proven by the behaviour of the inhabitants; they scarcely use the air conditioner even in the tropical climate, their electricity fees are just 25 USD per month, thanks to the wind flow and other passive design methods.

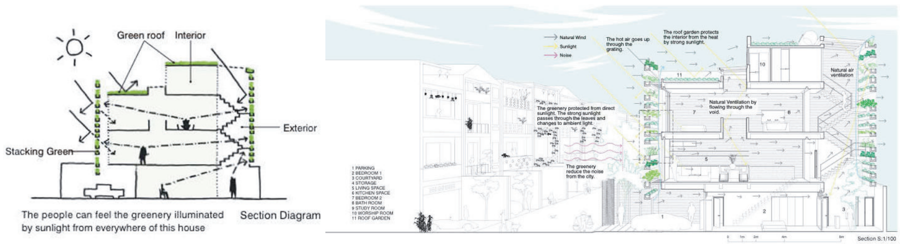

FIG. 3.6 Stacking green house – diagram section

FIG. 3.7 Stacking green house - façade design

3.2.4 The passive house

This house is a new built private house which is partly used as office. It was designed with passive strategies which means no air-conditioner is used. The house was built mainly with local material with low embodied energy. Operating the house accordingly to the outdoor environment is very important to maintain indoor thermal comfort. Doors and windows systems are design carefully and should be operated manually in different programs, see Figure 3.8 (E4G, n.d.).

FIG. 3.8 Design of the 'Passive house' in Hanoi, V-Architects

Ground floor system: if the outdoor temperature is within 17-33 Celsius degree then all the aperture should be opened. First floor system: The upper glass part is shaded when if outdoor temperature is above 32. The lower louvre part is opened in 17-30 range or if the indoor temperature exceeds the outdoor temperature. The lowest temperature is 7°C in January and the indoor temperature is 14°C. Highest outdoor temperature is 37°C in July and the indoor temperature is around 33° C. This is an average room temperature. Analysing indoor thermal performance using CFD shows that at the hottest time of the year, temperature at the centre of the room is just 30-31°C which can easily be cooled down by small fan.

3.2.5 Bi Eco Suite

Bi Eco Suites is the first project in Hanoi to achieve certification under the LOTUS Homes v1 green building rating system (see figure 3.9). LOTUS is a set of voluntary green building rating systems developed by Vietnam Green Building Council (VGBC), a project of the non-profit Green Cities Fund, based in California, USA. The LOTUS GOLD Certification is part of a comprehensive endeavour of the project owner to promote sustainability and protect the environment, including promoting organic-based products and a plastic-free environment.

FIG. 3.9 Bi Eco Suite, Hanoi, Vietnam. Clockwise from top left: front entrance, indoor design, application of air source heat pump, simulation model to test bioclimatic approach.

The Bi Eco Suite is a terraced house that was designed with no glazing areas on the west façade and a WWR of 3.1% on the east façade. This project employed low-W double glazing windows to avoid unwanted heat gain. The coefficient of performance (COP) of the used HVAC system is almost 50% higher than the National Technical Regulation 09 requirements. Besides, 95% of the appliances (including artificial lighting) are labelled as energy-efficient according to national standards. This building uses an air-source heat pump with COP of 4.2 for water heating. Finally, a rooftop solar PV of 9.6 kWp was installed on the rooftop to generate electricity onsite.

3.3 Conclusion

A number of so-called 'green houses' in Vietnam are presented in this chapter. These are renovation and newly built housing projects in Vietnam, where the architects applied both bioclimatic design approach and new active design elements to improve housing performance. The variety of the solutions in those projects proves that there is a great potential for improving thermal performance and energy efficiency in both renovated and newly built houses in Vietnam.

Table 3.1 summarises design strategies that were applied in the design of the houses. Passive design strategy is popular but active design strategies are still overlooked in the first 4 houses. In general, facade design is the most popular design strategy. It can be a double layer facade, a green facade, a high performance glazing area, or an adaptable facade. In the case of the Bi Eco Suite, apart from the facade design, the house is also equipped with active design measures to achieve better energy-efficiency and it is the only one that was awarded with the Green Home Certificate. All things considered, although green housing design is at the moment not popular in Vietnam and they can be approached differently, there is a moving trend towards more sustainable and energy-efficient housing design. Projects that not only apply bioclimatic design measures but also integrate active measures can bring a promising housing performance, both in terms of indoor environment quality and energy efficiency.

TABLE 3.1 Summary of selected green homes in Vietnam

Houses	Passive design strategy					Active design strategy		
	Natural ventilation	Facade design	Courtyard/ light-well	Evaporative cooing	Thermal insulation	EE equipment	Solar PV	Heat pump
Le Binh		x	x	x	x			
The Mesh	x	x	x	x				
Stacking Green		x	x					
Passive house	x	x						
Bi Eco Suite		x				x	x	x

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4 Energy Efficiency Design Approach for Vietnam

This chapter is a slightly modified version of a conference paper titled ‘Refurbishing houses to improve energy efficiency – Potential in Vietnam’, published in the proceeding of the Passive Low Energy Architecture (PLEA) 2017 conference in Edinburgh. In this chapter, figures were added to illustrate the design measures better.

4.1 Introduction

Vietnam has undergone a lot of changes in its history. This includes different wars against Eastern and Western invaders as well as the development of a socialist society. As a result, Hanoi, the capital city of Vietnam, is therefore very rich in architectural styles and typologies which are reflected in its urban pattern. Most recently, the economic reform of 1986 called ‘Doi moi’ has had a huge impact on the Vietnamese society. The rapid economic growth and privatisation of the market has resulted in the appearance and significant development of the ‘new tube house’ which soon became the most dominant housing type in Vietnam. The spontaneous development of this housing type helped to solve the housing shortage in the context of urbanization and modernization. However, they also take major responsibility for a more sustainable housing stock in Vietnam. Nevertheless, little is known whether the new tube houses, the most dominant housing typology in Vietnam, can be renovated to offer adequate living conditions for the occupants, can tackle the issue of energy shortage, and can adapt to climate change. This chapter introduces the potential of refurbishment design measures for energy efficiency in Vietnamese tube houses.

4.2 The tube houses

4.2.1 New tube houses

A new tube house layout and the spatial composition of a traditional one are presented in Figure 4.1. A new tube house is normally built in a rectangular plot with the width of 3-6 metre and the depth of 10-20 metre, 3 to 5 storey high. Within this narrow plot of land, it's courtyard is often limited. The typical structure type is concrete frame and brick masonry.

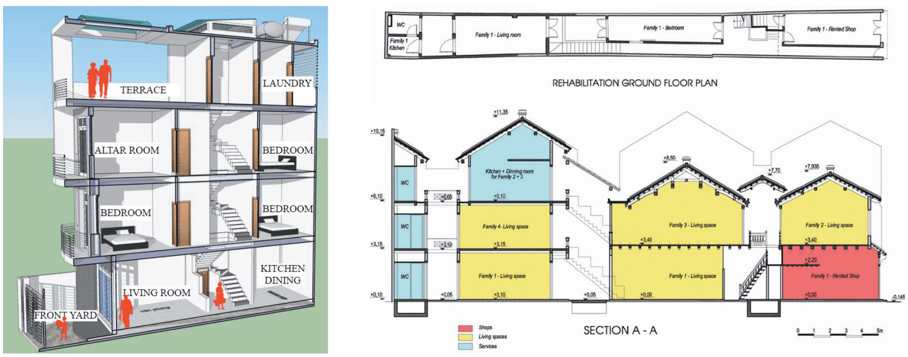

FIG. 4.1 Layout of a typical new tube house (left) and a traditional tube house (right) in Vietnam

Several features of the traditional and new tube houses were compared as shown in Table 4.1 (To, 2008). Traditional tube houses are more sustainable both in terms of spatial composition and climate responsive architecture elements.

TABLE 4.1 Comparison of the traditional tube houses and the new tube houses

	Traditional tube house	New tube house
Average plot size	3.5m x35m	4.5m x 20m
Inner courtyard	Yes	Limited
No. of storey	1-2	3-5
Building materials	Ceramic roof tiles, wood beams, brick walls, plaster	Reinforced concrete bearing frame, brick walls, plaster

4.2.2 Climate design in traditional tube houses

There are three main climatic regions in Vietnam from North to South, but there are some common climatic features that most houses have to deal with. Firstly, the high annual solar radiation result in great unwanted heat gains in building. Traditional tube houses applied double layer windows, with wooden shutter to block the direct sunlight and at the same time provide natural ventilation. The roofs are usually high and ventilated since the sun position is very high in the summer. Shading is provided by eaves and trees, while the later also benefit the houses with evaporative cooling. The houses were usually painted light colour to reflect the radiation. The high temperature and humidity make natural ventilation a mandatory design strategy in almost every house. Popular measures are high ceiling, large openings and the use of inner courtyard. Thermal mass is not applicable due to the low diurnal and seasonal temperature different. Most houses use local lightweight construction instead. Finally, most traditional houses have pitch roof because of the high annual rainfall. However, rain water harvesting is not yet considered though it has a huge potential to reuse this resource. Figure 4.2 below illustrates some of the bioclimatic techniques in traditional houses.

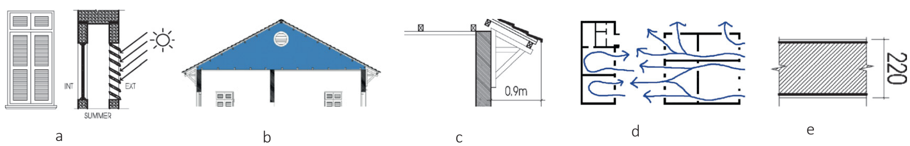

FIG. 4.2 Some climatic design strategies in traditional houses of Vietnam
a. Double layer window, b. ventilated roof, c. deep eaves, d. natural ventilation, e. lightweight construction

4.3 Energy efficiency design approach

Both passive and active measures for refurbishment can reduce energy consumption in houses and provide better living conditions. Passive design, or similar strategies such as bioclimatic design or environmental design, uses architectural measures and considers the local climate, such as air and sun, in providing thermal and visual comfort without using additional energy.

Active measures, on the other hand, consume a certain amount of auxiliary energy. This chapter discusses both active and passive measures for Vietnamese context.

The Trias Energetica, introduced in the late 1980s (Lysen, 1996), lists sustainable measures for buildings according to their significance to sustainability. The concept includes three steps. The first step is to reduce energy by improving thermal performance, reducing heating and cooling loads. The next step involves generating and using renewable energy sources as much as possible. Finally, when non-renewable energy use is inevitable, this step consists of exploiting the non-renewable energy efficiently.

Introduced in 2002, Cradle to Cradle (C2C) is a new concept of sustainability (Mcdonough, 2002). It focused on closing material cycles and producing only food at the end of a lifetime. Although the applications of this philosophy were mainly in the materials and products level, there are great opportunities that it can also be used for sustainable buildings and urban planning (Van Den Dobbelsteen, 2008).

Inspired by the C2C approach, Dobbelsteen (2008) have proposed new strategy with three steps for sustainable building, see Figure 4.3. Basic idea is to create loop cycles of energy and material flows so that no waste is dumped in to nature. The first step is similar to the first one of the Trias Energetica, reducing energy demand. It is the most important step in all strategies and is often referred as passive design or bioclimatic design. The next steps, inspired by C2C, are to recycle the waste flows both internally and externally. The final step is to supply the house with sustainable energy sources and let waste be food. In term of energy efficiency, these new strategy steps consider the use of waste heat in the cycles of energy, materials and water.

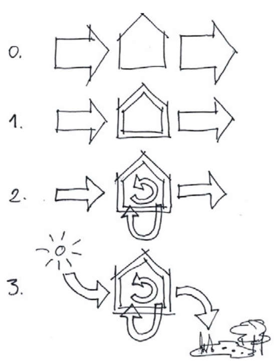

FIG. 4.3 The New Steps Strategy (Dobbelsteen, 2008)

4.4 Design approach for indoor environment and energy efficiency in Vietnam

In Vietnam, the National Technical Regulation on Energy Efficiency Buildings (NTREEB) provides mandatory technical standards to achieve energy efficiency in the design, new construction or retrofit of civil buildings (MOC, 2017). These standards apply to 6 categories, namely building envelope, ventilation and air-conditioning, water heating, interior lighting, energy management equipment and elevators or escalators. These standards cover both active and passive measure and also align with the Trias Energetica concept. Table 4.2 below summarizes potential design measures for refurbishing new tube houses. Application of these design strategies in Vietnam context will be discussed in the following parts of this chapter.

TABLE 4.2 Potential refurbishment design strategies for housing in Vietnam

Design strategies	Detail measure	Potential	Involving Building Element
Solar control	Orientation, massing	Limited	
	Natural control (trees) Shading devices	High	Opaque envelope
Natural ventilation	Cross ventilation	High	Windows Internal dividing
	Stack effect	Low	Inner courtyard
Evaporative cooling (EC)	Direct EC (trees, pond)	Moderate	Courtyard Envelope
	Indirect EC	Limited	Envelope
Passive solar gain	Direct gain (windows, envelope)	High	South Façade
	Indirect gain (sun space)	Limited	South Façade
Thermal mass	High thermal mass walls	Limited	Building envelope
Daylight	Side Windows Light well/ Courtyard	High	Windows Courtyard
Thermal Insulation	Highly insulated envelope	High	Roof
Solar energy	Photovoltaics (PV cells)	Moderate	Roof
	Solar collectors	High	Roof
Biomass	Algae/Bio waste	Limited	
Active heating/cooling	Ground source heat pump	Limited	Underground
	Air source heat pump	Moderate	Wall
Lighting and appliances	Energy efficiency equipment Automation system	High	Equipment

4.4.1 Passive design strategy

Avoid overheating

Located in a subtropical climate region, the main climate characteristics of Vietnam are a high annually temperature and high solar radiation. Therefore, overheating becomes the biggest problems in houses that passive design needs to deal with. There are several techniques that are used to prevent this phenomenon, such as solar control, natural ventilation and green building envelope. In order to achieve highly efficient cooling effect in a building, normally more than one system is applied.

Solar control (orientation/ shading device)
In Vietnam, the most preferable orientation is south and south west because it helps to catch the prevailing cool winds and easily avoid direct solar gain. High solar radiation and the low sun position make the west the least favourable orientation. However, for tube houses, where orientation options are limited, this principle only applies when the house has more than one façade. In refurbishment projects, changing orientation is usually not possible.

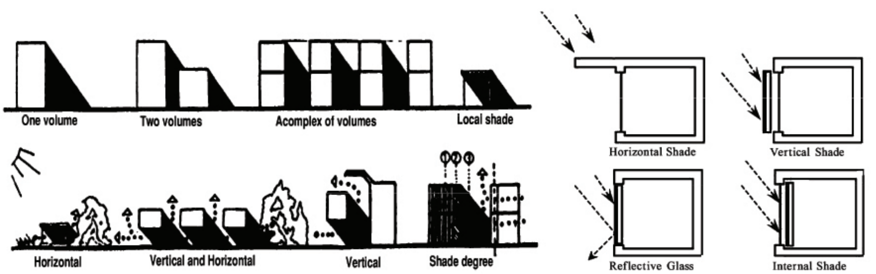

FIG. 4.4 Different kinds of shading for bioclimatic buildings in hot climate

When the house has an unfavourable orientation, for example west, an additional shading solution can control the solar access. Firstly, shading can be achieved through architectural massing. A service space that does not require high thermal comfort can be used as a protective layer for the internal living space from the heat gain. This measure requires intensive refurbishing, usually when extra space is needed. Natural elements such as trees or shrubs can shade the building from sunlight and provide additional evaporative cooling of both indoor and outdoor environments (Moore et al., 2001). As tube houses usually are built on the whole plot, there is lack of space to allocate additional trees in an existing project.

Green facade, however, is an alternative. Finally, a shading device is the most efficient element to block solar radiation. Apart from being more efficient, external shading devices are easier to retrofit than an internal one (Almusaed, 2010). Examples of shading options are shown in Figure 4.4.

Natural ventilation

Natural ventilation is the most popular and most important measure to deal with overheating in the hot and humid climate. First, it helps cool the human body by the effect of evaporation of sweat and by convection. In this case, the air speed needs to be at least 0.2 m/s for the cooling to be effective (A. T. Nguyen, 2013). Furthermore, building structures with high thermal mass, heated during daytime, can be cooled down using night ventilation provided that the temperature at night is within or below comfort zone. Finally, it helps prevent condensation in the high humidity environment.

Natural ventilation can be classified as three main types: cross ventilation, single side ventilation and stack ventilation (Irving et al., 2005). In Vietnam, stack ventilation is not efficient due to the small different temperature between indoor and outdoor temperature. Therefore, wind-driven ventilation is the main ventilation strategy, see Figure 4.5 (A. T. Nguyen, 2013).

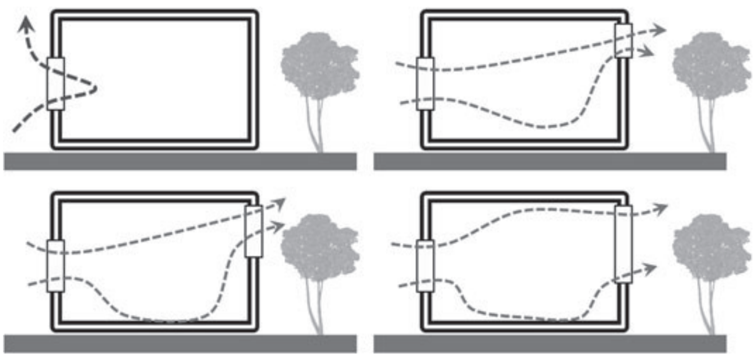

FIG. 4.5 One side ventilation and cross ventilation in different situations

In Vietnam, there are different kinds of monsoon winds. Good understanding of the monsoon wind can help supply the buildings with a fresh cool breeze in summer as well as avoid cold winds in winter. However, natural ventilation requires good control of air quality. In big cities, for example Hanoi or Ho Chi Minh City, sometimes air quality is very poor. The air quality index of these places can sometimes be very high, and there are dust and pollutants in the air.

Therefore, no matter the ventilation system, there should be always an option to control the amount of air allowed into the buildings. Filtering layers such as greenery systems are recommended (Armijos Moya et al., 2018).

Evaporative cooling

Evaporative cooling is not efficient in hot and humid climate area because high humidity level increases thermal discomfort (Almusaed, 2010).

Passive solar use

In winter time, where the outdoor temperature can drop to a very low level, heating is needed to ensure a comfortable living space for occupants. The heating season occurs in the northern parts of Vietnam which are affected by the cold monsoon wind. The winter climate of northern Vietnam is not that severe compared to the winter in temperate climates as in the Netherlands. However, traditional Vietnamese architecture tends to mainly solve the problem of hot summers, maximizing opening, using lightweight structures. Therefore, the indoor temperature in wintertime can be very cold and require a lot of heating.

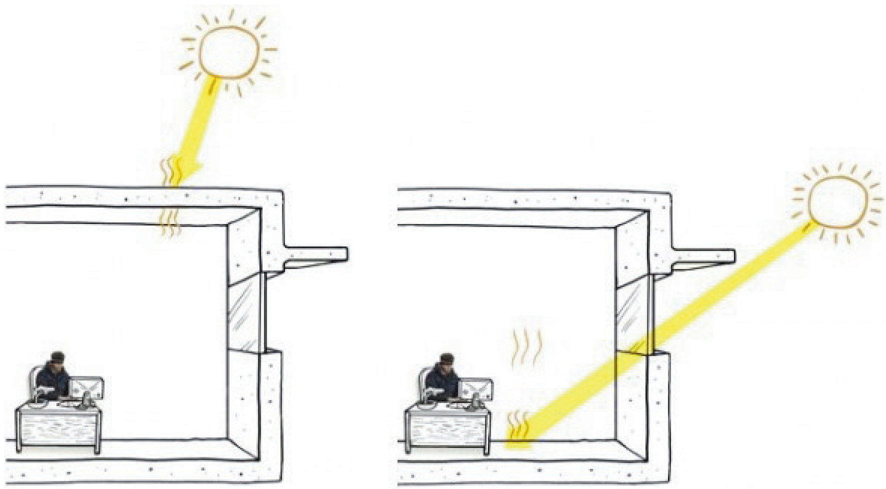

FIG. 4.6 Direct solar gain through roof/wall and glazing

Passive solar strategies are widely used in the temperate climate, making use of the energy from the solar radiation to heat the internal space without mechanic equipment. Solar gains can be achieved directly (through glazed area, see Figure 4.6) or indirectly (sunspace and thermal mass). Passive solar gains are mainly achieved on the south façade of a building (or north façade if the house is in the southern hemisphere). It is also a limitation of this strategy. Passive solar design is not feasible if the house is shaded by other buildings or trees, or, in case of the tube house, if the south façade is not available.

Sunspace

One main advantage of a sunspace is that it provides occupants with extra living space. However, it also has some shortcomings. Firstly, a sunspace might lead to extreme overheating in summertime, especially in a hot climate of Vietnam. The glazed parts need to be openable and be protected by shading devices. In that case, a sunspace works as a terraced area or a veranda. Moreover, sunspace is usually considered less efficient as it saves less energy in comparison with its cost. In refurbishment of a tube house, an additional sunspace is not always available if the house uses all the space of its plot.

Thermal mass

In climates that are constantly hot or cold, the thermal mass effect can actually be detrimental. All surfaces of the mass will tend towards the average daily temperature; if this temperature is above or below the comfortable range, it will result in even more occupant discomfort due to unwanted radiant gains or losses. Therefore, in warm tropical and equatorial climates buildings tend to be very open and lightweight.

Heat Protection

Thermal Insulation

In the Vietnam summer time, it is essential to protect the building from heat gains. High sun angles make the roof to be the most important element to be protected from radiative heat gains. Insulation on the roof is usually done with a layer of low emissivity material and a ventilated cavity. A bright colour paint can help the walls to reduce heat gains from radiation. However, because of the high humidity, natural ventilation is encouraged and windows are usually open. The small difference in temperature between the outdoor and indoor space makes the resistance to heat conduction less significant. In winter time, thermal insulation can help reduce heat loss and heating demand.

Air tightness

The winter of Vietnam is not so harsh compared to countries in a temperate climate. However, existing housing is facing problems of air leakage or infiltration. Together with a poor insulated opaque envelope, it makes the heating demand becomes much higher.

4.4.2 Active design strategy

Renewable energy sources

Utilizing renewable energy sources is an important step in both Trias Energetica and C2C-inprired approach. Such power sources come from the sun (photovoltaic, solar collector), the wind (wind turbine), the earth (geothermal energy) or biomass.

Photovoltaics (PV) energy

Vietnam has a constant solar energy source, see Figure 4.7. In the North, solar radiation intensity ranges from 2.4 to 5.6 kWh/m2/day while in the Central and the South, energy from solar irradiance varies is distributed uniformly from 4 to 5.9 kWh/m2/day (N. T. Nguyen & Ha-Duong, 2009). However, efficiency of PV systems in the tropical climates is not necessarily better than that in the temperate climate. This is mainly due to the fact that PV cells efficiency largely depends on the cell surface temperature. The higher the temperature, the lower the efficiency (Bahaidarah et al., 2013). The main solution to this problem is to cool the cells by using water or air on top or under the cells surface.

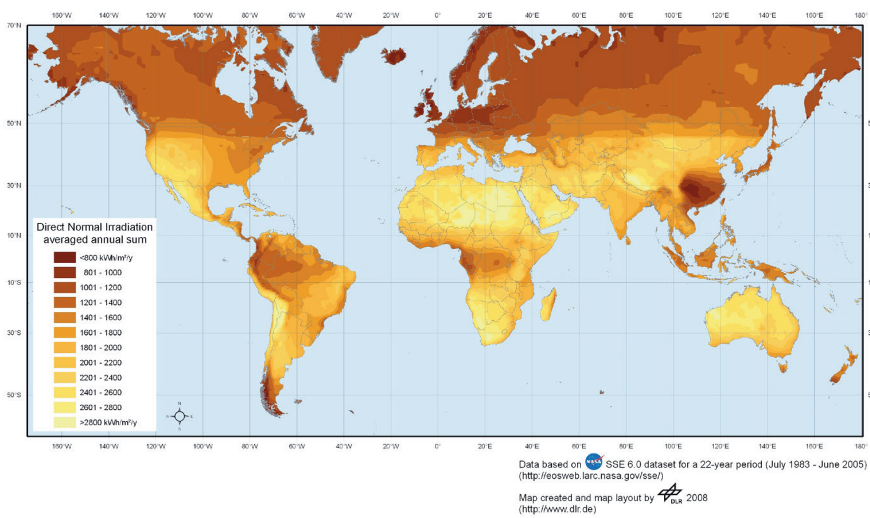

FIG. 4.7 Map of World Solar Energy Potential

Solar thermal systems

Solar thermal systems are quite popular in Vietnam because of its easy installation, low cost and availability of solar radiation. Installation of solar collectors and water tanks is easy, see Figure 4.8. However, in refurbishment projects, it is often required to also replace the plumbing system because traditional ones were not designed for hot water and such replacement is usually more complex. It could be a good solution when the owner wants to replace the service system in the house after a long time use.

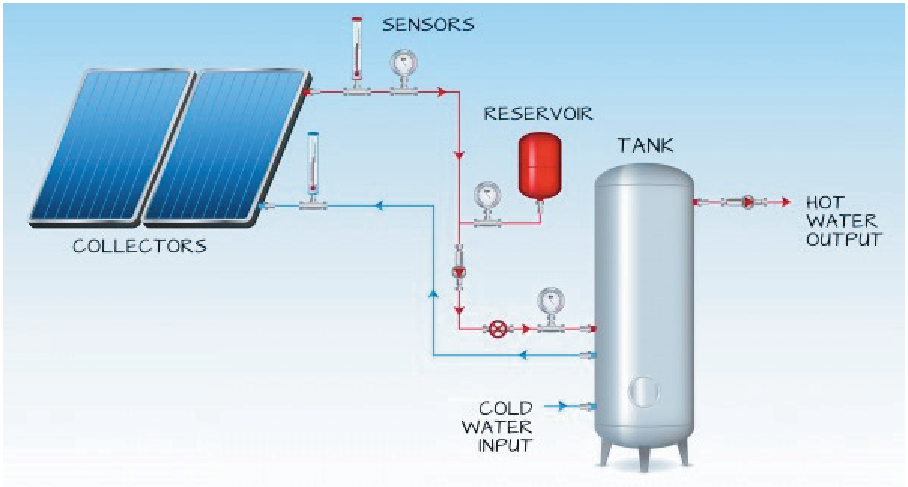

FIG. 4.8 A typical solar hot water system

Biomass

Biomass systems often require a specific area to burn the fuel to generate heat. Therefore, this energy source is more popular in rural areas than in high density urban area of Vietnam.

Active cooling/heating

Air source heat pump

Contemporary Vietnamese houses often do not employ enough natural ventilation due to the limited design parameters. Furthermore, the outdoor temperature is not always healthy. Air-conditioning systems are widely used in urban area of Vietnam to introduce fresh air with an appropriate temperature, ensuring indoor air quality.

A survey conducted for 400 households of Ho Chi Minh city shown that ownership rate of air-conditioners was more than 60% in 2012 (Matsumoto & Omata, 2017). However, low coefficient of performance (COP) air-conditioners often consume too much energy and thus increase the environmental impact of the buildings.

Ground source heat pump

In climates with high average air temperature levels and little temperature fluctuations, the application of geothermal energy is very limited (Eicker, 2014). Furthermore, geothermal heat pumps are usually incorporated into new buildings projects and are not suitable for refurbishment project because their installation involves digging into the ground and the cost is usually quite high. Therefore, GSHP is not applicable in housing refurbishment in Vietnam.

Efficient use of non-renewable sources

Heating and cooling

In Vietnam, where both heating and cooling are required, air-conditioner often carries both duties in one single system. Efficiency of the air-conditioning system can be improved by increasing insulation for the pipes system. It is also important to keep indoor air temperature cool as long as possible. Therefore, reducing heat transfer through building envelope also help reduce energy consumption of the air-conditioner (Konstantinou, 2014). The Vietnamese National Building Code of Energy Efficiency Buildings set out certain requirements for air-conditioning system (MOC, 2013).

Lighting and appliances

In Vietnam, electrical appliances and lighting accounted for 11% and 8% energy use in residential building respectively (MOC, 2013). Improving energy efficiency of such equipment during refurbishment can contribute to the total energy saving of the houses. To reduce the energy consumption of this part, low energy efficient products should be replaced. Furthermore, the government also issues a regulation framework for the energy labelling program and directives for implementation (Prime Minister of Vietnam, 2011). Energy efficiency of appliances can also be improved by using smart control system with human sensors and automatic programming function.

4.5 Conclusions

In Vietnam, popular passive design strategies include solar control, natural ventilation and evaporative cooling. However, tube houses constraints limit the effectiveness of passive design measures. For example, orientation is generally not changeable. Small land plots and high demands of living spaces do not allow many options for massing and courtyard although a courtyard is a very important feature of a traditional tube house. Thermal insulation layers are mostly found on the roof. Air-tightness can efficiently prevent the houses from losing heat in winter. Passive solar gain might work for the cold winter of Vietnam directly or indirectly (sun space). Geothermal cooling and thermal mass are not recommended for renovating houses in Vietnam.

Active design strategies are generally not popular in Vietnam yet. Although the country has a high annual solar radiation, solar energy is mostly captured by solar collectors that provide hot domestic water. This system is easy to install and has high efficiency. Solar photovoltaics have not been applied widely because they are often – wrongly, considering the recent price of PV - considered not cost effective compared to the traditional fossil sources and they are mostly used for off-grid areas. Biomass is another clean energy source that can be used for homes. But it is not suitable for urban housing since it takes up spaces for burning and might harm air quality and human health. Using highly efficient equipment and lighting appliances can potentially reduce energy consumption in housing. To promote using energy-efficient equipment, it requires the commitment of the government, manufacturer and potential users.

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5 Solar power potential in Vietnam

5.1 Introduction

There is a growing number of countries that have set new goals for renewable energy. Around 140 nations show their great interest in this energy type (Duong et al., 2019; IRENA, 2019). Among the alternatives energy sources, photovoltaic (PV) power is still one of the fastest growing industry in the worlds (Tadjer & Habi, 2016). In 2016, 303 GW of solar power was generated and fed to the grid in the world. It is projected that the installed capacity of the PV can reach up to 1100 GW in 2023 with generating capacity of 1700 TW (REN21, 2018). Prior to 2006, majority of solar power was generated in Japan and Europe. Since 2014, PV production capacities of other Asian nations, including Vietnam, grew significantly (Jäger-Waldau, 2019).

Recent development of PV technology has enabled cheaper production cost of solar power systems, as well as reduced operation and maintenance costs. Electricity costs from PV are becoming more competing with those from fossil fuel sources. Installation costs of solar panel has reduced significantly from 3,5 – 4 EUR/Wp to 0,18 – 0,39 EUR/Wp in the period 2008 – 2020 (Solarserver, n.d.).

Vietnam’s National Energy Development Strategy prioritised the uptake of renewable energy and had the goal of increasing renewable energy up to about 11 % of total commercial primary energy in 2050. The national power development plan aimed to reach 12 GW of PV power by 2030 (Prime Minister of Vietnam, 2016).

5.2 Solar energy potential in Vietnam

5.2.1 Climatic regions

Vietnam is located in South East Asia, ranging between latitudes 9°N and 23°N. Its climate is strongly defined by the tropical monsoon, with high temperatures and and a high relative humidity. According to the Köppen-Geiger climate classification system (Kottek et al., 2006; Peel et al., 2007), there are 3 main climatic regions in Vietnam: Cwa, Am, Aw in the North, Centre and the South, respectively.

Most parts of Vietnam are dominated by the south-eastern wind from May to September, coming in from the long coast line. Northern Vietnam is affected by the cold north-eastern wind from October to April. Main rain season lasts from May to September. There is not much rain during remaining time of the year. The centre region has a distinctive climate pattern. Winter is the rainy season and in the summer, there are often hot-dry wind and tropical storms. Annual rainfall in most parts of the country is above 1000 mm (Schmidt-Thomé et al., 2014).

5.2.2 Solar power capacity in Vietnam

Countries in the hot tropical climate are usually supposed to have abundant solar radiation, thus plenty of potential for solar energy. Vietnam has a constant solar energy source. In the North, solar radiation intensity ranges from 2.4 to 5.6 kWh/m^2/day, while in the Central and the South regions, energy from solar irradiance is distributed uniformly from 4 to 5.9 kWh/m^2/day (Nguyen & Ha-Duong, 2009).

Solar power has been used in Vietnam since the 1990s, but it is mainly used for remote areas that are far from the national power grid, such as mountainous areas and islands. Decision number 11 , issued in 2017, introduced a feed-in tariff (FIT) for grid-connected (Prime Minister of Vietnam, 2017). In two year (2017-2019), the solar power capacity in Vietnam increased from 8 MW to 4.46 GW (IEA, 2018). and 5.6 GW at the end of 2019 (IRENA, 2020). The FIT application period was extended until the end of 2021. Expected new tariffs range from USD 0.067 to USD 0.109 per kWh (IRENA, 2020).

5.3 Solar energy potentials in the built environment of Vietnam

Depending on scales, there are three types of solar power generations in the market: residential rooftop PV, factory rooftops and PV plants. A solar plant has a large capacity of 5 MWp to around 1 GWp. Rooftop solar power is becoming essential for business with the capacity of 20 kWp to 1kWp. Private rooftop systems, which are generally less than 5 kWp, are receiving increased popularity (Duong et al., 2019).

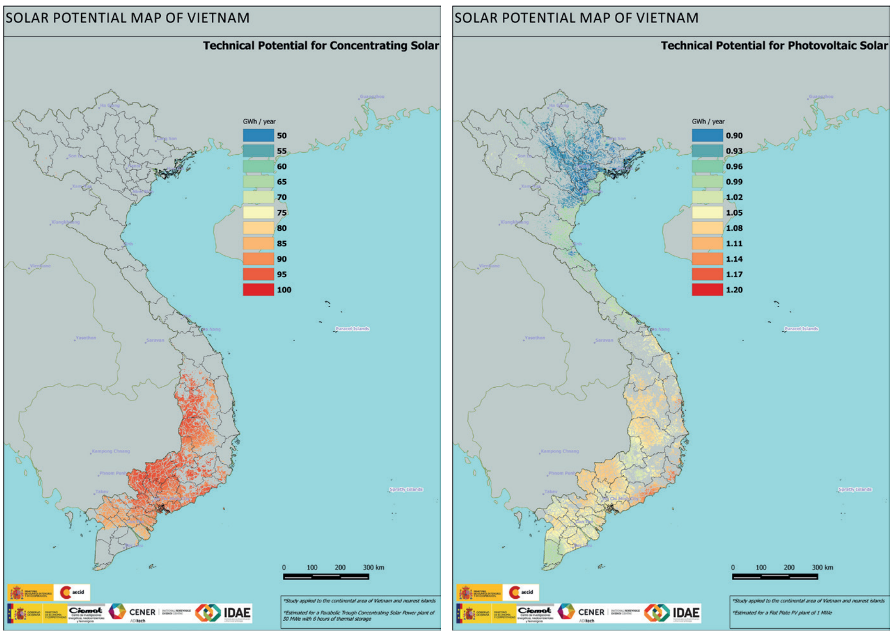

FIG. 5.1 Technical Potential of Concentrating solar power (Parabolic trough) and Flat plate PV in Vietnam

5.3.1 Solar power plants

Vietnam has high potential for solar power generation. One of the major trends of producing sustainable electricity are PV plants. The development of this energy source requires knowledge of spatial distribution of potential areas. Polo et al. (2015) presented the solar resources map and of the potential location for PV plants. The mapping was computed from satellite-derived data and meteor station data. The areas available for Concentrated Solar Power (CSP) systems are the Central Highlands and Southeast regions of Vietnam. The Southeast, Central Highlands, Mekong River Delta, the coastal areas and northeast are potential regions for putting PV plants, see Figure 5.1.

5.3.2 Rooftop PV

Since the 2000s, grid-connected PV power systems have been studied for application of building and resident home in Vietnam. A grid-connected PV power station in Hanoi city with a capacity of 22 kW was installed and tested for its effectiveness (GDE, 2015). PV modules absorb solar energy and generate the power. The DC/AC inverter is used to convert the direct current (DC) from the PV module to the alternating current (AC) and transmit it into the utility power grid (Boxwell, 2019; V. M. Phap et al., 2019). When the system's output power exceeds the user's demand, the excess electricity goes through electric meter into the utility grid. When the electricity production does not meet users' demand, they have to buy the additional power from the grid. There would not be any interruption in the flow of power because of the instantaneous of the connection between the solar power system and the grid (V. Phap & Nga, 2018). In 2017, the Government of Vietnam issued the supporting policy for the uptake of solar power. According to the Decision, the unused electricity generated from the PV power station can be sold back to the grid with a price of 9 EUR cent/kWh (Prime Minister of Vietnam, 2017). This policy has attracted many investors in installing rooftop PV power stations in Vietnam.

A grid-connected solar power system with the capacity of 15 kW was designed for a building to achieve a nearly zero-energy building (Truong et al., 2016). The PV arrays were installed in the area of this building to compensate the energy needed and these authors also researched to improve the power production efficiency of the PV system by using the Solar Tracker system. According to the simulations, the PV power station only produces 60% of its rated power and the optimal tilt for the PV cells is 15° in order to maximise yield.

Duong et al. (2019) built a 2 kW grid-connected rooftop PV system for a household in the centre of Vietnam. Both simulation and experiment were conducted to quantify the effectiveness of such a system. Results showed the operability of the system, which met the connection standard in Vietnam during the whole year. However, this research also pointed out the drawbacks of the current PV system. The Vietnamese government is currently offering a high price for purchasing electricity generated from solar energy, but it is projected that the price will be lowered in the coming years. This makes the payback period longer and reduces the economic values of the project. In addition, the development of rooftop systems might create grid problem of voltage deviation. Connecting a PV system to the grid randomly will cause phase imbalance.

5.4 Summary

Solar energy was known to have a great potential in Vietnam as the country has a high number of constant solar radiation. However, the production of solar electricity was only significant in recent years because of more favourable state policy regarding renewable electricity production. Until mid-2019, grid-connected PV capacity is accounted for 8.3% (4.46 GW) of the country electricity capacity.. It increased to about 5.6 GW by the end of the year. Potential locations for solar power plants were identified by computing solar radiation potential and restricted factor. The areas available for CSP systems are limited to the Central Highlands and Southeast regions of Vietnam. The Southeast, Central Highlands, Mekong River Delta, the coastal areas and northeast are potential regions for putting PV plants. In case of small production, it mainly concerned rooftop PVs on building or private housing. In 2017, the Government of Vietnam issued the supporting policy for the uptake of solar power. According to the Decision, the unused electricity generated from the PV power station can be sold back to the grid with a price of 9 EUR cent/kWh. This policy has attracted many investors in installing rooftop PV power stations in Vietnam. Both simulation and experiment were conducted to prove the effectiveness of a household grid-connected PV system.

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PART 2

Refurbishment potential

Part II investigates energy upgrade potentials and challenges of housing refurbishment in Vietnam. This part has 3 chapters: 6,7 and 8.

Chapter 6 presents the outcome of a housing survey. This survey is an extension of the 12 interviews in Chapter 2. The survey investigated characteristics of the existing houses, the actual energy consumption and reveals the 'performance gap' in the Vietnamese housing stock. This chapter also gives some insights into the current refurbishment activities in Vietnam, mainly for Northern Vietnam, and its potential for improving indoor environment as well as energy performance. This chapter is published as an article with the same title in the journal Smart and Sustainable Built Environment.

After identifying potential measures for refurbishing, it is important to validate their actual benefit in terms of comfort and energy use. There are several potential design measures mentioned in the previous chapters.. Chapter 3 presented several current green dwellings in Vietnam and the common design measure in all of the cases was facade design. Chapter 4 also pointed out the potential of solar shading and using a green building envelope. Results from the housing survey in chapter 6 suggested that there is a relation between thermal insulation and the thermal performance of the buildings. Moreover, current national technical regulations also focus on the facade design and thermal insulation and this regulation can be applied to small private buildings in the future.

This is the reason that the façade is investigated in more depth in two experiments on site in chapters 7 and 8. The first study is a housing performance simulation for different types of facades, presented in chapter 7. A typical tube house was selected to be modelled and simulated in the Design Builder software. Housing envelops that followi Vietnamese standards and Dutch standards were examined and compared. This chapter was presented at the CLIMA congress in Bucharest, Romania in 2018.

The second study is a physical experiment in a typical row house where the effect of a green façade on energy demand and comfort inside is investigated, see chapter 8. Different scenarios were set up to compare results between the green facade, an aluminium shading device and a bare facade. This chapter was published with the same title in the Journal of Facade Design and Engineering.

6 Improving Energy Efficiency in Private Housing

A survey of Challenges and Potentials in Vietnam

This chapter is reproduced from ‘Improving energy efficiency in Vietnamese tube houses: A survey of sustainable challenges and potentials’, published in the journal Smart and Sustainable Built Environment.

6.1 Introduction

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 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% (Burgett, 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 (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 chapter investigates 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% of the current housing stock, tube houses or attached row houses are the main target of this research.

6.2 Literature review

The first part of the study investigated status of the current housing stock in Vietnam. Most available data of housing is extracted from the national population and housing census which was conducted in 2009 (GSO, 2010). Data from the census is 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 result, the majority of the current houses were built after 1986. Among the housing typology, private housing was accounted for 99% and attached row houses alone was accounted for more than 70% (GSO, 2010).

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 (Ly et al., 2010; A. T. Nguyen et al., 2011; Phe & Nishimura, 1991). Ly et al., (2010) conducted a housing survey in 4 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. William et al., (2013) found that adoption of sustainable retrofit in United Kingdom 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 (Nazirah 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 private sector, including developers and contractors, are mostly commercial organizations, hence depend significantly on the government incentive programmes, as mentioned above. Low cost technology were preferred by the providers because cutting-edge technology were often perceived as less effective (William et al., 2013). Nazirah 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% of the people did not have the intention of applying energy efficiency measures in their houses over the next 10 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 (Nair et al., 2010; Pettifor et al., 2015). Other barriers to the energy efficiency intervention were also defined as aesthetic tastes and effect on lifestyle (Crosbie & Baker, 2010).

Actual energy savings also depend largely on user behaviour. Nguyen & Aiello (2013) studied different projects in Europe and the United States 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% 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 focusing on the user/home owner's perspective.

6.3 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 (P. A. Nguyen et al., 2016) and several studies on housing in Vietnam (Ly et al., 2010b; A. T. Nguyen et al., 2011). The survey is an online questionnaire in Vietnamese created with Google Form and was sent to Vietnamese respondents through email 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, see appendix A. 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 2 months. 153 households participated in this survey. Although the selection of the respondents was random, the first 10 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 was 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.

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 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 2 main groups by using 9 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 6.1.

TABLE 6.1 Summary of houses categories/colour coding

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

The classification was based on widely accepted literature of bioclimatic and energy-efficient design (Almusaed, 2010; A. T. Nguyen, 2013; P. A. Nguyen et al., 2017). Such classification is true for most parts of the country.

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., 2003), the houses will be categorised as follows:

- a building is “green” if more than 50% of criteria is marked as green
- a building is “red” if more than 50% of criteria is marked as red
- 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.

6.4 Descriptive analysis

Respondents

Among 153 responses recorded, see Table 6.2, there are 142 persons (93%) under the age of 40 and only 11 persons (7%) are 40 or older. Most respondents are aged between 25 to 39, which accounts for 77% (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% (127 people) are located in the Northern part and only 17% lives in the other regions of the country, Central and South.

The number of people in a family ranges from 1 to 7 and the most common composition is a 4-person family (28%). Three and five person families accounted for 18% and 20%, respectively, while 2-person and 6-person families accounted for 12% each. Single persons and big family compositions (more than 6 occupants) presented less than 10% of the total, see Table 6.2.

TABLE 6.2 Characteristics of the study population

House color	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

The traditional Vietnamese custom is to look for a stable home for the whole family. It is therefore no surprise that 118 persons (77%) stated that they were living in privately owned houses. About 15% 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

Housing characteristics are summarized in Table 6.3. Tube houses or attached row houses are the main target of this research. They account for 62% of the houses in this survey. About 28% of the houses are apartments and the remaining 10% are detached and semi-detached houses. Among the 95 tube houses, 78 houses (82%) are at least 3-storey high, and 77 houses (81%) have a plot size of 60 square meter or lower. Courtyard are presented in 12 houses (13% 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 1 to 2 storey high and are often bigger and include inner courtyards.

TABLE 6.3 Housing characteristics of the survey in 2016 among Vietnamese inhabitants

Housing typology	Apartment		Attached		Detached		Semi- detached		Total	
	Count	%	Count	%	Count	%	Count	%	Count	%
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

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TABLE 6.3 Housing characteristics of the survey in 2016 among Vietnamese inhabitants

Housing typology	Apartment		Attached		Detached		Semi- detached		Total	
	Count	%	Count	%	Count	%	Count	%	Count	%
External wall										
Brick wall 100-150mm, no insulation	13	8.5	35	22.9	3	2.0	1	0.7	52	34.0
Brick wall 100-150mm, with insulation	1	0.7	7	4.6	0	0.0	1	0.7	9	5.9
Brick wall 200-250mm, no insulation	10	6.5	35	22.9	5	3.3	0	0.0	50	32.7
Brick wall 200-250mm, 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
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

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TABLE 6.3 Housing characteristics of the survey in 2016 among Vietnamese inhabitants

Housing typology	Apartment		Attached		Detached		Semi- detached		Total	
	Count	%	Count	%	Count	%	Count	%	Count	%
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

Building age

Most of the houses were built in the last 30 years (95.4%), which means after the Economic reform of 1986. Almost half of the houses (49%) was built in the most recent 10 years, about one third (34%) was built in the earlier 10-year period and 12.5% 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 – 2005) accounts for approximately half of the total housing stock.

Building function

85% 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 8 options to select from: North, East, South, West and 4 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 2 main construction types: reinforced concrete (62%) and load-bearing masonry (21%).

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. 90% 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% of the houses. In terms of insulation, 70% 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% of the transparent windows are single glazed, while 18% is double glazed. Popular window frames are wood and aluminium (88%) which can be explained by their economic price. 36 times the wooden shutter was mentioned to block direct sunlight and protect the house from overheating.

Discussion: Ly's investigation also found that the reinforced concrete frames and brick external walls are dominant (Ly et al., 2010b). 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 3 to 5 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% 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%). A small light-well was mentioned 43 times and inner courtyards were recorded in 14 answers (9%).

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 5-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%) indicated that the thermal environment in their house is bad or very bad, see Figure 6.1.

Ly et al., (2010b) 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.

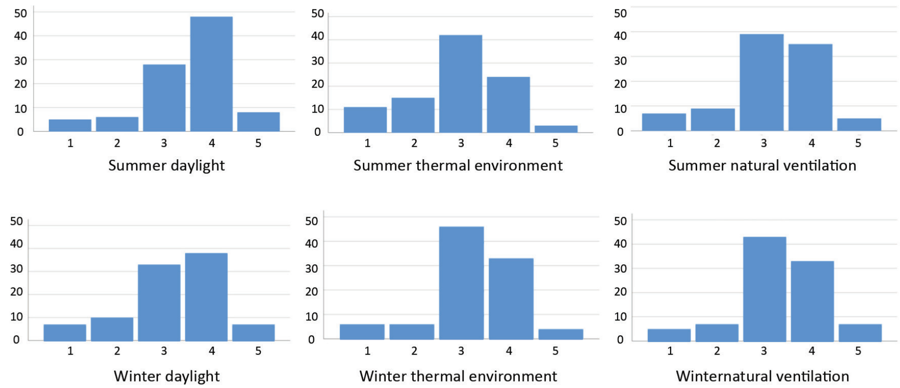

FIG. 6.1 Frequency of indoor environment self-assessment (1 = very bad, 5 = very good)

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% of the families used only electricity, 65% 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% of the families use the air-conditioner and 93% of the people have water heaters. The respondents were mainly located in the Northern part of the country where there are 2 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% of the answers and 47% of the respondents use equipment with energy efficient labels. Compared to Ly's results in 2010, where only 3% of the surveyed houses installed either solar collectors or photovoltaic cells or energy efficiency equipment.

6.5 Energy performance indicator

This chapter 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.

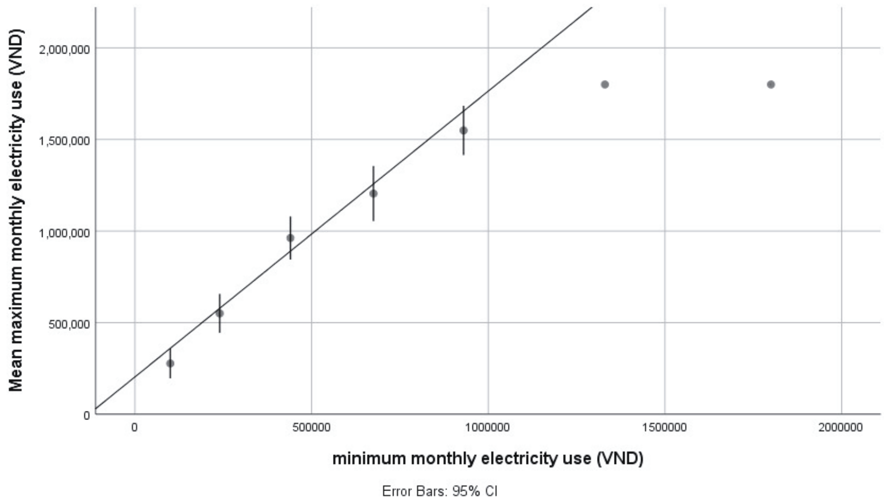

FIG. 6.2 Maximum and minimum monthly energy use in households

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 6.2. 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 = $(204 \pm 68) \times 10^3 + (1.56 \pm 0.13)$ * 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 = $(84 \pm 125) \times 10^3 + (200 \pm 30) \times 10^3$ * 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 6.3.

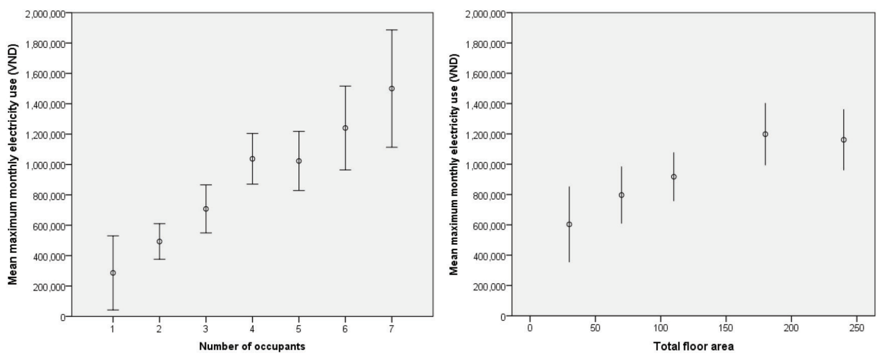

FIG. 6.3 Relationship between maximum monthly energy consumption and number of occupants, total floor area

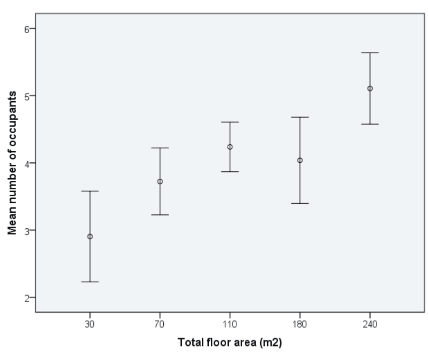

FIG. 6.4 Scatterplot graph showing the relationship between the number of occupants and the total floor area

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

Figure 6.4 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.

6.6 Results and Discussions

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 6.4.

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 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.

TABLE 6.4 Correlation between indoor environment and maximum monthly energy consumption with building characteristics

	Indoor environmental comfort		Energy consumption per person	
	Correlation coefficient	Significance value (p)	Correlation coefficient	Significance value (p)
Orientation	-.105	(.234)	-.096	(.281)
External walls	.251**	(.004)	-.096	(.277)
Windows configuration	-.098	(.267)	.084	(.346)
Roof detail	.223*	(.011)	.094	(.289)
Courtyard	.082	(.354)	.084	(.341)
Solar control	.153	(.081)	.027	(.762)
Use of energy efficiency equipment	-	-	-.147	(.096)
Use of solar collectors	-	-	.133	(.133)
Indoor environment	-	-	-.096	(.277)

**Correlation is significant at 0.05 level*
***Correlation is significant at 0.01 level*

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 Figure 6.5 & Figure 6.6. 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 insulation in order to get rid of unwanted heat as fast as possible (A. T. 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, 2013). 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.

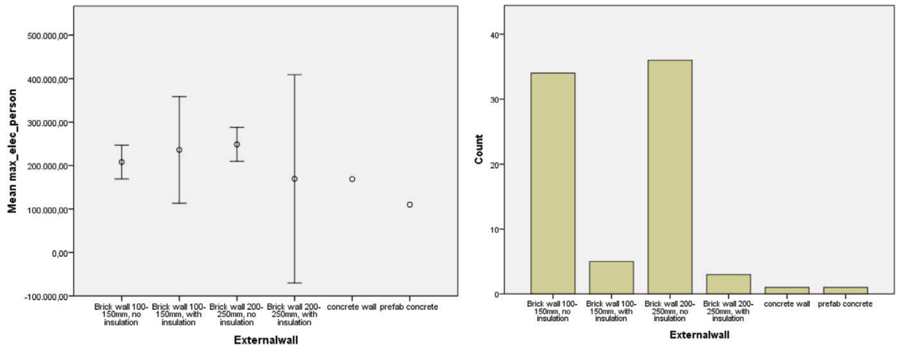

FIG. 6.5 Left: Scatterplot graph of external walls type & mean of maximum monthly energy consumption per person (kWh). Right: Number of cases with different types of external walls

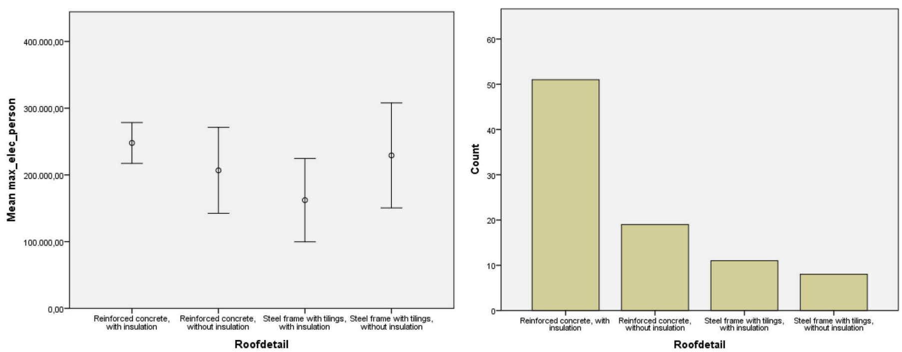

FIG. 6.6 Left: Scatterplot graph of roof type & mean of maximum monthly energy consumption per person (kWh). Right: Number of cases with different types of roof

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 3 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 1 or 2 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 (Ortiz et al., 2017; Yoshino 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 (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.

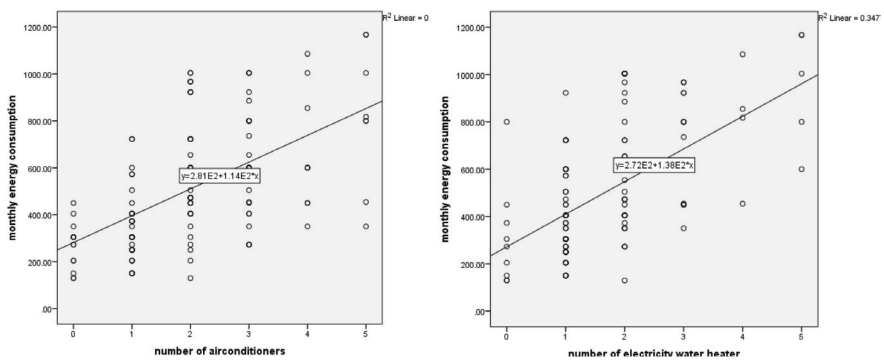

FIG. 6.7 Scatter plot showing relationship between maximum monthly energy consumption (kWh) and number of air-conditioners and electrical water-heaters

TABLE 6.5 Regression analysis showing relationship between monthly energy consumption (kWh) and number of air-conditioners and electrical water-heaters

Model		Unstandardised Coefficients		Standardised Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	244	35		6.9	.000
	number of air-conditioners	61	21	.307	2.8	.005
	electricity water heater	83	25	.354	3.2	.001

Figure 6.7 and Table 6.5 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 6.7. 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 a larger use of energy, it warrants further investigation to find out how to reduce energy in houses.

Discussion: In general, 90% of the houses have air-conditioners to improve their indoor environment (Table 6.6). 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 1 to 3 AC units (78% of the total number of cases and 87% 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% of the "very bad" and 31% of the "bad" indoor comfort houses do not have any air-conditioners, see Table 6.6. To further test the hypothesis that houses without air-conditioner do not have a good comfort, such houses were further investigated.

TABLE 6.6 Crosstab table of number of air-conditioners and self-assessment of thermal comfort in summer

Summer thermal comfort		Number of air-conditioners			
		0	1-2	3-5	Total
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%

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% were built in the last 10 years, and more than 30% were built in the previous decade. 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%. In general, ten houses were graded as "red" and only 2 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 (Jung et al., 2013).

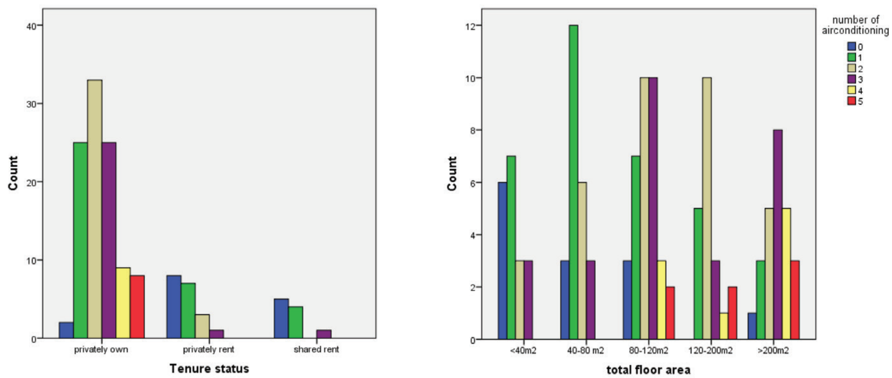

FIG. 6.8 Characteristics of air-conditioner-free houses

Figure 6.8 shows the number of air-conditioners by tenure status and total floor area of the houses. Among 120 private owned houses, only 2 of them do not have any air-conditioning units while 45% 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.

6.7 Refurbishment study

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 6.9).

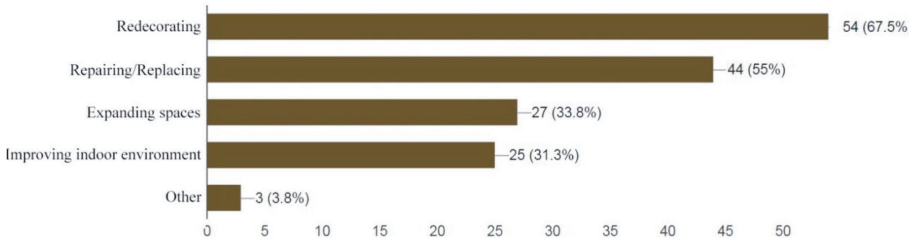

FIG. 6.9 Reasons for refurbishing houses according to the respondents

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 10 years, see Figure 6.10. 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.

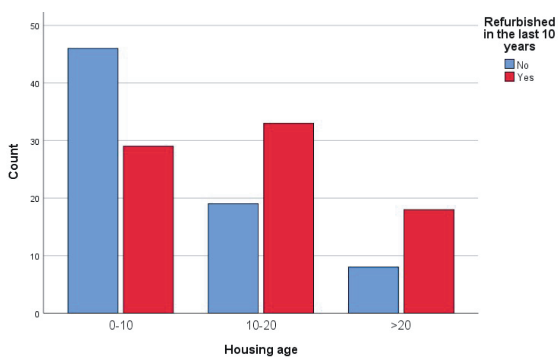

FIG. 6.10 Houses that are being refurbished in the last 10 years and their ages

Refurbishment in the last 10 years has led to changes in housing performance in terms of indoor environment and energy consumption. Figure 6.11 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.

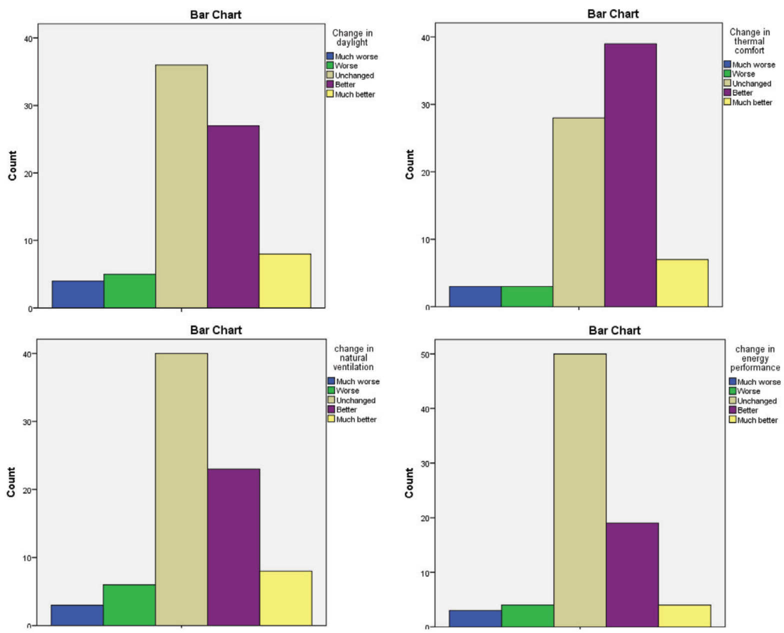

FIG. 6.11 Change in housing performance after refurbishment

Refurbishment in general improves the building performance. Table 6.7 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, the building performance remained unchanged or improved for at least 86% 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% of the cases, whereas these rates in the redecorating and expanding sections ranged from 11% to 14%).

TABLE 6.7 Refurbishment content and change in housing performance

		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%

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% of the cases. These rates only vary from 24% to 40% 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% of the respondent were satisfied with their homes and did not have the need to improve their current homes. 12% of them wanted to renovate the houses but did not have sufficient funding. The rest 24% of the homes were rented properties so the occupants did not want to or were not allowed to refurbish their houses, see Figure 6.12.

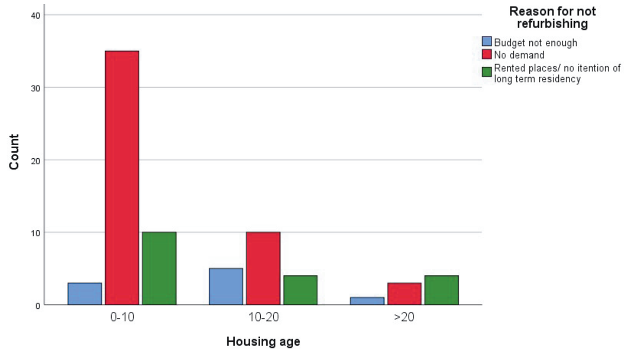

FIG. 6.12 Reasons for not refurbishing houses

Occupants perceived energy bills in most cases as not expensive nor cheap. 64% of the respondents stated that the bills were reasonable for them (Figure 6.14). 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). 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 6.13. 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.

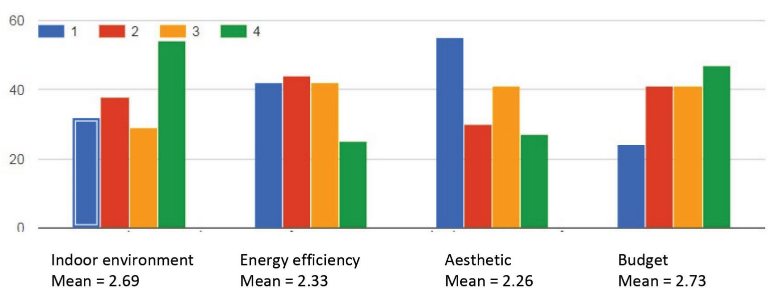

FIG. 6.13 Ranking of different criteria in refurbishment decision

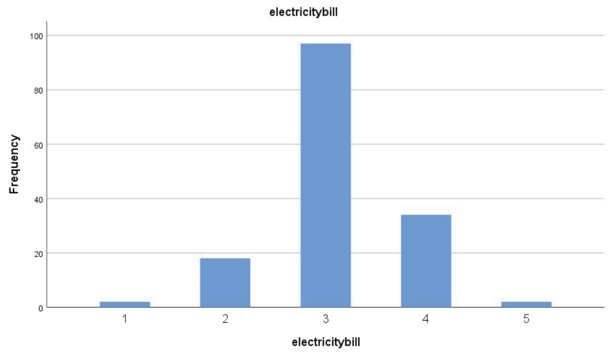

FIG. 6.14 Occupants perception of energy bills. 1: cheap, 3: neutral, 5: expensive

6.8 Conclusions

This chapter presents results of a housing survey in Vietnam, focusing on building characteristics, energy performance and refurbishment activities. There are few studies on the energy use of households in Vietnam, especially actual energy consumption. Previous studies focussed on the relationship between building parameters and indoor environment (Ly et al., 2010b; A. T. Nguyen et al., 2011) 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.

Firstly, 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 A. T. Nguyen (2013) and partly agrees with the paper of Ly et al., (2010b) 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 focusing 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.

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7 Facade design simulation

This chapter is a reproduced conference paper titled ‘Facade Refurbishment For Energy Saving In Tube Houses – A case study in Hanoi, Vietnam’, published in the proceeding of the CLIMA Congress 2019 in Bucharest, Romania.

7.1 Introduction

The residential sector, which accounts for more than 31% of total energy consumption (IEA, 2012), has been addressed as one of the most important sectors that can reduce the total energy consumption in Vietnam. It is estimated that there are more than 22 million residential units in Vietnam (GSO, 2010). There is a great demand for refurbishment strategies for energy upgrading the current Vietnamese housing stock. Among those dwellings, the tube house, or attached row house, is the most dominant housing typology which accounts for more than 70% of the total living units (GSO, 2010). This chapter investigates the energy upgrade potential of different façade refurbishment options for Vietnamese tube houses.

7.2 Literature study

Facade refurbishment for energy efficiency has been profoundly investigated and was proved to bring many benefit to the energy upgrade of the current housing stock. A facade refurbishment toolbox was developed to estimate energy performance of different design measures in early design stages in temperate climate (Konstantinou, 2014). Several potential general refurbishment design strategies were defined for energy efficiency in the tube houses of Vietnam (P. A. Nguyen et al., 2017). Many of them involved the renovation of the existing building envelope. Measures include thermal insulation and shading device for the opaque envelope, passive solar gain for windows and glazing area, and natural ventilation and evaporative cooling using green walls and roofs. This paper investigates only thermal insulation and shading devices.

Current thermal comfort theory and air conditioning practice mainly concern the situation where occupants are awake during daytime. However, in residential buildings, people spend a considerable amount of time sleeping and therefore energy consumption of air-conditioning during night time is important. Moreover, thermal comfort during night time is different from normal comfort model. Changing thermal insulation of a bedding system affects the optimum operative temperature significantly (Lin & Deng, 2008). A programmed air-temperature change can potentially reduce almost one third of the cooling load during the night (Lan et al., 2016). This paper takes into account the sleeping thermal comfort and air-conditioning behaviour during the night time. During the model calibration process, heating and cooling patterns were customized accordingly to the actual occupants' behaviour.

7.3 Methodology

A typical tube house was selected as a case study house. It is located in the urban area of Hanoi, the capital of Vietnam, and the plot size is 4x12 metre. The house is 4-storey high and has 2 facades at the front and rear. It has reinforced concrete frame, 220mm brickwork external walls and single glazing windows, see Figure 7.1.

On-site measurement was carried out to collect the data of energy consumption of the equipment, indoor and outdoor temperature (see 7.3.1). Information about the design and construction of the case study house was gathered to set up a model in Design Builder software version 4.7. The model considered all aspects from the surrounding landscape until the material of a building component. The model was calibrated by the measured data (see 7.3.2). The model was simulated with different refurbishment options to investigate energy upgrade compared to the reference case (see 7.3.3 & 7.3.4).

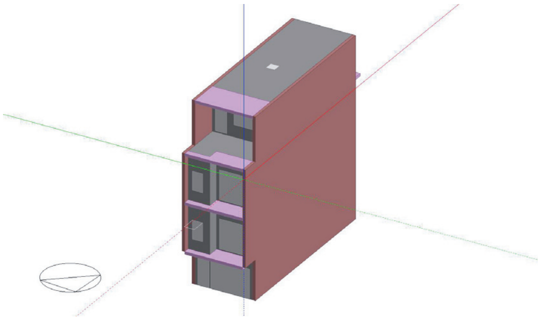

FIG. 7.1 Design Builder model of a case study house

7.3.1 Onsite monitoring

The building performance was monitored for 2 months, December 2017 and January 2018. The selected period was subject to the arrangement with the house owners. Moreover, in winter months, the air-conditioners were less likely to be used and it would be easier to calibrate the model with the non-conditioned space. When the air-conditioners were not in use, the building is natural ventilated through windows and doors by the users. Outdoor and indoor temperature and energy consumption were measured by Sense and Source, monitoring equipment that was developed by the Plugwise company, see Figure 7.2.

FIG. 7.2 Plug-wise unit installed for energy measurement

Figure 7.3 shows the location of the measurement units in the house. Currently, there are only 2 occupants living in the house and they mostly occupy the lowest two floors. The ground floor is mainly equipped with kitchen appliances such as induction cooker, refrigerator, microwave oven. Both the living room and bedroom on the first floor are equipped with air-conditioners that are capable of both heating and cooling. A water boiler is located in the bathroom on the first floor for daily showering. Most of pluggable electrical equipment was measured. The lighting system could not be measured because the cables are inside the walls. A washing machine on the top floor is out of range of the monitoring system hence is also not measured. However, it is rarely in use and can be estimated easily by simple calculation. Monthly energy bills were recorded to quantify consumption of unmeasured equipment.

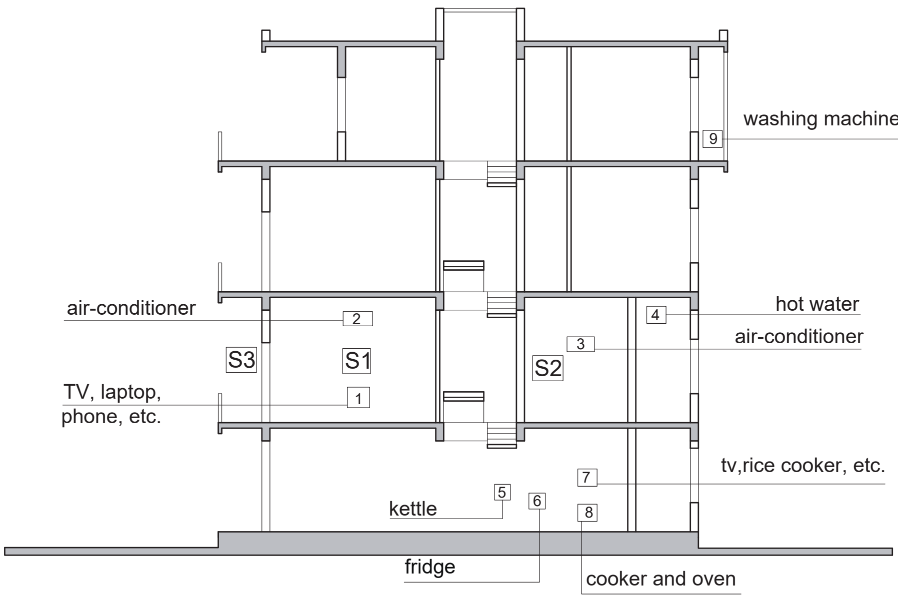

FIG. 7.3 Locations of the measurement units in the house

7.3.2 Model Calibration

Calibration of a housing model is an important step to check how well the model can predict housing performance by comparing it with data of the actual building. The calibration procedure included different steps, see Table 7.1.

TABLE 7.1 Summary of modifications to the model

Run	Recorded changes
1	Simple model with construction parameters
2	Update holiday schedule Change ventilation setting Update lighting schedule
3	Update building orientation Update infiltration setting
4	Update new weather data New setting for air conditioner and infiltration
5	Update occupant density Update shading device
6	Update Heating and cooling setting
7	Update Heating and cooling setting Update electrical equipment data

TABLE 7.2 Different criteria for calibration runs

Run	4	5	6	7	ASHRAE
NMBE	1.7%	3.4%	2.3%	0.8%	<5%
CV(RMSE)	5.5%	6.0%	4.9%	3.9%	<15%
Regression	0.52	0.54	0.71	0.75	>0.75

Onsite-measured outdoor temperature and humidity, along with solar radiation and outdoor wind data which were acquired from the Hanoi meteorological station (World Bank, n.d.) were used to compose a weather file. Housing information was used to create a model in Design Builder software. Finally, the simulated hourly indoor temperature was compared with the measured hourly indoor temperature to evaluate the accuracy of the model. The correlation between the simulated and measured data was improved by adjusting uncertain input variables within an reasonable range. Those variables are natural ventilation scheme, occupant activities, HVAC system settings, equipment specification. The model is calibrated after 7 calibration runs, where the residual reaches certain threshold defined in ASHRAE standards (A. T. Nguyen, 2013), see Table 7.2. It is generally accepted that the statistical approach which applies two statistical indicators - Normalized Mean Bias Error (NMBE) and Coefficient of Variation of Root Square Mean Error CV(RMSE) – is the most reliable measure to verify the calibration (A. T. Nguyen, 2013).

Another important measure to evaluate the model is to use the regression analysis to check to correlation of the measure and simulated data. Actual bedroom temperature and simulated bedroom temperature are plotted in Figure 7.4 & Figure 7.5. The final model at calibration run 7 met the statistical standards and also the bedroom temperature values at run 7 were the closest to the measured data. The model is good enough and is considered to be calibrated.

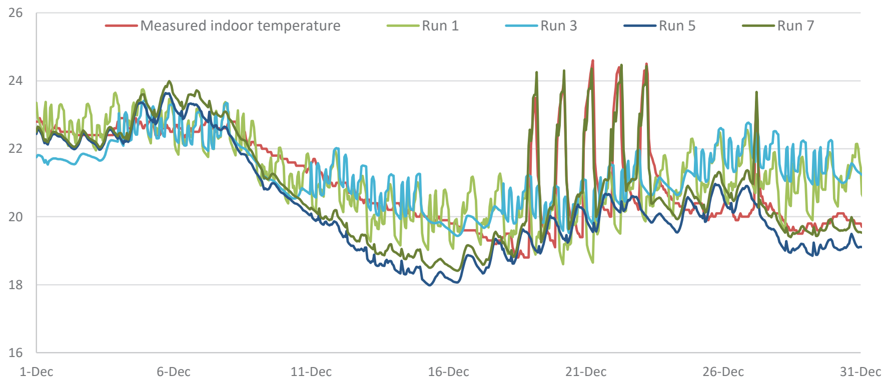

FIG. 7.4 Bedroom simulated and measured temperatures

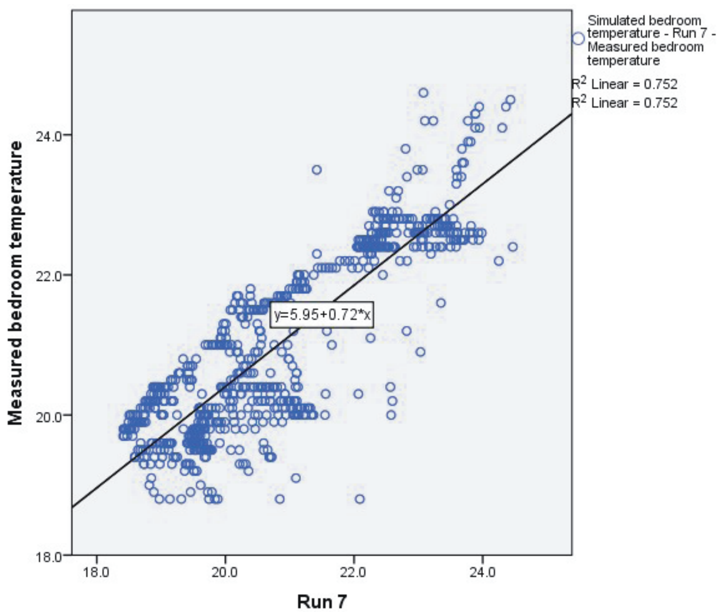

FIG. 7.5 Bedroom measured & simulated temperature at run 7

7.3.3 Building Simulation

In order to examine the different refurbishment measures, full-year simulations of calibrated EnergyPlus models of the house were conducted. Thermal performance and energy performance were simulated. A full calendar year simulation can assess housing performance rather than only the heating or cooling period. The EPW weather file of Hanoi was used, instead of the measured weather file. Calibrated EnergyPlus model of the house was also modified to fit with a one-year scenario. HVAC system was also scheduled in a simpler way, operated by schedule and temperature – triggered mechanism. The heating set-point was 21.5°C and the cooling set point was 28.5°C.

Currently, only two persons occupy one bedroom in the house and only one air-conditioner in this bedroom is active. However, in the simulation scenario, 2 out of 3 bedrooms were occupied, which represents a typical family situation in a similar size tube house in Vietnam. Therefore, two air-conditioners were included in the energy consumption calculation.

7.3.4 Facade Refurbishment options

The housing façade includes external walls, roof, external opening/glazing area, and facade components such as shading devices, balcony. Only two bedrooms require heating and cooling in the house, therefore only external walls and glazing openings are considered to be renovated because they are directly connected to the conditioned spaces. The roof construction mainly benefits the performance of the top floor which is currently unconditioned.

Two refurbishment methods are carried out. The first method is the regulation method. One of the objectives of the larger study of the author is to provide recommendation for the energy efficiency regulation for the tubes houses in Vietnam. Therefore, envelop construction recommended by different technical regulations were applied, see Table 7.3. The Vietnamese technical regulation for energy efficiency (MOC, 2017), which only applies to the large-scale buildings, was the first to consider. Dutch standard for the building envelope (Van Overveld et al., 2012) was also tested.

Adding shading devices is the second method. Shading devices are a popular low-cost solution to prevent direct solar gain and overheating in summer. The benefit of adding shading devices to the bedroom on the second floor was investigated.

The simulation calculated the performance of the bedroom when a 0.5m and 1m overhangs were added. Furthermore, external blinds with medium reflective slats (solar reflectance of 0.5) were also investigated.

TABLE 7.3 Facade refurbishment options by regulation

	External Walls	Windows
Current detail	220mm brick work, no insulation, U = 3.197 W/m2K	Single glazing, U = 5.778 W/2K, SHGC = 0.819
Vietnamese regulation	Wall 1 - U max = 1.8 W/m2K	Glazing 1 - SHGC max = 0.63
Example	Add 10mm of extruded polystyrene, U = 1.682 W/m2K	Double glazing, SHGC = 0.69 U = 2.7 W/m2K
Dutch regulation	Wall 2 - Umax = 0.29 W/m2K Rc= 3.5 m2K/W	Glazing 2 - Umax = 2.2 W/m2K
Example	100mm brick work, 120mm XPS extruded polystyrene, 100 mm concrete block, plastering, U= 0.26 W/m2K	Double glazing, SHGC = 0.67 U = 2.1 W/m2K

7.4 Results and Discussion

7.4.1 Measurements Results

Figure 7.6 illustrates the measured temperature in the month of December 2017. The outdoor temperature ranged from 15° to 25° C. The indoor temperature did not vary much and reached a low at 19°C. From the 18th until the 23rd and on the 27th of December, the air-conditioner was turned on during the night time in the bedroom. This explains the fluctuation of indoor temperature in Figure 7.6. The bedroom air-conditioner was only used for a number of hours during the night.

The house utilizes electricity as the main and only energy source for daily use. High consumption equipment are the air-conditioners and the boiler for domestic hot water. Figure 7.7 & Figure 7.8 show the monthly energy consumption in 2017 and energy consumption by the appliances in December 2017.

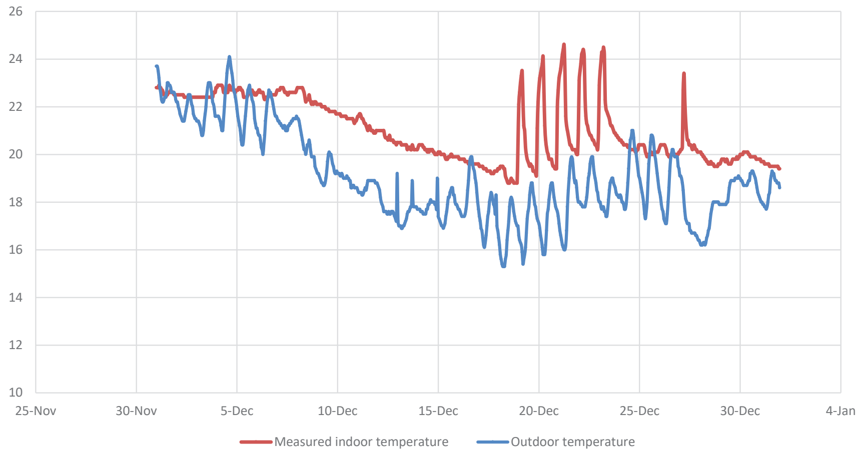

FIG. 7.6 On-site measured outdoor and indoor temperature

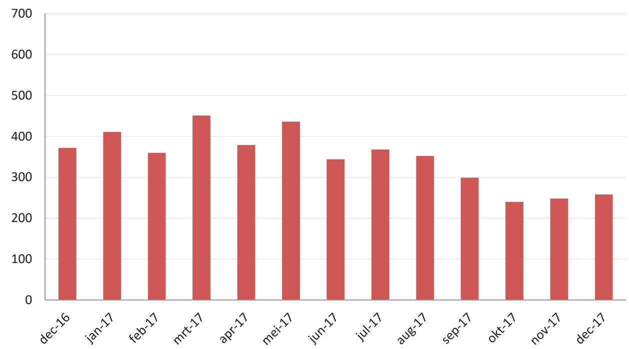

FIG. 7.7 Monthly energy consumption in 2017 (kWh)

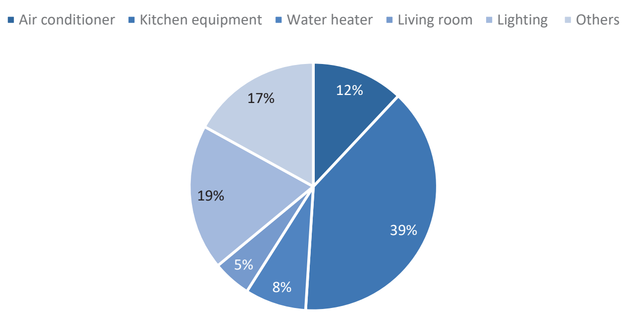

FIG. 7.8 Appliances consumption December 2017

Total actual energy consumption in 2017 was 4518 kWh and the average monthly consumption was 376 kWh. Energy use in summer time was generally higher than that in winter. Peak energy consumption was in May but not June or July due to the summer vacation. Energy use in March was highest because the house was occupied by guests during that period.

Total energy use in December 2017 was 258 kWh. Only 11.6% of the energy was used for heating. Kitchen appliances (refrigerators, induction cooker, ovens) accounted for the largest energy use (38.8%). The lighting system also consumed a considerable amount of energy (18.9%).

7.4.2 Simulation Results

Simulated consumption of the reference house is shown in Table 7.4. Annual electricity usage is around 5500 kWh. The amount of energy spent for heating and cooling accounts for one-third of the total energy consumption. Electrical appliances take the largest share (45%), while lighting and hot water consume 15% and 7% of total energy consumption, respectively.

TABLE 7.4 Simulated annual consumption – reference house

	Energy (kWh)	Percentage (%)
Heating	575	10%
Cooling	1244	22%
Lighting	843	15%
Equipment	2448	44%
Hot water	397	7%
Total	5509	100.0%

7.4.3 Regulation based refurbishment

The ultimate goal of the research is to reduce energy consumption in the house therefore the analysis focuses on how much energy is saved by utilizing different refurbishment methods. Table 7.5 presents simulated heating and cooling demand of the houses after refurbishment. Retrofitting the facade accordingly to the current Vietnamese technical regulation (wall 1 and glazing 1) does show some improvements but minor (less than 6% of total heating and cooling energy). Double glazing windows do not show much different in energy performance. While heating energy varies less than 2.6%, cooling energy is reduced by less than 4.4% and total heating and cooling performance is improved by 3% for Glazing 1 and almost 4 % for Glazing 2.

TABLE 7.5 Simulated energy consumption of different facades*

	Heating	Saving	Cooling	Saving	HVAC	Saving
Current	577	-	1245	-	1823	-
Wall 1	530	8.2%	1180	5.3%	1710	6.0%
Wall 2	439	24%	1081	13.2%	1521	16.6%
Glazing 1	564	2.3%	1205	3.3%	1769	3.0%
Glazing 2	562	2.6%	1191	4.4%	1754	3.8%
W1 + G1	516	10.7%	1137	8.7%	1653	9.3%
W2 + G2	423	26.8%	1012	18.8%	1435	21.3%

** see Table 7.3 for the values of walls and windows*

Although applying Vietnamese regulation on external walls and windows separately does not show significant improvement, utilizing both of them at the same time brings acceptable results, 9 % reduction in air-conditioning consumption.

Applying Dutch standards into facade refurbishment shows desirable reduction in energy consumption. Highly insulated walls as followed the Dutch requirement shows significant reduction in heating demand (24%) and cooling demand (13%). Combining with double glazing windows, heating demand is expected to be reduced by 26.8%, 18.8% for cooling energy and 21% for both heating and cooling.

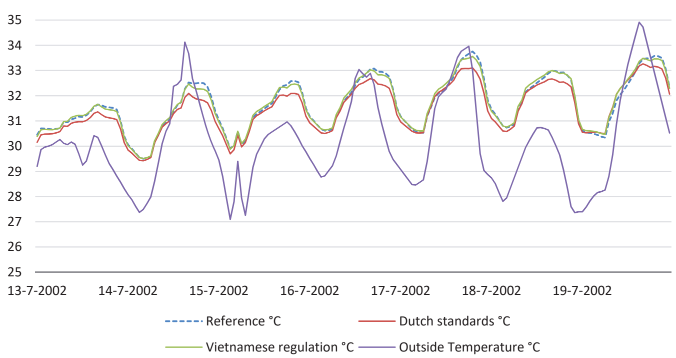

FIG. 7.9 Simulated bedroom temperature during summer week

Regarding thermal performance, bedroom temperatures of the reference case and refurbished case following Vietnamese and Dutch regulations during a summer week are plotted in Figure 7.9. Air-conditioner was off. As can be seen from the graph, thermal performance of the Vietnamese regulation refurbished case is very similar to the reference case. Highly insulated facade following Dutch regulation also shows little improvement during night-time period but reduces peak temperature during daytime up to 0.8°C. Indifferences in night-time temperatures support the hypothesis that reduction in cooling energy is due to the "cold loss prevention" rather than reducing indoor air temperature. Lower peak temperature during summer time can be explained by the thermal mass provided by a 100mm layer of concrete block that was added to the existing construction. It also suggests potential further energy saving if air-conditioner is used during the day.

7.4.4 Shading device refurbishment

As described above, three different types of shading options were simulated in the model. Results of energy performance are plotted in Table 7.6. Simulation results reveal that, despite being regarded as an effective bioclimatic design measure, shading device leads to limited improvement in energy performance. All of the shading options have negative effect during heating season because there is less direct solar heat gain. A 0.5-meter and a 1-meter horizontal shading device only reduce cooling demand by 3% and 6% respectively. Shading 3, which includes external blinds, shows a 12.6% reduction in cooling demand but increases heating demand by 5.1%. In general, shading devices have a maximum reduction of 7% in total heating and cooling energy.

In this simulation, an external blind works more effectively than an overhang because the window is oriented to the southwest where the sun angle is very low in the afternoon. By then, the horizontal shading devices are less likely to block as much direct solar radiation as an external window blind. Therefore, selecting an appropriate shading device type is important to achieve desirable results in energy performance.

Shading device also helps improve indoor environment in the bedroom, though little. Figure 7.10 plots the bedroom temperature during a summer week of July. The overhangs help reduce the bedroom temperature by approximately 0.1°C while the external blind brings the temperature down by up to 0.3°C.

TABLE 7.6 Simulated energy consumption of the shading options

	Heating	Saving	Cooling	Saving	HVAC	Saving
Current	577	–	1245	–	1823	–
0.5m overhang	584	-1.3%	1208	3.0%	1792	1.7%
1m overhang	592	-2.6%	1171	6.0%	1764	3.2%
External blind	607	-5.1%	1089	12.6%	1696	7.0%

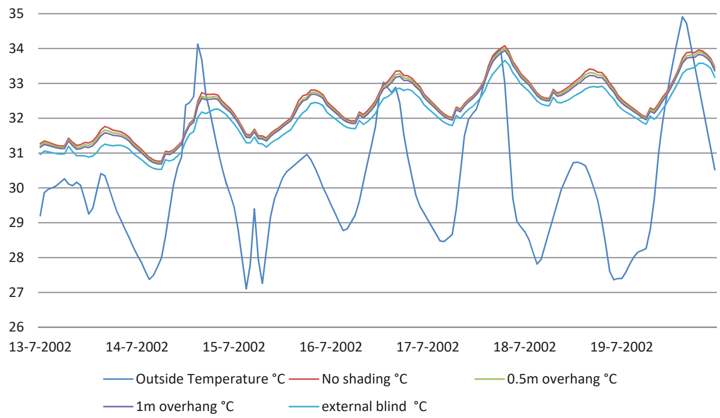

FIG. 7.10 Simulated bedroom temperature with different types of shading

7.4.5 Discussion

The benefit of highly insulated facade during the heating period is foreseen but its notable reduction in cooling demand is quite promising, considering the fact that it gives much more improvement compared to shading devices performance, the well-known believed-to-be-effective measure. This can be explained by the operation schedule of the air conditioner system or the occupant behaviour. The air conditioner is only turned on at nights and when it is necessary. Therefore, bioclimatic measures that help improve indoor climate during day time is less relevant to energy consumption. Highly insulated facade, on the other hand, helps prevent the “cold loss” and the sensible cooling helps reduce cooling demand during the nights. However, energy performance was only simulated with night time air-conditioning. Further investigation on the effect of highly insulated facade on daytime air-conditioning performance is recommended to confirm the benefit of such refurbishment options.

7.5 Conclusion

This chapter investigated the energy upgrade potential of different facade refurbishment options. A calibrated Design Builder model was created to simulate energy performance of different cases. Vietnamese technical regulation of energy efficient buildings and Dutch standards were the two main guidelines for the selection of refurbished facade, along with shading device renovation.

The simulation results showed that applying the Vietnamese technical regulation, which is currently only applied to large-scale building, can save up to 9% of energy for heating and cooling. More interestingly, highly insulated facade that followed the Dutch standard led to much more favourable results of 21% reduction in air conditioner energy consumption. It is worth to note that such an improvement was achieved with a night-time operation of air-conditioner only, as this is how the system was working in the reference house. The bedroom thermal performance suggests that the highly insulated facade helps to reduce the energy consumption by the “cold loss prevention” effect. Day-time air-conditioner usage might also be improved due to the lower peak temperature.

On the other hand, shading devices were tested on a southwest facade window. Despite being regarded as an effective refurbishing measure, horizontal overhang had very limited benefit of less than 6% reduction in cooling energy. An external blind can save up to 12.6% of cooling energy. However, as all three shading types had a negative effect in the heating season, the maximum annual saving was only 7%.

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8 Effects of a vertical green facade on the thermal performance and cooling demand

A case study of a tube house in Vietnam

This chapter is reproduced from an article titled 'Effects of a Vertical Green Façade on the Thermal Performance and Cooling Demand – A Case Study of a Tube House in Vietnam' published in the journal Façade Design and Engineering.

8.1 Introduction

Traditional Vietnamese architecture has often been designed with bioclimatic principles to maintain a good thermal environment without the help of a mechanical heating or cooling system. A Vietnamese proverb that describes green bioclimatic principles as follows: "to plant palm trees at the front (south) and banana trees at the rear (north)". The high palm trees at the front provide shading and at the same time enables the cool summer air to ventilate the house. On the other hand, the lower banana trees at the rear help to block the cold northeaster wind in winter.

Despite its popularity in the past, plants and trees are limited around contemporary tube houses. A 'tube house' is a contemporary attached row house in Vietnam with a narrow width and long depth. The contemporary tube houses were built after the economic reform in 1986. While one can easily find green aspects in a traditional rural house in Vietnam, high-density population and fast-growing urban development leave less room for trees to grow in the cities. Maintenance is also the reason for not having a lot of plants in and around the houses. The lack of greenery might not only negatively affect the energy and indoor climate performance of a single house but may also contribute to the urban heat island (UHI) effect (Szkordilisz, 2014).

FIG. 8.1 A housing refurbishment case in Vietnam. Left: old house. Right: refurbished house

Recently, with a clear aim to improve the aesthetic and thermal performance, more and more houses are built with integrated greenery. Such trends were applied by famous Vietnamese architects such as Vo Trong Nghia, Hoang Thuc Hao and Nguyen Hoang Manh. Figure 8.1 shows a housing refurbishment case by Vo Trong Nghia, where he redesigned the façade with a whole new greenery layer. In Vietnam those projects are collated under the name of green buildings or sometimes also referred to as sustainable buildings. However, there is little scientific evidence that shows the actual benefit of green solutions. The research presented in this chapter conducts an experiment of the greenery system on an existing tube house of Vietnam. The experiment investigates the effect of vertical greenery on the thermal behaviour and energy consumption and compares it with an aluminium shading device and a normal bare facade.

8.2 Literature review

Green walls (GW) are categorised based on their construction and characteristics (Manso & Castro-Gomes, 2015). They can be classified in two main groups: green façades (GF) and living walls systems (LWS) (Dunnett & Kingsbury, 2004; Köhler, 2008). In green façades, walls and windows are often covered by climbing plants, whereas LWS often have integrated supporting materials and technology so greenery can grow uniformly on an extended vertical surface. There are direct green façades (plants grow directly on the wall surface) and indirect green façades (plants grow on a supporting system) (Manso & Castro-Gomes, 2015). Different types of green walls are shown in Figure 8.2

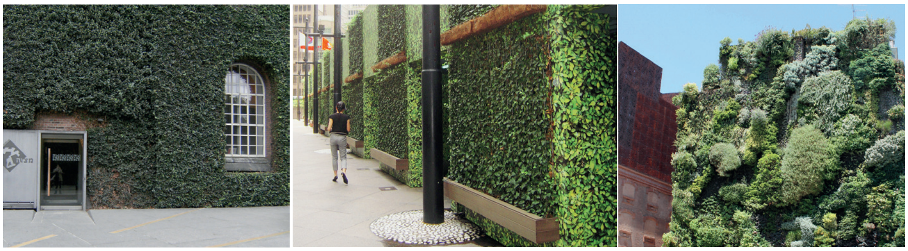


FIG. 8.2 From left to right: direct green façades, indirect green façades, living wall system

Previous studies have investigated the effects of green facades and living wall systems on the building environment and the energy performance (Table 8.1) . Vertical greenery systems work as a natural sun shading since, compared to a bare façade, they reduce the air surface temperatures behind the green layer (Kontoleon & Eumorfopoulou, 2010; Perini et al., 2011). Evapotranspiration effects of the plants were confirmed by a slightly lower air temperature and higher air humidity of the space between a normal facade and a green façade (Pérez et al., 2011). The maximum cooling effect of a greenery system is reported during the summer period, and better efficiency is found in locations with higher solar radiation. A greenery system also mitigates the urban heat island effect by lowering the air temperature in large urban area (Alexandri & Jones, 2008; Wong et al., 2010). In terms of energy saving, a green façade has much potential to reduce the cooling load in both temperate and hot climatic regions (Coma et al., 2017; Haggag et al., 2014; Pérez et al., 2017). Effects of green façades on the thermal and energy performance in winter conditions are still debatable (Raji et al., 2015).

TABLE 8.1 Summary of previous experiments on green façades & living wall systems

#	Location Time	Facade – Plant type	Method	Key Findings/ Reference
1	Spain 2011 - 2013	Green façade Ivy, Honey suckle, Boston Ivy & Clematis	Experiment on 2 house-like cubicles (2.4x2.4x2.4 meter)	(Coma et al., 2014) Reduction of up to 14°C on outside wall surface temperature. No significant energy saving was found
2	Spain 2014	Green façade Boston Ivy	Experiment on 2 house-like cubicles (2.4x2.4x2.4 meter)	(Pérez et al., 2017) DSGF can provide comparable shadow factor values to other factors, such as façade setbacks, cantilevers, etc. Reduction of outside surface temperature Energy savings are dependent on orientation
3	Spain 2014 - 2015	Green façade Ivy Ever green	Experiment on 3 house-like cubicles (2.4x2.4x2.4 meter)	(Coma et al., 2017) Energy saving in summer: up to 58% (GW) and 34% (GF) Energy saving in winter: up to 4.2%
4	China	Living wall system	Experiment on 2 thermal labs	(Chen et al., 2013) Outside surface, inside surface and indoor temperature reduce by a maximum of 20.8, 7.7 and 1.1 Celsius degree respectively The LWS closer to the wall perform better in cooling effect.
5	Singapore 2010	Living wall system	Experiment on 8 living wall systems on a wall only	(Wong et al., 2010) Reduction in surface temperature
6	Hong Kong 2011–2012	Living wall system	Experiment on external wall of a n apartment	(Dahanayake & Chow, 2017) Reduction in surface temperature and outdoor mean radiant temperature during intense exposure period
7	UAE July	Planter boxes of vegetation	Experiment on an existing school building, 2 east-facing classrooms were selected.	(Haggag et al., 2014) Peak time indoor temperature is reduced by at least 5 Celsius degree Air-conditioning energy is reduced by 20%
8	Netherlands 2017	Direct GF & LWS based on planter boxes and mineral wools	Experiment on a climate chamber (1.1x1.4x1.4 meter)	(Ottelé & Perini, 2017) Due to the insulation layer, no difference in indoor temperature was found Green facades help bring surface temperature differences of up to 5.8°C in the summer and 2.1°C in the winter

Among the research on vertical greenery systems, many studies physical experiments and measurements. Table 8.1 summarises the experiments on green facades and living wall systems. These experiments were located in Spain, the Netherlands, China, Singapore, Hong Kong and the United Arab Emirates (UAE) in the period from 2010 to 2018. The 3 studies in Spain were carried out by the same authors. The Spanish chosen plant species was Boston Ivy, which grew in a double skin green façade. The studies in Asia had a more diverse selection of plants, with different plant types in a living wall system or in planter boxes. Most of the studies were conducted in a laboratory environment (Chen et al., 2013; Ottelé & Perini, 2017), or in a real outdoor context but with small-scale prototypes (Coma et al., 2014, 2017; Pérez et al., 2017; Wong et al., 2010). The main reason for that is the lack of the greenery in the field and the diversity of the experimental outdoor conditions between the cases such as orientation and environmental parameters (Ottelé & Perini, 2017). Furthermore, in a laboratory, boundary conditions are controlled easily and different types of greenery can be compared under the same environmental conditions. The most commonly measured value was the surface temperature of the external wall and the improvement in this regard was generally quite substantial. The experiment in China showed a significant reduction in outside surface temperature of 20.8°C. However, the living walls system in this case only helped to reduce the indoor temperature by 1.1°C.

Conclusions from these experiments are that in general, green walls can help to reduce the surface temperature efficiently in both a temperate and warm tropical climate. However, the improvement of the indoor temperature is rather limited. The green wall only has a significant effect in the extremely hot climate of the UAE, where the peak indoor temperature was lowered by 5°C (Haggag et al., 2014). Nevertheless, the experiments showed considerable savings in air-conditioning consumption, 20% in the case of the UAE school and 34% and 58% in the case of the Spain cubic units. The former case was less effective in energy saving despite its greater thermal performance. This could partly be because the former case was a real building experiment while the latter was a lab-based experiment.

No such experiment on green walls was found in Vietnam. Among the studies, Singapore is most similar to Vietnam in terms of climate conditions. However, that experiment was designed only for testing the surface temperature without any internal spaces.

8.3 Experiment design

8.3.1 Climatic conditions

The experiment house is located in Hanoi, the capital city in the northern part of Vietnam, under the humid subtropical climatic conditions defined according to Koppen-Geiger climate classification (Kottek et al., 2006) as Cwa (warm temperate; winter dry; hot summer). Generally, Hanoi is affected by seasonal monsoon winds. It has a short cold and dry winter; the air temperature can reach as low as 5°C. Protection from the cold wind from the northeast is required. The summer is hot and the air temperature can reach up to 40°C. Annual precipitation is considerably high. The average rainfall in summer is approximately 300 mm per month (Nguyen et al., 2011).

8.3.2 Experiment spaces

The selected rooms are a bedroom on the second floor and a living room on the first floor, both facing southwest, in a typical Vietnamese tube house. The dimensions of the rooms are 3.3 x 4.6 x 3.9 meter (w x l x h). The front façade consists of single lightweight masonry wall with a big window of 7.2 m^2 (56% of the external wall area) for each floor. The external walls are made of 110mm brick work with 15mm of cement plaster on both sides. The U value is 2.57 W/m^2-K. The windows are made of 6mm grey single glazing within an aluminium frame and a U value of 5.78 W/m^2-K. At the front, the first floor is covered with the climbing plants. The second-floor façade has an aluminium shading device. Its solar transmittance is 0 and its solar reflectance is 0.5. The back side of the room is a glass wall with an aluminium frame that connects to the staircase. On both right and left sides of the rooms are single masonry walls adjacent to neighbour walls. Current rooms are equipped with 12,000 Btu (British thermal unit) or 3.52 kWh air-conditioners which provide both cooling and (electric) heating. The existing building is presented in Figure 8.3

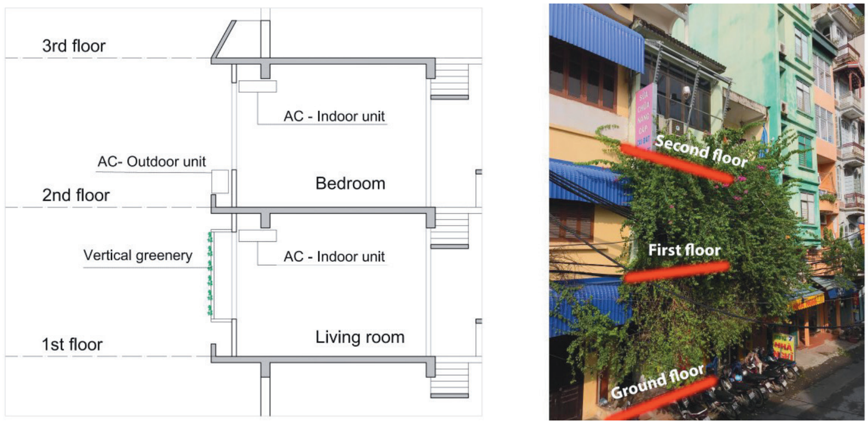


FIG. 8.3 Existing Vietnamese building for experiment

8.3.3 The plants

In this study, the plant has already grown and covered most of the 1st floor facade. The other façade has an aluminium shading device. The plant type is Bougainvillea, a climbing tree which is regularly found in Vietnam thanks to its fast growth and low maintenance.

8.3.4 Monitoring equipment

The performance of the two similar spaces is simultaneously measured. One of the spaces has a greenery system on the facade. There were eight measurement configurations in total, as listed in Table 8.2

Two Sense data loggers (Plugwise) were put inside the rooms to measure the indoor temperature and relative humidity. Three other Sense data loggers were installed just outside the windows to measure the outdoor temperature and relative humidity of the first, second and third floor. The temperature sensor has a range of 0 to 60˚C; the relative humidity sensor has a range of 5 to 95%. The accuracy of the data loggers is: temperature: 0.3°C at 25°C and 0.8°C at 60°C; relative humidity: 2.2% between 10%- 90%, 3.2% in other conditions. Two Circle units (Plugwise, Type F) were connected to the two air-conditioners in the two rooms to measure electricity consumption. The accuracy is 5% ±0.5W for current usage and 1% ± 0.2W for cumulative usage. All the Plugwise sensors were wirelessly connected to a computer and data were retrieved from the same software named Source. A solar data logger (Voltcraft) was used to measure the solar radiation on the façade. The sensor was oriented 45° from the horizontal plane and faced directly southwest. The reason for this was that the shading device and the leaves on the green façade have the same 45° inclined position, facing the sun directly in the afternoon. The sensor has a range from 0 to 1999 W/m^2 with an accuracy of 5% or 10W/m^2. All data is recorded at 15-minute intervals and presented in hourly intervals. The location of the equipment is presented in Figure 8.4.

TABLE 8.2 Equipment names and measuring parameters

#	Equipment	Symbol	Measuring
1	Sense 1	S1	Second floor outdoor temperature and relative humidity
2	Sense 2	S2	Second floor indoor temperature and relative humidity
3	Sense 3	S3	First floor outdoor temperature and relative humidity
4	Sense 4	S4	First floor indoor temperature and relative humidity
5	Sense 5	S5	Third floor outdoor temperature and relative humidity
6	Voltcraft	V	Solar radiation on the front southwest facade
7	Circle 1	C1	Electricity consumption of second floor air-conditioner
8	Circle 2	C2	Electricity consumption of first floor air-conditioner

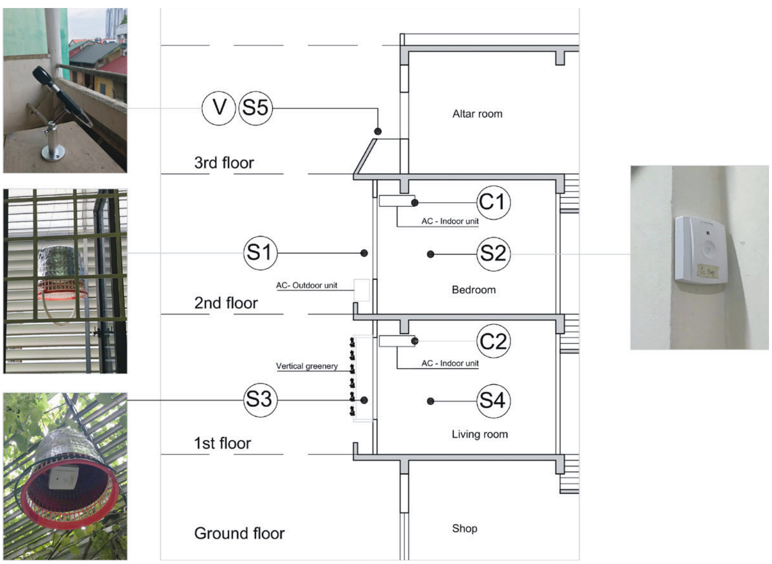


FIG. 8.4 Locations of the measurement equipment

8.3.5 Measurement plan

The experiments were conducted during the summer months of July and August 2018. During this period, the two rooms were vacant to make sure that there is no variation in heat gain from occupants and equipment. Details of the measuring schedule are shown in Figure 8.5.

FIG. 8.5 Three scenarios of the experiment

The first scenario aims to validate if the two rooms have similar thermal performance. From the 9th until the 15th of August, both facades were bare and from the 26th of August until the 03rd of September, both facades were shaded.

The second scenario compares the thermal performance and the energy consumption of the room with a green façade (first floor) with the room with a bare façade (second floor), from the 27th of July until the 8th of August. From the 10th of July until the 24th of July, the performance of green façade room (first floor) and shaded façade room (second floor) were compared under scenario 3.

The order of the scenario did not align with the time sequence because the experiment was conducted on a real building where a green façade is a climbing plant. Once the plant was removed, it could not grow back in a short period of time.

Scenario 2 and 3 both lasted about 2 weeks. During the first week of each scenario, the rooms were both naturally ventilated and only the temperature and humidity levels were monitored. During the other weeks, air-conditioners were both used for 5 hours in the afternoon, and the energy for cooling was recorded. The air-conditioners were set at the same cooling set-point of 27°C, based on a study of adaptive thermal comfort by Nguyen (Nguyen et al., 2012). Outside the air-conditioned periods, the rooms were always naturally ventilated.

8.3.6 Boundary conditions

This research specifically investigates the performance of an existing urban tube house in Vietnam. The energy consumption comparison is more valid in a real building case. The ideal setting was to compare between two identical adjacent houses. However, it was not possible to have access to two such houses, so two similar rooms in one house were selected. The selected rooms were in two different levels of the house so the existing spaces might not perform exactly the same. This limitation has been taken into account in the analysis and the presented result section.

The limitation of this experiment is that there were only two spaces available so we could only compare two different façade types at a time. Therefore, this study did not focus on comparing different greenery systems but mainly investigated the differences in performance between a room with a green façade and one without a green facade.

The experiment recorded both the temperature and humidity levels of the spaces. Green façade might have interaction with the humidity level of the indoor spaces and hence influences the perception of the temperature. However, within the scope of this paper, the investigation of humidity is temporary neglected. Thermal inertia might have some effects on the performance of the rooms. However, as the rooms have a lightweight construction, thermal inertia effects were not considered within the scope of this paper.

8.4 Results

8.4.1 Solar radiation

Solar radiation was measured because it provides radiative energy as well as stimulates the evaporation process in the greenery system, see Figure 8.6. Although July and August were hot months, solar radiation was not very high due to overcast skies and heavy rainfall during this time of the year. The maximum and minimum daily solar radiation was 1869 Wh/m^2 and 129 Wh/m^2 respectively. The average daily solar radiation was 921 Wh/m^2. During the period from the 24th until the 27th of July and from the 14th until the 20th of August, the measurement equipment was not working properly and data is missing. Solar radiation often peaked at 15:00 because the main orientation of the house is South-West.

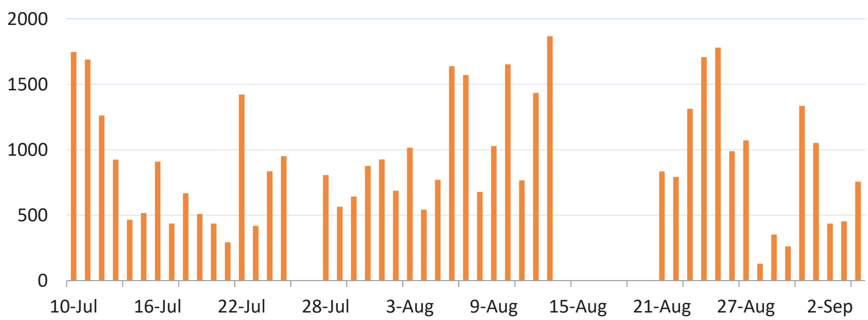


FIG. 8.6 Daily solar radiation during experiment period (Wh/m2)

8.4.2 Thermal performance

8.4.2.1 Thermal performance of the two rooms

This part presents an overview of the thermal performance by showing the highest and lowest daily temperature of the two rooms during the whole period (Figure 8.7) and on one of the hot days during this period, July 31st, in the cross section; see Figure 8.8.

In general, the minimum outdoor temperature was not lower than 25°C. The maximum daily outdoor temperature varied during the period. Outdoor air could reach up to 42°C on the hottest day while the peak temperature on the coolest day was only 27°C. Although this was summertime, the rainfall could be really heavy and constant on some days, which caused a fluctuation in the temperature measured. The indoor temperature generally had a smaller fluctuation range and did not exceed 35°C. In all cases the peak temperature of the second-floor room was generally higher than on the first floor room.

Regarding the performance on the 31st of July, the outdoor temperature reached as high as 37.6°C at 15:00 and cooled down to 26.5°C at 03:00. A thermometer put outside the 3rd floor showed that in the shaded area on the terrace the outdoor temperature was reduced to 35.4°C, which was 2.2°C lower than the temperature in the unshaded area. The climbing plants on the first floor provided significant cooling as the air temperature decreased 4.7°C to 32.8°C. The first-floor room was the coolest indoor space, where the temperature went down to 29.7°C, a 3.1°C further reduction behind the external wall with window glazing. Surprisingly, the indoor temperature of the second-floor room was also as low as 31.4°C, which led to a 6.2°C difference with the outdoor temperature, a relatively great difference compared to the expected outcome of a bare façade without shading or greenery. This also meant that the indoor temperature difference between the two floors was only 1.7°C. It is also worth to note the on the 31st of July, the maximum solar radiation was only 209 W/m^2, hence the effect of direct solar gain was not so significant. Such a minor difference was also believed due to the heat transfer between the floors. As the rooms accumulated heat during the day and peaked at 15:00, there was also a heat transfer through the slab between the floors which dragged the air temperature of the spaces closer to each other. The performance difference between the two façade types might be larger.

On the following night, the outdoor temperature lowered to 26.5°C. As can be seen from the figure, the indoor temperature was the same at 28.5°C, 2°C higher than outdoors, regardless of the façade type. The green façade in this case did not have much influence on the indoor temperature.

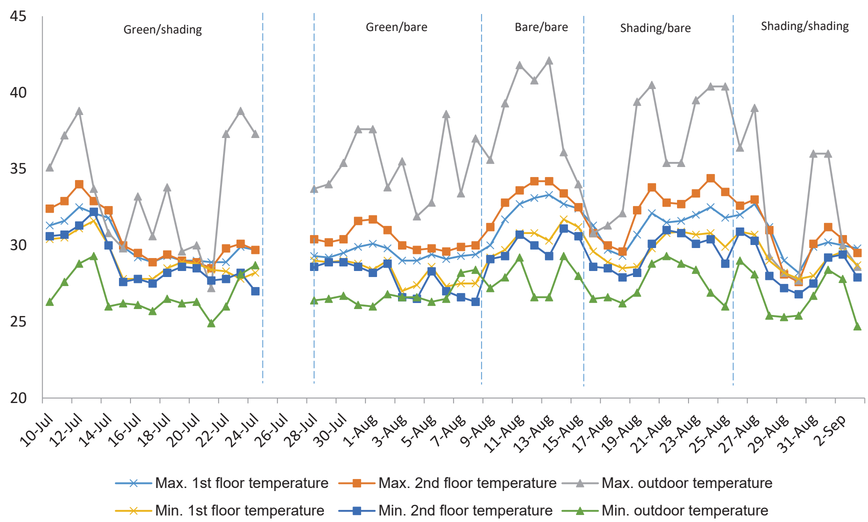


FIG. 8.7 Maximum and minimum daily outdoor and indoor temperature (°C)

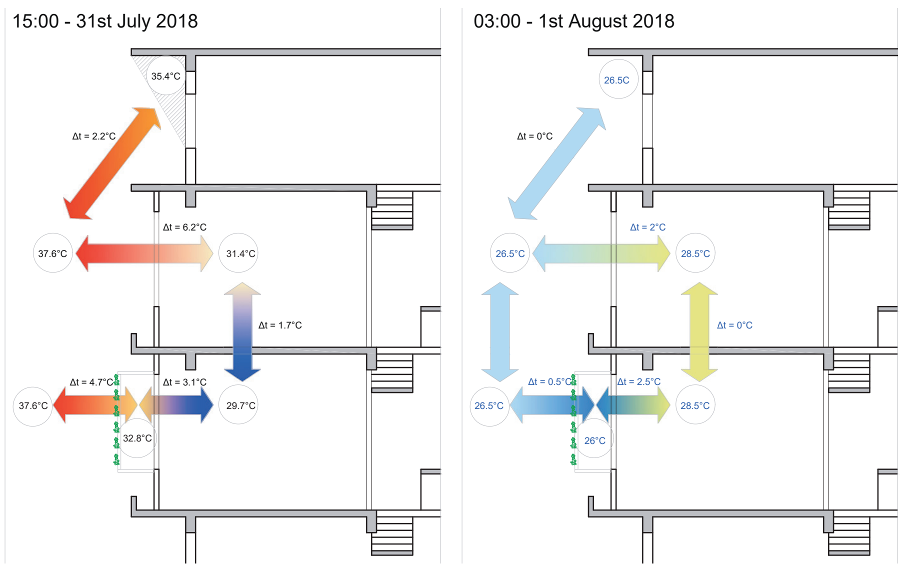


FIG. 8.8 Peak day time temperature and lowest night temperature during the period

8.4.2.2 Temperature of a room over a day

The relation between the indoor and outdoor temperature was examined by plotting them against each other in different periods, see Figure 8.9. The measurement period was from the 18th until the 24th of August. Each of the colours represents 15-minute-interval temperatures for one day. The two values do not have a simple linear relationship. The daily temperature pattern has a looped shape that comprises of two curves. The temperature often rises following the lower curve, peak around early afternoon and then slowly cool down following the upper part of the curve. For some days, although the outdoor temperatures were similar, the indoor values were different because the starting temperature of each day was different. In other words, the indoor temperature also depends on the average temperature of a longer period rather than just on one-day weather conditions. Internal heat gains accumulated after a few days could result in higher indoor temperatures compared to the first day. Therefore, analysing the thermal performance of the rooms should cover a longer period with constant microclimate conditions. A stable external environment in an extended period leads to more accurate performance of the internal space, enhancing the validity of the comparison.

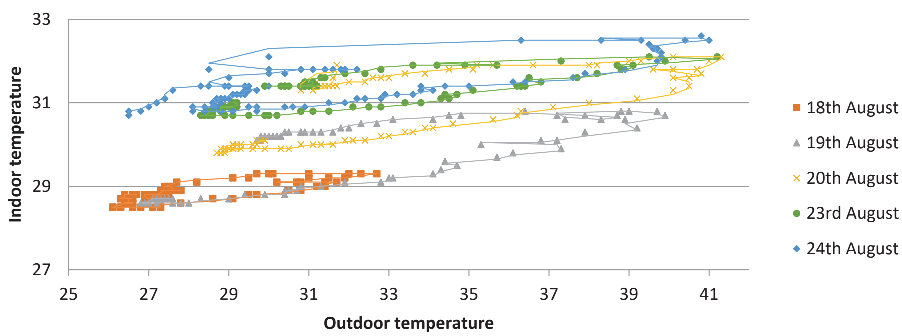
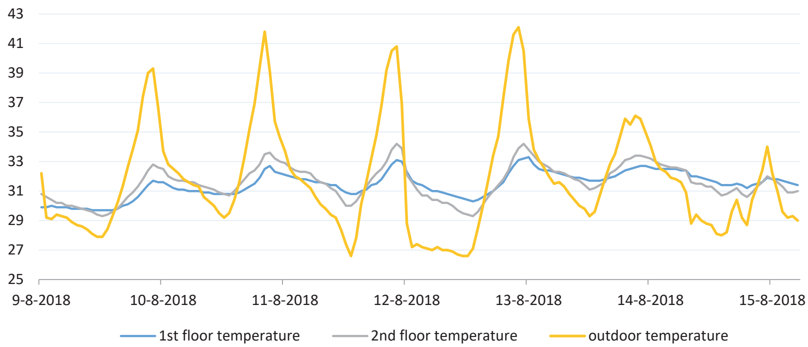


FIG. 8.9 Indoor and outdoor temperature of the first floor room with shading device (18th until 24th of August)

8.4.2.3 Comparison of thermal performance for different scenarios

Scenario 1:
Similar facade (9th – 15th August & 26th August – 3rd September)

Due to the fact that the experiment was based on a real case study, the experiment started with a comparison between two façade types (green façade & bare façade) and ended with a scenario with the two floors having the same façade type. The latter period aimed at examining the similarity in performance of the two spaces by comparing thermal data. There were two periods that the two floors had the same configuration. The first period was from the 9th until the 15th of August where both the facades were unshaded. During the last period, from August 26th until September 3rd, both windows were shaded by similar aluminium shading devices.



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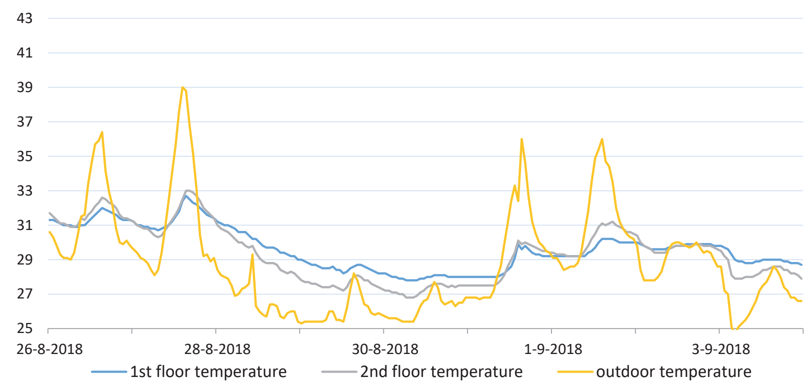


FIG. 8.10 Outdoor and indoor temperature of the two floors (°C). [a] 9th to 15th of August (unshaded facade), [b] 26th of August to 3rd of September (aluminium shading devices)

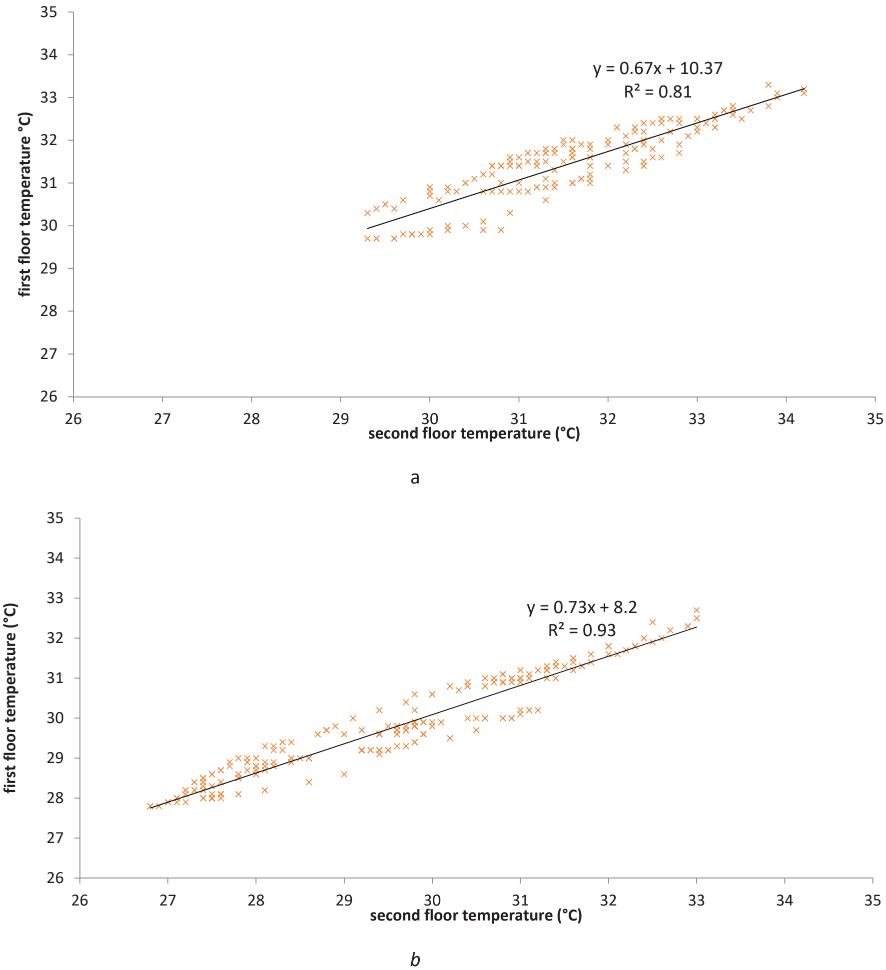


FIG. 8.11 Scatter plot of indoor temperature of the two floors (°C). [a] 9th to 15th of August (unshaded facade), [b] 26th of August to 3rd of September (aluminium shading devices)

Regarding the indoor temperature, although the shape of the graphs was similar, there were still differences up to 1°C throughout the days, see Figure 8.10. During the days, the second-floor room was often slightly warmer during daytime and cooler at night, compared to first floor room. The correlation between the indoor temperatures of the two floors is shown in the scatter graph in Figure 8.11 with the R^2 values of 0.81 for the first period and 0.93 for the latter. However, the values deviate from the average fit lines. Such behaviour can be explained by the slightly larger exposure of the second floor; a part of the second-floor ceiling was the 3rd front balcony floor. Another reason could be the thermal insulation effect of the floor layers. The second floor is closer to the roof and acts as an insulation layer for the first floor. Therefore, the upper room was heated up at noon and was cooled down at night quicker than the lower one.

The thermal mass effect was also found while comparing the indoor temperature of the first floor, second floor and third floor (top floor), as shown in Figure 8.12. The lowest floor temperature, indicated by the blue line, did not vary and the top floor temperature (green line) fluctuated the most.

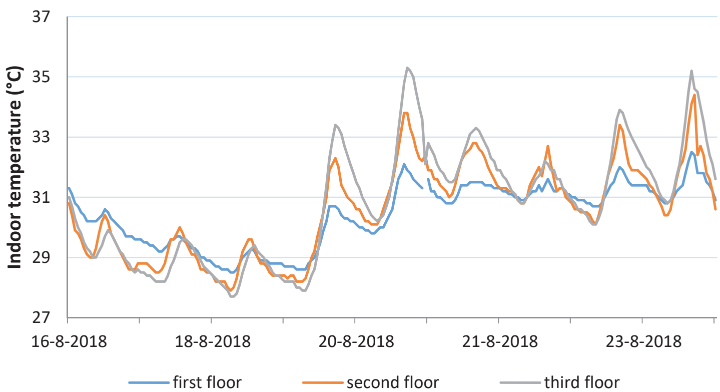


FIG. 8.12 Indoor temperature of the 1st, 2nd & 3rd floor during the period from the 16th until the 24th of August (°C)

Although the two rooms were configured similarly, it is important to note that indoor temperatures were not exactly equivalent. Nonetheless, the strong correlation in performance of the two spaces with same façade settings is significant enough to continue comparing performance of the rooms in other scenarios.

Scenario 2:
Green façade & unshaded façade

During two weeks, from the 27th of July until the 9th of August, the green façade on the lower floor was kept and compared to the unshaded façade on the upper floor. The rooms were naturally ventilated during the first week and air-conditioned during the afternoon of the second week. The thermal performances of the rooms were measured during the first week and are shown in Figure 8.13. At night, there was no temperature difference between the two spaces. The indoor temperature of the second floor rose quicker during the days and peaked at around 2°C higher than the lower floor temperature.

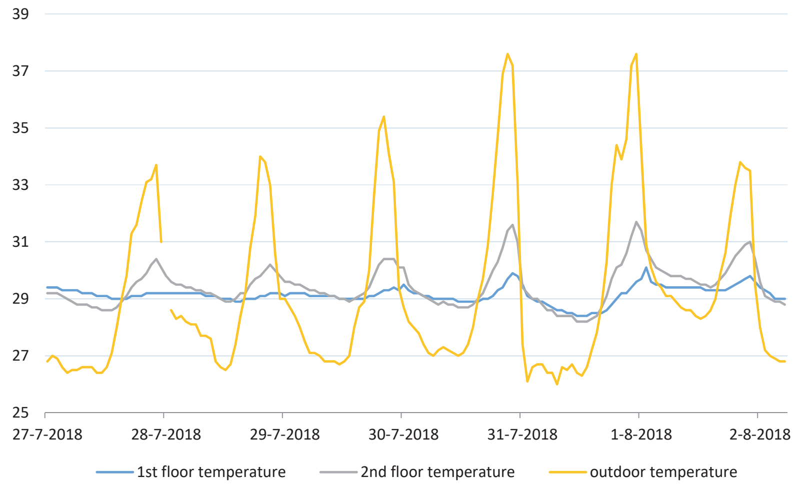


FIG. 8.13 Indoor and outdoor temperature measured on the 1st & 2nd floor from July 27th - Aug 2nd (°C)

Two ways are suggested to compare the performance of the two façade types. The first method is to directly compare the indoor temperature of the two rooms over the same period (27th July until 2nd August), when one room was unshaded (second floor) and the other room was covered with a green façade (first floor). With this method, the thermal mass effect or difference in the levels of the rooms need to be considered (see scenario 1). With the second method, the thermal mass effect can be eliminated by comparing the performance of the same first floor room over two different periods, in which the room was unshaded (9th to 15th August) or equipped with a green façade (27th of July to 2nd of August). This method does not take into account the difference in other climate factors, such as solar radiation, wind speed, relative humidity or precipitation.

Comparing two rooms in the same period (27th July – 2nd August)

This part compares the thermal performance of the first floor (green façade) and the second floor (bare façade). Figure 8.14 shows the indoor temperature difference between the two floors and the outdoor temperature over the same week. The climate condition of the week was stable as 4 out of 6 days the outdoor temperature ranged from 26 to 35°C. During those days, the temperature difference was around 1 to 1.2°C. The other two days had higher peak temperature of 37.6°C resulting in a higher indoor temperature difference. The green façade room was up to 2.1°C cooler than the other.

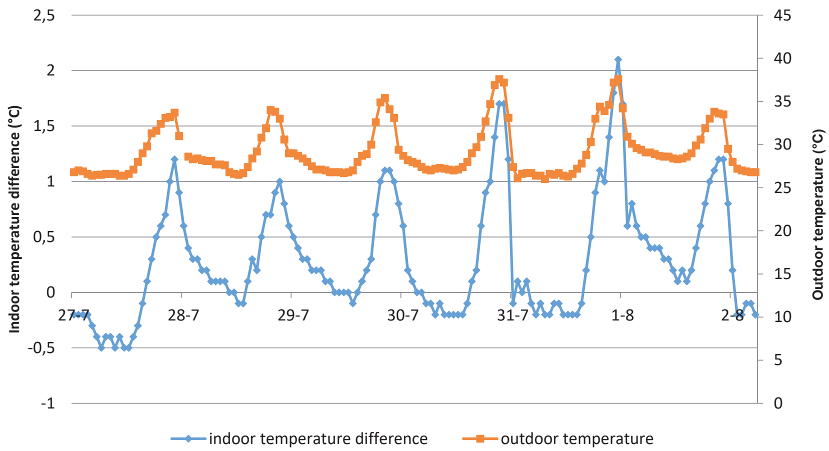


FIG. 8.14 The indoor temperature difference between first floor (green facade) and second floor (bare) and outdoor temperature (July 27th until August 2nd)

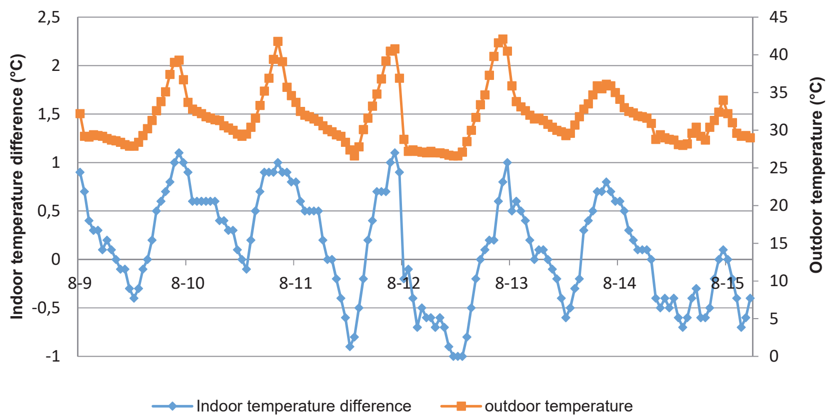


FIG. 8.15 The indoor temperature difference of the two floors and outdoor temperature (09th - 15th August)

Taking into account the differences in the levels of the rooms (as discussed in scenario 1), the temperature difference of the two rooms from the 9th until the 15th of August, when both rooms where unshaded, was plotted in Figure 8.15. During the first four days, the maximum outdoor air temperature was high, ranging from 39.3°C to 42.1°C. However, the temperature difference was only around 1°C. On the 15th of August, when the maximum outdoor temperature was only 34°C, the indoor temperature of the two rooms were very similar, with the highest temperature difference only 0.1°C. Combining the results of the two periods, the green façade is shown to lower the indoor temperature by at least 1°C compared to the bare façade (temperature difference of 2.1°C compared to 1°C on warmer days, and 1°C to 0°C on cooler days). This result is similar to Chen's findings (Chen et al., 2013), where the living wall system helps to reduce the indoor temperature by 1.1°C.

Comparing the same room in two different periods

Figure 8.16 shows the indoor and outdoor temperature of the first-floor room against each other during the two periods mentioned in the second comparison method. The differences in indoor temperature during the same outdoor temperature are visibly quite large (2°C on average). However, section 8.4.2.2 showed that indoor temperature also depends on the average temperature of the building over a longer period. The average indoor temperature in the two periods are not the same because the outdoor temperatures are not the same. Therefore, the benefit of the green façade over the bare façade cannot be proven based only on this comparison.

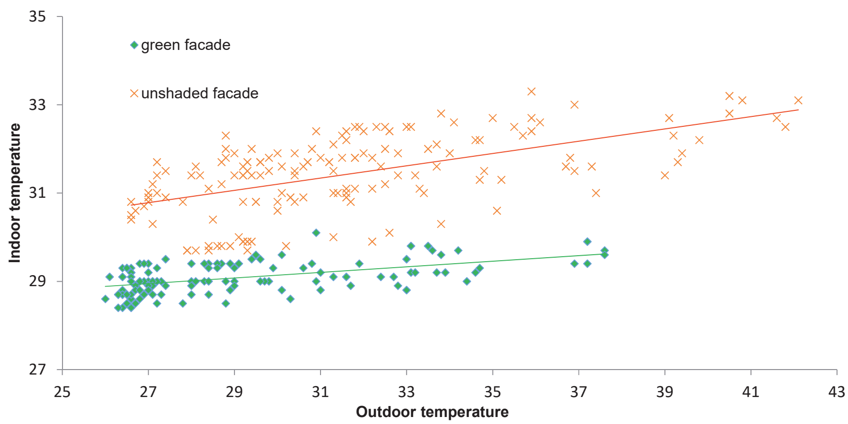


FIG. 8.16 Indoor and outdoor temperature of the 1st floor with a green façade (July 27th - August 3rd) and an unshaded façade (August 09th – 15th)

Scenario 3:
Shading device & bare facade (16th – 24th August)

This part discusses the benefit of a shading device on the performance of the rooms. During the period from the 16th until the 24th of August, the first floor was shaded by the aluminium shading device while the upper floor was unshaded. Measured data of indoor and outdoor temperatures were shown in the Figure 8.17.

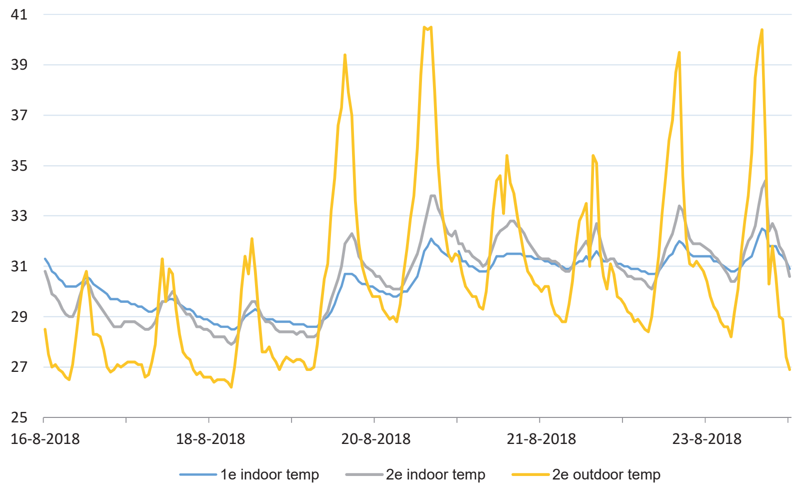


FIG. 8.17 Indoor and outdoor temperature of 1st & 2nd floor 16th -24th August (°C)

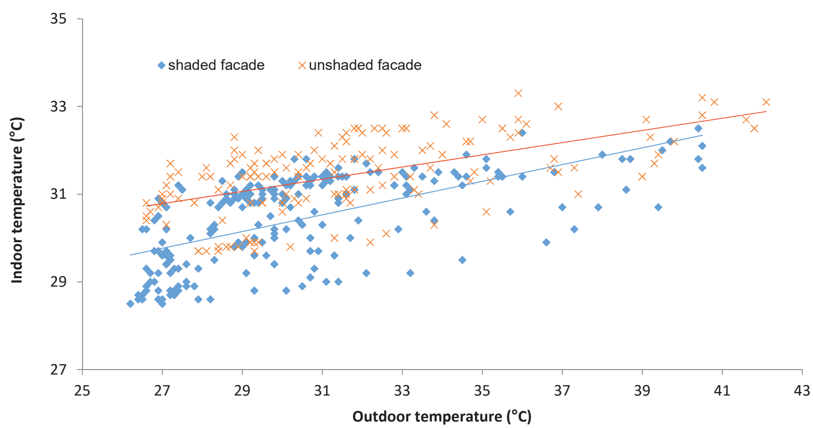


FIG. 8.18 Indoor and outdoor temperature of the 1st floor when unshaded (9th – 15th) & shaded (16th – 24th)August

There are differences in indoor temperatures between the two rooms. The second floor (bare facade) was warmer during the day and cooler at nights and highest difference was 1°C at noon. However, since the performance of the two rooms is different even in when the facades are the same, such a comparison might not reflect exactly the difference in performance of the two facade types. Therefore, indoor and outdoor temperatures of the 1st floor during the two different periods were plotted in 0The first period is from 9th to 15th August where the room was unshaded, the second period is from 16th to 24th August where the room is shaded by the aluminium shading device. In both periods, the second-floor room was unshaded. Generally, the shading device helped to reduce the indoor temperature of the room. The differences peaked at around 1°C when the outdoor temperature is not high (27 - 29°C). At higher outdoor temperature (higher than 35°C), the average temperature difference is not more than (0.5°C). The larger effect at a lower outdoor air temperature range can be explained by the difference in outdoor conditions of the two periods. During the shaded period (16th until 24th of August), the maximum air temperature was lower than 32°C, see Figure 8.17 & Figure 8.18.

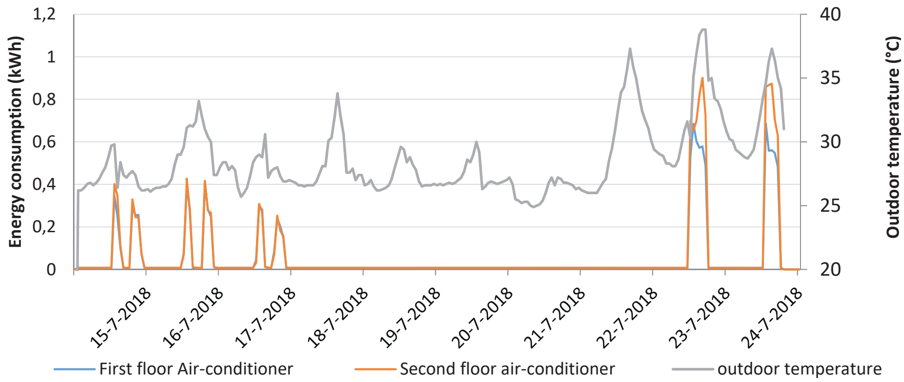
As discussed above, both shading devices and greenery improve the performance of the tube house facade by lowering the indoor temperature in warm weather conditions. Considering the above results, the green facade is believed to have a slightly better cooling effect compared to the shading device.

8.4.3 Energy performance

There were 2 periods where air-conditioners were being used and monitored for assessing the energy performance of the different façade types. The first period was from the 15th until the 24th of July, with the green façade on the first floor and a shading device on the second floor. Air-conditioners were used on the 15th, 16th, 17th, 23rd and 24th of July. The total number of hours in use was 25 hours. The cooling set-point was 27°C, based on a study of adaptive thermal comfort by Nguyen (Nguyen et al., 2012) . There was not much difference in the consumption during the first three days when the outdoor temperature was not high; see Figure 8.19. Moreover, in the first three days, 5 hours of air-conditioning were divided in two sub-periods of 2 hours and 3 hours, from 12:00 until 14:00 and from 16:00 until 19:00. Because it takes some time to cool the space to the desired temperature level, short air-conditioned period can lead to a minimum difference in performance of the two rooms. On the 23rd and 24th of July, the outdoor temperature was higher and the air-conditioned period was 5 consecutive hours and a different consumption was recorded. In total, the first-floor unit consumed 12.39 kWh while the upper one's consumption was 14.75 kWh. The difference was 12.5% in total cooling energy.

The second air-conditioned period was from the 3rd until the 8th of August, with the exception on the 5th of August. There was a green façade on the first floor and an unshaded façade on the second floor. The cooling set-point was 27°C and the heating hours were 5 consecutive hours during the day, from 12.00 until 17.00. Difference in the consumption was clearly seen in 0The first floor required much less energy to be cooled down compared to the second floor.

Energy consumption was 13.44 kWh and 20.87 kWh for the first floor and second floor respectively, which resulted in an energy saving of 35%.



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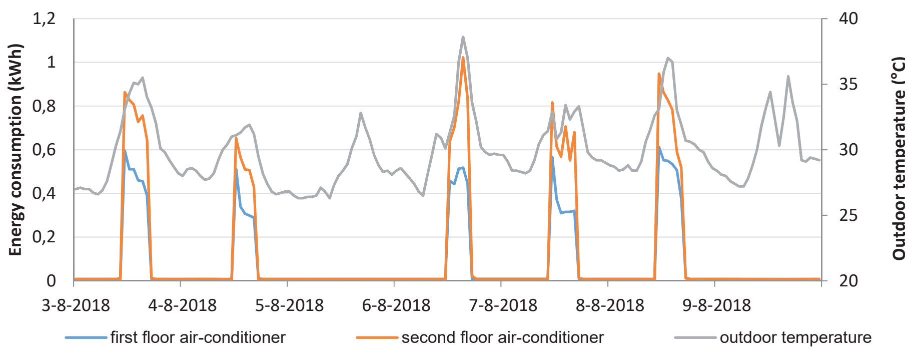

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FIG. 8.19 Air-conditioner electricity consumption of the two rooms (kWh) and outdoor temperature (°C). [a] 15th - 24th of July, [b] 3rd - 9th of August

8.5 Discussion & Conclusion

The two rooms were configured exactly the same in two floors and they were tested for difference in performance. The higher room is warmer when the outdoor temperature is higher. The maximum difference was in the afternoon when the outdoor temperature was at its peak. At cooler outdoor condition (at night or cooler days) the higher room had lower temperature.

This difference in thermal performance alerts the follow-up tests to take this effect into account as a boundary condition.

During the 2 months of experimental period, the outdoor environment was not stable. There were some hot days where the temperature exceeded 40°C and there were cooler days with lots of rain. This had some effects on the results of the paper. Similar research in the future is recommended to consider this boundary condition before conducting experiment to enhance the quality of the results.

The indoor temperature of the green façade room and the bare façade room were compared. The first test compared two different rooms (first floor and second floor) in the same period and the other test compared the same first floor room in two different periods. Both of them showed that there is a potential reduction of up to 1°C in indoor temperature by applying a green façade.

A room with an aluminium shading device was also tested. The shading device was equally effective as the green façade, for example, 1°C lower in indoor temperature compared to the bare façade, when the outdoor temperature is not too high (lower than 30°C). However, when the outdoor temperature rises beyond 30°C, the aluminium shading device became less effective and the peak difference was only 0.5°C.

Despite little improvement compared to the shading device, the green façade is still recommended in this specific case because of the following reasons. Firstly, measurements of temperatures just behind the green façade show that the green façade can help to reduce the outdoor temperature and improve the thermal performance of outdoor spaces. A lot of houses with green façades can contribute to a greater improvement in urban scale. Secondly, plants and trees in general have many other benefits such as purifying the air, noise cancelation, creating a relaxation atmosphere for the occupant etc. Finally, in term of thermal performance, the leaves of this climbing plants will naturally fall off during winter season which allows direct solar gain and hence reduces heating cost

In terms of energy consumption, the green façade in this case could save up to 35% of the cooling demand during the days, if the air-conditioners were used for 5 consecutive hours. Such a difference might be due to the 1°C temperature difference provided by the green façade, as discussed in section 8.4.2.3. During the cooler days, the energy consumption for cooling is less, hence the energy saving of the green façade is also lower, or the air-conditioning is even not necessary. A significant energy saving was seen when the peak outdoor temperature is higher than 33°C. Energy savings on winter days for heating need further investigation to have a better assessment of the benefits of a green façade.

The current construction of the building is lightweight masonry, single glazing windows, no thermal insulation and high infiltration rate. Such practice is very popular in Vietnam as it is believed to enhance passive cooling, removing heat from the building. However, as the outdoor conditions are becoming hotter, especially in the urban area, using an air-conditioner is often inevitable. In that case, it is recommended that residential buildings need a higher performance envelope. It can prevent heat gain from the external hot air temperature and save further cooling energy. It is also suggested that, for the same total duration of air-conditioning period, air-conditioners should be used in an uninterrupted period, rather than in multiple, separated shorter periods, for better energy saving.

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PART 3

Integrated design strategy

In the previous part, several experiments were conducted to examine the effectiveness of facade design options, one of the most important refurbishment design measures. Results have shown that a green wall can potentially reduce both indoor temperature and cooling load in the summer. Besides, a highly insulated facade, as opposed to the popular lightweight, uninsulated structure in Vietnam, would also contribute to the reduction of heating and cooling demand. Part III of the thesis does not focus on how much energy can be saved, but rather discusses how the design measures can be systematically organized and combined together as an integrated solution. Furthermore, a vision for the future sustainable housing stock will also be discussed.

Part III explores the application of potential design measures by investigating outputs of an international design workshop (GASC), being held in Vietnam in 2019. Students from Delft University of Technology and two other Vietnamese universities worked together to propose integrated solutions for energy-efficient refurbishment of existing tube houses in Hanoi. From the workshop, a new strategy was developed. This design approach is presented in section 9.3.3.

As important as the existing housing stock should be, chapter 11 also discusses the future sustainable tube house model for Vietnam. Future sustainable housing should both inherit the traditional values and meet the demand of urban developments in the coming future. Beside energy efficiency, other important sustainable aspects are: circular economy, urban densification, and social interaction.

A new approach to a residential neighbourhood as well as housing design are proposed as an effort to contribute to a more sustainable cities in Vietnam.

One of the challenges for the uptake of sustainable architecture in Vietnam is the lack of awareness of the people as well as limited of sustainable architecture education in design schools. Chapter 10 assesses outcomes of the international design workshop. Lessons learned from this workshop are crucial and should be adapted in future events to maximize educational results on sustainability.

Many of the materials using in this part were derived from the international design workshop GASC 2019. There is an overlap between the chapters 9, 10 and 11 because they are selected to be published as separate papers required a repeat of a lot of background information. The total amount of information was too large to put it all in one chapter. The repeated parts are greyed out for easier reading.

9 Integrated design for sustainable tube houses in Vietnam

This chapter is submitted to the Journal of Green Building.

9.1 Introduction

The need for energy efficiency in housing stock in Vietnam

Adapting to climate change, being less dependent on fossil fuel and reducing carbon footprint are major sustainable challenges in the worlds nowadays. In the last decade, Vietnam has been active in contribution to the mutual target of sustainability. The Vietnamese government has performed several actions including the National Energy Efficiency Program for the period 2006-2015 (Prime Minister of Vietnam, 2006). In this program, one of the key project is to establish a legal framework for energy efficiency in construction management, industrial production and equipment. In 2013, the Ministry of Construction has issued the National technical regulation on energy efficiency buildings (QC:09/2013/BXD) which apply to both newly constructed buildings and renovation of existing buildings. This regulation was recently updated in 2017 with the newest standards.

Housing in Vietnam

Tube houses are attached row houses in Hanoi. There are traditional tube houses, which were first built in the beginning of the 20th century in the ancient quarter, and new tube houses, which were mainly built after the economic reform in 1986 and are scattered all over the city. A traditional tube house has a very narrow width (normally 2.5 -4.5 meter) while its depth is very long, 9-10 times the width. Originally, a tube house is 1-2 storey high. Courtyards exist in tube house as a key element to maximize ventilation and daylighting, the number of courtyard depends on the depth of the house. The fact that many families live together in one house has led to lack of space and poor environmental condition (Phe & Nishimura, 1991). Nevertheless, the original structure and design of traditional tube house is still considered to be an eco-sufficient spatial composition, more advanced in terms of community connection, energy usage and flexibility of change (To, 2008) and adapting fairly to the climatic conditions (A. T. Nguyen et al., 2011)

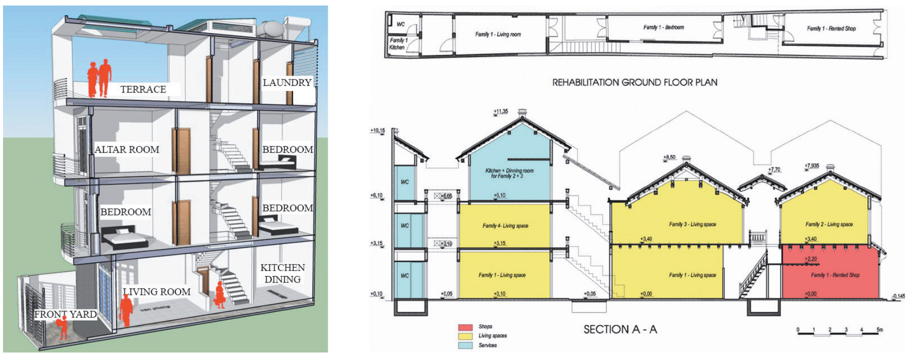


FIG. 9.1 Layout of a typical traditional tube house (left) and new tube house (right) in Vietnam

A new tube house layout and the spatial composition of a traditional one are presented in Figure 9.1. A new tube house is generally built in a rectangular plot with a width of 3-6 meters and a depth of 10-20 meter, and is 3 to 5 storey high. Within this narrow plot of land, courtyard is often limited. The typical structure is concrete frame combined with brick masonry.

Energy efficiency context in Vietnam

Rules and regulations

Accounting for more than 31% 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 (IEA, 2012). The Vietnamese government is aware of the importance of saving energy in buildings. Within the framework of the National Energy Efficiency Program (NEEP) for the 2006-2015 period, the 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). The NTREEB only applies to large-scale buildings but not to small houses, although the small houses account for almost 99% of the housing stock (GSO, 2010). The NTREEB focus on building envelop, HVAC system (heating, cooling, and air conditioning), lighting, and electrical equipment. In addition, the Vietnam Green Building Council (VGBC) was established in 2007 to raise awareness and build capacity for the development of green buildings in Vietnam.

Sustainable buildings

In Vietnam, most of so-called energy efficiency buildings are public ones because the recent National Technical regulation on energy efficiency only applies to buildings with more than 2500 square meter of total floor area. Small scale sustainable houses are often known as “Green Home” or “Passive house” which are labelled by the architects but do not comply to any standards. Contemporary architects who apply sustainable, green architecture are Vo Trong Nghia, who was awarded the Prince Claus Award 2017. Other contemporary architects are Hoang Thuc Hao and MIA architects. The list of some of Vo Trong Nghia’s sustainable housing projects can be found in the Table 9.1 below.

TABLE 9.1 List of sustainable housing projects by Vo Trong Nghia architect (Vo Trong Nghia, n.d.)

	Project	Year	Project type
1	House for trees	2014	Newly built
2	Le Binh House	2013	Refurbishment
3	Stacking green house	2011	Newly built
4	Breathing house	2019	Newly built

During the week of GASC 2019, the students had a chance to take part in a private lecture where two Vietnamese architects, Tran Dai Nghia and Nguyen Tuan Nghia, presented their recent projects and their view on sustainable architecture. It was an interesting experience to the students to see how architects in practice apply design strategies and principles into actual housing projects.

9.2 The GASC 2019

9.2.1 Overview of the GASC 2019

Green Architecture for Sustainable Communities (GASC) is an event being held by Delft University of Technology (TUD) and two Vietnamese universities: Hanoi Architectural University (HAU) and National University of Civil Engineering (NUCE) with an aim of boosting sustainable development in the built environment of Vietnam. The GASC often involves a symposium, a design workshop and several discussion panels focusing on sustainability topics.

Continuing the success of the GASC 2017, the GASC 2019 took place in Hanoi, the capital of Vietnam. The event was being held from the 15th to the 20th of September 2019. This time, the symposium and design workshop focus on the design strategies for energy efficiency in private urban houses – so called “tube houses” in Vietnam – aiming towards zero energy homes.

9.2.2 Description of the student design workshop

One of the key parts of the event is the student design workshop. Students from all three universities -TU Delft, Hanoi Architecture University and National University of Civil Engineering- worked together in groups under the guidance of academic experts and practice architects in order to propose interventions to an existing tube house in centre Hanoi and convert it into a more sustainable, energy efficient house, preferably zero-energy house.

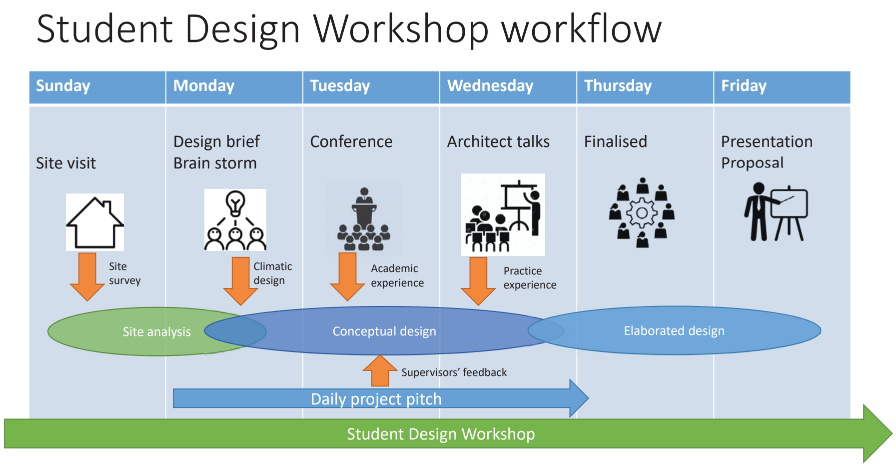


FIG. 9.2 Student design workshop progress

Figure 9.2 describes the progress and activities of the workshop during week. The workshop is divided into 3 main stages. In the first stage, the students analyse and discuss the potential and challenges of their own case. During site visit and design brief session, the students talked to house owners about their wishes and they asked mentor architects about specific issues in the projects.

During the second phase, the groups need to brainstorm and define their design concept, trying to persuade each other and the mentors on how these design concepts can benefit to the whole plan of the proposal. Feedback and discussion are extensively given. At this stage, the students attend the GASC conference to help themselves bring up new ideas. The main theme of the conference was “sustainable and energy efficiency housing”. Participated speakers are professors and lecturers from the three universities. They presented the latest research on sustainable approach for housing in the Dutch and the Vietnamese contexts.

The conference was followed by an architects’ talks, where practical Vietnamese housing projects were introduced. The groups then finalised the idea into a specific design of a new house in the last stage. Again, difficulties in translating ideas into solution were being discussed and solved with the help of the mentor architects. Design proposal were assessed by a jury of experts in term of design, thermal and energy performance and sustainability. After the workshop the students were asked to complete a questionnaire to evaluate the implementation of the student design workshop and describe their own experiences taking part into this event. The results are given in the next chapter.

Student groups

There were in total 33 students taking part in the workshop. Eighteen of them were from HAU, ten from NUCE and five from TUD. The students taking part in the workshop were both bachelor and master architecture students. All of the TUD students were currently doing their master study. Majority of the Vietnamese students were undergraduate. Since there was a variety of students' experience level and cultural backgrounds, the group division rules was as such that every group had students from all universities and each group should have students from 3rd year of study until master students. There were initially 8 groups of 4 to 5 students. However, due to the absent of some students on the first day of the workshop, the students were re-divided into 6 groups of 5 to 6 students. There were 5 TUD students in total so there is one group (group number 2) that had no TUD student.

9.2.3 Information on design strategies

Five student groups were assigned to work on three different tube houses. Each of the houses has its own characteristics and specific requirements from the house owners. Apart from getting to know the cases through the design brief and the site visit, the students were also equipped with background information about design approach and design measures through the GASC activities. Journal papers on design strategies, which are mentioned in the Figure 9.3, were included in the materials given to the students at the beginning of the workshop.

Academic from TU Delft and 2 Vietnamese universities, and experts shared their latest works in the field during the conference. At a later stage, there was a talk from two local architects that showed their recent projects and their thoughts on sustainability issue. Having a broad range of materials in hand, the student discussed and decided to integrated different design measures in their own projects. The application of the design measures was discussed in the later part, regarding their suitability, effectiveness and how well they were put up together as one integrated design. Table 9.2 lists different activities and the main knowledge provided.

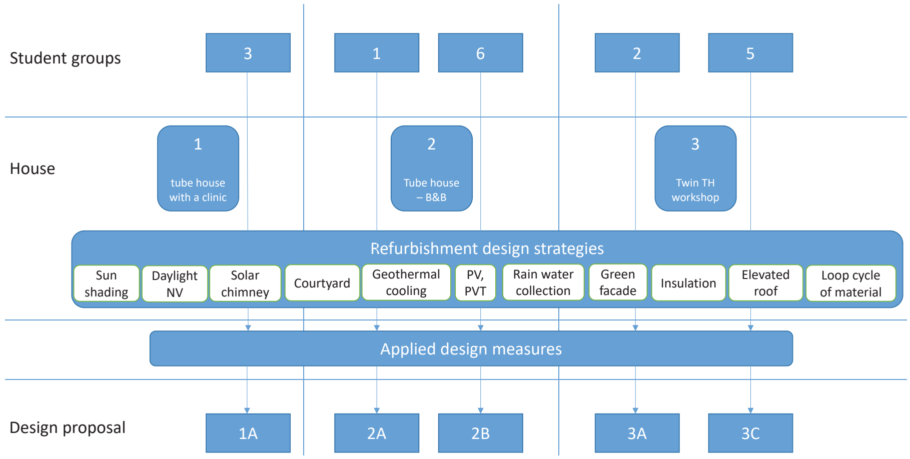


FIG. 9.3 Diagram showing students groups organisation and applied design measures

TABLE 9.2 List of workshop activities and its content

	Activities	Main topics/materials
Site visit (Sun)	Experience the real house Talks with house owner	Photos, Q&A
Introduction speeches (Mon)	Introduction of design brief Introduction of links to published materials on design and housing	Energy efficiency design approach Vietnamese tube houses including: bioclimatic design, indoor environment, energy, greenery, user behaviour.
GASC 2019 conference (Tues)	Presentation of TUD representatives Presentation from HAU & NUCE representatives	Dutch approach to sustainable homes Bioclimatic design in Vietnam Another view on tube houses
Talks by two architects (Wed)	The architects shared their real project experience	Sustainable approach Local material Rain water collection
Daily supervision (all days)	Guidance and feedback from supervisors	Architecture Sustainable design Building technology
Student group work (all days)	Exchanging of student ideas	Sustainable design Architecture
Final presentation (Friday)	Feedback from jury members	Architecture Practical matter

9.2.4 Description of the workshop cases

The houses selected for the workshop were typical contemporary tube houses which were located in different parts of the city, see Table 9.3. House owners were interviewed for their renovation needs and requirements. Apart from that, the students were instructed to adapt sustainable and green architecture principles in their proposal.

TABLE 9.3 Summary of the selected houses

	House 1	House 2	House 3
Plot Size	Small - 40m2	Small – 40m2	Large – 120m2 (twin)
Function	Mixed (clinic)	Mixed (homestay)	Mixed (workshop)
Potentials	- Low density (2 occupants) - Owner's preference of plants and greenery - Main orientation of South West - Large street width	Two main orientations - chances for cross ventilation - space expansion on the higher levels - More room to redesign the facade	- Large floor plan - Openable from the front and rear façade
Challenges	Small spaces	Small plot size Small street	- Privacy issue - Pollution of the workshop

9.2.4.1 House 1 – Bui Xuong Trach street

The first case is located in one of the high-density areas of the city. The existing house lies in a 40 square meter land plot. There are six floors in total. The ground floor is used as a traditional medical clinic which is run by the owner himself. The living spaces, including living room, two bedrooms, kitchen and dining room are located on the next 3 floors. The vacant fourth floor is temporarily used as a storage place. The top floor features the altar room, a typical setting in Vietnamese culture, along with terrace and a small garden. The couple lives here permanently and sometimes they have guests staying overnight. The plot of 40 square meter is small but overall, there is no demand for extra living spaces due to the small number of occupants. The owner has a specific demand of adding more green spaces in their house not only for his own interest but also for his herbs-based medical practice. Floor plans and pictures of the house are shown in Figure 9.4.

FIG. 9.4 Floor plans and photos of the house number 1

9.2.4.2 House 2 – Lac Nghiep street

The second case has the same plot land of 40 square meter and is also located in a densely populated area, see Figure 9.5. It has 4 stories, which is more common in Vietnam. Unlike many other attached row houses, this house is located at the corner of an intersection, hence it has two main façades, south and west. The owner has the intention of converting the house into a combination of living spaces on the top floor and a home stay service on the lower floors.

FIG. 9.5 Photos of the house number 2

9.2.4.3 House 3 – Au Co street.

The last site has the largest plot land of 120 square meter and it is actually twin tube houses owned by a large family, see Figure 9.6. The whole first two floor were used as a tailor workshop. The higher floors are divided into 2 separated areas with their own staircases. There are many issues with privacy in this house as all the users share the common entrance. There are 6 occupants living in the house and 10 other workers working daily on the ground floor.

FIG. 9.6 Floor plans and photos of the house number 3

9.3 Design strategies for sustainable and energy efficient houses

9.3.1 Method

Different design strategies were provided to the groups, including the bioclimatic design approaches as well as active design elements. Examples of these are solar shading, natural ventilation, insulation, green façade, courtyard and open space, geothermal cooling, solar chimney, solar thermal, photovoltaics, rain water collection, and waste recycling. The students were encouraged to integrate any other strategy if they thought it necessary. Based on the existing conditions of the houses, user demands and sustainability requirements, the groups applied design strategies described above and proposed renovation interventions to the houses. Each group had their own way of applying the design strategies and the quality of the proposals also varied. The design strategies were assessed by the experts, who were involved in the workshop, by five criteria: technical feasibility, performance, economics, aesthetics and durability/maintenance.

The following part of the paper discusses the application of design strategies qualitatively. Finally, the paper will propose a stepped design strategy for tube houses. The stepped design strategy, inspired by Cradle-to-Cradle (C2C) theory, aims at minimising resources and closing the resource loop in the built environment (Van Den Dobbelsteen, 2008).

9.3.2 Design strategies discussion

9.3.2.1 Overview of applied design strategies

The student groups applied design strategies that they acquired from the materials provided, the conference, the actual projects of the Vietnamese architects, or from their own projects. Table 9.4 below summarises which design strategies were included in the final outcomes.

TABLE 9.4 General overview of applied strategies

Strategies	Group 1 (House 2)	Group 2 (House 3)	Group 3 (House 1)	Group 5 (House 3)	Group 6 (House 2)
Solar shading	X	X	X	X	X
Greenery	X	X	X	X	X
Courtyard / Lightwell	X	X	X	X	-
Solar chimney	X	-	-	X	X
Geothermal cooling	X	X	-	X	-
PV	X	X	X	X	X
Solar thermal	X	-	-	-	-
Rainwater collection	X	X	X	X	X
Waste recycling	-	X	-	-	-
Insulation	-	-	X	X	-
Elevated roof	-	X	X	X	-
Natural ventilation	X	X	-	X	X

The most popular design measures were solar shading, greenery, photovoltaics (PV) and rain water collection, which were applied by all groups. The first two were well-known design measures. They existed in traditional Vietnamese architecture. Using PV was favourable despite its questioned cost-benefit evaluation. The potential of PV is promising because there is ever more research on increasing the efficiency of PV and lowering its production cost. Solar thermal was a low-cost measure to reduce the energy demand for domestic hot water (DHW) but was seen only in the proposal of group 1. The use of solar thermal can be integrated in the PV system, known as photovoltaic thermal hybrid solar collector (PV-T).

Rainwater collection has large potential for domestic water use in Vietnam due to the great annual rainfall. The lack of existence of such a measure in contemporary housing project can be explained by the lack of space for a water tank in modern houses, and by considering the low water price and hence economic savings. However, in a sustainable housing project, such a design measure should always be included if possible.

Courtyards, or their smaller version, light-wells, were also widely used by most groups. Courtyards and open spaces are important components in traditional dwellings. They provide daylight, natural ventilation, fresh air and social space in a house. They did not exist yet in the investigated houses, not even in house 3 with a large plot size. Group 1 and group 3 could only integrate a small light-well in the house, and group 6 had no courtyard/light-well in the proposal because of its small site size.

Design strategies follow general principles. However, as the scales of the houses vary, and the other boundary factors, applied measures also adapt accordingly. In the GASC2019, the students worked with three cases (see Table 9.3). The first houses is a small house of 40 square meter in the city centre, there is only one openable façade in the front. The second one has the same size as the first one, but it has two openable façades at the front and at one side. The third house is much bigger with 120 square meter and it has two openable façades at the front and at the rear. Characteristics of the houses have a strong influence on the measures taken. Courtyard is an important design element, but it was only included in proposal for house number 3. In the first two houses, the other students could only integrate a small light-well of less than 2 square metre. Cross ventilation was feasible in the house number 2 and 3 where two openable façades presented. In house number 1, the student tried to boost ventilation only through the staircase shaft in the middle of the house. The PVs were also popular among the groups. While most groups had PVs on the roof, group 6 (house2) designed PVs on both the roof and the west façade of the houses with an aim to generate enough all the electricity demand. The following part evaluates the strategies, for examples, the use of different elements individually. Rain water collection is excluded because it does not concern the energy consumption of the house.

9.3.2.2 Design strategies discussion

A Solar shading

Technical feasibility

The application of solar shading is considered as simple and easy to install as it is normally a lightweight component added on the existing structure of the house. Therefore it is one of the most popular design strategies, not only in the workshop but also widely used in most of Vietnamese homes (Nguyen et al., 2019c) It can be in the form of an overhang above the windows, wooden/composite/aluminium louvres, a shading system for the whole front façade, or a (elevated) roof. Figure 9.7 illustrates different sun-shading options proposed by the groups. Group 1 added bamboo louvres to the west façade of the house whereas group 3 and group 5 designed whole planter boxes systems that create shade for the front façade. Shading devices were also provided in the form of a roof. Such a roof will not only shade the building: the open space underneath will also be naturally ventilated and the conductive and convective heat gain from the top of the building reduced. Group 2 focused on designing an elevated roof to protect the house from the sun with the high position in the summer. All of the shading proposals were integrated with greenery.

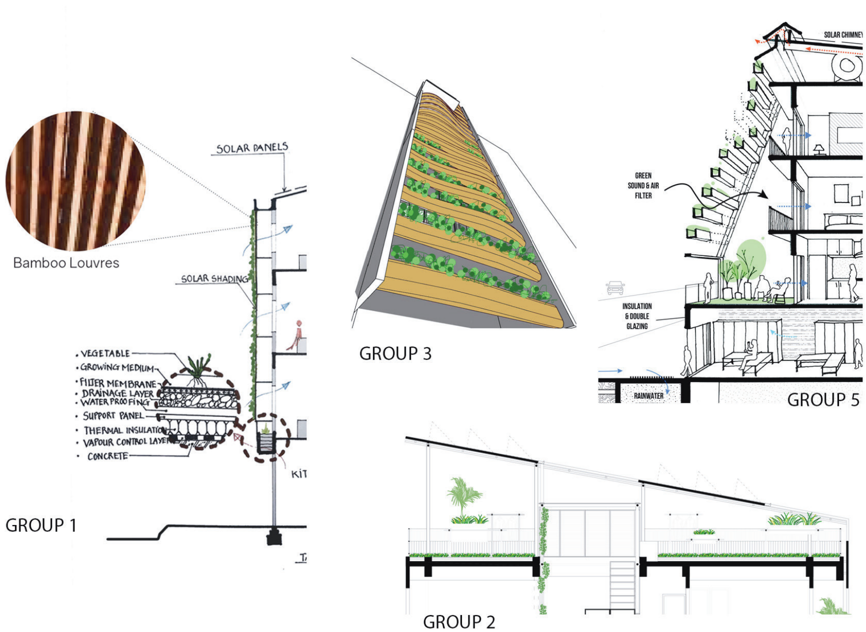


FIG. 9.7 Illustrations of shading devices in the proposals of the student groups

Performance

A shading device has a high potential to block solar radiation if it is designed appropriately. In contemporary tube houses, shading devices at the south façade are usually in the form of an overhang above the windows with a width of 60-80 cm. Shading is also needed at the West and Southwest façade which receives a lot of radiation in the afternoon. Lower sun positions in the West might lead to a preference of vertical shading options. An aluminium shading device was found to reduce indoor air temperatures by up to 1°C in the summer (Nguyen et al., 2019a).

Economy

Installing sun-shading often does not cost a lot. It usually does not required demolition or change in housing structure.

Aesthetics
Solar shading acts as an important architectural element appearing on the front façade of any Vietnamese tube house. It brings 3-dimensional property to the façade, casts shadow on other elements. Sometimes, sun-shading consists of balconies that even contribute more to the overall look of the house. Design of shading devices should be in conjunction with building orientation, massing, and the design of openable windows.

Maintenance
Popular materials for solar shading are aluminium, concrete or composites. They often have high durability and need little maintenance.

B Green façade

Technical feasibility
All six groups integrated greenery in their design. In the smaller houses (number 1 and 2), climbing plants were proposed on the façade, in combination with the shading device (see Figure 9.8). In the larger house (number 3), the greenery appeared on both the front façade and the newly designed courtyard. The larger site of house number 3 in this case plays the prerequisite role and defines the new courtyard and the green walls. The elaboration of greenery was also clearer in the case of the larger house. The feasibility of a green façade is high, as it can be combined with the shading device.

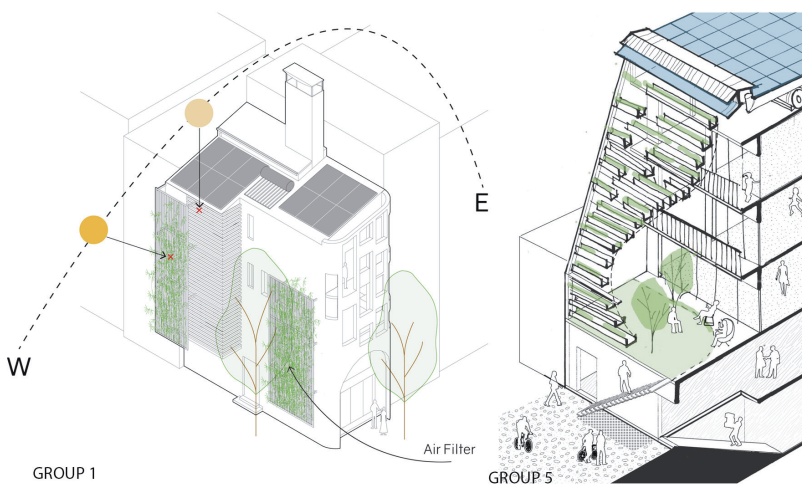


FIG. 9.8 Illustrations of green façade in the proposal of the student groups

Performance

The use of greenery in housing has many benefits. It helps to provide evaporative cooling, air purification, noise and dust reduction, and creates natural and environmentally friendly spaces in houses. The outcome of this strategy can be a green façade (green walls or green roof), and plants that grow in open spaces such as a courtyard or terrace. Green façades were investigated by many researchers (Coma et al., 2017; Nguyen et al., 2019a; Ottelé, 2011; Pérez et al., 2011; Perini et al., 2011). An experiment of a green façade in Vietnam showed a 8°C temperature difference between the indoor and outdoor temperature and energy saving was possible up to 35% (Nguyen et al., 2019a)

Economy

Application of greenery in general is more costly compared to a shading device because it consists of both the supporting structure and the plants itself. However, it is often still reasonable, considering its multiple environmental and social benefits. It often also not requires demolition or changes in structure of the house.

Aesthetics

Mentioned as one of the benefits, a green façade creates a natural friendly look for the house. And in most cases, it is considered as improving the aesthetics of the house. The application of greenery by many famous Vietnamese architects such as Vo Trong Nghia and Nguyen Hoang Manh, also confirms the popularity of this component.

Maintenance

A green façade needs regular maintenance as it is a living body. The level of maintenance depends on the type of green façade and the type of plant itself. Some climbing plants, such as Bougainvillea, are self-growing and need less maintenance (Nguyen et al., 2019c). Hanging planter boxes or potted plants might need more maintenance.

C Thermal insulation

Technical feasibility

A façade is an important element that defines the appearance of a building and that affects the thermal and energy performance. Current Vietnamese building practice usually has a lightweight construction and little insulation. Adding insulation material to the existing external walls does not take a lot of effort, but rather space. Wall insulation was mentioned in the proposals of group 3 and group 5. However, it was not elaborated well in the proposal, nor in the final presentation.

Performance
Thermal wall insulation does not work effectively in the Vietnamese climate when the building is naturally ventilated and when passive cooling is used. A high-performance façade can reduce energy consumption for heating and cooling when air-conditioners are used frequently and inevitably (Nguyen et al., 2019c). However, considering the negligible heating demand and the dominant application of natural ventilation, wall thermal insulation is not recommended. An additional benefit of high thermal insulation values can be noise reduction.

Economy
Application of thermal insulation is not considered budget-friendly because of its controversial effect on the thermal performance of the building. Extra thermal insulation can reduce heating demand in winter but might increase cooling load in summer. Investing in highly airtight doors and windows might be worthwhile when noise pollution is a problem in the area.

Aesthetics
Adding insulation materials often can have a significant effect on the overall appearance of the house. Depending on the original state of the house, the situation after-insulation can be aesthetically different or similar, when it is again covered by cladding and/or plastered and painted.

Maintenance
Many regions of Vietnam have a rather warm and wet climate. The regular high relative humidity might make insulation materials less durable and extra maintenance is required. This does not apply if insulation material is synthetic and/or hidden behind the façade.

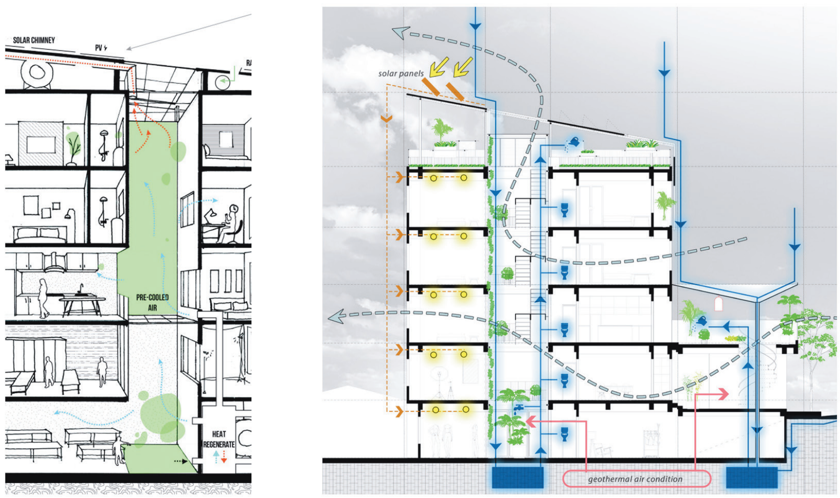
D Courtyard

Technical feasibility
Adding a courtyard to an existing house often means that there must be some demolition and less indoor space. This strategy is more feasible in larger houses (such as house number 3 in the workshop). In smaller house, adding a courtyard is rather difficult. In that case, a light-well is often considered an alternative. Figure 9.9 presents the new courtyard of house number 3, designed by group 2 and group 5. Group 2 integrated a green façade on one side of the courtyard to enhance the cooling effect. It was also shown that the courtyard was designed to serve daylighting and stack effect ventilation. Group 5 proposed a courtyard as an instrument to circulate the indoor air after being drawn up from a geothermal heat pump. The system

included the use of a solar chimney underneath the roof, in order to increase the air flow rate.

Performance

The courtyard is a popular feature in traditional Vietnamese architecture as it provides better ventilation and daylight for the house (Nguyen et al., 2011). It often goes together with greenery or water to make use of the evaporative cooling effect.



GROUP 5 GROUP 2

FIG. 9.9 Illustrations of courtyard design in the student group proposals

Economy

Adding a courtyard means that part of the existing house needs to be demolished, from the ground floor to the top. Sometimes, the structure of the house is also changed. Moreover, the area of indoor living space is also significantly reduced. Therefore, adding a courtyard to the house can be a huge investment.

Aesthetics

A courtyard, integrated with greenery, often composes a recreation area in the house. In most projects, such an area is the key element of the house. It mostly has a positive effect on the aesthetic value of the house.

Maintenance

The courtyard itself, except for cleaning and tidying, does not require maintenance as it is just an open and empty space. A higher ventilation rate in this area reduces the humidity and hence reduces the probability of fungi or wall deterioration. Maintenance of the courtyard is then mainly for elements included in the courtyard, such as greenery or pond.

E Ventilation – Stack effect – Solar chimney

Technical feasibility

In the warm climate of Vietnam, getting rid of unwanted heat and avoiding overheating is one of the main tasks of passive design. Utilising prevailing winds for cooling was widely used in vernacular dwellings. However, in the urban context, densely populated neighbourhoods leave little space for natural ventilation. Cross ventilation was considered in the proposals of house number 2, where there are two openable façades. The stack effect was used in most cases to enhance ventilation rate. Stack effect ventilation is driven by the pressure difference, created by the difference between outdoor and indoor air temperature. During cooling season, cooler air at the lower level of the building rises up through the house and escapes at the top levels. A staircase or light-well can contribute to the stack effect. With a similar principle, the solar chimney is designed at the top of the house to enhance the stack effect. Glazing and heat absorption material is used to heat up the air at the top of the solar chimney. The greater temperature difference leads to a greater pressure difference, hence better ventilation. Group 1 presented the design of a solar chimney (Figure 9.10).

Performance

The stack effect was utilised widely in the housing context of Vietnam, often combined with stairwells.. Research has shown that a solar chimney is operable in the tropics and that the most important factor that influences the air flow rate is the width of the chimney (Tan & Wong, 2013). The solar chimney is expected to enhance the ventilation rate in the tube house typology of Vietnam.

Economy

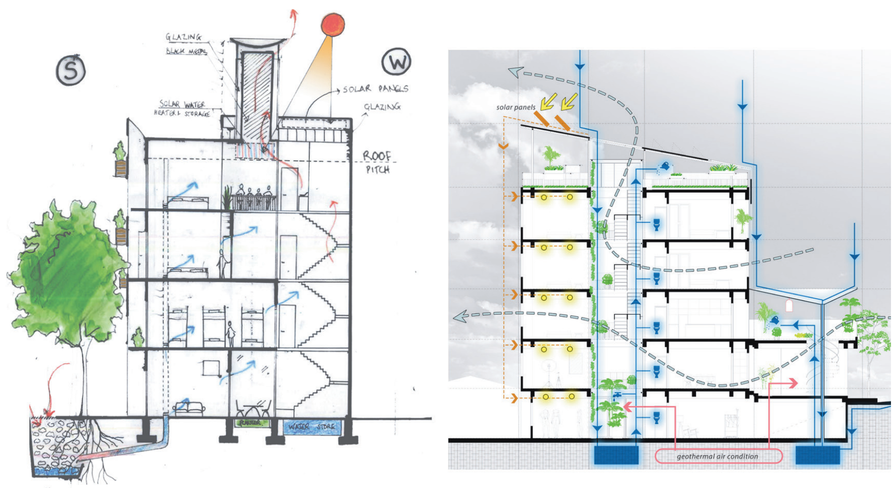
The installation of a solar chimney into an existing stairwell/shaft would not cost a lot of money but it is expected to contribute to the ventilation rate of the building.

Aesthetics

Designing for stack effect ventilation and a solar chimney in principle would not be seen by the users themselves, but could be visible from a distance, influencing the aesthetic value of the house.

Maintenance

A solar chimney system generally requires little maintenance when using durable materials (glazing, metal). High temperatures in the solar chimney can affect materials that are not fit for this application.



GROUP 1 GROUP 2

FIG. 9.10 Illustrations of cross ventilation, stack effect and a solar chimney in the proposals

F Geothermal cooling

Technical feasibility

The underground temperature is relatively stable (the annual mean value of the local climate) and lower than the air temperature in the summer of Vietnam. Air that is induced from an underground system can help cool the indoor space without using a lot of energy. However, such a system requires an inlet from outside for fresh air. Moreover, the limited underground space and low foundation of an existing house make the application of geothermal cooling limited. There are three groups that proposed this solution, as shown in Figure 9.11. However, geothermal cooling was poorly explained and was mainly designed as graphical principle. Therefore, geothermal cooling is not yet recommended for refurbishing tube houses in Vietnam.

Performance

Outdoor air is drawn into the ground, where it is cooled down by the stable temperature of the underground environment before it is induced into the rooms. In areas with a high average temperature and little temperature fluctuation (i.e. the tropics), the effect of geothermal cooling is limited (Eicker, 2014). Moreover, this process often needs support from a heat pump that also uses energy. Therefore, the efficiency of this strategy is strongly dependent on the location where it is applied.

Economy

The use of geothermal cooling is not recommended for Hanoi because it is not budget-friendly, even when it is possible. The amount of excavation work and installation of air pipes underground is significantly high considering its contribution to cooling of the building.

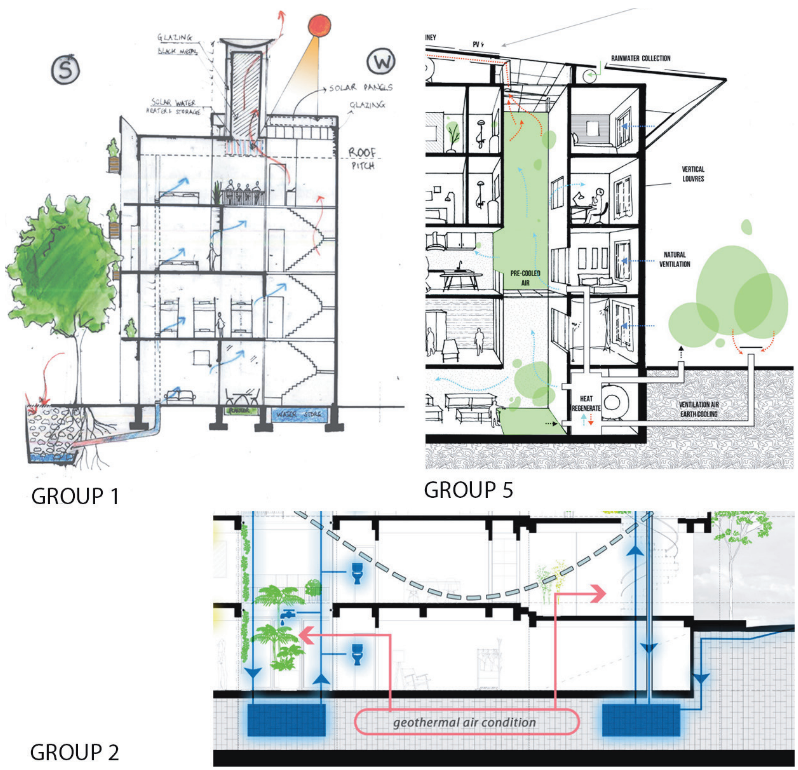


FIG. 9.11 Illustrations of geothermal cooling in the student group proposals

Aesthetics

The system is underground so it has no effect on the aesthetics of the house.

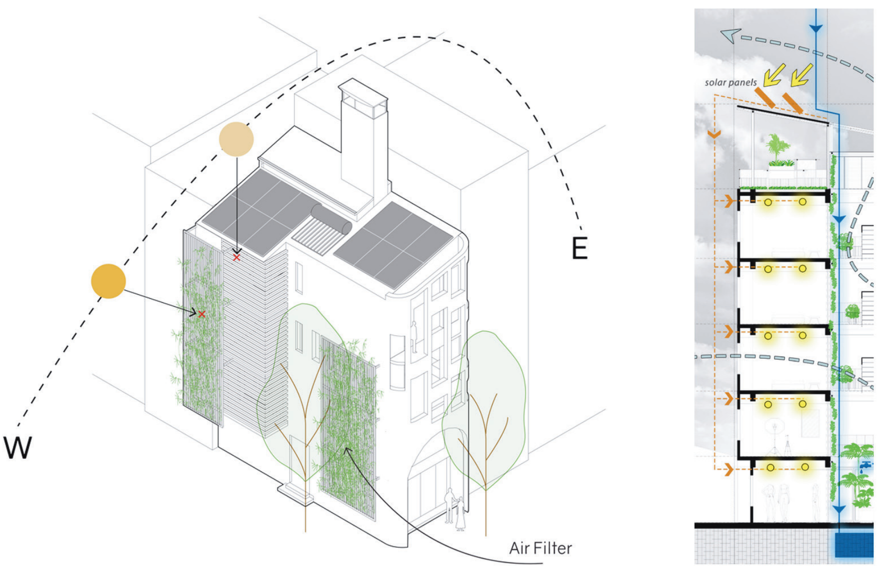
Maintenance

A geothermal system is located underground. Normally, this should not require a lot of maintenance, when designed well. When designed inappropriately it may get deteriorated or clogged easily, requiring extensive maintenance.

G Photovoltaics

Technical feasibility

Photovoltaics (PV) use solar energy to generate electricity for domestic appliances. It has significant potential because Vietnam has a high annual solar radiation capacity. In the North, solar radiation intensity ranges from 2.4 to 5.6 kWh/m^2/day while in the Central and the South, energy from solar irradiance varies from 4 to 5.9 kWh/m^2/day (Nguyen & Ha-Duong, 2009). The installation of roof top units is also feasible because PV systems are detached components. Photovoltaics were widely recognised among the student groups. Figure 9.12 illustrates a PV application in one of the students' proposals.



GROUP 1 GROUP 2

FIG. 9.12 Illustrations of solar thermal and PV in two of the student groups proposals

Performance

The potential of producing electricity that can compensate the household energy consumption is so appealing that all groups covered the roof with PV, and even the façade, as in the case of group 6. An experiment of a PV system in centre region of Vietnam with a capacity of 2 kW showed that the monthly electricity generated ranged from 166 kWh in winter months to 303 kWh in summer months (Duong et al., 2019).

Economy

The application of PV used to be limited because of its higher price, compared to the average income of Vietnamese users. In 2017, the Vietnamese government issued a feed-in-tariff where people can sell excessive solar electricity back to the grid (MOIT, 2017). Since the policy came into effect, it has raised the economic value of the PV systems and boosted their application rate in private households significantly.

PV systems have a payback time of 8 to 12 years, depending on how they are used by the occupants (Duong et al., 2019).

Aesthetics

PV system is mainly visible on the roof and does not affect the aesthetic quality of the house a lot when the roof is not visible. The PV might be installed at the front façade and can be integrated into shading devices. New technology also makes PV more appealing as it can have any colour or even be transparent, but with a loss of efficiency.

Maintenance

PV systems require some maintenance, but not a lot when installed properly.

H Solar thermal

Technical feasibility

Similar to PV systems, solar thermal uses solar energy to generate heat for domestic hot water. A solar thermal roof top unit is easy to install. However, an appropriate plumbing system is required; many old piping were not designed to handle high-temperature water. A solar thermal collecting system was well-presented by group 1 in Figure 9.12.

Performance
Solar thermal was mostly neglected: it existed in only one group proposal. However, this system is widely used in the building practice of Vietnam. It has a relatively low investment cost and can work effectively under the high solar radiation sky of Vietnam (Nguyen et al., 2017).

Economy
In terms of economy, solar thermal is relatively cheap and already used by many Vietnamese households (Nguyen et al., 2019c).

Aesthetics
A solar thermal system does not affect the aesthetic quality of the house as it is located on the roof.

Maintenance
Solar thermal requires little and simple maintenance.

9.3.2.3 Evaluation of design strategies

Based on the discussion in 9.3.2.2, design strategies were given points on the scale of 5 to justify their usage. If one strategy scores 5, it means that the strategy brings about a great positive effect to the overall performance of the house, or that it has the highest quality. On the other end, score 1 means that the strategy brings about a negative impact or has the lowest quality. Score 3 means that the strategy is neither good or bad or that it has no effect on the respective competency.

Table 9.5 and Table 9.6 explain how many points are given to the strategies, as well as what the scores mean. For example, geothermal cooling scores 2 in technical feasibility, which means that it is not feasible for refurbishment of tube houses and not recommended, while solar shading and solar thermal are the most feasible ones. The green façade has a high score in most competencies but only scores 2 in maintenance because it requires extra effort to keep the system working properly.

TABLE 9.5 Grading of design strategies on the scale of 5

	Technical feasibility	Performance	Economy	Aesthetics	Durability/ Maintenance
Solar shading	5	4	4	4	5
Green facade	4	5	4	5	2
Insulation	4	2	3	3	2
Courtyard	3	5	3	5	4
Ventilation – Stack effect	4	4	4	3	4
Geothermal cooling	2	3	1	3	2
PV	5	4	4	3	3
Solar thermal	5	5	4	3	4

TABLE 9.6 Explanation of the grading system

	1	2	3	4	5
Technical feasibility	Not feasible	Unlikely feasible	Neutral	Feasible	Highly feasible
Performance	No benefit/ negative effect	Very little effect	Moderate effect	High performance	Very high performance/ multiple benefits
Economy	Expensive/ Not cost effective	Slightly expensive	Neutral	Affordable	Very affordable/ Cost effective
Aesthetics	Much worse	Worse	Neutral	Better	Much better
Maintenance	Require lots of maintenance/ expertise	Require regular maintenance	Occasional maintenance	Little maintenance	No Maintenance

The evaluation of the strategies with five criteria is visualised in Figure 9.13. In general, the strategies recommended are sun-shading, green façade, natural ventilation, solar thermal and PV because they all score 4 or higher on technical feasibility, performance and economic aspects. There is, however, a concern about the maintenance of the green façade. Therefore, the design of a green façade should carefully consider the type of façade, type of plants and how the plant is growing within the provided structure.

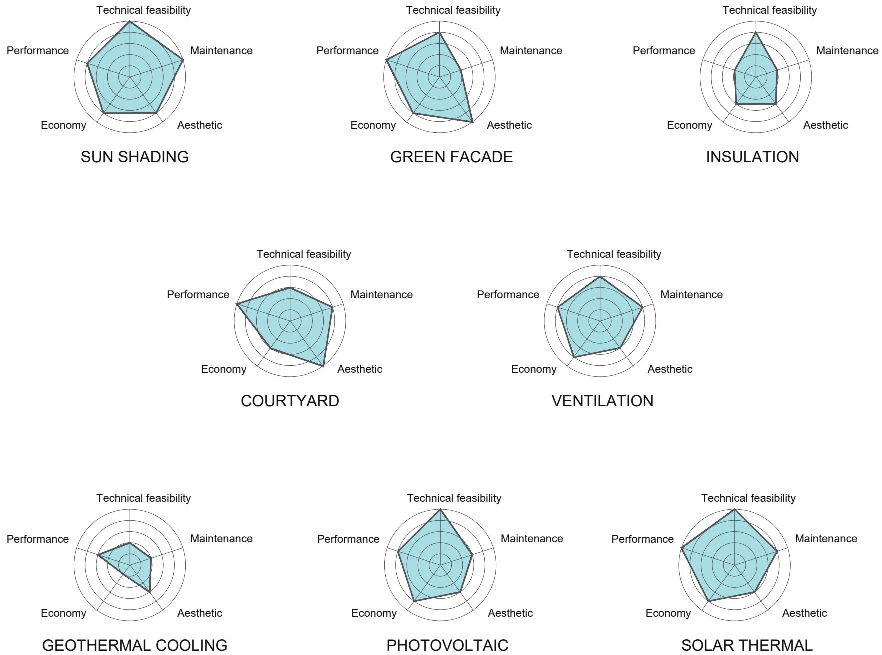


FIG. 9.13 Evaluation of different sustainable design strategies in Vietnam

A courtyard is an important element that should also be considered for housing (re) design. There are some barriers to the application of a courtyard in a refurbishment project, such as with small urban houses in Vietnam: often there is not enough space for a courtyard. High costs due to demolition and less living space is also a hindering factor since the budget of Vietnamese occupants is one of the most important drivers for decision making in refurbishments (Nguyen et al., 2019a).

Thermal insulation provides some benefits to housing performance, such as preventing heat losses in the heating season, and noise reduction. However, it is not recommended because of its small or even negative effect in the cooling season (in case the house uses natural ventilation and has little or no solar shading) and regarding maintenance issues. Geothermal cooling is basically not feasible for existing Vietnamese tube houses in Hanoi as there is not enough underground space for the system. The amount of work and the cost to install the system into an existing house is really high compared to the cooling benefit that it might bring.

9.3.2.4 Integrated design of the design measures

Design strategies are introduced as a single measure to either reduce, reuse or produce energy and other resources. However, in the proposals, they are designed to be integrated, meaning that they can be combined, interact with each other in different ways and bring different effects to the overall performance of the house. That is where the design skills of the architect are required.

During the workshop, the student groups came up with different integrated solutions, depending on the actual condition of the buildings and design skills of the students. This part discusses how the measures should be applied and, more importantly, combined in a tube house. All design strategies are divided into 3 categories based on their location in the house. The first one is related to the front façade, consisting of the façade construction, shading devices, green façade. The second set concerns the courtyard and its surrounding elements to enhance ventilation and cooling, such as greenery, solar chimney and geothermal cooling. The last part is the combination of production systems, including photovoltaics, solar thermal and rain water collection.

A Façade design – Shading – Greenery

In housing projects, the façade is designed as an integrated element that can fulfil multiple tasks such as aesthetics, protection and thermal regulation. Considering sustainability, façade design often involves insulation, shading devices, greenery, and energy production (photovoltaics).

The elements mentioned above were applied in the design proposals of the students in the workshop. These elements can stand alone; for example, insulation was added to external walls, shading devices were added to windows. They can be one element that has multiple functions, as greenery and PV panels themselves also can create shade for the building, as in the case of group 3, 5 and 6. They can be combined to work together; for instance, the climbing plant is growing on the louvre shading device in the proposal of group 1 (see Figure 9.14).

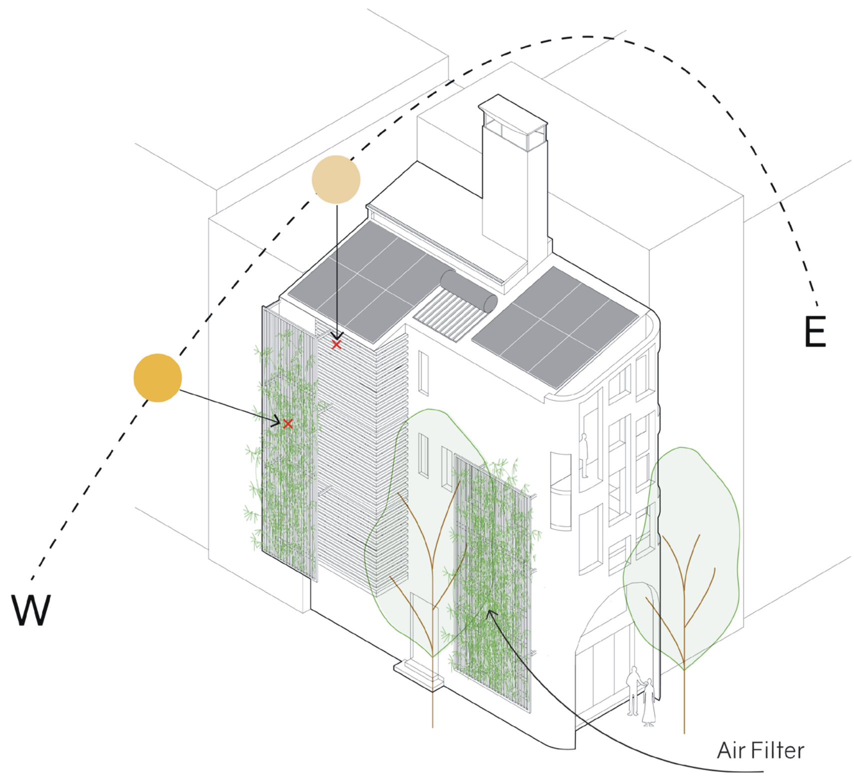


FIG. 9.14 Façade design with combination of shading device and greenery

B Courtyard – greenery – solar chimney

A courtyard, greenery and solar chimney should be considered to be integrated where possible. Because of their relatively close proximity, each of the strategies can benefit from the other, apart from its own function. In this composition, the courtyard is the core element because it is the place for the greenery to grow and its vertical connection helps to circulate the air and exhaust the air through the solar chimney. The courtyard can provide a lot of daylight, but it can also get very warm in case of direct solar irradiation. A solar chimney with dark-coloured materials should be designed to absorb direct solar radiation. Greenery, on the other hand, creates evaporative cooling to cool the air inside the courtyard. The temperature difference between the cool air inside the courtyard and the warm air in the solar chimney causes the air to rise and ventilate the building. Figure 9.15 shows a good example of such a system. However, in the proposal, it was not clear how the courtyard is shaded.

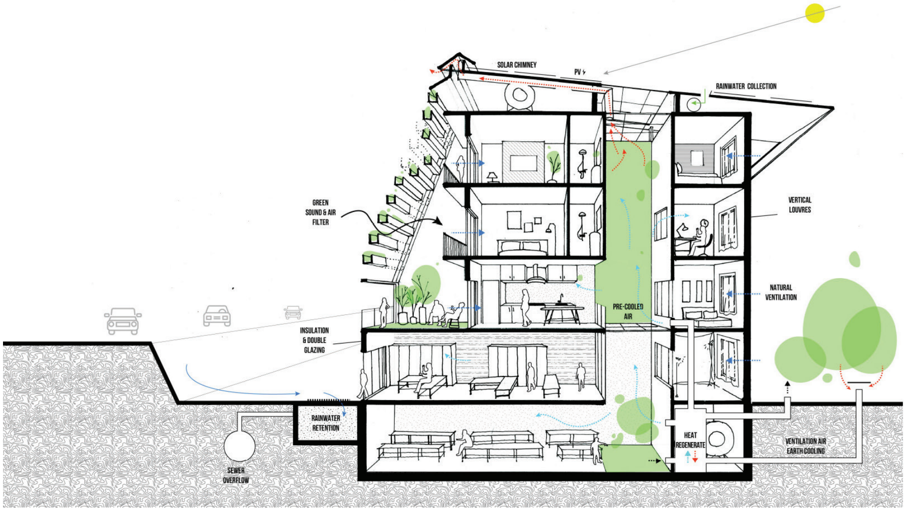


FIG. 9.15 Integrated design of courtyard, greenery and solar chimney

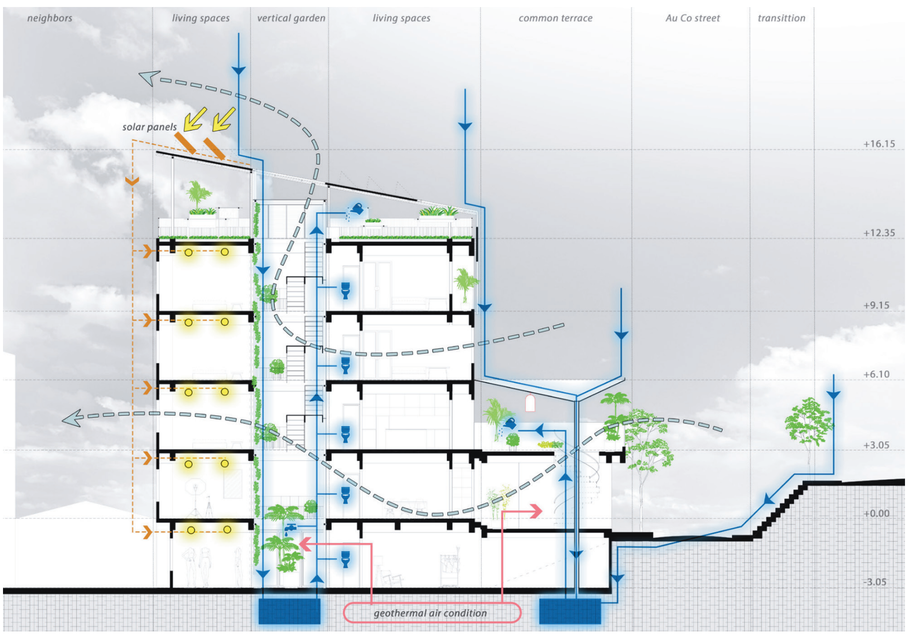


FIG. 9.16 Example of solar power collection and rain water collection

C Photovoltaics – solar thermal – rainwater collection

In terms of utilising natural, renewable resources, solar thermal, PV and rain water collection are in the same category since they share the same location on the roof (see Figure 9.16). Because the roof area in a tube house is limited, it is recommended to use the photovoltaics thermal hybrid solar collector (PV-T) as it is the combination of solar cells and solar thermal collector. The overall efficiency of PV-T technology is higher than PV and solar collector separately (Mojiri et al., 2013). Thermal energy is captured to heat up the water for domestic hot water, therefore solar cells are cooled down. The lower temperature improves the efficiency of the electricity generating process and also improve the cells' lifespan (Tripanagnostopoulos et al., 2003).

9.3.3 Design strategies for sustainable tube houses in Vietnam

In the previous section, we have discussed the results from the student design workshop GASC 2019. Based on the results, there are a number of lessons that we can learn regarding sustainable design strategies for refurbished tube houses in Vietnam.

9.3.3.1 The stepped strategies

There are many design measures that can be applied to a sustainable and energy efficient refurbishment project. Depending on specific case, certain strategies could be used. The application of the design measures should follow certain steps. Such steps were introduced first in the Trias Energetica (AgentschapNL, 2012; Lysen, 1996), and in the New Stepped Strategy (Van Den Dobbelsteen, 2008) which was inspired by the Cradle-to-Cradle concept (Mcdonough, 2002). Design for tube houses in Vietnam could follow a similar stepped strategy. With the results from the workshop and other related research (A. T. Nguyen et al., 2011; P. A. Nguyen et al., 2017), the stepped strategies are modified for to the local context of Vietnam, as described below.

9.3.3.2 Stepped strategies for Vietnam

Applying the stepped strategy in the Vietnamese context retains the three steps structure: Reduce, Reuse and Produce. However, Vietnamese architecture deals with a warm tropical climate, so cooling is the main target of the measures. Figure 9.17 shows the three strategic steps. The first step starts with smart bioclimatic design, with the main objective to avoid overheating, thus reduce energy demand for cooling. This step consists of three approaches, protecting the building from direct solar gain, promoting natural ventilation and using evaporative cooling. In this step, most of the measures are well-known by designers and can be found in traditional bioclimatic architecture. Solar control can be achieved by massing, for example, by using service mass as shading for the main living block. This can also be done by designing the building envelop carefully. Popular existing measures are elevated roof, roof thermal insulation, and shading devices or overhangs. An open floor plan with appropriate opening design is good for natural ventilation and for removing excessive heat. However, in current urban tube houses, two of the most effective measures, the green façade and the courtyard, are often absent. The main challenge for the courtyard is the limited living space. Secondly, maintenance often discourages the owners to include a green façade. In the Vietnamese stepped strategy, It is strongly recommended that these measures should always be considered and applied.

The next step is to reuse potential waste flow internally and/or externally. Renovation activities can be implemented with reused or recycled materials. For example, new walls can be built from recycled bricks and doors and windows can be reused from another project. Used water from the shower or the kitchen sink can be treated to be used for flushing the toilets. Food waste can be used to make compost for the garden or vegetable growing in the house. All of the examples do not have a direct impact on the end-user energy consumption, but can potentially reduce the primary energy for producing and transportation of resources. In this step, so far no measure have been proposed by the students for reusing or recycling waste heat.

The last step concerns the sustainable production of resources. Domestic hot water can be supplied by solar thermal. Photovoltaics cells converts light energy into electricity for household consumption. With the newest regulation from the government, house owners can sell unused solar-power electricity to the grid, solar PVs in private houses are expecting to grow in the coming years (MOIT, 2017). Rain water collection is also a potential design measure to provide water for all purposes. It can also be integrated with the green roof.

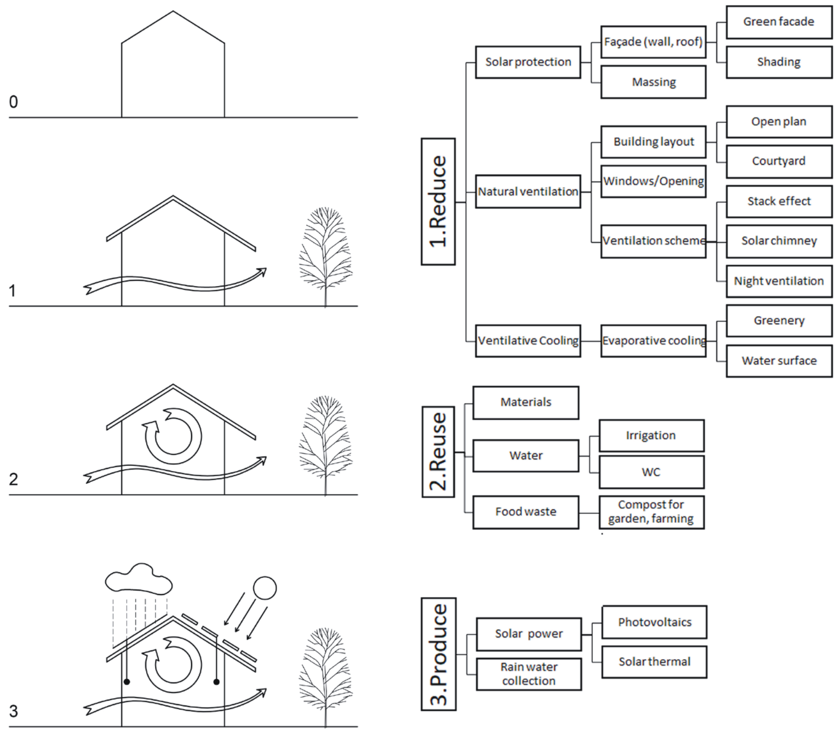


FIG. 9.17 Sustainable design strategies steps for tube house refurbishment in Vietnam

9.4 Discussion

The GASC 2019 event, including the GASC conference and the student design workshop, was a great opportunity to collaborate and promote sustainability in the built environment of Vietnam. By putting together students of different Vietnamese and Dutch universities, there was a chance to learn, test and exchange many design strategies.

Criteria

The student groups worked on different cases of Vietnamese tube houses and they each proposed a sustainable and integrated re-design of the designated house. Design measures that were applied in the workshop were discussed and evaluated by five criteria: technical feasibility, performance, economy, aesthetics and maintenance. Most of them are applicable except for thermal wall insulation and geothermal cooling as they are not effective in general.

Strategic steps

From the workshop, a new strategy was developed, which was adopted from the Dutch New Stepped Strategy (Van Den Dobbelsteen, 2008). The new strategy consists of three steps: 'Reduce', 'Reuse' and 'Produce'. The design strategy for Vietnam differs from the original one as it mainly deals with overheating issues rather than trying to preserve heat as in the temperate climate of the Netherlands.

Green architecture

Recently, more Vietnamese architects pursue the 'green' architecture principles and their new private housing projects often apply bioclimatic design measures, which are mentioned in the first step of the proposed strategy. However, some potential features, such as courtyards and green façades, are often absent in urban tube houses due to space and maintenance limitations. Moreover, the majority of existing tube houses were built 10 to 30 years ago. Many of them were not built with consideration of a comfortable indoor environment and energy conservation. The owners also often prioritise budget and aesthetics over performance when refurbishment is required (P.A. Nguyen et al., 2019a). A new stepped design strategy is essential as an initial guideline for both architects and house owners for future new built or refurbishment projects.

Reuse

The second step of the strategy proposed ('reuse'), which suggests reuse of waste energy, available materials and other resources, has limited potential in the housing stock of Vietnam. Currently, these measures do not have visible economic benefits and are not appealing to house owners and architects. However, they help preserve our limited resources and make our built environment more sustainable.

Solar energy

The last step of the strategy ('produce') mainly encourages the use of solar power for electricity and domestic hot water. There is currently an uptrend of installing PV in Vietnamese private houses since the introduction of the feed-in-tariff in 2017. These actions, however, were mainly the reaction of the people who look for financial benefit from the national policy rather than part of an integrated plan for sustainable transformation. Nevertheless, this phenomenon suggested that the promotion of sustainable and energy efficient tube house design might be achievable if there is a proper incentive program or a new mandatory regulation as in the case of public buildings.

Synergy

The workshop outcomes also suggested that design measures should be applied and combined in three main groups to amplify the effect of each. Firstly, greenery and sun-shading should be considered together in protecting the house from direct solar gain. A courtyard, greenery and solar chimney work well together in ventilating houses, providing cooling, and filtering air from fine dust. Combining the solutions creates synergy in functionality and sustainability. Finally, solar thermal, PV cells or the combined version, PVT, along with rain water collection help to make the best use of renewable resources for the users' needs. And they can all be collected from the building's roof. These combinations are based on the location of the component involved as well as their compatibility in integration.

Lessons for Vietnamese energy legislation

The strategic steps and the lessons learned from the workshop are expected to bring new ideas and approaches to the built environment of Vietnam. The development of sustainable housing stock is quite fragmented in both legislation and construction practice. Current construction law in Vietnam only concerns sustainability and energy efficiency for public buildings with a total floor area larger than 2500 square meter. This national technical regulation for energy-efficient buildings only provides standards for the building envelope and energy-efficient electrical appliances (MOC, 2017). There is no guideline for designing or renovating of private houses or other building types in general.

Concluding

An integrated stepped strategy is a good start for sustainable housing design in Vietnam. It covers most of the required state-of-the-art steps to achieve sustainability in the private housing sector. Based on the three steps, architects and house owners can work together to formulate targets for their future homes or renovated one. On the other hand, the government can use the steps to develop more detailed regulations and guidelines to enforce and encourage the uptake of energy efficient housing in Vietnam.

Acknowledgement

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10 An educational evaluation of the international student design workshop

GASC 2019

This chapter was published by the journal Discourse and Communication in Sustainable Education. Title of the article is 'Sustainable Design Education – An Evaluation of the International GASC 2019 Student Workshop in Hanoi, Vietnam'.

10.1 Introduction

Sustainability in the built environment can only be achieved when different parties are involved and take action. In Vietnam, legislative and institutional challenges are often perceived as the biggest obstacles to sustainable buildings. However, social and cognitive barriers were presented as the main problems that hinder the development of green and sustainable architecture (Nguyen et al., 2017). In recent years, green buildings and sustainable homes in Vietnam are mostly the products of a new generation of architects. Therefore, as in educational institutions, inspiring and teaching architecture students how to design sustainable architecture is an important mission.

Green Architecture for Sustainable Communities (GASC) is an event organised by Delft University of Technology (TUD) and two Vietnamese universities: Hanoi Architectural University (HAU) and National University of Civil Engineering (NUCE) with the aim of boosting sustainable development in the built environment of Vietnam. This event aimed at transferring the latest theoretical and practical sustainability knowledge from the international experts to the architecture students. Different activities, including a symposium, a design workshop and several discussion panels on sustainability topics, were held simultaneously within an one-week period. Continuing the success of GASC 2017, GASC 2019 took place in Hanoi, the capital of Vietnam. The event was held from the 15th to the 20th of September 2019. This time, the symposium and design workshop focused on the design strategies for energy efficiency in private urban houses – so called "tube houses" in Vietnam – aiming for zero-energy homes.

During the workshop, students were given information through several sources, including research papers, scientific and practical lectures, and design studio guidance. They also had extensive discussions and feedback within and across the groups. This chapter investigates what the students learned and how they gained knowledge and skills of designing sustainable architecture.

10.2 Design education

Designing is often considered as a complex skill, which is personal, creative and open-ended (Dreyfus et al., 2000). Teaching and learning of this skill follow the conception of the design process. In design education, teachers are often master practitioners who know the operating skills, ways of thinking and communicating where novice students want to learn these moves and design vocabularies (Waks, 2001). Although designing is often an implicit activity (Dreyfus et al., 2000; Lawson, 2006), researchers have shown that making explicit is important in design education (Kolb, 2014; Reigeluth, 1983). It is important that teachers and students often talk about the design process in the studio. Five generic elements were defined to help the tutors and students making explicit in the design learning process. They are: *experimenting or exploring and deciding, guiding themes or qualities, domains, frame of reference or library, laboratory or visual language* (van Dooren et al., 2014).

The traditional way of design education is done through design studios and this is still an effective way to help the student learn design skills (Cross, 1982). Sustainable architecture programmes often combine the studio with workshops and lectures on sustainable and climate design (Dobbelsteen & Linden, 2007). Another effective way of learning, used for smart and bioclimatic design, is self-directing learning, where the students can choose a specific sustainability topic to study and use this information to create their own design manuals (Dobbelsteen & Linden, 2007).

In GASC 2019, the student design workshop combined the design studio with sustainability lectures, which were given during the conference, and architect talks. With the help from the universities' teachers, intensive discussions and guidance were conducted daily. The students, however, did not have time for a design manual, but they were free to study sustainable design strategies and decide their own approaches.

The students were guided with a holistic approach to sustainable design, including ecological, technical and social aspects. In terms of ecology, main topics discussed were bioclimatic design, greenery, daylight, indoor thermal comfort, natural ventilation, acoustics and air quality. The technical part covered energy efficiency, water usage and materials. Local culture and user behaviour were mentioned as the social aspect of sustainability.

The student design workshop was carefully set up and assessed. One of the main outputs was a design proposal that was presented by each group at the end of the week. The proposals were evaluated by jury members, including university lecturers and architects. A post-evaluation questionnaire was conducted to assess the effectiveness of the workshop. Other researchers also conducted surveys to evaluate the effect of design courses or workshops (Dobbelsteen & Linden, 2007; Tunçer, 2009).

10.3 Method

Student group division

There were in total 33 students taking part in the workshop. Eighteen of them were from HAU, ten from NUCE and five from TUD. The students taking part in the workshop were both bachelor and master architecture students. All of the TUD students were doing their master study. The majority of the Vietnamese students were undergraduates. Since there was a variety in the experience level and cultural background of students, the group division rule was such that every group had students from all universities and that each group had students from the 3rd year of study until master students. Initially, there were 8 groups of 4 to 5 students. However, due to the absence of some students on the first day of the workshop, the students were re-divided into 6 groups of 5 to 6 students. There were 5 TUD students in total, so there was one group (group number 2) that had no TUD student.

Activities in the workshop

The Vietnamese and Dutch students have different backgrounds and have learnt different approaches to sustainable architecture. Vietnamese students have a deeper understanding of the local housing typology, local climate and traditional design measures. TUD students are master students who have more experience in and knowledge on technology and energy efficiency in particular. Therefore, the students were given reading materials prior to the workshop, so they could learn from each other's expertise.

Figure 10.1 describes the activities of the workshop over the week. The workshop was divided into 3 main stages. In the first stage, the students analysed and discussed the potential and challenges of their own case. During site visits and design brief sessions, the students talked to house owners about their wishes and they asked mentor architects about specific issues of the projects.

During the second stage, the groups brainstormed and defined their design concept, discussed with each other and with the mentors on how these design concepts can benefit the whole plan of the proposal. Feedback and discussion were extensively applied. In this stage, the students also attended the GASC conference to obtain new ideas.

The main theme of the conference was 'sustainable and energy-efficient housing'. Participating speakers were professors and lecturers from the three universities. They presented the latest research on sustainable approaches for housing in the Dutch and the Vietnamese contexts.

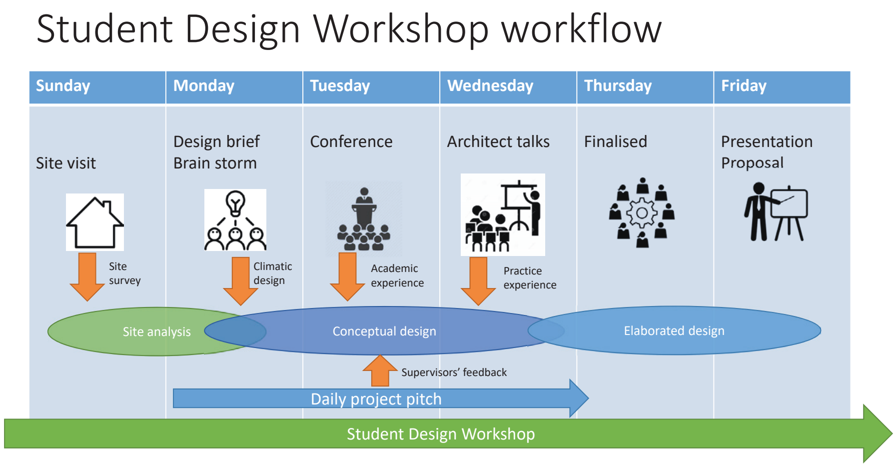


FIG. 10.1 Student design workshop progress (author's graphic)

The last stage consisted of architect talks, where practical Vietnamese housing projects were introduced. Informed by these, the groups finalised the idea into a specific redesign of a house. Again, difficulties in translating ideas into solutions were being discussed and solved with the help of the mentors.

Design proposals were assessed by a jury of experts in terms of design, thermal and energy performance, and sustainability. After the workshop, the students were asked to complete a questionnaire to evaluate the implementation of the student design workshop and describe their own experiences taking part in this event. The results are given in this chapter.

Constructive alignment of the workshop

The set-up of the workshop was based on the constructive alignment, a theoretical concept for teaching and learning in higher education (Biggs, 1996). The main idea of the concept is to align the learning objectives with the teaching/learning activities and the final assessment. Table 10.1 presents the content of this triangle relationship.

The learning objectives of the student design workshop were to teach the student sustainable design applied to the specific case of Vietnam tube houses. The students were expected to learn about sustainable design strategies through literature and lectures, to understand and analyse the current context of the cases, including its potential and challenges, to apply the sustainable design measures and integrate them into the proposal, and to present and evaluate the qualities of their proposal.

TABLE 10.1 Constructive alignment of GASC 2019

Learning objectives	Teaching and Learning Activities	Assessment
Understanding the context (Vietnamese culture, housing typology, the cases)	Site visit Design brief	-
Understanding Dutch approaches to sustainable homes	Conference Design brief	-
Understanding bioclimatic design in Vietnam	Conference Design brief Architect talks	-
Analysing and applying design measures Designing the proposal	Group work Daily project pitch	Formative assessment
Presenting outcomes (presentations, posters and physical models)	Final presentation	Summative assessment

In addition, the TUD students were expected to learn about the Vietnamese culture and housing context by doing site visits and by reading materials, as well as to understand local design approaches by attending lectures by Vietnamese researchers and local architects. The Vietnamese students were also expected to learn about the sites even though they already have a background of the Vietnamese context. They should learn about integrated design approaches from the TUD professors' lectures and reading materials. During the group work discussions, all students needed to analyse the problems and potentials, and to apply design strategies to their own proposals. They should be able to show their design skills and visualise their ideas through sketches and physical models.

Finally, the students needed to learn to present and defend their works in daily project pitches and during the final presentation. The assessments were done through daily supervision and during the presentation sessions.

Set up of the questionnaire

The in-house questionnaire had two main parts, see appendix B. In the first part, the dichotomous questions asked the students if they had learned certain design aspects during GASC 2019 and if they had applied them in their proposals. The aspects asked about were: architecture, urban planning, building technology, floor plans and layout options, sustainability, bioclimatic design, energy, water, materials, greenery, indoor thermal comfort, daylight, ventilation, acoustics, air quality, and user behaviour. The second part, including scaling questions, focused on the experiences of the students with the different activities happening during GASC 2019. The activities were: site visits, introduction speeches, Vietnamese architect talks, the GASC 2019 conference, design supervision, student group work, cultural/networking activities, and the final presentation of the student groups. There was also room for the students to give feedback to the organisers. The questionnaire is presented in the appendix of this paper.

10.4 Results

10.4.1 Evaluation of teaching activities

There were 28 questionnaires collected after the workshop. Fifteen of them were from HAU students, nine from NUCE and four from TUD (see Figure 10.2). As mentioned previously , the students taking part in the workshop were both bachelor and master architecture students.

Students were asked if they had taken part in the projects and if they could indicate how much they had learned in each activity by replying “take part only”, “learn something” or “learn a lot”. The participation rate and the indication of the students are shown in Figure 10.3 .

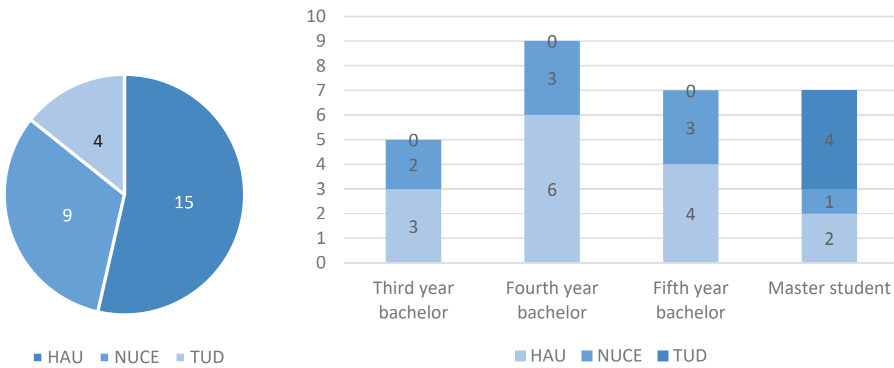


FIG. 10.2 Characteristics of the students participating in the questionnaire

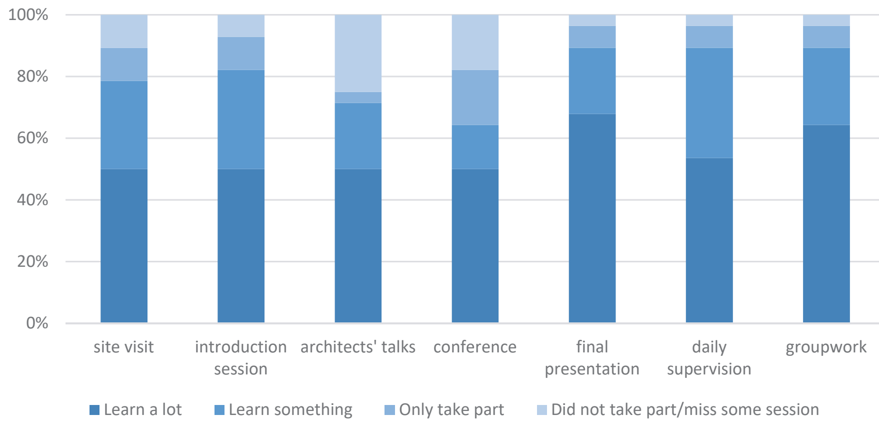


FIG. 10.3 Participation rate and indication of knowledge gained from different activities

Many activities had a participation rate above 90%, except for the architect talks and the GASC conference. In any event, at least 50% of the respondents stated that they took part and learned a lot from those activities. Ninety percent of the students learned something from the daily supervision, student group work and final presentation. These were all interactive activities where the students discussed within their group and had question-and-answer sessions with either supervisors or jury members. The learning rate was lower for activities that had less room for discussion and feedback, such as the introduction session and the conference. It is noted that the architect talks were considered successful with a high learning rate of 71% compared to the participant rate of 75%.

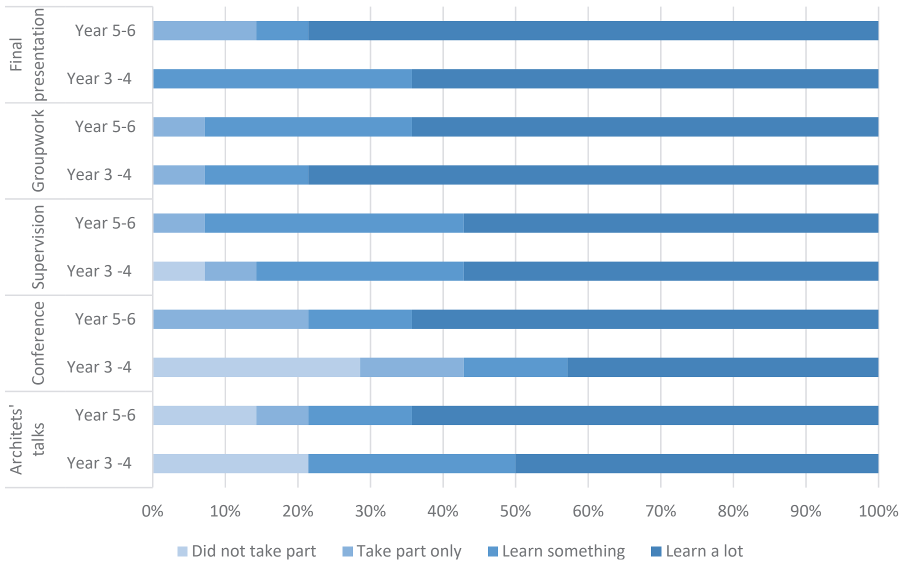


FIG. 10.4 Learning rate of 2 student groups

Grouping students of different years of study together not only maintained balance between groups but also created an environment where younger students could learn from senior students. Figure 10.4 shows the learning rate of the students in different activities in different educational stages. Students in their 3rd and 4th bachelor year were more likely to learn from peers during the group work. However, last-year bachelor students and master students had more experience and learned more from the conference, architect talks and the final presentation. The student learning rates from daily supervision were similar. In general, such a workshop can create good opportunities for all the students to learn, although the senior students with more experience might catch up with the work and benefit more from the different activities.

10.4.2 Evaluation of design topics

10.4.2.1 Questionnaire results

The students indicated whether they had learned and applied certain aspects in the design workshop. The descriptive results are shown in Figure 10.5. There were

6 general aspects asked about architecture, urban planning, building technology, floor plans & layout, sustainability and bioclimatic design. According to the results, the students were more likely to learn about architecture and sustainability in general (96%) rather than urban planning (54%). Although urban planning is part of sustainable architecture, the fact that the students investigated a specific case of a private house explains why urban planning was considered not so relevant. Knowledge of building technology, layout and bioclimatic design were gained by more than 80% of the students. It is worth noting that building technology learning and applying was slightly higher with 89%, while it was 82% for layout and bioclimatic design. This indicates the benefit of having experts from TUD as supervisors and lecturers, as well as background knowledge from the TUD students on the overall outcome of the workshop. TUD students themselves responded that they had learned more about building technology and that they had applied that to the project.

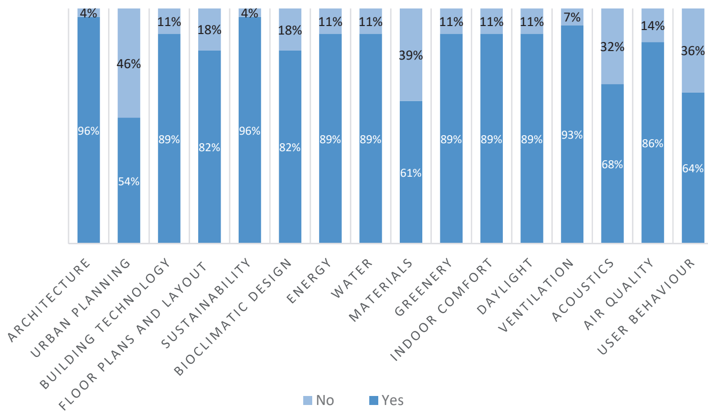


FIG. 10.5 Rates of student that had learned and applied different aspects from the workshop

Specific aspects of sustainable design were also investigated. The results show that the students learned both about bioclimatic design aspects such as using plants and trees, daylight and natural ventilation, air quality, as well as about sustainability aspects such as energy and water management. The positive response rate was around 90%. However, not all the topics were covered in the workshop. The students reported less learning and applying knowledge of sustainable materials, acoustics design and user behaviour. The lack of investigation might be due to the limited time frame of the workshop and the complex application of the three factors.

10.4.2.2 Workshop results of applied strategies

The student groups applied design strategies that they acquired from the materials provided, the conference, the actual projects of the Vietnamese architects, on their own projects. Table 10.2 below summarises which design strategies were included in the final outcomes.

TABLE 10.2 General overview of applied strategies

Strategies	Group 1	Group 2	Group 3	Group 5	Group 6
Solar shading	X	X	X	X	X
Greenery	X	X	X	X	X
Courtyard / Lightwell	X	X	X	X	-
Solar chimney	X	-	-	X	X
Geothermal cooling	X	X	-	X	-
PV	X	X	X	X	X
Solar thermal	X	-	-	-	-
Rainwater collection	X	X	X	X	X
Waste recycling	-	X	-	-	-
Insulation	-	-	X	X	-
Elevated roof	-	X	X	X	-
Natural ventilation	X	X	-	X	X

The most popular design measures were solar shading, greenery, photovoltaics (PV) and rain water collection, which were applied by all groups. The first two are well-known design measures. They exist in traditional Vietnamese architecture. Using PV was favourable despite a questionable cost-benefit evaluation in Vietnam. The potential of PV is promising, nonetheless, because there is ever more research on increasing the efficiency of PV and lowering its production cost. A solar thermal collector was a low-cost measure to reduce the energy demand for domestic hot water (DHW) but was seen only in the proposal of group 1. The use of solar thermal can be integrated in the PV system, as a photovoltaic thermal hybrid solar collector (PVT).

Due to the high annual rainfall, rainwater collection has a great potential in Vietnam. The lack of existence of such a measure in contemporary housing projects can be explained by the lack of space for a water tank in a modern house, the low water price and hence low economic benefit. However, in a sustainable housing project, if possible, such a design measure should always be included.

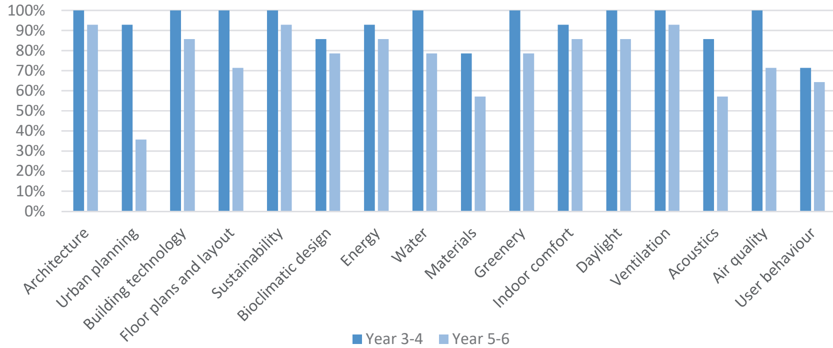
A courtyard, or its smaller version, a light-well, was also applied by most groups. Courtyards and open spaces are important components in traditional dwellings. They provide daylight, natural ventilation, fresh air and social space in a house. They did not exist in the houses investigated, even not in house number 3 with the largest plot size. Group 1 and group 3 could only integrate a small light-well in the house, and group 6 had no courtyard/light-well in the proposal because of their small site.

10.4.2.3 Discussion of workshop results

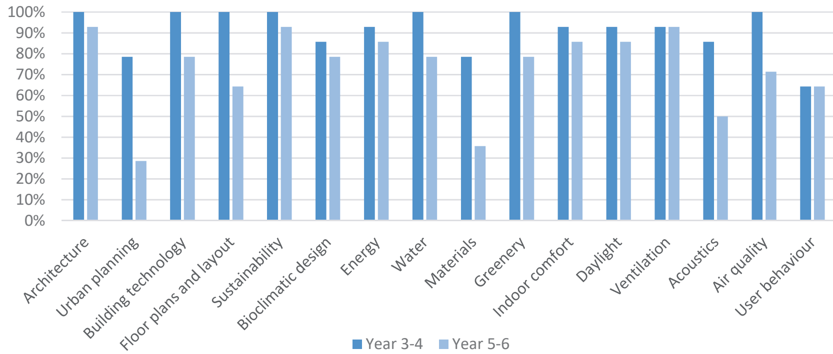
The evaluation results from the questionnaire and the workshop outcomes were aligned with each other. Popular design strategies applied concern bioclimatic aspects such as solar shading, natural ventilation, greenery, cooling, indoor environment and energy productions (PV, solar thermal). They are also shown in the questionnaire responses as most students learned something on bioclimatic design, energy, water, greenery, comfort, daylight, ventilation and air quality. Urban planning, sustainable materials and user behaviour were among the aspects of which students learned not much, and they were also absent in the design proposals.

The students indicated that they learned about technology and energy saving. However, the measures that make use of solar energy were not clearly integrated. While all groups chose to use PV to generate electricity, only one group considered the use of solar thermal, which can also be integrated into PV. Three out of five groups proposed to have a solar chimney but the design of such a system was simple and lacked explanation.

The main objective of the workshop was to teach the students about sustainable design strategies and how to apply the strategies into the proposal. Figure 10.6 shows the learning rate and application rate of different design aspects by the students. We divided the students into two main groups, junior students of year 3 and 4, and senior students of year 5 and 6 (master students). Junior students generally learned more from the workshop than the senior students. The junior students claimed a learning rate of 100% in 9 out of 16 categories. This response was expected because the senior students are more experienced and already have part of the knowledge. However, the number of senior students that learned from the workshop is still high, which indicates that knowledge has been transferred to the students.



a



b

FIG. 10.6 (a) Learning rate and (b) application rate of junior and senior students

In architecture and bioclimatic design parts, or indoor comfort, daylight and ventilation, the learning rate of both student groups are high and similar to each other. These aspects are widely embraced by the students because they are closely connected to the design process and are often easier to present in the design proposal. Sustainable materials, acoustic and user behaviour were either not covered enough during the workshop or less attractive to the students. Both learning rate and application rate for these factors are lower, compared to the others, especially for the case of senior students. It could also be due to the high level of detail and the technical level for knowledge on materials and acoustics. The abstract idea of user behaviour might have had little influence on the design process.

Regarding resources, energy efficiency and water usage were the two most popular measures that most students learned about and applied to their project. Since energy efficiency was one of the key missions in the design brief, it was often discussed during the workshop. In the final output of the workshop, it was translated to the presence of PV, solar thermal, and active cooling measures. Rain water collection was introduced during the 1-hour talk of the two local architects. The presentation of how the architects brought their ideas to real buildings was good inspiration to the students. This suggests a future workshop should involve more practical examples for the related topics.

10.4.3 Evaluation of the assessment of the projects

The formative assessment of the workshop was mainly done through the daily project pitches. The summative assessment was the final presentation on the last day. During the 5-minute pitches, the students practiced presenting their ideas through sketches and models. The pitches often consisted of a problem statement and proposed measures. Student groups could give feedback to each other, so they could both analyse and reflect on the pros and cons of all the cases. Most groups did this part well. However, there was one group in which the ideas and discussion were dominated by a senior student. The junior students in that group did learn from the more experienced one, but they did not learn to reflect and give feedback, as observed by the mentor. This problem is sometimes seen in the East-Asian culture, where hierarchy is important. This behaviour should however be avoided in such workshop activities. In this specific case, the specific student group was preselected from a group of friends. This suggests that the selection process of students in the future should avoid clumping of friends, and the difference in student backgrounds should not be too big.

At the end of the week, the students presented their final product in front of a jury. The students demonstrated their ability to do research on the case studies and the design measures. They were also capable of utilising the sustainable design principles within the existing structure, considering the owners' wishes. As winner, the jury selected the proposal that according to them integrated best the sustainable design strategies and the aesthetic aspects, as well as functional aspects of the house. All groups proved that the students learned from sustainable principles and that they applied these to the design of existing tube houses.

Students' feedback on the workshop

The students provided feedback to the organisers to enhance the quality of future events. Positive comments often included the diversity of the student backgrounds, participation of practice architects and a good workshop plan. Things named to be improved were the language barrier and student selection.

The diversity in nationalities, universities, and experience of the students was one highlight point of the workshop. The TUD students could learn from the Vietnamese culture, the different design approaches from a different climate region, the local methods of construction and materials. On the other hand, the Vietnamese students could learn from novel technology and various technical skills from the experienced TUD students.

The presence of local architects from practice through the talk show activities, supervision and final presentation was highly appreciated. They provided guidance and a more practical way to approach a project. Lessons learned from their past projects were very helpful to the students, especially in the later part, when the students transferred their ideas to architecture drawings. Some students indicated that more involvement of architects was desired.

However, there were still some shortcomings that need to be addressed in the future. These mainly refer to the student selection process. The students selected in some cases had insufficient English language proficiency, communication skills and group work skills. The problem often related to the junior students with lack of experience and skills. Solution for this issue is that there should be only one recruitment party to select the students from all over the university. In this workshop, each of the universities sent students selected by their own; the only standard and criterion was the year of study.

Another problem was the fact that the number of TUD students was small compared to Vietnamese students. Vietnamese students had little chance to learn from their foreign peers. The large number of group members of 5 to 6 even worsened the situation. The communication between the groups was also more difficult as the Vietnamese students tended to speak Vietnamese to each other.

10.5 Conclusion

GASC 2019 was an international event aiming at bringing architecture students from Dutch and Vietnamese universities together to work on sustainability projects. The main objective of the workshop was to help the students learn sustainable design skills and strategies and to have them apply these in real housing projects in Vietnam. During the workshop week, the students were exposed to many activities, including site visits, an international conference on sustainability, lectures by local architects, daily supervision from international experts and a final presentation day. A post-workshop questionnaire was developed to assessed the quality of the workshop. Results have shown that most activities were successful in transferring sustainable knowledge to the students. The results from the questionnaire were in line with the workshop outcomes, the design proposals. Both of them have shown the capabilities of the students to understand sustainable theory, to analyse design strategies in the specific cases and to apply that knowledge into the design proposals. The design process of the students was repeated every day with project pitches and the students reflected on their own projects as well as on works of others.

More junior students claimed to have learned sustainability design measures more from the workshop than the senior ones, because less experienced students had more to learn. However, most of them showed a high learning and application rate. Students learned more about bioclimatic designs and related topics such as daylight, natural ventilation, indoor comfort and greenery, as these were better covered during the workshop and easier visualised in the design proposal. Sustainable aspects of energy efficiency and water usage were also of great interest as these were applied widely in the design proposals, including PV and rain water collection.

The student selection process was the main issue for this GASC 2019 workshop. It is suggested that the students should be selected in terms of quality and communication abilities. Applications for the workshop is recommended to be handled by one party only. The students should also have a similar background or year of study. There was an incident of a dominant student that prevented discussion and learning opportunities for younger students. The proportion of foreign students and local students should also be taken care of, so students can learn more from each other. For future events, more involvement of architects from practice is recommended. The students showed their interest in practical projects, especially from local architects.

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11 Future Sustainable Tube Houses in Vietnam

This chapter is submitted to the Journal of Green Building.

11.1 Introduction

The basic definition of sustainable development, as in the Report of the World Commission on Environment and Development, is "… development that meets the needs of the present without sacrificing the ability of future generations to meet their own needs." (WCED, 1987). This sustainable development definition considers economic, social and environmental factors. This model was used widely by sustainable housing researchers (Tosics, 2004; Winston, 2007). It is also used to develop a sustainable housing model for Vietnam in this paper. Other features that can also be considered are culture (heritage, custom) or architecture (aesthetic, decoration). These factors are interconnected and cannot be considered separately. For example, bioclimatic design principles help improve indoor comfort (environmental aspect) and energy efficiency (economic aspect).

Sustainable development is so broad, it is almost impossible to design a completely sustainable housing model for future tube houses. This chapter will contribute to a more sustainable housing stock by identifying the following aspects energy efficiency, circular economy, urban densification and social connection (Figure 11.1).

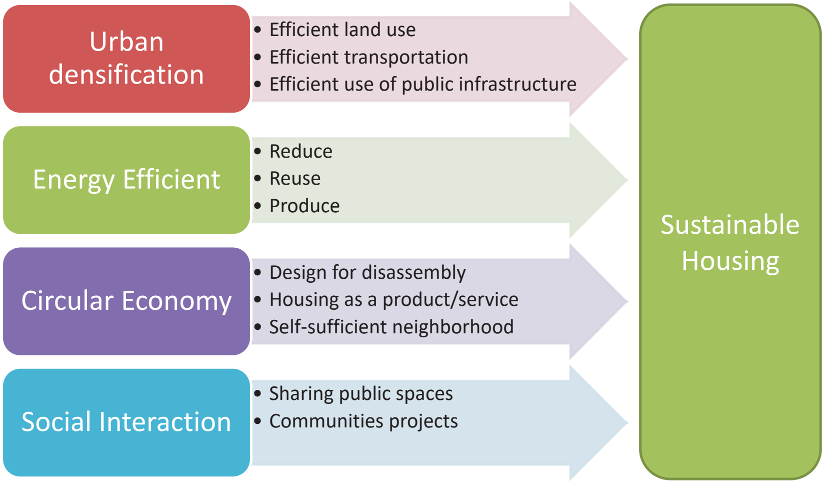

FIG. 11.1 Sustainable features of future housing

The Vietnamese government is well aware of the importance of energy efficiency in the built environment and has taken actions to reduce energy consumption in building sector. The National Technical Regulation on Energy Efficiency Buildings was issued with an aim of reducing energy in large public buildings (MOC, 2017). However, this regulation is not applied to private row houses and it was also not developed for small dwellings. In 2017, the state introduced the feed-in-tariff that the residents can sell back unused solar electricity back to the grid (MOIT, 2017). This action has enabled the widespread installation of Photovoltaic on rooftops of single-family houses.

Current built environments around the world mainly follow the linear economy (LE) model, which is identified as "take-make-dispose". This conventional model is often unsustainable and leads to environmental issues, for example, inefficient use of natural materials, waste generation and high carbon emissions (Anne & Vincent, 2019). The circular economy (CE) aims to preserve the resources and close the cycle loop of the products, components, and materials as much as possible (Ellen MacArthur Foundation, 2013). Several principles such as Cradle-to-Cradle (C2C) (McDonough & Braungart, 2002) or regenerative design (Lyle, 1996) are developed for the CE. The transition from the LE to the CE model is an important step toward a sustainable built environment.

The tube house, or attached row house, is one of the most dominant housing typologies in Vietnam, especially in the urban areas of the country. These houses originate from the traditional city houses hundreds of years ago, which were constructed with bioclimatic and sustainable considerations. However, most of the contemporary row houses, which dated from the last 30 years, had to adapt to the rapid urbanisation and soon lost many of its traditional values. The densification of the cities and the spontaneous development of residential neighbourhood are the main drivers for the current form of the housing typology.

Social sustainability is a broad concept that aims to address the social goals of sustainable development. Social sustainable topics include social capital, social cohesion, social inclusion and social exclusion (Dempsey et al., 2011). Social sustainability in this chapter mainly concerns the social cohesion and interaction of occupants.

This chapter aims to define a future sustainable urban housing typology which both inherits the traditional values and meets the demand of urban developments in the coming future. A new approach to a residential neighbourhood as well as housing design are proposed as an effort to contribute to more sustainable cities in Vietnam.

11.2 Housing development

Housing in Vietnam has adapted to the national historical context and user needs (Figure 11.2). In the first half of the 20th century, urban area in Vietnam is very limited as the country was still enduring its war with the French invaders and among themselves. During this period, urban citizens mainly resided in traditional tube houses in the city centre, or in collective living quarters (KTT) starting from the 1960s. The traditional tube houses are often seen as the sustainable housing model from environmental viewpoint (Kim, 2007; To, 2008). Detached houses were for French and high-positioned Vietnamese officers.

After the economic reform in 1986, the number of dwelling units has increased drastically to meet the demand of the people who migrated to the big cities. A lot of tube houses were built during this period. Due to the lack of an urban management and the low-income of the owners, most houses were self-built without any regulation and sustainable design considerations (McGee, 2009).

The people who had previously lived in the KTT also started to move to urban attached houses in the expanded area of the cities. These unregulated tube houses offered spatial flexibility, but had a negative impact on the urban environment with an unsustainable densification pattern (Seo & Kwon, 2017). The technical infrastructure in these districts are not sufficient and the accessibility is limited due to the narrow alleys.

FIG. 11.2 Housing development in Vietnam

Since the 2000s, many new houses were still self-built but they were more regulated. Developers started to invest in new urban areas in the outskirts of the cities. These projects were planned and designed according to the rules and regulations. Again, people moved from the inner cities to these new urban areas, looking for better housing quality. Although the residents were not yet satisfied with the public services, housing quality and management, they still encountered a much improved living environment compared to their previous place in the city centre (Luan, 2014). There is an inevitable trend moving toward the development of these new urban areas, where the most preferred housing typology is still the tube house or attached row house (Seo & Kwon, 2017).

11.3 Traditional tube houses

11.3.1 Description of traditional tube house

The character of a traditional tube house includes the following: a very small front (2-4 meter), a depth varying from 20 to 50-60 meter, and in general, 2 storeys high. Inner courtyards were employed to enhance daylight and natural ventilation and were used for outdoor activities. The front areas on the ground floor were used as shops.

FIG. 11.3 Traditional tube house. Number 47 Hang Bac Street, Hanoi

There are various explanations for the extremely narrow front of the traditional tube house. One of which is that it was the result of a division of inheritances. Another hypothesis proposed that the houses had initially been developed from the market stalls a long time before the streets came into existence (Phe & Nishimura, 1991). To (2008) stated that the narrow width was due to the fact that the feudal government taxed the households by their houses' front width. As the settlement increased in population, the houses extended inwards and formed the tube-like houses.

The urban pattern of the Old quarter can still be recognised, nowadays. However, although most of the houses still retain their tube shape, not many of them are in their original form but have transformed into the new tube houses. Figure 11.3 illustrates a traditional tube house in old quarter of Hanoi which retains parts of its in original form (the front two-storey blocks). The rear three-storey parts were renovated in 2003.

11.3.2 Climate design in traditional tube houses

There are 3 main climatic regions in Vietnam from North to South, but there are some common climatic features that most houses have to deal with. Firstly, the high annual solar radiation result in large unwanted heat gains in building. Traditional tube houses applied double layer windows, with wooden shutters to block the direct sunlight and at the same time provide natural ventilation. The roofs are usually high and ventilated since the sun position is very high in the summer. Shading is provided by eaves and trees, while the later also benefit the houses with evaporative cooling. The houses were usually painted light colour to reflect the solar radiation. The high temperature and humidity make natural ventilation a mandatory design strategy in almost every house. Popular measures are high ceiling, large openings and the use of an inner courtyard. Thermal mass is not applicable due to the low diurnal and seasonal temperature difference. Most houses use a local lightweight construction instead. Finally, most traditional houses have a pitch roof because of the high annual rainfall. However, rain water harvesting is not yet considered though it has a huge potential for reuse. Figure 11.4 below illustrates some of the bioclimatic techniques in traditional houses.

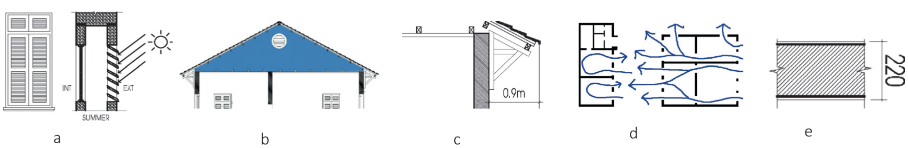

FIG. 11.4 Some climatic design strategies in traditional houses of Vietnam (A. T. Nguyen et al., 2011)
a. Double layer window, b. ventilated roof, c. deep eaves d. natural ventilation, e. lightweight construction

The physical form and the spatial composition of the traditional tube houses were studied by To (2008) and Hung (2007) (see Figure 11.5). The combination of building blocks and inner courtyards or void spaces was highly appreciated as it brings many benefits. Having many inner courtyards allows the traditional houses to have access to daylight and natural ventilation. This eco-efficient spatial composition helps to improve thermal environment of indoor and outdoor spaces, and reduce energy consumption for cooling and lighting. The void spaces also bring flexibility and adaptability to the houses. Expansions can be made when there is a demand for living space in the future. In addition, the division of buildings blocks within the houses enables modularisation of the construction components. Although the traditional houses were never built with prefabrication or with modular units, such strategies can be applied in future housing projects with the help of novel construction technology and computer-aid design (CAD). Finally, the open spaces in houses provides opportunities for resident to interact and create social bond within families or neighbourhood.

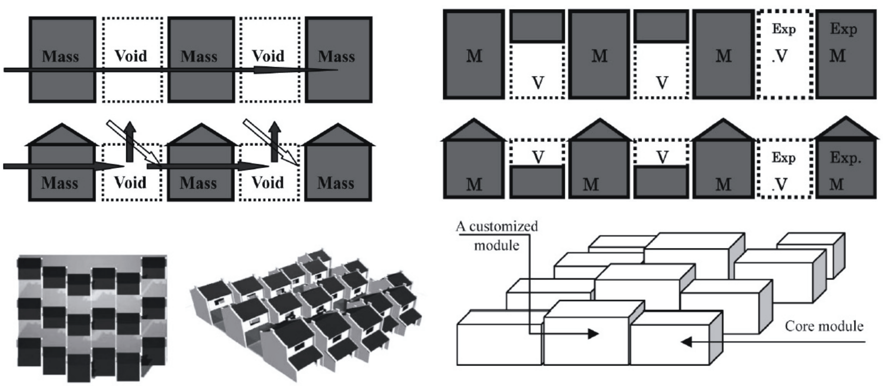

FIG. 11.5 Sustainable spatial composition of traditional tube houses (To, 2008)

11.4 Contemporary tube houses in Vietnam

A contemporary tube house layout and the spatial composition of a traditional one are compared in Figure 11.6 and Table 11.1. A contemporary tube house is normally built in a rectangular plot with a width of 3-6 meter and a depth of 10-20 meter; 3 to 5 stories high. Within this narrow plot of land, the courtyard is often limited. The typical structure type is a concrete frame and brick masonry. Traditional tube houses are more sustainable both in terms of spatial composition and climate responsive architecture elements.

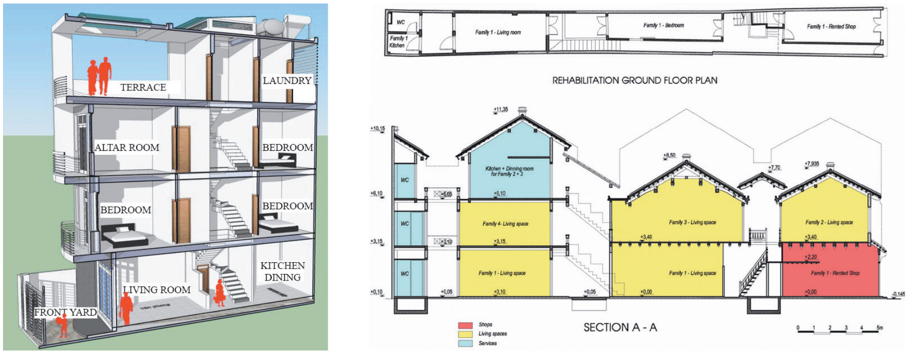

FIG. 11.6 Layout of a typical new tube house (left) and a traditional tube house(right) in Vietnam

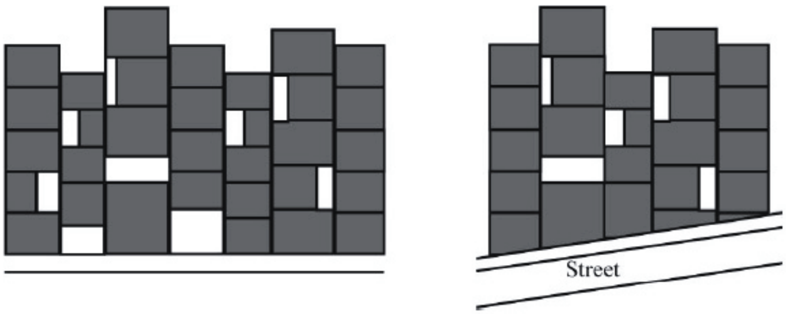

FIG. 11.7 Examples of typical new tube houses group layout (To, 2008)

Current tube houses characteristics have been criticised because of their spontaneous development and lack of sustainable consideration (P.A. Nguyen et al., 2019; To, 2008). The spontaneous development of the tube houses is the main reason for its unregulated façade, hence chaotic townscape. In addition, due to its smaller size, most tube houses are built on the full plot, leaving no space or very little space for a courtyard. Another issue is that the house is owned by single family, leading to insufficient land use, since the density is still low. There are still houses with inner courtyards, or more likely, a small light-well. Unlike the traditional houses, those little void spaces are not interconnected between houses, making the connection and ventilation on a larger scale not possible, see Figure 11.7. Future tube houses should have similar plot area as the contemporary tube houses because they are more suitable and affordable for a single family household. However, design of future tube houses needs to consider the sustainable of the traditional houses, such as the existence of interconnected courtyards in a neighbourhood pattern.

11.5 Future tube house design

Housing in different periods have their own characteristics that reflect its eras' socio-economic context and met the demand of the housing market. Table 11.1 presents properties of tube houses in different periods and its potential adaptation in the coming futures. Traditional tube houses were built in time where urbanization was not the norm. The land plots back then were rather large (60 – 100 m^2). The buildings were divided into several block which were separated by inner courtyard. Contemporary houses were divided in much smaller land plots (40 – 60 m^2). They were often built on the whole plot and up to the maximum possible floors. However, the occupants' density in the new houses is not necessarily higher than in the vernacular ones as the old houses served multiple families. The future houses should have similar or higher density than both of the precedents. A preferred option is to have a low construction volume but higher rate of occupants per floor area.

TABLE 11.1 Characteristic of existing tube houses an potential features of future tube houses

	Traditional TH	Contemporary TH	Future TH
Economic	Larger land plot (60-100$m^{2)}$ Low rise (1-2 storey) Low plot ratio (leave room for courtyard) Multifamily	Smaller land plot (40-60$m^{2)}$ Higher building (3-5 storey) High plot ratio (90-100%) High building Single family	Lower plot ratio for more open space Higher building to keep up with high density Single family for ownership Multifamily if possible
Environmental	Bioclimatic design approach Local, eco-friendly material	Less room for bioclimatic design	Energy efficient design Circular design
Social	More public, semi-public space for social interaction	Less public, open space for social interaction	Provide public space for social interaction

In term of design strategies, traditional houses had to adapt to the natural settings and were less dependent on equipment and technologies. Contemporary tube houses were the results of the rapid urbanization after the economic reforms. They had less room for eco-efficient design and maximizing usable living space were prioritized. The housing stock needs to change in order to tackle climate change and the scarcity of finite resources. Energy efficient and circular design strategies are recommended.

The social aspects of the housing design also need to be taken into consideration. The economic development led to a busy life style of the urban citizens. Housing prices also rose significantly and a seek for affordable housing has become more difficult than ever. The lack of open public spaces is a great challenge in big cities in Vietnam. It leads to several problems, such as poor social interaction, lower life quality.

11.5.1 Energy efficiency

New-built houses have large potential to be energy efficient. Architects can apply energy efficient design strategies in their own ways without the restrictions of existing buildings. In order to achieve the better energy performance, design measures for new homes should follow the Vietnamese 3-step strategy: Reduce, Reuse and Produce (P. A. Nguyen et al., 2020) (see Figure 11.8).

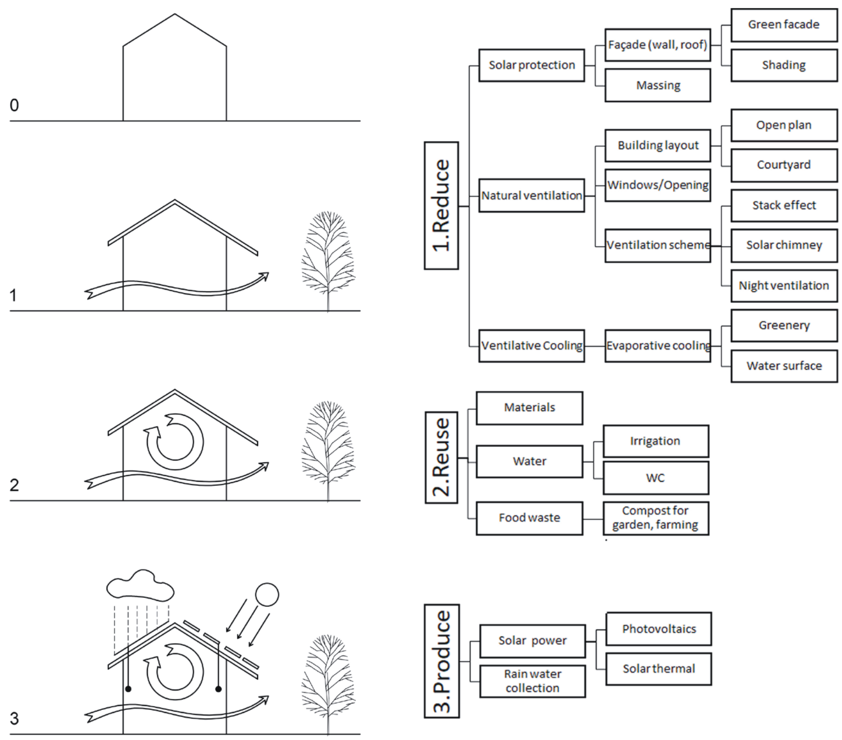

FIG. 11.8 Energy efficient design steps for Vietnamese tube houses

The first step, 'Reduce', employs smart bioclimatic design strategies. The main objective is avoiding overheating, thus reduce cooling demand. The three main approaches are: protecting the building from direct solar gain, promoting natural ventilation, and using evaporative cooling. Massing is a potential measure for solar control. For example, service mass can be used to provide shading for the main living block. Façade design also contributes to reduce direct solar gains. Popular measures are elevated roof, roof thermal insulation, and shading devices or overhangs. An open floor plan with appropriate opening design is good for natural ventilation and for removing excessive heat. Inner courtyard with greenery (or green façade) are great examples of spatial planning and façade design for energy efficiency.

The second step aims at reusing potential material/ waste flow internally and externally. Construction materials can utilise reused or recycled materials. For examples, new walls can be built from recycled bricks, doors and windows can be reused from another project. On the other hand, used water from the shower or the kitchen sink can be treated to be used for flushing the toilets. Food waste can be used to make compost for the garden or vegetable growing within the house. All these measures do not have direct impact on the end-user energy consumption, but can potentially reduce the primary energy for producing and transportation of resources.

The final step considers the sustainable production of resources. Domestic hot water can be supplied by a solar thermal system. Photovoltaic cells convert light energy into electricity for household consumption. With the newest regulation from the government, house owners can sell unused solar-power electricity to the grid, solar PVs in private houses are expecting to grow in the coming years (MOIT, 2017). Rain water collection is also a potential design measure to provide water for all purposes. It can also be integrated with the green roof.

11.5.2 Circular design

In Vietnam, the economic model in general and the built environment in particular, is developing significantly in the last few decades. Although the development of the building stock was at some point not under control due to the management of the state, the quality of the newly built buildings has been increasing in recent years. New innovative ideas are widely embraced in Vietnam, including green architecture, energy efficiency, smart cities, and circular economy. However, the CE model in the built environment of Vietnam has not been implemented yet.

The application of CE in the built environment can be learned from others. A recent example is a temporary courthouse in Amsterdam. The aim was that the building was totally circular and the building was designed as a product. It was supposed to serve as a temporary court house for five years, and after that, to be disassembled and relocated elsewhere for another function (Amsterdam smart city, n.d.). At product level, a modular, yet mass-customizable and recyclable product can contribute to a more circular housing stock. TU Delft, AMS-institute, housing associations and industry partners have together created a Circular Kitchen (CIK). The project included a technical design as well as a business model. The modular design of CIK separates kitchens parts based on their life spans and applied circular life cycles for each of them (van Stijn & Gruis, 2019).

At the city scale, the circular economy also appears in projects where certain capital, resources are communally owned and exploited. “Blijstroom”, which translates to “happy electricity”, is a local energy collective in Rotterdam, The Netherlands. The collective rents roofs from public and private buildings places PV cells on these roofs. Any nearby resident can invest in the PV cells and thereby become a member of the collective. Electricity production electricity selling back to the grid are measured annually. All members receive a share of the revenue depending on their share in the PV cells (Blijstroom, n.d.). Another idea for such a project could be a local plant factory which is financed, operated and managed by local residents. Such projects might bring several benefits. First, it provides local products which require much less transportation cost and energy. The quality and food safety can be controlled as it was done by the locals and for the locals. Jobs will be created for nearby residents as well.

The existing tube houses in Vietnam were often self-built and without management and regulations. Therefore, the application of modular units or design-for-disassembly principles has to face the challenges of unstandardized components and products. The circular economy model is, however, possible for the housing projects in new urban areas where the row houses are standardized with typical design. Circular design can start at material level, where local, recyclable materials should be prioritized. At product level, components such as the CIK, or detachable windows, doors have great potential to be circular. The new tube houses can replicate the layout in the traditional tube houses, where building blocks were separated by courtyards. By doing so, smaller housing blocks can be made modular and the design of the houses can be customizable by adding or removing certain units. At neighbourhood scale, large rooftop areas can be rented out for energy collective as in the case of Rotterdam.

11.5.3 Urban densification

Compact cities are often considered as an effective urban form that can contribute to the overall sustainability (Storch et al., 2008). The definition of compact cities might have different implications. Compact cities with high density and mixed-use building types can reduce the number of private transportations and promote efficient use of public transport. It can help protecting rural land by reducing urban sprawl. Higher density residential areas also create opportunities for social interaction and social cohesion. There would be more people being served by the same amount of public infrastructure in a dense urban area.

However, rapid urbanization and the scarcity of land creates challenges for sustainable urban development. Non-effective governance can result in an unsustainable form of densification and urban compaction (Zhu, 2012). Cities in Vietnam, such as Hanoi and Ho Chi Minh city, already have a highly compact urban form. This is not the result of the city urban planning, but because of the unregulated development that 9took place in the 1900s. Self-built housing has always dominated the housing sector in Vietnam. Until 2014, 75% of the housing stock was still self-built, 15% was realized by commercial companies and 10% was state-driven (WB, 2015).

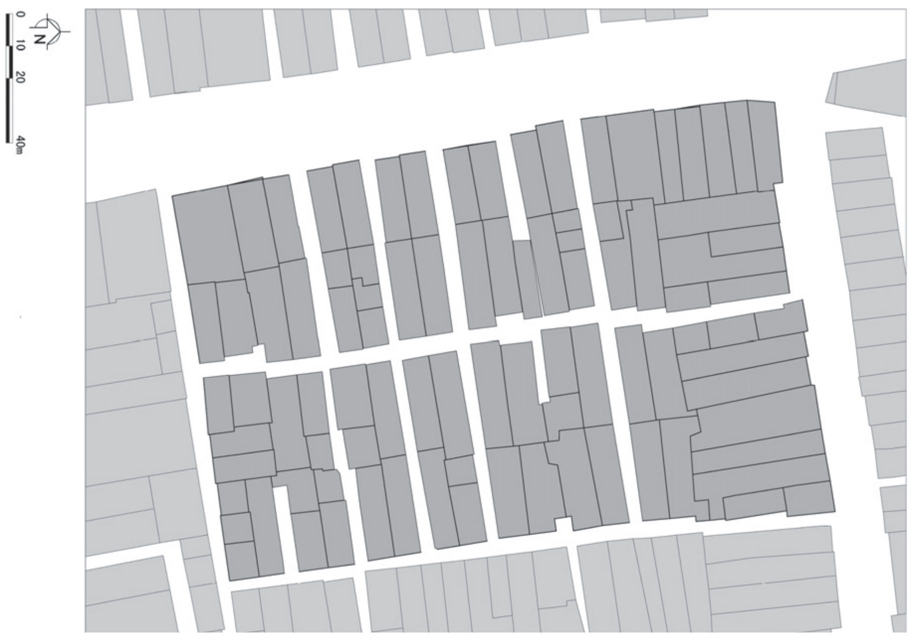

FIG. 11.9 Self-built housing block in Ho Chi Minh city Vietnam (Zhu, 2012)

Figure 11.9 presents a self-built housing block in Ho Chi Minh city with a form of densification: low plot-ratio (total building floors divided by site area) and high site coverage (the land area covered by buildings divided by the site area). The plot ratio is about 0.85 and the site coverage is 85%. The buildings in this block are mostly 1 storey high. This composition might be good for the living environment (more open space, ventilation), but it will not meet the increasing demand of housing space (Zhu, 2012). In the city centre, houses are often built up to 5 floors and cover the whole land plot, the plot-ratio can rise up around 3-4 and site coverage is almost 100%. However, this compact form is not favourable for the occupants in terms of thermal comfort and social connection.

Urban densification is also discussed for its relationship with the energy performance of building. In Europe, urban transformation toward compact cities might affect solar access because of self-shading or overshadowing by adjacent buildings (Barresi, 2018; Lobaccaro & Frontini, 2014). Solar irradiation is important factor for passive solar use (solar heat gain) or active use such as photovoltaic (PV) for example. In Vietnam, solar access is also essential but in a different direction. Active use of solar energy, such as solar thermal and PV, are promoted and widely embraced. On the other hand, shading devices are preferred as a passive way to avoid overheating in the subtropical climate of Vietnam. A sustainable housing model for Vietnam should, on the one hand, harvest enough solar energy for active use, and on the other hand, protect itself from direct solar gain.

11.5.4 Social interaction

Researchers commonly agree that public spaces, such as neighbourhood parks, are important elements of social interaction (Moulay et al., 2017). Streets do not only act as traffic infrastructure but also as an urban public space where social activities and social functions occur. Commercial streets are often lively and by many locals participate during the day which provides great potential for interaction (Mehta, 2009). This observation can also be seen in typical Vietnamese urban areas where fronts of tube houses are used as local shops or services. Within a building, the internal courtyard represents a communal space where family members can gather and have quality time with each other. The rapid and spontaneous housing development in Vietnam in the early 2000s created a huge high density neighbourhood that can only be accessed by small alleys. There was really limited amount of public space, such as street activities and internal open space within urban houses. These problems should be avoided in new urban areas and attention needs to be paid to public spaces in order to improve social cohesion.

11.6 Example of a sustainable tube house model

This section applies the sustainable design principle to a future tube house design. This design is the result of the Green Architecture for Sustainable Communities (GASC) 2019 design workshop. In this workshop the students were asked to provide a design for a sustainable housing prototype in a new urban area of Vietnam. Architecture students from TU Delft and two Vietnamese universities worked together under the supervision of climate design experts and local architects.

The task was to design a new row house prototype which will be built in a new urban area in the outer area of the city. The plot size is 5 metre by 15 metre and the maximum number of storeys is 5 (see Figure 11.10). The plot size of 75 square metre is larger than a similar housing type in the city centre, which is approximately 40-50 square metre. The aim was to design a single house which can be combined to form an entirely sustainable housing block/neighbourhood.

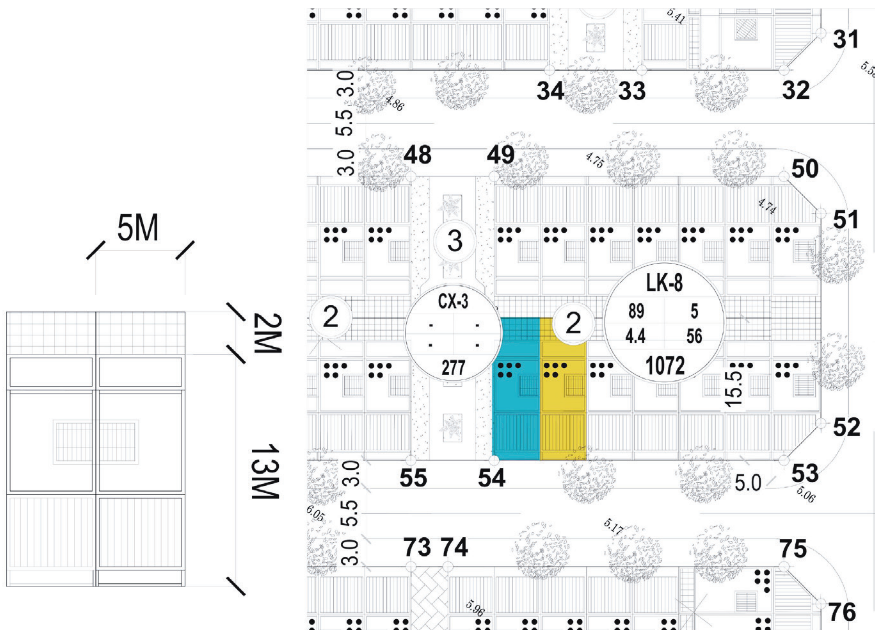

FIG. 11.10 Master plan of the investigated neighbourhood

FIG. 11.11 Communal spaces introduced in the proposal

In this design, bioclimatic design measures are applied to improve the indoor environment by introducing daylighting, natural ventilation, use of greenery, and rain water collection. A photovoltaic system was also added to generate electricity for the occupants. The proposal introduced several communal spaces within and between the houses. Although the volume of the building blocks is similar, the fronts of the houses were not aligned completely. Houses with different setbacks create communal spaces as shown in Figure 11.11. The publics spaces, labelled in red at the front and the rear, can be used by multiple households for social interaction. There is also a private courtyard for each household. By introducing two types of courtyards, there are many possibilities for the users to interact with the neighbours as well as within their own family.

The inner courtyards help to create ventilation across the tube houses and provide daylighting for the indoor spaces (see Figure 11.12). Fresh air can flow from the front to the rear of the house with cross ventilation. The first private courtyard can also help to create a stack effect and draw more air into the houses, enhancing the ventilation rate. Moreover, the unaligned arrangement of the housing blocks helps to create ventilation across the houses (see Figure 11.11). The multiple open spaces also allow access of daylighting to all rooms.

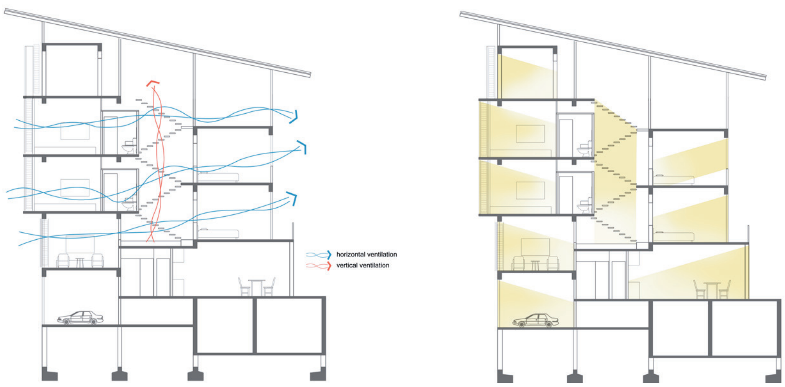

FIG. 11.12 Natural ventilation and daylighting in the proposal

Figure 11.13 describes the water system in the houses. There are three flows of water running in the houses. In Vietnam, water from the grid is not used directly. It is first stored underground and later pumped to another tank on the roof to be used as daily cool tap water. This clean water is also used for the solar thermal system on the roof where the water is heated and stored on a separate tank. It is later used as domestic hot water. Rainwater is collected and stored on the roof. Rainwater is used for flushing the toilets and watering the plants. With this system, clean water is saved by using rainwater and the energy used for heating the water is also reduced.

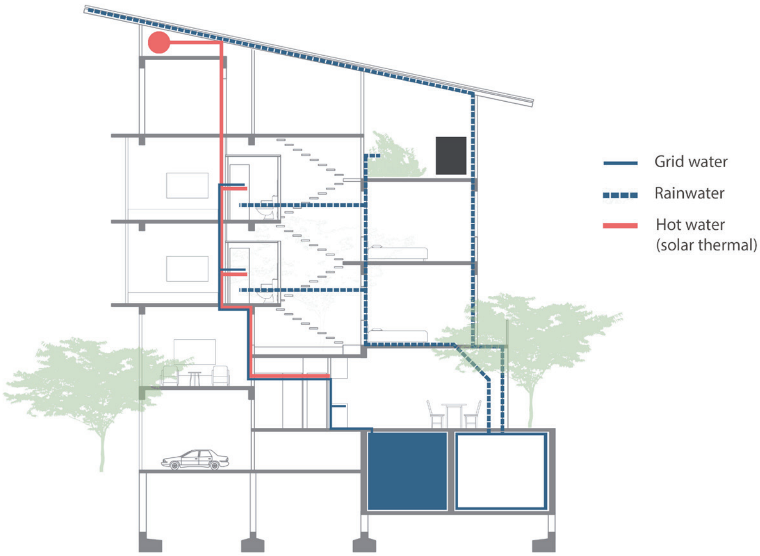

FIG. 11.13 Water system in the proposal

PV cells are installed above the roof in each house to generate electricity. Depending on the actual orientation of the houses, PV's can have a different arrangement to maximise covered area and have optimised solar angle (Figure 11.14). This layer of PV's can also act as an elevated roof that provide shading for the houses and the private courtyard underneath.

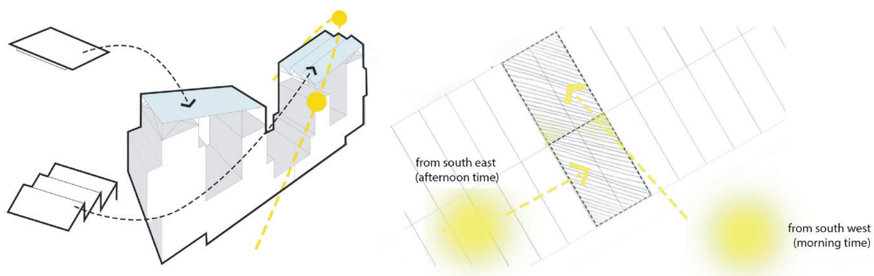

FIG. 11.14 Arranging PVs array on the rooftop

11.7 Discussion

This design takes into consideration of both the energy efficient design and the social cohesion aspect of sustainable development. Several changes and considerations can be made to further improve sustainability of the houses. First, the overall urban density in this neighbourhood might be lower than existing ones due to the dedicated spaces for internal courtyards. There are two ways to tackle this. Considering the public courtyard being used by multi households, other service areas can also be shared to minimize the required living space in each family. For example, shared parking space, laundry service or storage area can be placed underneath the public courtyard to form a shared core. Moreover, one current unit can be divided into two sub-units, separated by the first private courtyard. This solution can lower the chance of under-occupying houses and create more flexibility in the tenure status and affordability of the houses. Such sharing solution might be feasible because more and more young people are living more independently and small family composition (1-2 person family) is increasing. In addition, this new generation is also more open to new society and economy model where sharing is core to many aspects of life. There are successful examples of such model in Vietnam, such as Airbnb (sharing living space) or Grabcar (sharing transportation).

Another new approach to this proposal is the application of circular economy principles. As discussed above, this concept is not yet available in Vietnam but it has potential. Particularly, because the courtyards separate the houses into several parts, this makes it easier for building blocks to be assembled from identical modular components, from doors and windows to walls and floor panels, and furniture like the CIK example. Such components should be made with the design-for-disassembly principle in mind to increase the recycling opportunity and he overall life span of all products. Another application of the circular economy is the collective solar energy production. A collective group of local residents can together rent the roof top of the houses to build a network of solar PV and solar thermal. Electricity will be used directly by the residents or feed into the grid (or a communal tank in case of hot water). With the introduction of a new feed-in-tariff by the government in 2017, use of solar PV is becoming more and more popular and this business model is feasible.

11.8 Conclusions

The development of the housing stock in Vietnam only really took off since the economic form in 1986. Since then, the amount of housing units has increased significantly. The most popular house now and in the near future is still the tube house because of its economic value and affordability. Therefore, the mission of improving sustainability in the housing stock should rely on this housing typology. This paper studied the value of the traditional and contemporary tube houses and investigated where new principles and ideas can fit into the future design of tube houses. Many aspects of traditional houses can still be valuable features in the future homes.

This study does not aim to portray an optimum design of sustainable tube houses, but rather identify and discuss sustainable aspects that should be considered on top of functional requirements or aesthetic pReferences. The sustainable aspects are urban densification, energy efficiency, circular design principle and social interaction. An example of a sustainable design of a building block was presented.

Future sustainable housing approach should start from a larger scale rather than just the building level. At neighbourhood level, building blocks should be designed with consideration of both public and private open spaces, and more importantly, they must be connected between row of houses. The introduction of such public open spaces has multiple benefits to the overall sustainability of a community. Firstly, public spaces create opportunities for occupants to interact and improve social cohesion. Urbanisation in Vietnam has led to the lack of public spaces, resulting in several issues such as social isolation, social annoyance and anonymity (L. Nguyen et al., 2020). These problems should be avoided in future housing projects. Although parks and squares are more likely to exist in new urban areas than in the city centre, a small public space in a small neighbourhood is also a great alternative because of its close proximity and self-management ability. Furthermore, the additional open spaces lowered the construction density in the new neighbourhoods compared to those in the city centre. Living spaces such as living room, bedrooms, or kitchen and dining area might have to sacrifice some space.

In addition, design of future tube house is recommended to follow a 3 steps strategy for energy efficiency (P. A. Nguyen et al., 2020). The three steps are ‘Reduce’, ‘Reuse’ and ‘Produce’. The first step mainly refers to bioclimatic design such as natural ventilation, use of shading device, daylighting, evaporative cooling and so on. These measures aim to improve the indoor environment and reduce the energy consumption for cooling in Vietnam. The introduction of an internal courtyard and public courtyards mentioned above contributes to many bioclimatic design measures of a tube house. The second step suggests recycle and reuse of different materials and resources. For example, houses can be constructed of recycled materials, or rain water can be collected and reused for irrigation. The last step is to produce energy onsite with a specific reference to photovoltaics and solar thermal.

On the economic point of view, a circular economy model should be considered at both neighbourhood and building level. Examples of this approach in the neighbourhood scale are solar energy collective and an urban farm. At building level, the application of CE sometimes overlaps with the second step of the 3 steps strategy above. Houses should be designed with the design-for-disassembly in mind. Each housing component should be treated as a product in which they can be manufactured, installed, and reused or recycled after its end of life cycle. Application of circular economy in the built environment has great potential but it requires a lot more research and pilot projects to be feasible and it involves the cooperation of investors, architects and industry suppliers.

To conclude, future tube house should both inherits the traditional values and meets the demand of urban developments. In order to become sustainable, design of future tube house needs to consider the following aspects: urban densification, energy efficiency, circular economy model and social interaction, from the city/neighbourhood level to the product/material level.

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12 Conclusions

12.1 Introduction

This research investigated a housing design strategy for energy efficiency and thermal comfort in the sub-tropical climate of Vietnam for new and renovated dwellings. The findings of this research support a sustainable, low-carbon built environment helping to avoid climate change. Currently, there is a lack of studies on sustainable and energy-efficient housing in Vietnam. The housing stock in Vietnam has boomed in the last few decades, especially in urbanised areas. However, the increasing number of housing units did not go along with housing quality, a healthy living environment or a sustainable building stock. Recent legislation only applies to public buildings but not the private housing sector, which accounts for the majority of the building stock. Therefore, this research aimed to contribute to a more sustainable building stock in Vietnam by improving the energy efficiency in new and renovated urban houses.

The research has been conducted with a variety of research methods and analyses, such as interviews and questionnaires with home owners, simulating and monitoring the thermal and energy performance of housing, conducting statistical analyses, holding a design workshop. This chapter presents the conclusions by answering the main research questions and the corresponding sub-questions. In addition, limitation of this research and recommendations for future research will also be presented.

This research started with examining the energy upgrade potential of the existing houses in Vietnam. Both passive and active refurbishment design measures were investigated for the Vietnamese context. Among the measures, a green facade has a large potential in energy saving. Effect of a green facade on thermal and energy performance was tested by conducting a physical experiment on a real tube house in Hanoi. Next, a stepped design strategy was introduced in a student design workshop in Vietnam. The participants were trained to apply sustainable and energy efficient design measures for Vietnamese tube houses.

In addition, the vision for designing future tube houses was discussed on several sustainability aspects: urban densification, energy efficiency, circular economy and social interaction. This research is expected to contribute to the establishing of a future national technical regulation for private housing in Vietnam.

12.2 Current conditions of the existing housing stock in Vietnam

The housing stock of Vietnam was largely characterised by the history of the country. The history of Vietnam had a lot of effect on urban planning and architecture in Vietnamese cities in general and in Hanoi in particular. Urban areas and their housing types reflect the character and ideology of the various periods. Urban houses themselves have their own distinctive character in the different historical periods and adapt, again, to the contemporary challenges. Most recently, the economic reform of 1986 started the introduction of the “new tube houses”, which then became the most dominant housing type in the whole country, accounting for about 75% of the total housing stock. Therefore, the existing “new tube houses” have an important role in planning more sustainable housing and energy preservation.

An interview, described in chapter 2, was conducted in March 2016 in Hanoi which investigated the new tube houses’ character and their potential for energy upgrade. The results indicate that the thermal performance of a third of the existing houses is unsatisfactory and people state that they spend a lot of energy on cooling and heating the spaces. Although the Vietnamese occupants do not include the energy upgrade in their refurbishment priority list, there are still chances to reduce the environmental impact of the current housing stock. The most important factor for a refurbishment plan is an improvement in the indoor environmental quality which, with a little incentive, could be combined with measures that also reduce the energy demand.

12.3 Possible energy-efficient design approaches for Vietnam

A number of so-called ‘green houses’ in Vietnam are presented in Chapter 3. Chapter 3 shows renovated and newly built housing projects in Vietnam where the architects applied a bioclimatic design approach to improve the indoor environment and the energy efficiency of the houses. Popular approaches were creating a shading layer on the façade, introducing open spaces and greenery for natural ventilation and for an evaporative cooling effect.

Potential energy efficiency design measures are introduced in chapter 4. The New Stepped Strategy, inspired by the Cradle-to-Cradle concept, was found to be suitable for application for modern tube houses in Vietnam. Both passive and active measures for refurbishment can reduce energy consumption in houses and provide better living conditions. In Vietnam, popular passive design strategies include solar control, natural ventilation and evaporative cooling. However, the tube house constraints limit the effectiveness of passive design measures. The orientation, for example, is generally not changeable. Small land plots and high demands of living space do not allow many options for massing and courtyards, although a courtyard is a very important feature of a traditional tube house. Thermal insulation layers are mostly found on the roof. Airtightness can efficiently prevent the houses from losing heat in winter. Passive solar gains might work for the cold winter of Vietnam directly or indirectly (via sun spaces). Geothermal cooling and thermal mass are not recommended for renovating houses in Vietnam because of the high investment and technical feasibility.

Active design measures, are generally not popular in Vietnam yet. Although the country has a high annual solar radiation, solar energy is mostly captured by solar collectors that provide hot domestic water. This system is easy to install and has a high efficiency. Solar photovoltaics used to be unpopular because they are often – wrongly, considering the recent price of PV – considered not cost effective compared to the traditional fossil sources and they are mostly used for off-grid areas. However, with the increasing lower price of PV cells and a recent state policy that allows excessive electricity to be fed back into the grid, photovoltaics are becoming more viable in Vietnam. Biomass is another clean energy source that can be used for homes. But it is not suitable for urban housing since it takes up space for burning and might harm the air quality and human health. Using highly efficient equipment and lighting appliances can potentially reduce energy consumption in housing. To promote energy-efficient equipment requires commitment from the government, manufacturers and potential users.

Solar energy was known to have a great potential in Vietnam, as presented in chapter 5. However, the production of solar electricity was only significant in recent years because of more favourable state policy regarding renewable electricity production. By the end of June 2019, the country had 4.46 GW of grid-connected PV capacity, equal to 8.3% of Vietnam's electricity capacity. It increased to about 5.6 GW at the end of 2019. For the solar power plants, a mapping of solar radiation components has been calculated from satellite-derived data, combined with solar radiation derived from sunshine duration and other additional sources. The areas available for Concentrated Solar Power systems are limited to the Central Highlands and Southeast regions of Vietnam. In the case of PV, the available areas are limited to the Southeast, Central Highlands, Mekong River Delta, all coastal areas and northeast regions of Vietnam. In case of small production, it mainly concerned rooftop PV on buildings or private housing. In 2017, the Government of Vietnam issued the supporting policy for the uptake of solar power. According to this decision, the unused electricity generated from the PV power station can be sold back to the grid with a price of 9 EUR cent/kWh. This policy has attracted many investors to install rooftop PV power stations in Vietnam. Both simulations and experiments were conducted to prove the effectiveness of a household grid-connected PV system.

12.4 Answer to the research question

The main question of this research is:

What are the design strategies for energy efficiency in Vietnam housing and how should they be integrated in an existing house as well as in a newly built house?

In order to answer the main research questions, the sub questions from the introduction are answered first.

What is the current practice and what are the drivers and challenges of energy-efficient refurbishment in Vietnam? (sub-question 1)

This part presented results of a survey on housing in Vietnam to investigate the current condition of the Vietnamese housing stock, see chapter 6. The survey focused on building characteristics, energy performance and refurbishment activities. 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: a reinforced concrete frame, brick masonry wall without insulation, and single-glazed windows combined with wooden shutters.

The survey also investigated the actual energy consumption and reveals the 'performance gap' in the 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.

Building design and construction have a strong relationship with the occupants' comfort level. Better designed houses usually result in a more comfortable living experience. 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. Refurbishment activities were also likely to have a positive effect on thermal performance of living spaces. The majority of houses that are more than 20 years old were recently refurbished and the house owners often included improving the indoor environment as a goal, along with other reasons.

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

How do energy-efficient design measures affect the energy consumption of tube houses in Vietnam? (sub-question 2)

In order to obtain actual values of energy saving and comfort after renovation, two studies have been done. The first one is a housing performance simulation for different types of facades, presented in chapter 7.

The second one is a real-life experiment in Vietnam where the effect of a green façade on energy demand and comfort inside is investigated, as in chapter 8.

A calibrated Design Builder model was created to simulate energy performance of different façade refurbishment options in Vietnam. Vietnamese technical regulation of energy-efficient buildings and Dutch standards were the two main guidelines for the selection of refurbished facade, along with shading device renovation. The simulation results showed that applying the Vietnamese technical regulation, which is currently only applied to large-scale buildings, can save up to 9% of energy for heating and cooling. More interestingly, a highly insulated facade that followed the Dutch standard led to much more favourable results of 21% reduction in air-conditioner energy consumption. It is worth to note that such an improvement was achieved with a night-time operation of air-conditioner only, as this is how the system was working in the reference house. The bedroom thermal performance suggests that the highly insulated facade helps to reduce the energy consumption by the 'cold loss prevention' effect. Day-time air-conditioner usage might also be improved due to the lower peak temperature. On the other hand, shading devices were tested on a southwest facade window. Despite being regarded as an effective refurbishing measure, horizontal overhangs had very limited benefit of less than 6% reduction in cooling energy. An external blind can save up to 12.6% of cooling energy. However, as all three shading types had a negative effect in the heating season, the maximum annual saving was only 7%.

A second study compared the performance of a green façade on a real house with to the performance of a similar room, which has a bare façade and, on a different period, an aluminium shading device. The indoor temperature of the green façade room and the bare façade room were compared. The first test compared two different rooms (first floor and second floor) in the same period and the other test compared the same first floor room in two different periods. Both of them showed that there is a potential reduction of up to 1°C in indoor temperature by applying a green façade. A room with an aluminium shading device was also tested. The shading device was equally effective as the green façade, i.e. 1°C lower in indoor temperature compared to the bare façade, when the outdoor temperature is not too high (lower than 30°C). However, when the outdoor temperature rises beyond 30°C, the aluminium shading device became less effective and the peak difference was only 0.5°C. Despite little improvement compared to the shading device, the green façade is still recommended in this specific case because of the following reasons. Firstly, measurements of temperatures just behind the green façade show that the green façade can help to reduce the outdoor temperature and improve the thermal performance of outdoor spaces. A lot of houses with green façades can contribute to a greater improvement on the urban scale. Secondly, plants and trees in general have many other benefits such as purifying the air, noise cancelation, creating a relaxing atmosphere for the occupant etc. Finally, in terms of thermal performance, the leaves of the climbing plants will naturally fall during the winter season, which allows direct solar gain and hence reduces heating costs.

In terms of energy consumption, the green façade of this case could save up to 35% of the cooling demand during the day, if the air-conditioners were used for 5 consecutive hours. Such a difference might be due to the 1°C temperature difference caused by the green façade, as discussed in section 8.4.2.3. During cooler days, the energy consumption for cooling is less, hence the energy savings of the green façade are also lower, or the air-conditioning may even not be necessary. Significant energy savings were seen when the peak outdoor temperature was higher than 33°C. Energy savings for heating on winter days need further investigation to determine better the benefits of a green façade.

How can energy-efficient design strategies be applied and integrated in tube house refurbishment projects in Vietnam? (sub-question 3)

To answer this question, an international design workshop (GASC) was held in Vietnam in 2019. Students from Delft University of Technology and two other Vietnamese universities worked together to propose integrated solutions for energy-efficient refurbishment of existing tube houses in Hanoi. From the workshop, a new strategy was developed, which was adopted from the Dutch New Stepped Strategy. The new strategy consists of three steps: 'Reduce', 'Reuse' and 'Produce'. The design strategy for Vietnam differs from the original one as it mainly deals with overheating issues rather than trying to preserve heat as in the temperate climate of the Netherlands. This design approach is presented in section 9.3.3.

Recently, more Vietnamese architects pursue 'green' architecture principles and their new private housing projects often apply bioclimatic design measures, which are mentioned in the first step of the proposed strategy. However, some potential features, such as courtyards and green façades, are often absent in urban tube houses due to space and maintenance limitations. Moreover, the majority of existing tube houses was built 10 to 30 years ago. Many of them were not built with consideration of a comfortable indoor environment and energy conservation. The owners also often prioritise budget and aesthetics over performance when refurbishment is required. A new stepped design strategy is essential as an initial guideline for both architects and house owners for future newly built or refurbished projects.

The second step of the strategy proposed ('reuse'), which suggests reuse of waste energy, available materials and other resources, has limited potential in the housing stock of Vietnam. Currently, these measures do not have visible economic benefits and are not appealing to house owners and architects. However, they help preserve our limited resources and make our built environment more sustainable.

The last step of the strategy ('produce') mainly encourages the use of solar power for electricity and domestic hot water. There is currently an uptrend of installing PV in Vietnamese private houses since the introduction of the feed-in-tariff in 2017. These actions, however, were mainly the reaction of people who look for financial benefit from the national policy rather than as part of an integrated plan for sustainable transformation. Nevertheless, this phenomenon suggests that the promotion of a sustainable and energy-efficient tube house design might be achievable if there is a proper incentive program or new mandatory regulations, as in the case of public buildings.

The workshop outcomes also suggest that design measures should be applied and combined in three main groups to amplify the effect of each. Firstly, greenery and sun-shading should be considered together in protecting the house from direct solar gain. Secondly, a courtyard, greenery and solar chimney work well together in ventilating houses, providing cooling and filtering air from fine dust. Combining the solutions creates synergy in functionality and sustainability. Finally, solar thermal, PV cells or the combined version, PVT, along with rain water collection help to make the best use of renewable resources for the users' needs. And they can all be collected from the building's roof. These combinations are based on the location of the component involved, as well as their compatibility in integration.

How can energy-efficient design strategies be applied in new housing projects in Vietnam and what is their contribution to the overall sustainability of the housing stock? (sub-question 4)

Chapter 11 studied the value of the traditional and contemporary tube houses and investigated where new principles and ideas could fit into the future design of tube houses. Many aspects of traditional houses could still be valuable features in future homes. This chapter also discusses sustainable aspects that should be considered on top of functional requirements or aesthetic pReferences. They are urban densification, energy efficiency, circular design principles and social interaction. An example of sustainable design was presented in section 11.6.

Future sustainable housing approach should start from a larger scale rather than just the building level. At neighbourhood level, building blocks should be designed with consideration of both public and private open spaces, and more importantly, they must be connected between row of houses. The introduction of such public open spaces has multiple benefits to the overall sustainability of a community. Firstly, public spaces create opportunities for occupants to interact and improve social cohesion. Urbanisation in Vietnam has led to a lack of public spaces, resulting in several issues such as social isolation, social annoyance and anonymity (L. Nguyen et al., 2020). These problems should be avoided in future housing projects. Although parks and squares are more likely to exist in new urban areas than in the city centre, a small public space in a small neighbourhood is also a great alternative because of its close proximity and self-management ability. Furthermore, the additional open spaces lowered the construction density in the new neighbourhoods compared to those in the city centre. Living spaces such as living room, bedrooms, or kitchen and dining area might have to sacrifice some space.

In addition, the design of future tube houses is recommended to follow a 3 step strategy for energy efficiency (P. A. Nguyen et al., 2020). The three steps are ‘Reduce’, ‘Reuse’ and ‘Produce’. The first step mainly refers to bioclimatic design such as natural ventilation, use of shading devices, daylighting, evaporative cooling. These measures aim to improve the indoor environment and reduce the energy consumption for cooling in Vietnam. The introduction of an internal courtyard and public courtyards mentioned above contributes to many bioclimatic design measures of a tube house. The second step includes recycling and reuse of various materials and resources. For example, houses can be constructed of recycled materials and rain water can be collected and reused for irrigation. The last step is to produce energy onsite with a specific reference to photovoltaics and solar thermal.

On the economic point of view, a circular economy model should be considered at both neighbourhood and building level. Examples of this approach at the neighbourhood scale are solar energy collectives and urban farms. At building level, the application of CE sometimes overlaps with the second step of the three-stepped strategy above. Houses should be designed with design-for-disassembly in mind. Each housing component should be treated as a product that can be manufactured, installed, and reused or recycled after its end of life cycle. Application of circular economy in the built environment has great potential but it requires a lot more research and pilot projects to be feasible and its application involves the cooperation of investors, architects and producers.

To conclude, future tube house should both inherit the traditional values and meets the demands of urban developments. In order to become sustainable, the design of future tube houses needs to consider the following aspects: urban densification, energy efficiency, the circular economy model and social interaction, from the city/neighbourhood level to the product/material level.

12.5 General conclusions

The starting point of this research was the lack of knowledge as well as lack of legislation for energy efficient housing in Vietnam. Current technical regulations only aim at large scale establishments while contemporary housing projects often do not have sustainable design measure. Houses were refurbished for other purposes than energy efficiency. On the contrary, the concept of housing refurbishment for energy efficiency is well known in most European countries, especially in the Netherlands. The need for energy saving in housing stock dated back from the energy crisis in 1970s. Since then, home owners have taken energy efficiency design measures for decades. Popular measures are wall-insulation, heat pump, low temperature heating system and solar PVs. They can be applied as a single measure or combination of several ones.

In order to boost energy efficient housing in Vietnam, this research mentions three main approaches. First, it is important to raise the awareness of the people as they are the investors, users, as well as the main beneficiaries of the private housing projects. Results from a survey showed that most of the Vietnamese people refurbish their houses for other reasons rather than saving energy. Since there is currently no mandatory energy and sustainability requirement that the houses need to meet, users' perspectives on sustainability and energy efficiency are important in both the design phase and the usage phase of the houses. However, most people also wanted to improve the indoor environment, which is a good start for an energy efficient home.

It is also important to educate architecture students in the sustainability approach. Results from chapter 10 showed that sustainability education, such as a design workshop, is a useful tool to transfer the knowledge to the architecture students. The students can apply both bioclimatic design measures and active design measures in designing sustainable, better indoor environment and energy efficient housing in Vietnam.

Next, the housing design process should follow a structured strategy for energy efficiency. Law makers, architects, contractors and house owners should all know about this approach to coordinate their actions. A three-step strategy is proposed in this research. The three steps are 'Reduce', 'Reuse', and 'Produce'. The first step, Reduce, consists of passive design measures. Most effective measures are sun shading, green façade, courtyard, and natural ventilation. The second step, Reuse, encourages the use of recycled materials in the design and construction phases.

Reuse of other resources during the operation phase, such as waste heat or rain water, is also recommended. The last step, aims to produce energy from renewable resources. Popular measures in this step are photovoltaics and solar thermal. Although this research proposes a 3-steps strategy, it also proposes that design measures should be integrated in a project in 3 main groups based on their core locations: the front façade, the inner courtyard and the rooftop. Examples of how to integrate those measures are shown in chapter 9 and appendix C.

The stepped strategy is not particularly new for the Dutch or European context, but has now shown to also apply to Vietnam. It is interesting to see a unique strategy works in two completely different regions in terms of climatic condition and construction practice. However, detail application of measures might be vastly different between Vietnam and the Netherlands. In Vietnam, most current green dwelling projects only employ bioclimatic design measure which is the first step. Design measures in the first steps also differ in the two countries. Basic design principle in Vietnam is to protect the building from direct solar gain, open up the building with void space, maximize ventilation opportunities and use greenery of water surface for cooling effect. On the contrary, Dutch housing is often has high insulation and maximize direct solar gain. There is also a different in the second step where direct reuse of energy is more difficult in Vietnam. Suggestions are to reuse water resources and construction material so indirect energy saving can be achieved in the manufacture stage. The last step is quite similar in both countries. With abundant solar radiation and recent incentives programme from the government, rooftop PV system and solar collectors in private houses are becoming more and more popular in Vietnam.

Results from different chapters in this paper can help estimate the energy saving of the Vietnamese housing stock. Potential energy savings of different façade options were examined in chapter 7 and 8. A simple shading device can help save annual energy consumption by 7% while an extensive refurbishment with a highly insulated add-on can save up to 21% in energy use. On the other hand, a green façade is recommended for refurbishment. It can help provide a healthy, nature-friendly environment and has shown to help reduce air-conditioning consumption in summer months by 35%. In general, if a technical regulation regulates insulated facade and green facade, air-conditioning is expected to have an average reduction of at least 20%. This reduction is equal to approximately 7% of an average household energy consumption. Chapter 5 discussed the benefit of solar energy, including the use of a solar thermal systems and PV cells. Around 30% of household consumption is dedicated to water heating. A simple solar thermal system can easily save energy for domestic hot water. Due to a limited number of sunshine hours, or energy saving, a cautious estimation of 3% household energy saving is estimated for this measure. On the other hand, a 2kW grid-connected rooftop PV system was referred to in chapter 5. Actual measurement showed that around 2700 kWh of electricity can be generated in a year. Because this is a grid-connected system, most of the PV electricity will be used. This amount of production is equal to half of the average household consumption (based on the survey data presented in chapter 6). As not all PV electricity is used directly by the house owners. The electricity must be transmitted back to the grid and distributed somewhere else. Electricity can be loss during this process by up to 10%. Energy saving estimation is reduced to 40% for this reason. In general, a total of 50% of household energy consumption can be saved by completely refurbishing the facade and adding a solar thermal system and a 2kW grid-connected PV system.

The energy saving on a larger scale can also be estimated. The survey in chapter 6 also indicated that, among 50% of the houses renovated in the last 10 years, 30% of the renovations concerned improving indoor environment and half of the cases involved adding or replacing housing components. This means about 15% of the total housing stock could be refurbished for improving housing performance in every ten years. If a mandatory national technical regulation, which at least concerns refurbishment of facade, use of solar thermal and PV system, comes into effect, 10% of the existing housing stock can be refurbished for energy efficiency in the following ten years. It is a cautious estimation, lower than the 15% rate above, because of the possible higher investment of energy efficient refurbishment. This can lead to an energy use reduction of 5% of the total housing stock.

Finally, energy efficient design should also be considered at an urban scale. A future tube house needs to be energy efficient and follow the above strategy. In addition, it also needs to meet the demand of other sustainability factors. A new tube house model should solve the issue of urban densification and has a good social interaction in the neighbourhood. Currently, the urbanization process has led to the issue of converting agriculture land into residential land which created pressure for the land resources. A circular economy model should also be applied to the new tube house from the material scale to the neighbourhood scale. An example of a future tube house model is presented in chapter 11 and appendix D.

12.5.1 Limitations of the research

This research was conducted with mixed research methods, including a housing survey, housing performance monitoring, energy simulations and an international design workshop. The stepped design strategy is considered as a holistic approach for energy-efficient housing design. However, there are several limitations that need to be addressed in this research.

First, chapter 6 presented results from a housing survey in which occupants were asked about their living spaces and refurbishment activities. 153 respondents were an acceptable number but a higher response rate would have been better in order to draw better conclusions. Moreover, some questions were not as specific as they could have been. For example, the monthly energy consumption answers were displayed as a range but not a specific number, because the questionnaire was conducted over an extended period. A specific number of electricity usage would be better for the correlation analysis.

In addition, chapter 5 investigated potential energy savings of different façade options, including an experiment of a vertical green façade. Other research often built identical prototype units and monitored thermal and energy performance of those units. Instead, this research monitored two identical rooms in existing tube houses, taking into account the surrounding elements such as adjacent buildings and urban landscape. However, the two rooms still have some differences. One room was located on top of the other, which created some thermal conductivity between the 2 rooms and the upper and lower spaces. This limitation was considered in the discussion of chapter 5.

12.5.2 Recommendations for future research

There are several recommendations for future research within the topic of energy efficient housing in Vietnam. Firstly, future research should address the limitation of this study by broadening its scope. Other research can investigate different housing types, in different climate zones of Vietnam with diversity of building characteristics and local culture. Such research can help portrait a complete picture of energy efficiency housing in Vietnam.

Moreover, there is a need to investigate the actual energy performance of tube houses where the new design strategy step is applied. This can be done with energy simulations with a validation step, or more preferably, by monitoring the performance of a real physical model/house. Results of this research can confirm the benefit of the new design strategy step and also give an indication of the possibility to achieve higher target, such as zero-energy homes. Besides the experimental study, a step by step development of a detailed technical regulation for energy efficiency of private housing in Vietnam should be carried out. A mandatory regulation should be a great push for the implementation of energy efficient housing design. It is also suggested that the regulation should focus on application of sustainable measures, such as internal courtyard and use of greenery.

Next, barriers to implementing energy efficient housing need to be addressed better, especially the economic one in the context of Vietnam. Cost and benefit analysis should be conducted extensively for every design measures and payback period of large investment should be investigated as well. Furthermore, research on low-cost, desirable performance measures are required to realize the design strategy step in practice.

Last, research of energy efficient strategy on a larger scale is desired. For examples, research on the urban heat island effect, urban morphology and urban design should be investigated. Solutions from a municipal level and neighbourhood level should be taken into account and synchronized with the local measures to achieve greater outcomes.

12.6 Outlook

This research investigates design strategies for energy efficient housing in Vietnam. This topic has been discussed extensively in many parts of the world, but the implementation of energy saving in Vietnam housing is very limited and individually. Although the majority of this research is about design measures for housing at individual building level, it is crucial to approach this problem in a broader context. It also requires involvements of different sectors and organisations.

For the short term, there is an urgent need for a new technical regulation aiming at the small scale private housing. That regulation would be mandatory for both new built or refurbished houses. This new technical regulation can be implemented in a period of time, for example, from 5 to 10 years. There should be different levels of required regulations and the rules should be tightened each year. For example, by 2030, all housing projects in Vietnam should have achieved the highest required level in the regulation. There should be incentives programs to support the realization of such practice and they should concern not only house owners, but also manufacturers and contractors. Based on this research, energy efficient design measures are important inputs for future construction legislation. Current energy efficient housing regulation only focuses on the building envelope and thermal insulation. It is recommended that other aspects should be included as well. For example, a minimum of 20% of plot area should be allocated to an inner courtyard and/or a garden area in newly built tube houses.

In addition, a minimum of 30% of facade area should be covered with greenery, on either on the front facade or on the roof. On the urban scale, a new housing development should only be approved if there is a collective renewable energy production (PV collective) and there is an urban farm established.

In the long run, urban planners should consider more about the effect of urban design on the energy use of the inhabitants. Open green areas are still crucial for cooling the urban surfaces. The urban infrastructure should take into account the energy transition from the traditional fossil fuel sources to the renewable energy produced centrally and/or locally. The urban form might also change significantly in housing typology or neighbourhood design to accommodate more energy efficient design measures and circular economy principles.

Appendices

APPENDIX A

Housing refurbishment questionnaires

Survey of housing, energy consumption and refurbishment

Dear Sir/Madam,

My name is Phan Anh Nguyen, a lecturer of Hanoi Architectural University and I am working as a PhD student of TU Delft, the Netherlands. I am conducting an survey of housing, energy consumption and refurbishment in Vietnam. I really hope that you can support my research by filling in this questionnaire.

This survey contains of 5 parts: general information, housing information, housing environment, energy consumption and housing refurbishment. It takes approximately 10-15 mins to complete this survey. Your participation are valuable for my research and it should contribute to improve housing performance in Vietnam. If you have any question, please contact via phananh.arch@gmail.com.

Sincerely thanks,
Phan Anh

General information

1 Please indicate your age *

Mark only one oval.

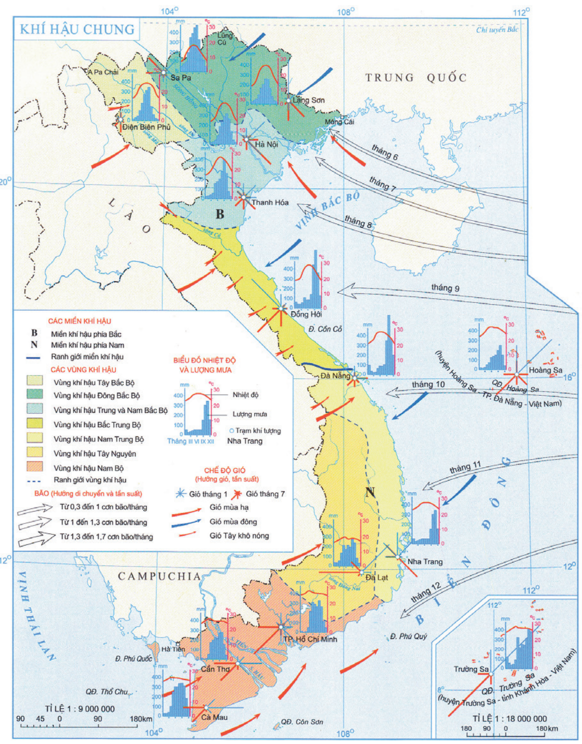
- Under 25
- 25-39
- 40-60
- Above 60

2 In which climatic region of Vietnam are you living in? *

Climatic region are shown in below map

Mark only one oval.

- West of Northern part
- East of Northern part
- South of Northern part
- North of Middle part
- South of Middle part
- Highlands
- Southern part



Climatic map of Vietnam

3 You and your family are currently living in

Mark only one oval.

- privately own house
- renting a whole house
- renting part of a house and share facilities with others
- Other:

4 How many people are there living in the house?

Mark only one oval.

- 1-2
- 3-4
- 5-6
- >6

Housing information

5 When was your house built? *

Mark only one oval.

- Within last 10 years (2006 - now)
- 10-20 years ago (1996-2005)
- 20-30 years ago (1986 - 1995)
- More than 30 years ago
- I don't know

6 What is the typology of your house? *

Mark only one oval.

- Attached row house
- Detach house
- Apartment
- Semi-detached house
- Other:

7 Apart from residential, is there any other function that your house provides? *

For examples: Commercial shop, workshop, office etc.

Tick all that apply.

- No
- Commercial
- Office
- Worshop
- Other:

8 How many openable facade does your house have? *

Mark only one oval.

- 1
- 2
- 3
- 4

9 What is the main orientation of your house? *

Choose one that closet to your house orientation

Mark only one oval.

- North
- South
- East
- West
- NW
- NE
- SW
- SE
- I don't know

10 How many floors are there? *

Apartment = 1; basement and attic are not included

Mark only one oval.

- 1
- 2
- 3
- 4
- >4

11 Total floor area of your house is ...

Mark only one oval.

- < 40m2 4
- 0-80 m2
- 80-120 m2
- 120-200 m2
- >200 m2
- I'm not sure

12 What kind of load-bearing structure of your house is?

Mark only one oval.

- Reinforced concrete frame
- Steel frame
- Load-bearing walls
- Wooden frame
- I don't know

13 Please describe detail of the external walls

material, thickness, insulation?

Mark only one oval.

- 100-150 mm brick walls, no insulation
- 200-250 mm brick walls, no insulation
- 100-150 mm brick walls, with insulation
- 200-250 mm brick walls, with insulation
- I don't know
- Other:

14 Please describe detail of glass windows

frame type, glazing type

Mark only one oval.

- Wooden frame, single glazing
- Wooden frame, double glazing
- Aluminum frame, single glazing
- UPVC frame, single glazing
- UPVC, double glazing
- I don't know
- Other:

15 Please describe detail of roof

structure, roofing, insulation?

Mark only one oval.

- Concrete roof, no insulation
- Concrete roof, with insulation
- Frame (wooden or steel), tiling (tiles, aluminum) no insulation
- Frame (wooden or steel), tiling (tiles, aluminum) with insulation
- I don't know
- Other:

Housing environment

16 Please indicate any source of daylight or natural ventilation in your house *
Tick all that apply.
◯ Side windows
◯ Skylight
◯ Inner courtyard/ lightwell
◯ Other:

17 Please indicate any devices of environment control *
Tick all that apply.
◯ Shading devices/canopy
◯ Double layer window
◯ Curtain
◯ Ventilation fan
◯ Other:

18 Your rating of indoor environment in summer time (May to August) *

Bad= too hot and uncomfortable; good = cool and comfortable

Mark only one oval per row.	Very bad	Bad	Neutral	Good	Very good
◯ Daylight	◯	◯	◯	◯	◯
◯ Thermal	◯	◯	◯	◯	◯
◯ Natural ventilation	◯	◯	◯	◯	◯

19 Your rating of indoor environment in winter time (November - February) *

Bad= too cold (or hot) and uncomfortable; good = warm (or cool) and comfortable

Mark only one oval per row.	Very bad	Bad	Neutral	Good	Very good
◯ Daylight	◯	◯	◯	◯	◯
◯ Thermal	◯	◯	◯	◯	◯
◯ Natural ventilation	◯	◯	◯	◯	◯

Energy consumption

20 What is the primary energy source of your house?
Mark only one oval.
◯ Electricity only
◯ Gas only
◯ Electricity and gas
◯ Other:

21 In average, how much did you paid for gas monthly?

Ignore this question if you do not use gas.

Mark only one oval.

- Less than 100.000 VND
- 100.000 VND - 200.000 VND
- 200.000 - 300.000 VND
- 300.000 - 400.000 VND
- 400.000 - 500.000 VND
- More than 500.000 VND
- I don't know

22 Maximum electricity use per month and which month is that?

Mark only one oval.

- Less than 100 kWh 100-200 kWh
- 200-300 kWh
- 300-400 kWh
- 400-500 kWh
- More than 500 kWh
- I don't know

23 Minimum electricity use per month and which month is that?

Mark only one oval.

- Less than 100 kWh 100-200 kWh
- 200-300 kWh
- 300-400 kWh
- 400-500 kWh
- More than 500 kWh
- I don't know

24 How many air-conditioner do you have?

Mark only one oval.

- 0
- 1
- 2
- 3
- 4
- >4

25 Frequency of air-conditioner usage		
Mark only one oval per row.	Frequently	Infrequently
Summer day	⬭	⬭
Summer night	⬭	⬭
Winter day	⬭	⬭
Winter night	⬭	⬭

26 How many electric water heater are there in your house?
Mark only one oval.
0
1
2
3
4
>4

27 Frequency of electric water heater usage		
Mark only one oval per row.	Frequently	Infrequently
Summer day	⬭	⬭
Summer night	⬭	⬭
Winter day	⬭	⬭
Winter night	⬭	⬭

28 Do you use solar water heater?
Mark only one oval.
Yes
No

29 Use of energy efficiency equipment
Energy label from level 4 to 5 or label of “energy efficency” (see pictures)
Mark only one oval.
Yes
No

Energy efficiency label

30 Do you and your family aware of energy saving?

Mark only one oval.

- Yes, we always try to save energy
- Yes, we sometimes we save energy, sometimes not
- No, we don't save energy

31 What do you think about the amount of money you pay for energy?

Mark only one oval.

- Too much
- Much
- Neutral
- Little
- Too little

32 How do you find the current electricity price plan?

Mark only one oval.

- Expensive
- Neutral
- Cheap

Housing refurbishment

33 Has your house been renovated in the last 10 years? *

Mark only one oval.

- Yes > Skip to question 34
- No > Skip to question 36

Refurbishment details

34 What were involved in these refurbishment?

Tick all that apply.

- Repairing/replacing of damage parts
- Redecorating
- Space expansion/ modification
- Improving indoor environment (add shading devices, thermal insulation ...) Other:

35 How do you find your house after refurbishment? *				
Mark only one oval per row.	Worse	Unchanged	Better	No answer
Daylight	◯	◯	◯	◯
Thermal	◯	◯	◯	◯
Natural ventilation	◯	◯	◯	◯
Energy consumption	◯	◯	◯	◯

Refurbishment priority

36 Why was the house not refurbished?

Tick all that apply.

- ◯ There was no demand for refurbishment
- ◯ We were short of budget
- ◯ This is not our own property
- ◯ We do not plan to stay at this house in a long term period
- ◯ Other:

37 If there anything in your house that you want to improve in the near future?

Tick all that apply.

- ◯ Aesthetic (building form, panting, interior design...)
- ◯ Expanding/modification for more convenient living space
- ◯ Improve indoor environment
- ◯ Reduce energy consumption
- ◯ Smart house (incorporation of automatic control system)
- ◯ Other:

38 Please rate the importance of the following factors for refurbishment design decision ? *				
1: most important > 4: least important				
Mark only one oval per row.	1	2	3	4
Improve Indoor environment	◯	◯	◯	◯
Lower energy consumption	◯	◯	◯	◯
Aesthetic	◯	◯	◯	◯
Budget	◯	◯	◯	◯

Thank you for your participation!

* *Required*

APPENDIX B

Design workshop questionnaires

Student info	
University:	
BSc /MSc and year:	
GASC2019 group number:	
Which Hanoi design site:	

Learning goals				
	Did you learn something about this? (yes/no)	Did you apply it in your design? (yes/no)	Will you use it in future designs? (yes/no)	Remark
Architecture				
Urban planning				
Building technology				
Floor plans and layout options				
Sustainability in general				
Bioclimatic design				
Energy - Energy savings - Energy exchange - Use of waste heat/soil - Energy production (PV)				
Water - Water savings - Waste water treatment - Rainwater storage and use				
Materials - Material savings - Reuse of waste material - Recyclable materials - Renewable materials				

>>>

Learning goals				
	Did you learn something about this? (yes/no)	Did you apply it in your design? (yes/no)	Will you use it in future designs? (yes/no)	Remark
Application of green (plants)				
Indoor comfort in general				
Daylight strategies				
Ventilation strategies				
Acoustics and noise reduction				
Air quality improvement				
User behaviour				
Vietnamese culture				
Dutch culture				

What subject(s) did you miss? Did you learn something from the different workshop activities?				
	Took part	Learned something	Learned a lot	Remark
Site exploration (Sun)				
Introduction speeches (Mon)				
Talk by two architects (Tue)				
GASC2019 conference (Wed)				
Final presentations (Fri)				
Design supervision (all days)				
Group work (all days)				
Other activities (e.g. cultural)				

Do you have any further comments, remarks about the workshop GASC 2019?

APPENDIX C

Design proposal - refurbished house

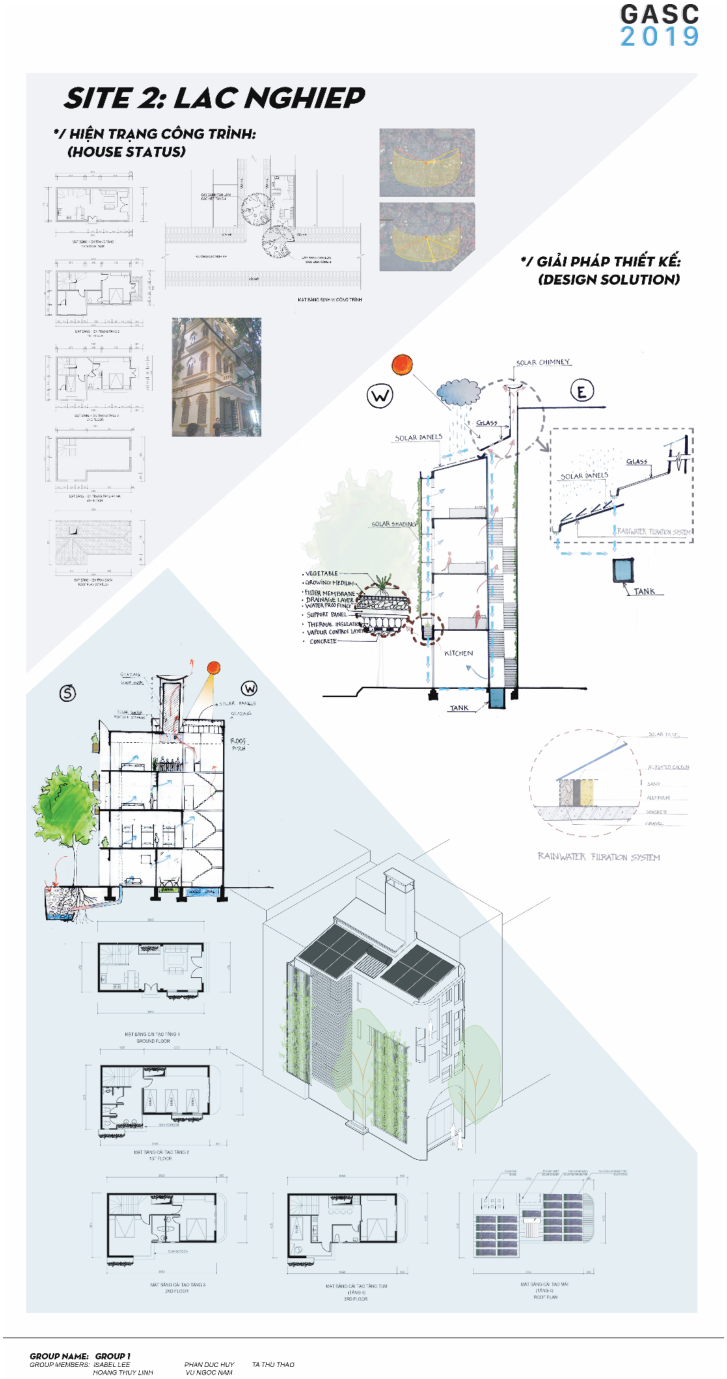
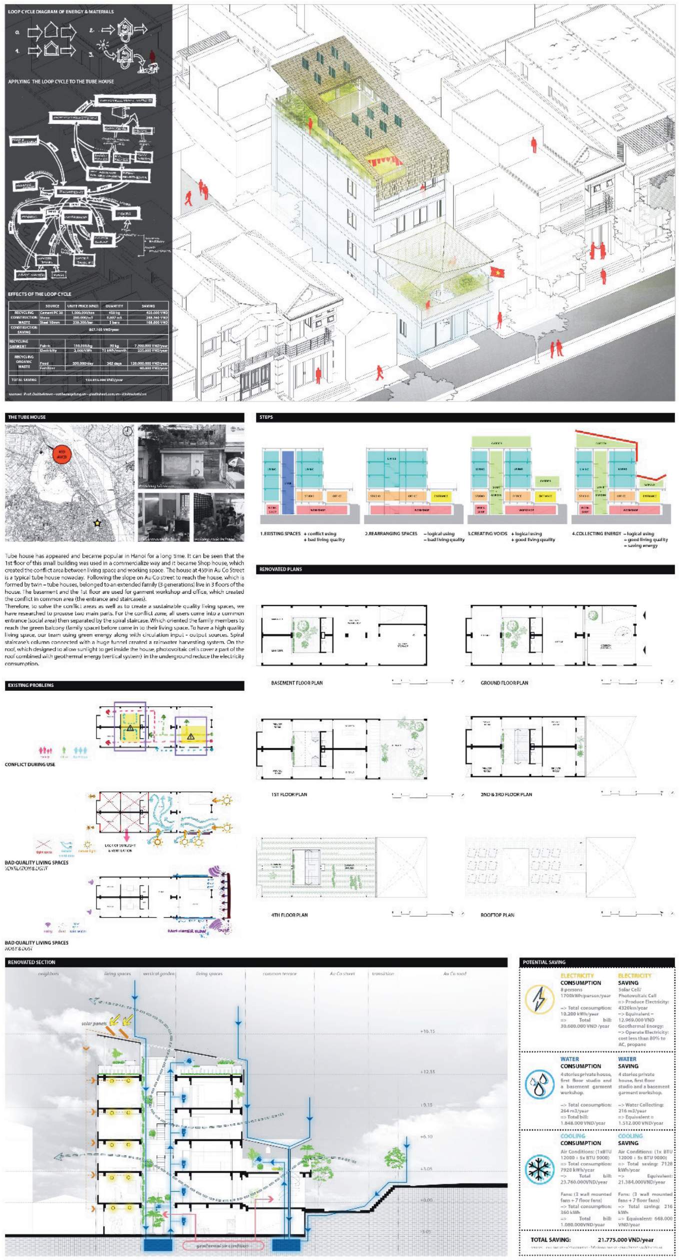

GASC
2019
SITE 2: LAC NGHIEP
*/ HIỆN TRẠNG CÔNG TRÌNH:
(HOUSE STATUS)
*/ GIẢI PHÁP THIẾT KẾ:
(DESIGN SOLUTION)
SOLAR CHIMNEY
GLASS
SOLAR PANELS
SOLAR SHADING
TANK
KITCHEN
VEGETABLE
GROWING MEDIUM
FIBER MEMBRANE
DRAINAGE LAYER
WATER PROOFING
SUPPORT PANEL
THERMAL INSULATION
VAPOUR CONTROL LAYER
CONCRETE
RAINWATER FILTRATION SYSTEM
MAT BANG CAI TAO TANG 3
2ND FLOOR
GROUP NAME: GROUP 1
GROUP MEMBERS: ISABEL LEE
HOANG THUY LINH
PHAN DUC HUY
VU NGOC NAM
TA THU THAO

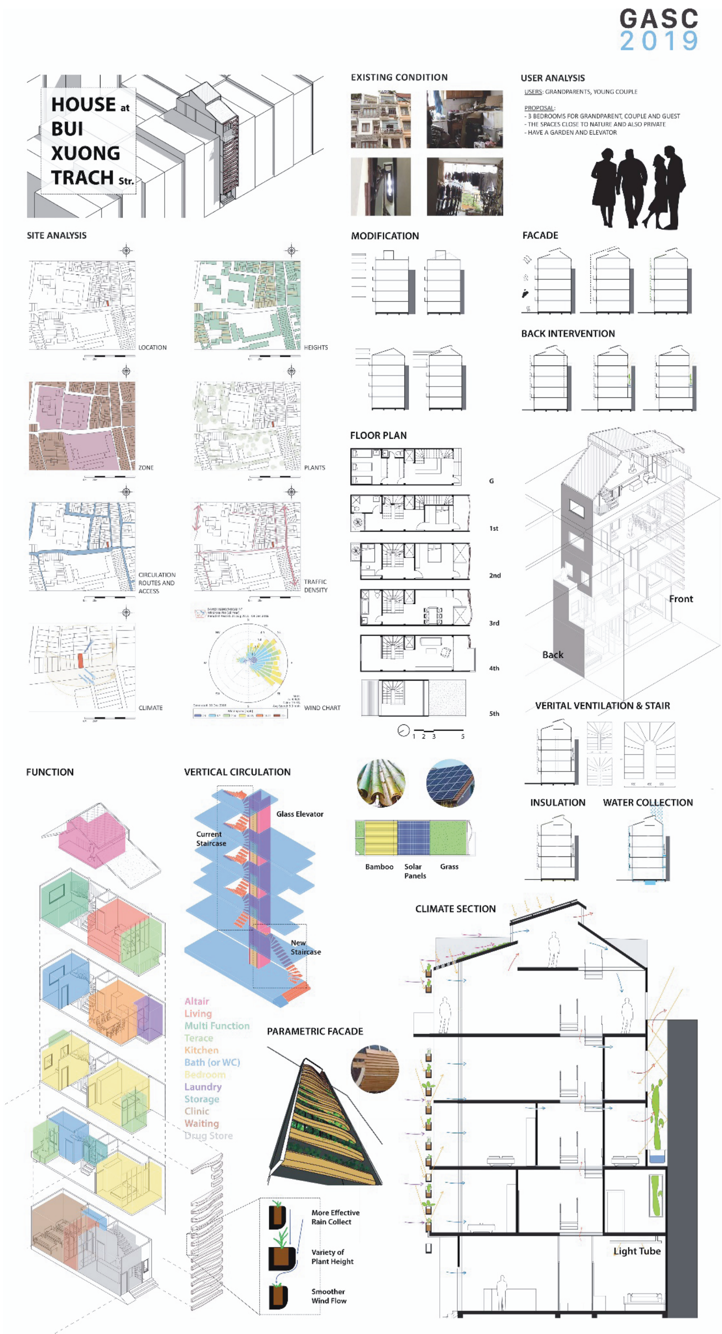
FIG. APP.C.1

GASC
2019



GROUP 2
NGUYEN BINH MINH - NGUYEN MINH TRANG - NGUYEN HA VI - HOANG THANH TUNG - TRAN HOANG MINH

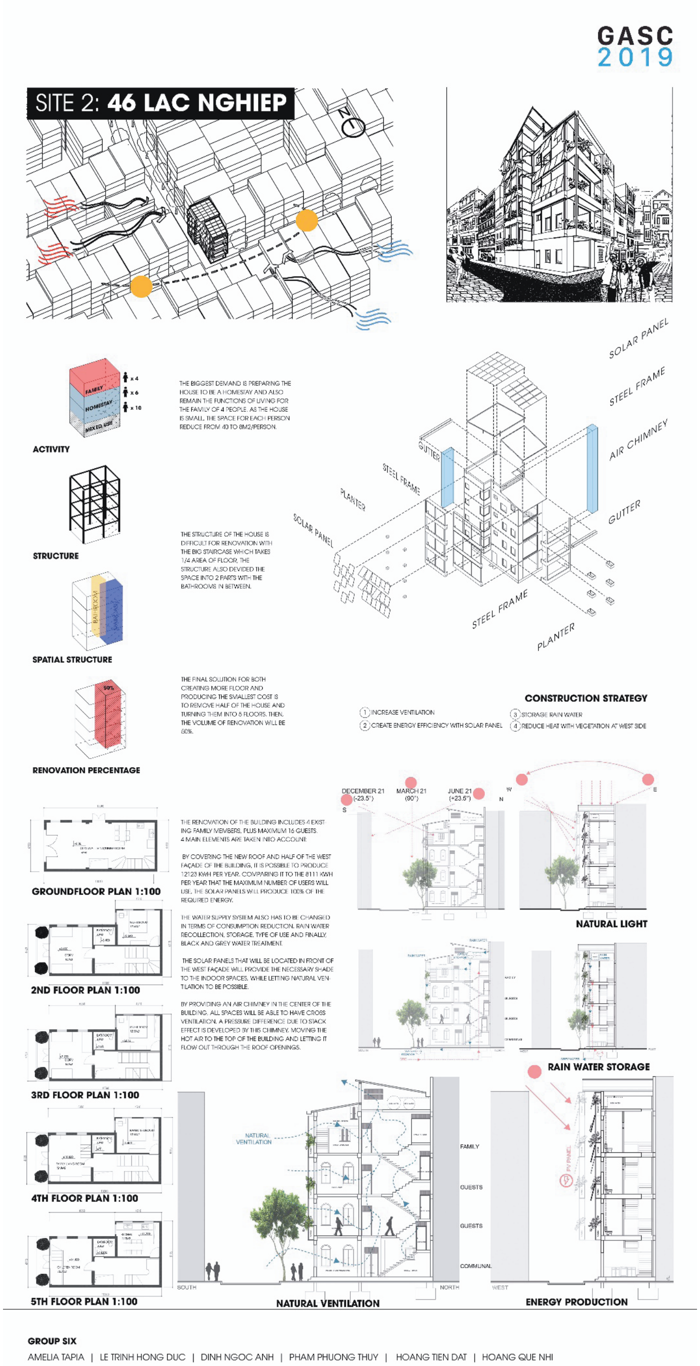
FIG. APP.C.2



GROUP 3

BADAR HAQ - TRỊNH QUỐC BẢO - NGUYỄN PHƯƠNG THÙY - LÊ THỊ NGỌC ANH - TRẦN NGÔ ANH DUY

FIG. APP.C.3



GASC
2019
SITE 2: 46 LAC NGHIEP
ACTIVITY
FAMILY
HOMESTAY
MIXED USE
x 4
x 6
x 10
THE BIGGEST DEMAND IS PREPARING THE HOUSE TO BE A HOMESTAY AND ALSO REMAIN THE FUNCTIONS OF LIVING FOR THE FAMILY OF 4 PEOPLE. AS THE HOUSE IS SMALL, THE SPACE FOR EACH PERSON REDUCE FROM 40 TO 8M2/PERSON.
STRUCTURE
THE STRUCTURE OF THE HOUSE IS DIFFICULT FOR RENOVATION WITH THE BIG STAIRCASE WHICH TAKES 1/4 AREA OF FLOOR, THE STRUCTURE ALSO DEVIDED THE SPACE INTO 2 PARTS WITH THE BATHROOMS IN BETWEEN.
SPATIAL STRUCTURE
RENOVATION PERCENTAGE
50%
THE FINAL SOLUTION FOR BOTH CREATING MORE FLOOR AND PRODUCING THE SMALLEST COST IS TO REMOVE HALF OF THE HOUSE AND TURNING THEM INTO 5 FLOORS. THEN, THE VOLUME OF RENOVATION WILL BE 50%.
SOLAR PANEL
STEEL FRAME
AIR CHIMNEY
GUTTER
PLANTER
CONSTRUCTION STRATEGY
1 INCREASE VENTILATION
2 CREATE ENERGY EFFICIENCY WITH SOLAR PANEL
3 STORAGE RAIN WATER
4 REDUCE HEAT WITH VEGETATION AT WEST SIDE
GROUNDFLOOR PLAN 1:100
2ND FLOOR PLAN 1:100
3RD FLOOR PLAN 1:100
4TH FLOOR PLAN 1:100
5TH FLOOR PLAN 1:100
THE RENOVATION OF THE BUILDING INCLUDES 4 EXISTING FAMILY MEMBERS, PLUS MAXIMUM 16 GUESTS. 4 MAIN ELEMENTS ARE TAKEN INTO ACCOUNT:
BY COVERING THE NEW ROOF AND HALF OF THE WEST FAÇADE OF THE BUILDING, IT IS POSSIBLE TO PRODUCE 12123 KWH PER YEAR. COMPARING IT TO THE 8111 KWH PER YEAR THAT THE MAXIMUM NUMBER OF USERS WILL USE, THE SOLAR PANELS WILL PRODUCE 100% OF THE REQUIRED ENERGY.
THE WATER SUPPLY SYSTEM ALSO HAS TO BE CHANGED IN TERMS OF CONSUMPTION REDUCTION, RAIN WATER RECOLLECTION, STORAGE, TYPE OF USE AND FINALLY, BLACK AND GREY WATER TREATMENT.
THE SOLAR PANELS THAT WILL BE LOCATED IN FRONT OF THE WEST FAÇADE WILL PROVIDE THE NECESSARY SHADE TO THE INDOOR SPACES, WHILE LETTING NATURAL VENTILATION TO BE POSSIBLE.
BY PROVIDING AN AIR CHIMNEY IN THE CENTER OF THE BUILDING, ALL SPACES WILL BE ABLE TO HAVE CROSS VENTILATION. A PRESSURE DIFFERENCE DUE TO STACK EFFECT IS DEVELOPED BY THIS CHIMNEY, MOVING THE HOT AIR TO THE TOP OF THE BUILDING AND LETTING IT FLOW OUT THROUGH THE ROOF OPENINGS.
DECEMBER 21 (-23.5°)
MARCH 21 (90°)
JUNE 21 (+23.5°)
S
N
W
E
NATURAL LIGHT
RAIN WATER STORAGE
NATURAL VENTILATION
FAMILY
GUESTS
GUESTS
COMMUNAL
SOUTH
NORTH
WEST
NATURAL VENTILATION
ENERGY PRODUCTION
GROUP SIX
AMELIA TAPIA | LE TRINH HONG DUC | DINH NGOC ANH | PHAM PHUONG THUY | HOANG TIEN DAT | HOANG QUE NHI

FIG. APP.C.4

APPENDIX D

Design proposal - new built house

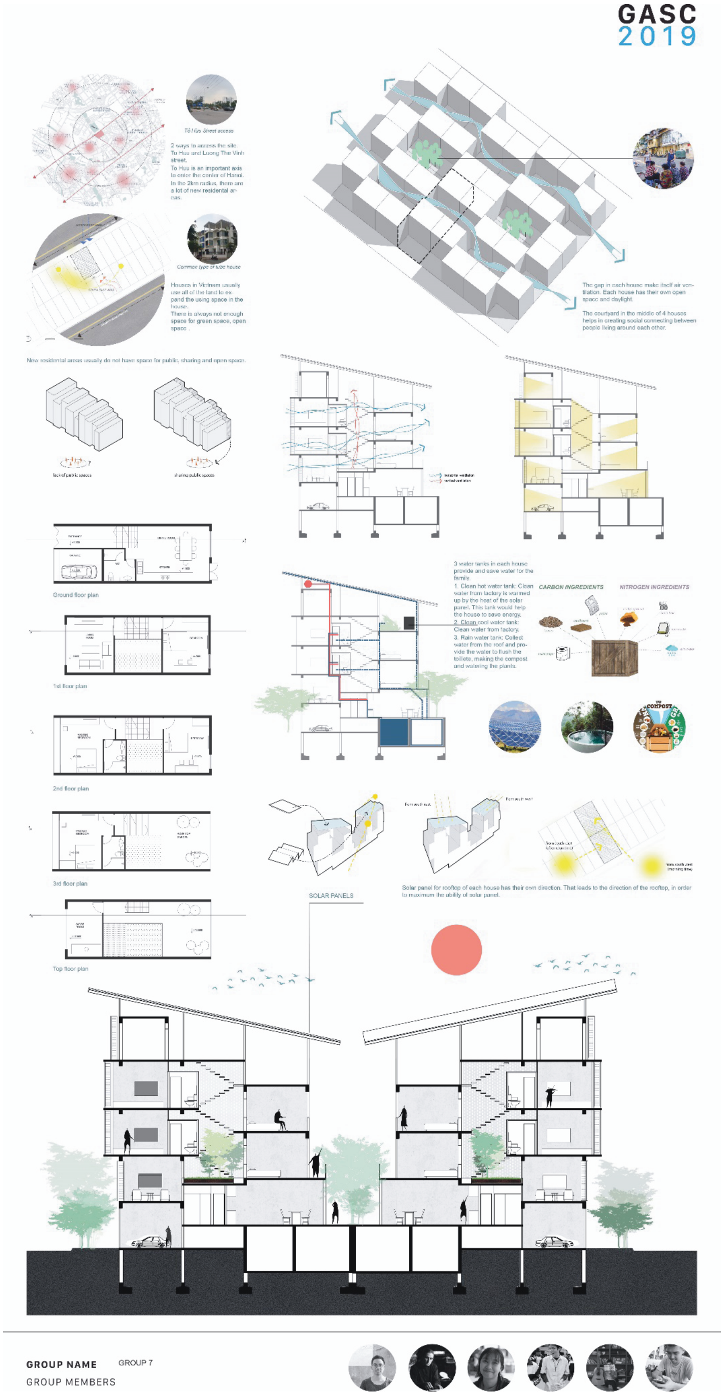

GASC
2019
Tô Hữu Street access
2 ways to access the site. To Huu and Luong The Vinh street.
To Huu is an important axis to enter the center of Hanoi.
In the 2km radius, there are a lot of new residental areas.
Common type of tube house
Houses in Vietnam usually use all of the land to expand the using space in the house.
There is always not enough space for green space, open space .
New residential areas usually do not have space for public, sharing and open space.
The gap in each house make itself air ventilation. Each house has their own open space and daylight.
The courtyard in the middle of 4 houses helps in creating social connecting between people living around each other.
Ground floor plan
1st floor plan
2nd floor plan
3rd floor plan
Top floor plan
3 water tanks in each house provide and save water for the family.
1. Clean hot water tank: Clean water from factory is warmed up by the heat of the solar panel. This tank would help the house to save energy.
2. Clean cool water tank: Clean water from factory.
3. Rain water tank: Collect water from the roof and provide the water to flush the toillete, making the compost and watering the plants.
CARBON INGREDIENTS
NITROGEN INGREDIENTS
COMPOST
Solar panel for rooftop of each house has their own direction. That leads to the direction of the rooftop, in order to maximum the ability of solar panel.
SOLAR PANELS
GROUP NAME
GROUP 7
GROUP MEMBERS

FIG. APP.D.1

Curriculum Vitae

Phan Anh NGUYEN

2004-2009 Bachelor Degree in Architecture
Hanoi Architecture University, Hanoi, Vietnam

2009-2010 Architect at HANLA JSC. Landscape Design Company, Hanoi, Vietnam

2010-2011 Master of Architecture in Environmental Design
University of Nottingham, Nottingham, United Kingdom

2011-2013 Architect at Vietnam Investment Consulting and Construction Designing JSC., Hanoi, Vietnam

2012-2015 Lecturer at Hanoi Architecture University, Hanoi, Vietnam

2015-2020 PhD candidate, Climate Design and Sustainability, Department of Architectural Engineering and Technology, Faculty of Architecture and the Built Environment, Delft University of Technology, Delft, The Netherlands

Publications

Journals papers

Nguyen, P. A., Bokel, R., & van den Dobbelsteen, A. (2019). Effects of a Vertical Green Façade on the Thermal Performance and Cooling Demand. Journal of Facade Design and Engineering, [S.l.], v. 7, n. 2, p. 45-64. doi: https://doi.org/10.7480/jfde.2019.2.3819.

Nguyen, P. A., Bokel, R., & van den Dobbelsteen, A. (2019), "Improving energy efficiency in Vietnamese tube houses: A survey of sustainable challenges and potentials", *Smart and Sustainable Built Environment*, Vol. 8 No. 5, pp. 366-390. doi:https://doi.org/10.1108/SASBE-01-2018-0002

Nguyen, P. A., Bokel, R., & van den Dobbelsteen, A. (2020). Sustainable Design Education – An Evaluation of an International Student Design Workshop in Hanoi, Vietnam. *Discourse and Communication for Sustainable Education*, 11(2), 20-32. doi:https://doi.org/10.2478/dcse-2020-0016

Nguyen, P. A., Bokel, R., & van den Dobbelsteen, A. Refurbishment design strategies for energy-efficient Vietnamese tube houses. Submitted to: *Journal of Green Building*

Nguyen, P. A., Bokel, R., & van den Dobbelsteen, A. Future Sustainable tube houses in Vietnam. Submitted to: *Journal of Green Building.*

Conference papers

Nguyen, P. A., Bokel, R., & van den Dobbelsteen, A. (2019). Facade refurbishment for energy saving in tube houses a case study in Hanoi, Vietnam. In *E3S Web of Conferences* (Vol. 111). EDP Sciences. doi:http://dx.doi.org/10.1051/e3sconf/201911103015

Nguyen, P. A., Bokel, R., & van den Dobbelsteen, A. (2017). Refurbishing houses to improve energy efficiency–potential in Vietnam. In *Passive Low Energy Architecture Conference (PLEA) 2017: Design to Thrive* (Vol. 3, pp. 4204-4211).

Nguyen, P. A., Bokel, R., & van den Dobbelsteen, A. (2016). Towards a sustainable plan for new tube houses in Vietnam. *International Planning History Society Proceedings*, Vol. 17 no.2. p. 211-222