# Renewable Cooling in Buildings

A study of Ho Chi Minh City and Hanoi, Vietnam

# Legal information

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The cover photo shows the Jakob Rope Factory Saigon in which the principles of passive cooling have been implemented: night ventilation, shading, thermal storage in heavy construction, and adiabatic cooling by plants for comfortable indoor climate.

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# Contents

# Executive Summary

The study takes up the challenge of the comprehensive question of sustainable cooling. It describes the situation given in the specific context of Vietnam as a dynamic environment in which there are plenty of opportunities for a transition to renewable energies: While solar power (PV) and wind have widespread potential to green energy-sourcing, challenges remain in the transmission and distribution of energy. The urban context poses additional challenges: Specific effects of cities such as urban heat islands and radiation, air pollution, as well as sealing of surfaces increase the need for cooling. Meanwhile, many modern buildings are not suited to decrease the need for cooling and high levels of pollution make it hard for citizens to make use of 'free cooling'. This already difficult starting position can create a negative momentum of its own: Poor thermal performance of buildings increases the need for active cooling, which at the same time ensures worse initial conditions if, for example, the electricity for air conditioning systems is generated from fossil fuels.

The study proposes a multi-stage process to move gradually towards more sustainable cooling. After assessing the renewable cooling context of Vietnam, it looks towards greening the process of cooling, first by analysing the potential for renewable integration. Then the topic of reducing active cooling is addressed. In order to work out the most important parameters for this, a simulation is created for two building types in each of the focus cities of this study, Ho Chi Minh City (HCMC) and Hanoi. The most important results are that passive measures, in particular a massive construction, shading, window to wall ratio (WWR) and the orientation of the building have a high influence on the temperature-wise acceptable hours of room temperature. Furthermore, technologies for cooling are assessed with a focus on economic viability and feasibility in the urban context. Results show, that solar PV installations are deemed the most feasible solutions for the remaining demand for cooling. As there are currently no operational feed-in-tariffs (FIT) any installation of renewables will have to cover simply the baseload posited by the building, with the future potential for expansion of installations desirable. The findings furthermore show that mechanised night ventilation is an even more significant component for improvement. In theory, the fitment and correct maintenance of filters for mechanised ventilation could improve air quality. However, especially smaller decentralised ventilation systems require regular and continuous maintenance.

Taken together, the ideas presented are inspired by vernacular themes offering increased potential for energy savings and thermal comfort and they try to approximate the reality in Vietnam as much as possible. The study presents different decision trees for developing projects and decisions to improve the sustainability of cooling, which can be found in the last section. While this study solely assesses local conditions in Vietnam, it can also provide impulses for other regions of the world.

# 1. Introduction

With over 3,000 kilometers of coastline, Vietnam spreads across two climate zones. Due to this exposed geographic position, Vietnam is seen as one of the countries most vulnerable to the impacts of climate change in the coming decade. Increasing energy consumption, rising $CO_2$ emissions and a rapidly advancing urbanisation rate pose additional challenges to Vietnam's booming economy.

To meet these challenges, the Vietnamese government is striving to create the necessary conditions to enable sustainable economic growth in line with the 2030 Agenda. Increasing the country's resource and energy efficiency has been given one of the highest priorities. Progressive urbanisation and the strong growth of metropolitan regions are currently leading to a sharp increase in energy consumption in the building sector. Buildings therefore play a very important role in improving the country's energy efficiency. The Copenhagen Centre on Energy Efficiency states: "Buildings play a very important role in improving energy efficiency in the country, with 30% of final energy consumption being attributed to this sector in 2015 (…) Residential buildings account for the largest share of energy consumption within the building sector with the highest consuming end-uses being lighting (19%) and air-conditioning (17%)" (Copenhagen Centre on Energy Efficiency, 2018).

This study, commissioned by the German Energy Agency (dena) on behalf of the German Foreign Office, aims to provide insight to ensure broad sustainability for the residents of Vietnam. First, the social and physical context of Vietnam is analysed (Section 2. Renewable Cooling Context of Vietnam), with emphasis on the urban environmental conditions and projected impacts of climate change. Renewable energy sources related to cooling are subsequently investigated (Section 3.1 Renewable energy supply). Parametric studies of two abstract building types, Primarily Uncooled Buildings (PUBs) and Primarily Cooled Buildings (PCBs), are undertaken to determine the impact of various building parameters on cooling demand (Section 3.2 Reducing Cooling Demand), trialling thousands of combinations of input parameters. Building on the context of the current state in Ho Chi Minh City and Hanoi, the resulting efficient cooling strategies (Section 3.3 Efficient cooling) aim to provide concrete recommendations for designers and developers seeking to realise greater adoption of renewable energy solutions in Vietnam (Section 4. Recommendations).

# 2. Renewable Cooling Context of Vietnam

The topic of refrigeration and cooling has become part of our everyday life: From early on, people used ice to store food safely. Even today, the safe storage and transport (in compliance with a cold chain) of food or particularly sensitive substances such as medicines is standard practice in many places around the world.

Nevertheless, a pleasantly cool environment is also essential for our own survival. In their study "Future of the human climate niche" (Xu et. al., 2019), the authors show how the global distribution of people could change in the future if some parts of the world would become almost uninhabitable due to severe heat. Indeed, it seems that humanity is currently stuck in a loop: “The growing demand for cooling will increase global warming – from emissions of hydrofluorocarbons (HFCs) used in cooling equipment and from CO2 and black carbon emissions from the mostly fossil fuel-based energy currently powering cooling. A transition to climate friendly and energy-efficient cooling, however, would avoid these emissions and allow an increase in cooling access that would contribute substantially to the Sustainable Development Goals (SDGs)” (United Nations Environment Programme and International Energy Agency 2020, p. 15).

In order to do so, it is necessary to analyse the context of the energy system as well as the changes to come within a certain geographical area. Since this study is specifically designed to analyse building cooling strategies and technologies in Vietnam, several local factors will be taken into account. The following chapter therefore addresses the political and governance system and climate pledges (2.1), climate change and its effects (2.2), the existing and possible future electricity infrastructure (2.3) as well as urban and building infrastructure, including architectural aspects (2.4 and 2.5).

## 2.1 Political Context and Climate pledges

The origins of Vietnam’s contemporary political and economic system are found following the French Indochina War and the subsequent division of Vietnam after the Geneva Conference in 1954. Leaders of the Democratic Republic of Vietnam (Northern Vietnam) took influence from Russian and Chinese socialist movements, adopting a Soviet-style command economy and political structure while the American-backed Republic of Vietnam (Southern Vietnam) pursued a market economy model (Vuong, 2010).

Involvement in several border conflicts, the slow disintegration of Vietnam’s primary trade partner, the Soviet Union, America’s trade embargo, and ineffective domestic policies paved way for “Đổi Mới”: the economic reforms of 1986, which introduced private markets to the previously command-based economy (Vuong, 2010). U.S. President Bill Clinton lifted the American trade embargo on Vietnam in 1994 thus enabling unrestricted international trade in markets such as Hong Kong, Singapore, South Korea, Taiwan and Japan (Duiker et al., 2022). The stability effected by peace time, reforms and access to foreign investment and trade led to the growth of the manufacturing and service sectors, diversification of exports, gross domestic product growth and increased standards of living (Glewwe, Agrawal and Dollar, 2004; Vuong, 2010).

While the historic city of Hanoi is slightly less populous now than the younger Ho Chi Minh City, the population of the Red River Delta region (North) is greater in number and density. Publicly owned enterprises play a large role in markets, with Vietnam’s various government ministries heavily involved in national development. Consequently, any urban-scale cooling strategies should consider the various central ministries, and their ability to coordinate effectively in addition to the efficacy of program enforcement. Otherwise, decentralised or market-based approaches could be considered more favourable.

Coal is seen as one of the drivers of Vietnams GDP growth over the last decades. Its status in current draft versions of Vietnams power development plans (PDP) remains unchanged: Coal is expected to carry a big share of the growing demand for energy (Pham 2022). However, at the UN Climate Change Conference in 2021 (COP26), Vietnams Prime Minister Pham Minh Chinh pledged that the country would achieve carbon neutrality by 2050, while also phasing out coal by 2040.

The government of Vietnam has just recently updated its Nationally Determined contribution (NDC), a document stating the countries' commitments as part of the Paris Agreement. The NDC, submitted on the 8th of November 2022, now states more ambitious goals than the update from 2020, a comparison taken from the NDC itself can be seen below.

| Sector | Unconditional contribution | | | | Conditional contribution | | | |
|---|---|---|---|---|---|---|---|---|
| | NDC 2020 | | NDC 2022 | | NDC 2020 | | NDC 2022 | |
| | *(%)* | *(Mt CO2eq)* | *(%)* | *(Mt CO2eq)* | *(%)* | *(Mt CO2eq)* | *(%)* | *(Mt CO2eq)* |
| Energy | 5.5 | 51.5 | 7.0 | 64.8 | 16.7 | 155.8 | 24.4 | 227.0 |
| Agriculture | 0.7 | 6.8 | 1.3 | 12.4 | 3.5 | 32.6 | 5.5 | 50.9 |
| LULUCF | 1.0 | 9.3 | 3.5 | 32.5 | 2.3 | 21.2 | 5.0 | 46.6 |
| Waste | 1.0 | 9.1 | 1.0 | 8.7 | 3.6 | 33.1 | 3.2 | 29.4 |
| IP | 0.8 | 7.2 | 3.0 | 27.9 | 0.9 | 8.0 | 5.4 | 49.8 |
| ***Total*** | **9.0** | **83.9** | **15.8** | **146.3** | **27.0** | **250.8** | **43.5** | **403.7** |

*Note (*): increasing GHG removal*

Figure 1: Comparison of emission reduction targets in NDC 2020 and NDC 2022 (Socialist Republic of Viet Nam, 2022)

The topic of "cooling" for buildings and logistics is addressed, in addition to a brief mention regarding cooling in mining. As part of the introduction the document refers to the pledges already made in the context of the COP26 and refers to emissions associated to and from refrigeration processes: "taking into account emissions of the air conditioning and refrigeration sub-sector under services and trade and conversion of the use, recovery, and partial destruction of HFCs in industrial processes." (Socialist Republic of Viet Nam, 2022, p. 3).

The government of Vietnam furthermore acknowledges the increased need for cooling due to higher temperature in the energy section of the document (Socialist Republic of Viet Nam, 2022, p. 15), stating that "increased temperatures increase the energy demand due to the use of cooling equipment". It therefore follows up on this in its proposal on reductions of energy usage by "Use of high-efficiency air conditioning and refrigeration equipment in commercial and residential services" (Socialist Republic of Viet Nam, 2022 p.7).

In the section on "Support in GHG emission reduction", the document states: "Improve energy efficiency and conversion in industrial production; in agriculture, fisheries, and forestry value chains; in transportation, including passenger, freight, and private transportation; and in construction and building management, including commercial buildings, offices, hotels, houses, factories, and manufacturing facilities (insulation, energy efficiency in lighting, cooling, water heating using solar energy, etc.)" (Socialist Republic of Viet Nam, 2022 p. 36).

In July 2022, Vietnam announced its Long-Term Strategy (LTS) for Climate Change, the so-called "National Strategy on Climate Change" as legislation No.896/QD-TTg. The website Energy Tracker Asia (Tachev, 2022) lists the plans commitments, as can be seen in the figure below:

**Targets for 2030**

- hydro, solar and wind power and biomass power will have at least a 33% share in total electricity generation,
- increased use of green energy in transportation,
- energy sector greenhouse gas emission reduction target of 32.6%,
- agricultural sector GHG emission reduction target of 43%,
- forestry and land use GHG emission reduction target of 70%,
- industry GHG emission reduction target of 38.3%
- and waste treatment emission reduction target of 60.7%.

**Targets for 2050**

- Energy sector emissions are to drop by 91.6%,
- agriculture sector emissions to be cut by 63.1%,
- forestry sector and land use emissions to reduce by 90%,
- waste sector emissions to drop by 90.7%
- and an industrial process emissions reduction target of 84.8%.

Figure 2: Vietnam's commitments under the new National Strategy on Climate Change (Tachev, 2022)

The unofficial translation by the United States Department of Agriculture shows that sustainable buildings and cooling, especially in an efficient or sustainable way are important to the Vietnamese government. The translation states in the section on reducing greenhouse gas emissions by sector: "To complete the system of regulations and standards on green buildings and green urban areas, ensuring that by 2050 the regulations and standards on green buildings and green urban areas are applied compulsorily to all newly-built works. To gradually reduce the use of Hydro-chloro-fluoro-carbon (HCFC) and Hydro-fluoro-carbon (HFC) refrigerants in cold chain, refrigeration and building air conditioning systems; improve cooling efficiency, reduce cooling demand and refrigerant consumption through building design and passive cooling solutions; promote the recovery, reuse, destruction and recycling of refrigerants and move towards the use of refrigerants with low global warming potential (GWP)"(Prime Minister - Socialist Republic of Vietnam, 2022).

The NDC and LTS thereby show that the government is aware of the problem of rising temperatures and an increase in the need for cooling solutions in the industrial, commercial and residential sectors and is focusing on sustainable cooling solutions. Both documents are the guiding concepts for various other plans, often developed with international support, that differentiate the various sectors of the economy or focus on environmental and social issues. These include the development plans for the energy sector described in the next section, which is one of the largest emitters in the country.

## 2.2 Climate and Climate Change

Located in the Indochinese Peninsula, the land area of Vietnam (~329 300 km2) is characterised by a relatively large north-to-south coastline (~3400 km) and extensive mountain ranges in its central and northern interior

(At 3,143m Phan-xi-pang is the highest natural point). According to the Köppen-Geiger climate classification, the two major metropolises of Hanoi and Ho Chi Minh City are located in subtropical (dry winter - Cwa) and tropical (savannah - Aw) climate zones, respectively. Climate projections by Rubel and Kottek (2010), predict an expansion of tropical conditions, covering 97% of Vietnam by 2100 (Figure 3, Figure 4).

| Class | Description | Temperature | Precipitation |
|---|---|---|---|
| Cwa | Dry winter humid sub-tropical climate | Warmest month > 22 °C | Driest month rainfall < 0.1 x wettest month |
| Cwb | | Coldest monthly avg. > 0 °C<br>All months avg. < 22 °C<br>More than 4 months avg. >10 °C | >10 x rainfall in wettest month (summer) as in the driest month (winter) |
| Aw | Tropical Savanna climate | Coldest month > 18 °C | Driest month rainfall < 60 mm |
| Am | Tropical monsoon climate | All monthly avg. > 18 °C | Heavy seasonal rainfall with dry season |

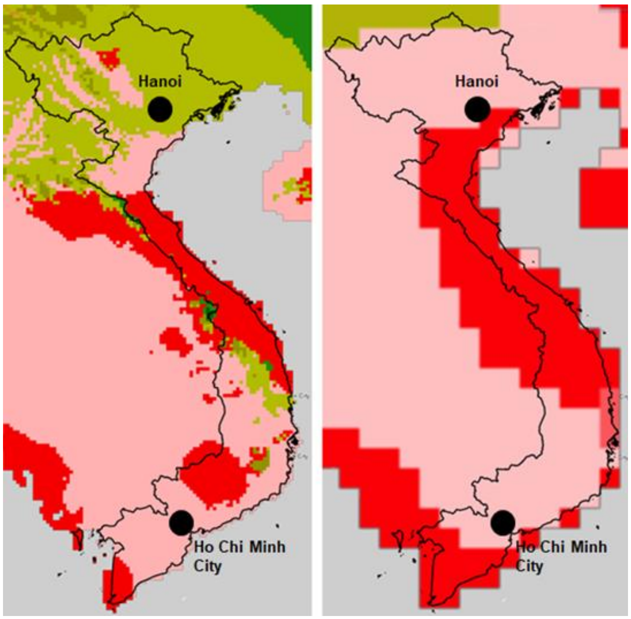


Figure 3: Koeppen Climate Classification Criteria (Rubel and Kottek, 2010)

Figure 4: Vietnam 2020 (left) and 2100 (right) climate classifications (Rubel and Kottek, 2010)

The contemporary climates of Hanoi and Ho Chi Minh City (HCMC) were analysed, given their population density and their locations in the characteristic climate zones of the North and South. Due to yearly variance in weather conditions, 'typical' and representative yearly data was generated by Climate.OneBuilding.Org (2022) through statistical analysis. In HCMC, the monthly average temperature shows little variance (25-30°C), while Hanoi experiences larger seasonal variations with summer conditions (25-30°C) and milder winter conditions (15-25°C) (Figure 5). Similarly, the solar insolation reflects a comparable trend, with HCMC experiencing little variance and Hanoi experiencing milder winter solar conditions (Figure 6). Annually, Hanoi receives approximately 30% less global horizontal irradiation (GHI) compared with HCMC.

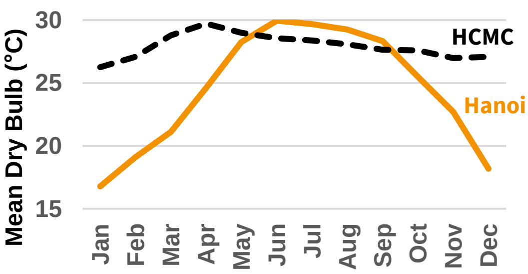


Figure 5: Mean monthly dry bulb temperature (GHI) (Climate.OneBuilding.Org, 2022)

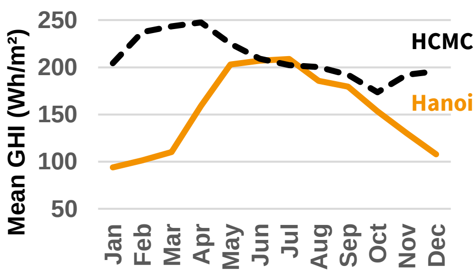


Figure 6: Mean monthly global horizontal irradiation (GHI) (Climate.OneBuilding.Org, 2022)

The demand of sensible (relating to temperature) and latent (relating to dehumidification) cooling in HCMC and Hanoi is similar during the summer months but differs drastically during cooler months. In air cooling processes, latent loads are introduced when the dew point temperature of air is reached, forcing water to condense as the dry bulb temperature further decreases. HCMC experiences prolonged summer humidity, with ~60% of annual ambient conditions featuring a dew point temperature above 23°C, defined herein as hot and humid (Figure 7). On the other hand, approximately 40% of Hanoi's ambient air conditions are hot and humid, while 30% have only mild conditions (dry bulb temperature ≤ 23°C) (Figure 7). The climate-change-driven expansion of tropical conditions is expected to significantly increase sensible and latent (dehumidification) cooling demand in conditioned spaces, with an approximate 20% increase of hot and humid ambient air conditions in currently subtropical zones (e.g. Hanoi).

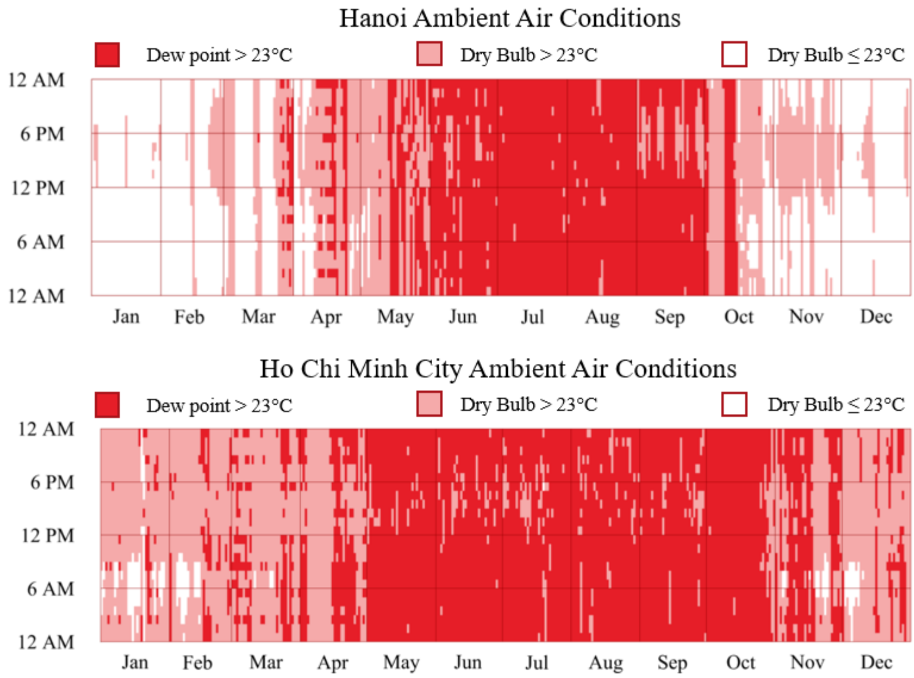


Figure 7: Subtropical (Hanoi) and Tropical (Ho Chi Minh City) Ambient Air Conditions (Climate.OneBuilding.Org, 2022)

## 2.3 Electricity generation and distribution

In the past twenty-five years, the Vietnamese population's access to electricity has increased from approximately 80% to 100% (World Bank, 2021a). Following the growth of residential and industrial sectors, total electricity generation in the country almost tripled between 2005 and 2014 (International Energy Agency, 2016). Vietnam was previously well known for its substantial use of hydroelectric generation; however, electricity production share is decreasing as the national potential for large-scale hydropower has been exhausted (International Energy Agency, 2016). Further, the hydropower electricity output varies drastically due to seasonal variability in rainfall during wet and dry seasons (International Energy Agency, 2016). To stabilise fluctuations in hydropower, natural gas fields in southern Vietnam feed combined cycle gas turbines (CCGT). However, a lack of grid infrastructure and uneconomical gas reserves in the north limit the potential of CCGT. The country's seventh energy plan - the Master Power Development Plan for the period 2011-2020 (PDP7) – has seen a dramatic expansion of power generation capacity primarily driven by coal-fired power (International Energy Agency, 2016).

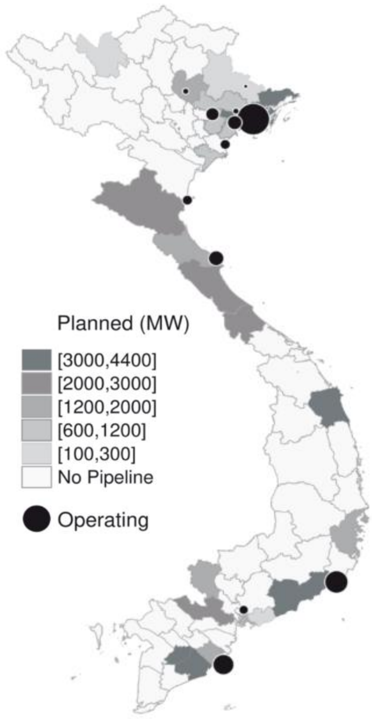


Figure 8: Operating and planned coal-fired electricity generation capacity until 2030 (Dorband, Jakob and Steckel, 2020)

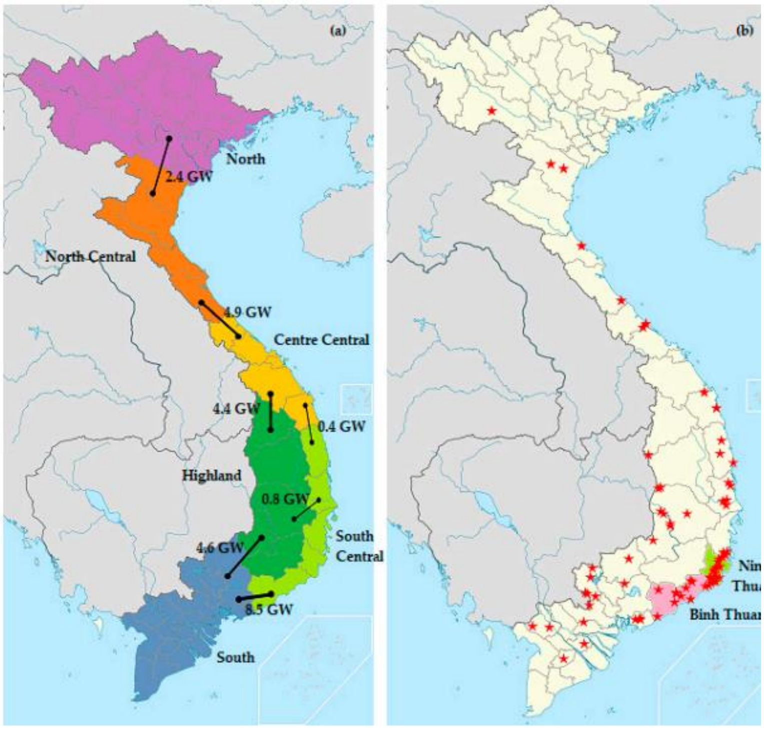


Figure 9: Transmission grid (left) and approved photovoltaic plants (right) in 2019 (Le et al., 2020)

While coal-fired electricity generation is considered by Vietnam to be the economically affordable solution to expand electricity access, the Ministry of Industry and Trade (MOIT) has consistently increased its renewable energy targets since 2007 (International Energy Agency, 2016). The Renewable Energy Plan aims to increase the renewable energy share (incl. hydroelectric) from 38% in 2020 to 43% by 2050, with caps on coal-fired power generation announced in 2016 (International Energy Agency, 2016). The draft version of the latest Master Power Development Plan for period 2021-2030 (PDP8) features continued exploitation of fossil-fuel-based electricity production as baseload (particularly an expansion of gas exploitation), with a marked increase in planned wind power capacity and a modest increase in planned solar, hydroelectric and biomass power capacities (Figure 10) (Baker & McKenzie, 2021). Vietnam has considered establishing nuclear power since 1995; however, in 2016 the National Assembly passed a resolution to postpone indefinitely major plans due to “economic conditions” (World Nuclear Association, 2022).

Vietnam’s electrical carbon intensity is expected to decrease in the future, and is dependent on its ability to generate, distribute and store renewable energy. Fuelled by a feed-in tariff (FIT) subsidy scheme, solar photovoltaic power plants and rooftop installations recorded booming growth, from 0.106 GWp installed in 2018 to approximately 5 GWp in 2019 (Le et al., 2020). The article by Le et. al. (2022) looks at the effects of the FIT, while also pointing to several other studies doing so. Currently, it is no longer possible to connect solar plants via the feed-in tariff; a transitional solution was recently adopted for wind. This is further elaborated in chapter 3.1.1. under "Economic considerations". However, there seem to be some changes on FITs: Especially 'transitional projects' could benefit from new regulations (Cooper & Tran, 2022). The prime minister has directed the developers of the National Power Development plan to look into solar rooftop power and its potential for self-consumption (MHM Vietnam, 2022).

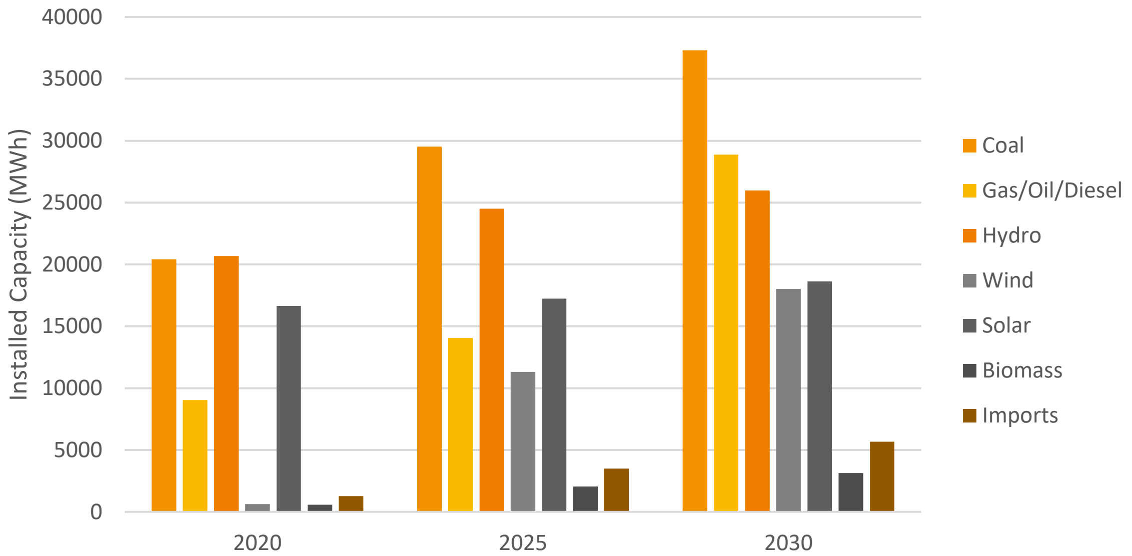


Figure 10: Planned Power Production Capacity of PDP8 until 2030. (Baker & McKenzie, 2021)

Developed photovoltaic installations and planned wind power developments are distributed primarily in the central and southern regions (Figure 9), with a significant underdevelopment in the northern regions. The boom of solar PV has put great pressure on the existing infrastructure, leading to frequent grid overloads, particularly in the provinces of Ninh Thuan and Binh Thuan where a large mismatch between supply and demand is observed (Le et al., 2020). South-to-north grid infrastructure upgrades are necessary if the densely populated Red River Delta region is to alleviate its coal dependence. Consequently, more expedient carbon reductions of grid electricity are expected in the south and central regions, while in the short to medium term, the northern regions will remain relatively carbon intensive.

## 2.4 Urban Context / Urbanisation

Located within proximity of the country's two breadbaskets, the Red River Delta (North) and Mekong Delta (South), the two historic metropolises of Hanoi (the capital, population 8.2 million) and Ho Chi Minh City (formally Saigon, population 9.2 million) constitute the majority of the increasing urban populous (United Nations Habitat, 2008; Vietnamese General Statistics Office, 2021). The demographic of Vietnam shows a strong working population, where children (0-14 years old) and the elderly (65+ years old) constitute less than 30% and 15% of the population, respectively (Figure 11). The population has grown from 62 to 98 million between 1986 and 2021, with roughly 57% of the Vietnamese population currently residing in cities (World Bank, 2021a). Accounting for 70% of the total economic output and attracting the most foreign direct investment, Vietnamese cities and towns act as the predominant drivers of economic development and rural-to-urban migration (United Nations Habitat, 2008). The highest positive migration in rates of 2020 are observed in the provinces of Binh Duong (+5.86%), Bac Ninh (+3.58%) and Ho Chi Minh City (+1.8%) – provinces with large industrial parks and training schools (Vietnamese General Statistics Office, 2021).

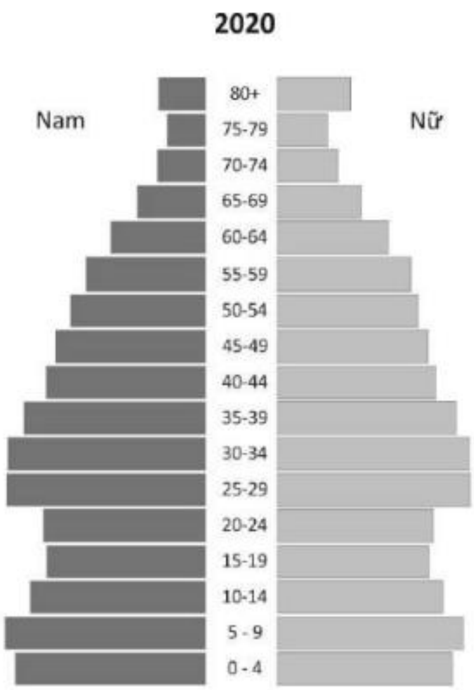


Figure 11: Vietnamese demographics as percentage of population (Nam = Male, Nữ = Female)
(Vietnamese General Statistics Office, 2021)

Rapid urbanisation also shows negative consequences, with poverty posing big challenges. In recent history, poverty density in the northern cities is far more widespread and homogenous than in the south, where greater national wealth and inequality is observed (Figure 12). UN Habitat (2018) attributes this to complex planning processes and overlaps in competences between administrative stakeholders:

> "There is a large disconnect between the beautifully drafted idealized plans (…) and the reality of urban development on the ground… Given the weakness of the urban planning and management, particularly in the city periphery, frequently informal urbanization takes place in [an] ad hoc, unregulated manner"(United Nations Habitat, 2008).

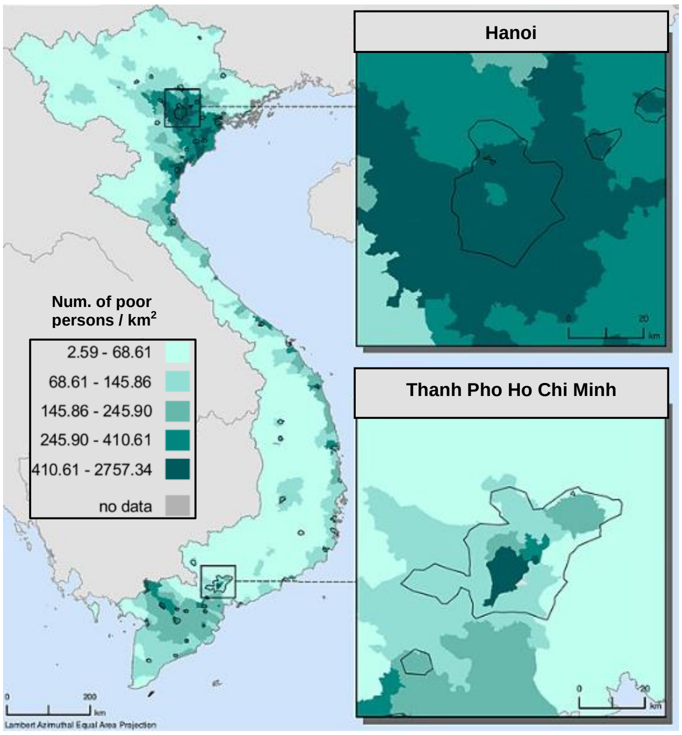


Figure 12: Poverty density
(Center for International Earth Science Information Network, 2007)

Figure 13: Hanoi air pollution
(©dena / Moritz Limbacher)

Additional to poverty density and inequality, urbanisation has also come at the expense of the local environmental, leading to:

- a large-scale loss and fragmentation of existing predominantly agricultural land,
- land and water pollution,
- worsening air quality,
- anthropogenic heat release / urban heat retention and,
- inadequate drainage (flooding).

Rapid motorisation of transport and coal-fired power generation, particularly in the north (Figure 13), are responsible for high levels of air pollution. Vietnam consistently ranks high in the list of countries with high air pollution. Vuong et. al. (2020) point out in their study on citizens' behaviour how great the influence is: "The air quality in Hanoi, the capital of Vietnam and the country's second-largest city, is much worse than at the national level due to the high volume of vehicles, construction, energy consumption, and heavy factories located there. In 2018, Hanoi had an average PM2.5 concentration of 40.8 µg/m3, a dangerous level for the general public and especially unhealthy for sensitive groups." (Vuong et. al., 2018, p. 2).

While surveying citizens of Hanoi, the researchers also found that preventive strategies, "such as air purifiers and living at home, are used to reduce the harmful effects of contaminated air, and a large proportion of respondents willingly endorse air safety activities." (Vuong et. al., 2018, p. 3). Although there is not any study with a corresponding methodology for the HCMC area or other cities, a Vietnamese study from 2019 found that across five locations in HCMC the average PM2.5 concentration lay at 36.3, exceeding WHO and national safety values (Hien et. al. 2019, p. 2242).

For more real-time data, the US Environmental Protection Agency (EPA) in conjunction with various US and local agencies uses Air Quality monitoring stations around the world, often located at US diplomatic missions, with historical data available. The so-called "Air Quality Index" also factors in additional pollutants, among them "ground-level ozone, particle pollution (also known as particulate matter, including PM2.5 and PM10), carbon monoxide, sulphur, nitrogen dioxide" (AirNow, 2022a). In the case of Vietnam, there is data available from Hanoi and HCMC. Historical data for this shows approximately 7288 data entries for HCMC (AirNow, 2022b) and 5539 for Hanoi, one for each hour of the days recorded in the data from January 1st to October 31st. Of those, 5492 are considered valid for Hanoi, 6930 for HCMC (AirNow, 2022b). Pointing to a high degree of pollution, with over 700 data entries for HCMC equalling hours of "Unhealthy for Sensitive Groups" or "Unhealthy" characterised levels of air pollution in 2022 (AirNow, 2022b). In addition to that, there are more than 4000 data entries characterised as "moderate" (AirNow, 2022b).

In Hanoi, the burden on residents is even higher: AirNow records more than 2000 entries characterised as "Unhealthy for Sensitive Groups" or "Unhealthy", with 16 values characterised as "Very Unhealthy" or "Hazardous", and more than 3000 entries as "Moderate" (AirNow 2022c).

Main reasons for air pollution with PM2.5 in the years of 2019 and 2020 were identified in a study by a coalition of Vietnamese and international non-governmental organisations (NGOs), funded by USAID. Their intricate and detailed results can be found on the dedicated website, detailing the sources of the air pollution: In HCMC, traffic accounts for 45% of the overall air pollution (mostly road traffic), industry 32% (mostly textile and food) and households and restaurants account for 23% (Hiện trạng bụi PM2.5 tại Việt Nam, 2022) For Hanoi, as well as nationwide, there is only a cross-reference to be found that, however, excludes important sectors such as shipping or construction (Hiện trạng bụi PM2.5 tại Việt Nam, 2022).

It is safe to say that air pollution poses a significant problem to a sustainable and healthy urban way of life. This directly affects solutions for building cooling as well: Only a low number of buildings are presumably equipped with ventilation systems with heat recovery and filters to provide clean inside air. These technologies can hardly be found in office buildings, while for most residential buildings, they might not be affordable. The vast majority of city dwellers does use natural ventilation at present, irrespective of the poor air quality, sometimes supported by mitigation measures such as air purifiers. This is unfortunately not something that can realistically be addressed through passive building design. In general, poor air quality can be seen as a systemic problem, similar to the heat island effect (see below), where it is very difficult to shield a single building from the surrounding context.

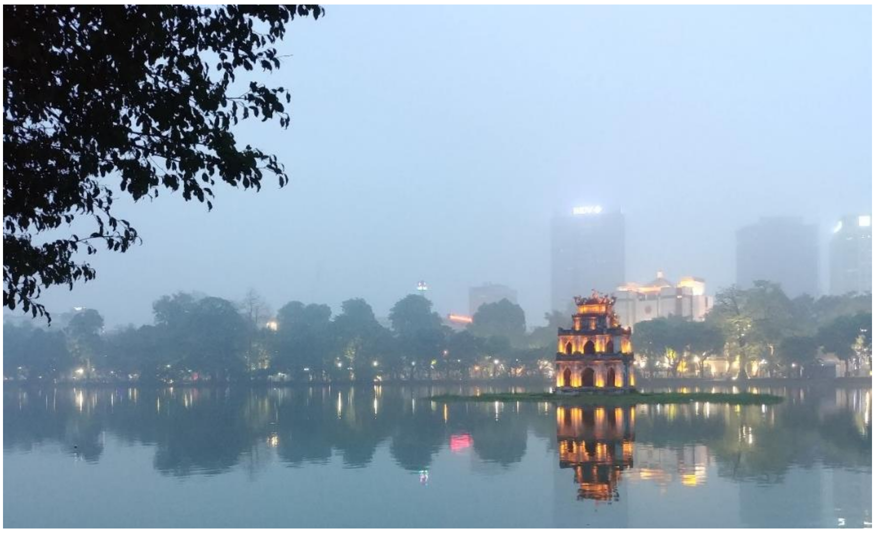

Figure 14: Smog over Hoan Kiem Lake, Hanoi (©dena / Moritz Limbacher)

Untreated municipal waste and wastewater have led to significant pollution of surface water, and lack of adequate drainage adds to flood risks (United Nations Habitat, 2008). Urban development is typically characterised by concrete multi-storey construction, deep urban "canyons", and high anthropogenic heat release. This change has transformed the local microclimate, resulting in cities experiencing Urban Heat Island (UHI) effects, and consequently an increase in cooling demand:

- HCMC has observed increasing night-time temperatures of 0.23-0.3 °C per decade (from 1990 to 2020) due to the surface heat island effect (Nguyen et al., 2022).
- Further, simulated average surface air temperatures show increases in pre-existing urbanised areas (+0.22 °C) and newly developed areas (+0.41 °C) of HCMC relative to less developed or agricultural areas (Doan, Kusaka and Ho, 2016).
- In Hanoi, urban-core mean surface air temperature for the month of July is expected to increase by 0.7 °C by 2030, accelerating since the period 1990-2010 (Doan, Kusaka and Nguyen, 2019).

Individual buildings can attempt to neutralise their contribution to the UHI through strategies such as increased vegetative cover or reflective surfaces. However, such strategies applied on a single building cannot offset the broader conditions, which give rise to the UHI, requiring a coordinated change in urban planning and development.

## 2.5 Architecture

### 2.5.1. Building context

Vietnamese building developments strongly correlate with the surrounding socio-economic environment, reductively defined below:

- *Urban*: high-density cities and towns, expressed as either two-to-five storey "shophouses"/ "tube houses" or high-rise developments (Figure 15).
- *Peri-urban*: lower density, sprawling development of city periphery, expressed as less complex single or double storey buildings
- *Rural*: lower density and traditionally agrarian focused development outside cities. Rural Vietnam is characterised by freestanding single or double storey buildings.

The focus of this study is primarily on the urban and peri-urban scale. As such, the rural contexts will only be referred to for context, when relevant.

Figure 15: Hanoi Urban Collage (©dena / Stefan Schirmer)

### 2.5.2. Building Energy Standards and Regulations

The following Vietnamese regulations are relevant for the topics of energy efficiency and cooling:

- QCVN 09:2017/BXD: National Technical Regulation on Energy Efficiency Buildings
- TCVN 5687:2010/BXD: National Technical Standard on Ventilation, Air Conditioning Design
- QCVN 06:2021/BXD: National Technical Regulation on Fire Safety of Buildings and Constructions
- QCVN 08:2009/BXD: National Technical Regulation on Urban Underground Structures, Part 2.

Beyond these local regulations, it is commonplace to refer to a variety of American Society of Heating Refrigeration Air conditioning Engineers (ASHRAE) standards, as these provide a further specific level of detail. ASHRAE standards referenced include:

- ASHRAE 62.1: Ventilation and Acceptable Indoor Air Quality
- ASHRAE Std 90.1: Energy Standard for Buildings Except Low-Rise Residential Buildings
- ASHRAE Std 55: Thermal Environmental Conditions for Human Occupancy
- ASHRAE Handbooks: HVAC Systems & Equipment / Fundamentals

Nguyen et al. (2011) found that Vietnam’s traditional architecture is well adapted to local natural conditions; however, extreme weather conditions presented a challenge in maintaining indoor thermal comfort. Traditional architectural practices, however, have been replaced with energy intensive construction techniques, which are characterised by:

- Concrete or masonry construction with no insulation,
- Large, mostly single-paned glazing,
- Commonplace use of air conditioning, limited by household income.

The standard QCVN 09:2017/BXD stipulates requirements for new-build and retrofit projects, but only applies to air-conditioned buildings with a Gross Floor Area (GFA) larger than 2500 $m^2$ (Ministry of Construction, 2017). Requirements cover the building envelope, Heating Ventilation and Air Conditioning (HVAC), lighting, and other electrical equipment (not including small power loads), and include:

- Overall Thermal Transfer Values (OTTV) for opaque building envelope elements must be $< 60$ W/$m^2$. The regulation recognises and rewards reflective roof coatings.

- Solar Heat Gain Coefficient (SHGC) requirements for glazing, calculated on a window to wall ratio (WWR) basis (Table 1).
- Minimum Coefficients of Performance (COPs) are specified for air conditioning equipment (air-cooled air conditioner min COP of 2.84 to 3.81 depending on capacity).
- Maximum Lighting Power Density (LPD) values are specified, showing similar values to ASHRAE Std 90.1.

| **QCVN 09:2017/BXD: Solar Heat Gain Coefficient (SHGC)** | | | |
|---|---|---|---|
| **WWR (%)** | **North** | **South** | **Other Orientations** |
| 20 | 0.90 | 0.90 | 0.80 |
| 30 | 0.64 | 0.70 | 0.58 |
| 40 | 0.50 | 0.56 | 0.46 |
| 50 | 0.40 | 0.45 | 0.38 |
| 60 | 0.33 | 0.39 | 0.32 |
| 70 | 0.27 | 0.33 | 0.27 |
| 80 | 0.23 | 0.28 | 0.23 |
| 90 | 0.20 | 0.25 | 0.20 |
| 100 | 0.17 | 0.22 | 0.17 |

Table 1: Regulated Solar Heat Gain Coefficient (SHGC) (Ministry of Construction, 2017)

The ability of this regulation to significantly reduce cooling demand must be weighed against the following:

- The regulation only applies to a fraction of new urban construction due to its GFA prerequisite.
- It may be possible to avoid or limit the impact of the regulation by not including air-conditioning as part of the submission plans, although this will likely be retrofitted at a later stage.
- The requirements of the regulation are typically very modest, requiring very little improvement to building envelope and services to meet the conditions set.

## 2.6 Summary and relevance to the topic of cooling

The previous chapter has shown in which contexts the topic of cooling is relevant. First, there is the issue of climate change: Climate change itself poses an enormous hurdle for Vietnam as a developing economy.

The government also makes it clear that international support is needed to achieve more emissions reduction. Not only does the climate present the country with already existing high levels of temperature, projections show that the tropical climate will cover the entirety of Vietnam in the year 2100. While, as things stand today, there is already a high demand for cooling in particular in the south, this means that the use of cooling technologies will ultimately increase throughout the entire country, as acknowledged in Vietnams NDC and LTS. The political targets set also cover the topics of cooling, with a focus on transport and logistics, but also buildings, where the need for efficiency and cooling technologies is highlighted.

Vietnam's governance system poses challenges when it comes to coordination, because fragmentation among ministries and unclear responsibilities might hinder progress in urban planning or political processes themselves such as governing legislation in certain sectors relevant to the topic of buildings, such as standard-setting. At the same time, the country's infrastructure is currently not capable of far reaching transmissions for electricity or cooling: While there is an uneven distribution of renewable energy availability (South: more solar and wind), neither the infrastructure nor the legislation (FIT, or other incentives) are currently in operation, although the government shows a high effort to change this.

This makes the use of electricity for cooling from renewable energies more difficult, especially in urban centres: Here, the sustainability aspect is harder to elaborate, due to the influx of citizens and city-/metropolitan-area specific problems. Among these are a very high rate of pollution, which can prevent natural ventilation, e.g. by simply opening a window. Additionally, urbanisation contributes to further land sealing, which increases flood risks and higher heat radiation, resulting in so-called urban heat islands. This increases the need for innovative or intrinsic approaches, since there is also less space for renewable energy installations with more complex buildings and higher rise towers. Meanwhile, building standards, where they are specifically required or elaborated by the Vietnamese authorities, are not very far-reaching or only take effect above a certain building size. Therefore, international standards are often used as a guide, which cannot cover all needs and local peculiarities.

# 3. Assessment of opportunities

The previous chapter outlined the framework in which the energy transition in Vietnam can take place. In addition to aspects of governance, analyses and forecasts of future developments in the field of electricity and urban development were also presented. This chapter now looks at the concrete technologies and strategies available in the field of cooling buildings. Chapter 3.1 will give an overview over the availability and viability of renewable energy that could be used in order to power cooling devices and solutions, chapter 3.2 covers the approach, the results and analysis of cooling simulations for PUB and PCB, while chapter 3.3 elaborates further on possibilities for reducing cooling demand in buildings.

## 3.1 Renewable energy supply

Active cooling processes demanded by hot and humid conditions typically require the use of electricity and vapour compression (VC) technologies. Strategies aimed at the reduction of carbon emissions related to cooling must, therefore, consider renewable electricity sources available in Vietnam (such as solar and wind power) along with ‘free’ sources of cooling (such as ground/water source cooling). Industrial scale renewable resources, such as hydroelectric and geothermal steam power generation, and potentially high pollutant renewable resources, such as biomass, are considered incompatible with urban and architectural integration and will not be considered in this study.

### 3.1.1. Solar

Solar energy potential is assessed in terms of the following key measurements:

- Global Horizontal Irradiation (GHI) (W/m²), which is the total irradiation from the sun on a horizontal surface, and
- Specific yield in kWh/kWp, which is used to indicate the estimated annual energy generation for a given installed photovoltaic capacity (
- Figure 16: Specific yield map of Vietnam (World Bank, 2020).

The GHI resource in Vietnam ranges between 1100 – 2100 W/m², with Hanoi on the lower end with 1320 W/m² peak, and HCMC receiving up to 1790 W/m² (World Bank, 2020). Using the GHI, yearly specific yield estimations were calculated as follows:

- Northern minimum: 1040 kWh/kWp
- Hanoi: 1070 kWh/kWp
- Central range: 1090 – 1480 kWh/kWp
- Ho Chi Minh City: 1440 kWh/kWp
- Southern peak: 1660 kWh/kWp

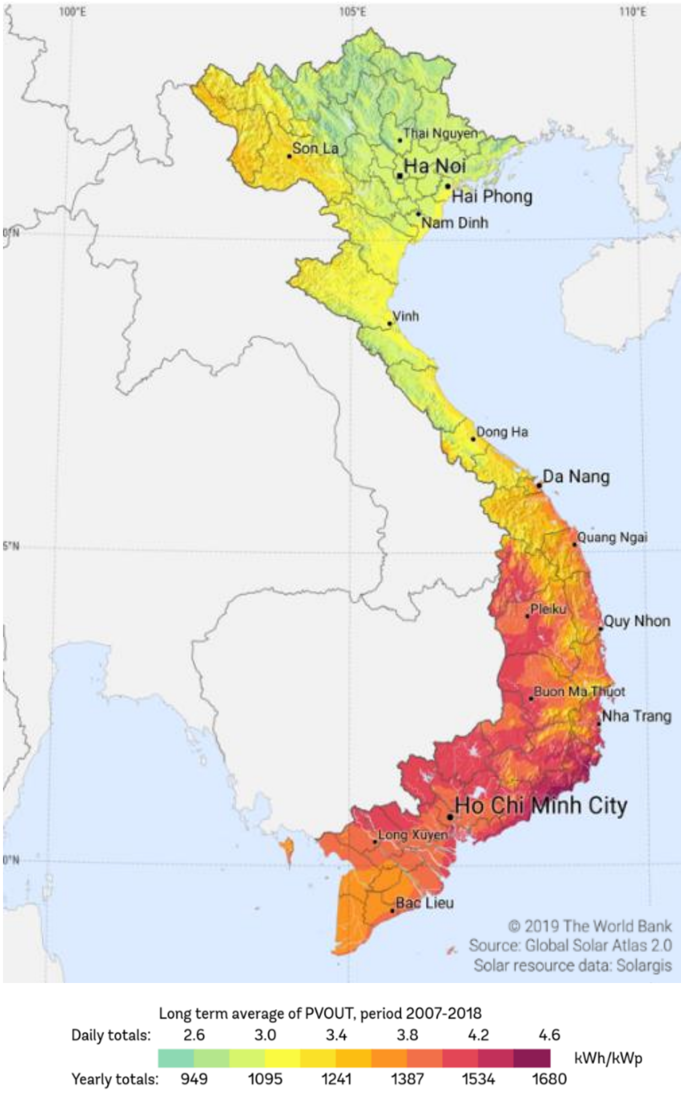

Figure 16: Specific yield map of Vietnam (World Bank, 2020)

### Photovoltaic technologies

Photovoltaic systems generate electricity from solar irradiation and can be easily incorporated into the urban environment as roof-mounted installations (Figure 17) or integrated within the building fabric as façade elements, canopy, or shading systems, known as Building Integrated Photovoltaics (BIPV). BIPV are expected to be commercial in nature due to the strong vertical character of urban development resulting in small roof footprints relative to building floor area. Due to the varying form factors and installation requirements of BIPV, panels typically use lower quality polycrystalline photovoltaics and are priced higher to offset additional manufacturing costs. However, with the advent of standardised, semi-transparent, or translucent (bifacial) photovoltaics, BIPV is expected to become more affordable. Therefore, it would be advisable to reassess the viability of BIPV in the future.

Figure 17: Rooftop solar installation at Jacob Factory, Binh Duong, Vietnam (©dena / Stefan Schirmer)

### Economic Considerations

Photovoltaic equipment for Vietnamese domestic use is typically imported from China, with less than 1% estimated to be both produced and installed locally (Nguyen, 2021). The bulk of production from the main domestic enterprise, Bach Khoa Solar Energy Company (Solar BK), is prepared for export to European and Indian markets. At the time of writing, the following estimates were obtained from Arup's Vietnam office for complete photovoltaic installations:

- Industrial roof installations: 500 – 600 € per kWp, and
- Office and residential: 600 – 900 € per kWp.

The use of Battery Energy Storage Systems (BESS) in photovoltaic installations is rare, and pricing is difficult to obtain. Based on previous project experience, the Arup office in Vietnam reported that BESS typically more than doubles the installation cost, with estimates as follows:

- Industrial roof installations: 1150 – 1350 € per kWp, and
- Office and residential: 1350 – 1900 € per kWp.

The sharp increase in installed PV capacity (Figure 18), has strained the country's transmission and grid infrastructure, with the government cutting down on feed-in-tariff policies. Since 2017, Vietnam implemented a Feed-in-Tariff scheme for solar PV installations, which enabled rooftop PV installations of 100kW or less, connected prior to December 2020, to sign a 20-year contract with Electricity Viet Nam (Vietnam's state-owned utility) to sell excess electricity to them at well-priced rates. The signing of contracts has ceased since the start of 2021, since no follow-up schemes were implemented since the expiry of the 2017 scheme. Therefore, no feed-in to the grid is currently allowed and an electronic inverter limiter is mandatory to cap

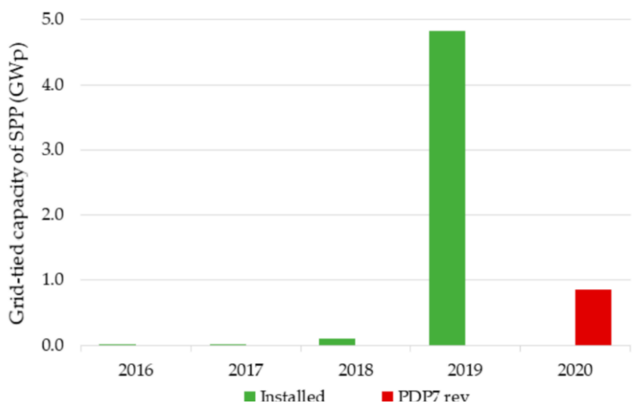


Figure 18: Total installed capacity in Vietnam by 2019 (Le et al., 2020)

the electricity generation when building electricity demand is lower than supply. The government's eighth power development plan was to be signed in May 2022, however, at the time of writing, this plan is yet to be finalised.

In response to the lack of feed-in options and the high cost of BESS, it is not economically viable to size the entire energy load demand since there is no opportunity to offset the excess energy from mid-day to morning or evening consumption and has a direct repercussion on the financial viability of photovoltaic installations.

A high-level payback period calculation (Figure 19, Figure 20) indicates the following:

- Payback can be achieved in 7 and 11 years for HCMC and Hanoi respectively, assuming the most economic capital and operational costs. At higher costs, payback can be delayed several years, or even not achieved in a 25-year lifespan.
- In HCMC a photovoltaic installation including BESS can potentially achieve a payback period within its lifespan (after approximately 23 years), assuming the most economic capital and operational costs. In Hanoi, this is not possible.

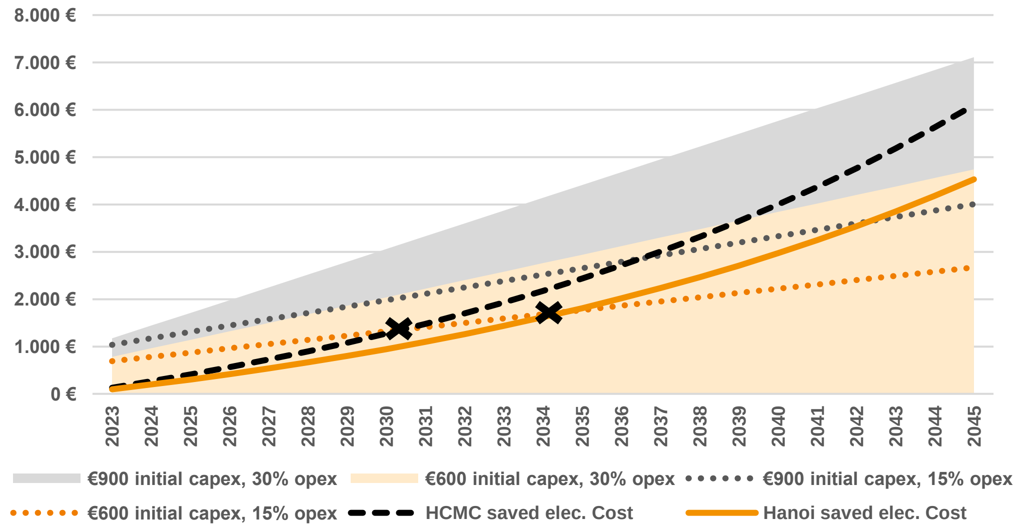

Figure 19: Arup's high-level payback period projections for photovoltaic installations without BESS.

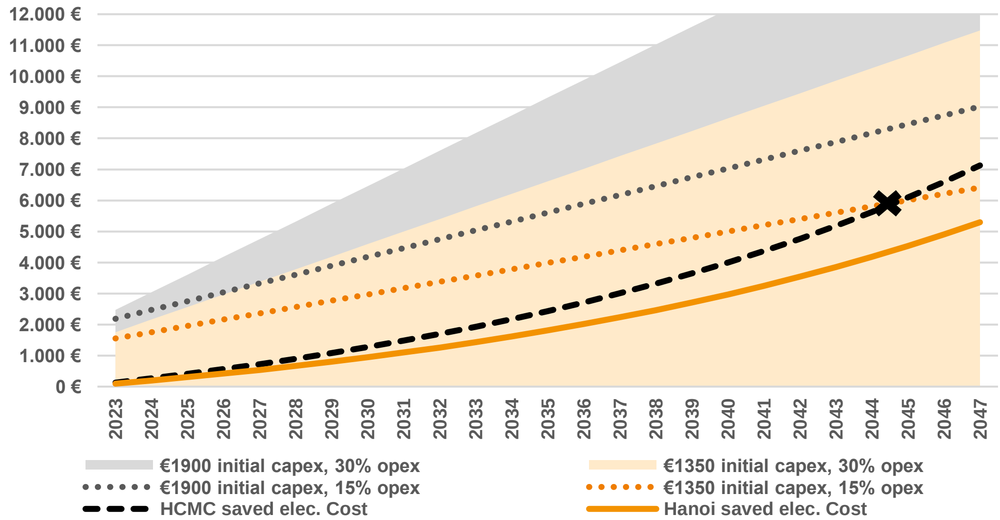

Figure 20: Arup's high-level payback period projections for photovoltaic installations including BESS.

Payback period calculations are subject to several factors, which should be confirmed on a project specific basis. To calculate a generalised estimate, the following parameters have been assumed:

- A 1070 kWh annual yield for a location in Hanoi, and 1440 kWh for HCMC, based on the high-level specific yield calculated for each city.
- A 0.5% annual degradation of yield.
- A starting electricity price of 8.9 ct/kWh, with annual increases of 6.63%.
- Photovoltaic capex costs per kWp of 600 € and 900 € excluding BESS (Figure 19); and 1350 € and 1900 € including BESS (Figure 20).
- Operational costs of 30% of capex annually (a typical international value) and 15% as a low-cost possibility. Operational cost is dependent on both equipment and labour costs, and may therefore be somewhat lower in Vietnam, although 15% may be optimistic.

Depending on the size of cooling installations or devices as well as the baseload supplied, solar PV could be considered an option for renewable cooling. However, due to a longer payback period and high initial costs, this might not be feasible for low-cost or smaller developments. Battery storage does not seem to be an option right now, but might become viable once the cost for small and medium-scale installations comes down.

### 3.1.2. Wind

Vietnam experiences mostly low to fair wind speeds, with smaller pockets of good wind resource around 7 – 8m/s at 100m above ground level (AGL)(Technical University of Denmark et al., 2021).

Typical mean wind speeds for the two major cities are as follows:

- Hanoi:
  - 2.0 m/s at 10 m AGL
    (Beaufort scale: light breeze)
  - 4.0 m/s at 100 m AGL
    (Beaufort scale: gentle breeze)
- HCMC:
  - 2.8 m/s at 10m AGL
    (Beaufort scale: light breeze)
  - 5.4 m/s at 100 m AGL
    (Beaufort scale: gentle breeze)

The wind resources in the urban centres of Hanoi and HCMC are not favourable; however, offshore wind, particularly in the south, and onshore wind in central regions are more promising (Figure 21). Wind energy may be viable at an industrial scale in coastal and specific rural inland locations, but this is not considered further as part of this study.

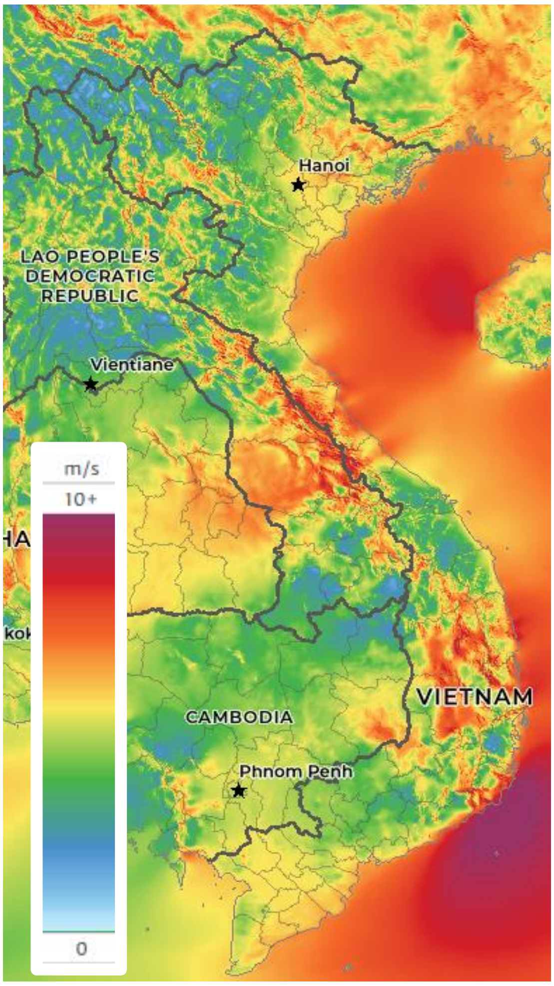


Figure 21: Average wind speed at 100m AGL (Technical University of Denmark, 2021)

### Wind energy systems

Wind Turbine Generators (WTGs) generate electricity from the wind and are typically found outside of cities, but a few options exist for urban applications.

There are two main types of WTGs in use globally:

- Vertical Axis Wind Turbines (VAWT) (Figure 22 left) are better suited to capturing wind closer to the ground and in environments where the wind is turbulent, which would usually be the case in built-up environments (industrial, commercial, and residential). They are also more compact, making them better for limited space applications. Furthermore, these are audibly and visually less obtrusive and impactful on their surroundings.
- Horizontal Axis Wind Turbines (HAWT) (Figure 22 right) are more appropriate for larger utility-scale applications or dedicated wind farms where "exposure" of the WTG to free wind is generally not a concern. These tend to require more space, be more visually obtrusive due to their axis of rotation and run louder than VAWTs.

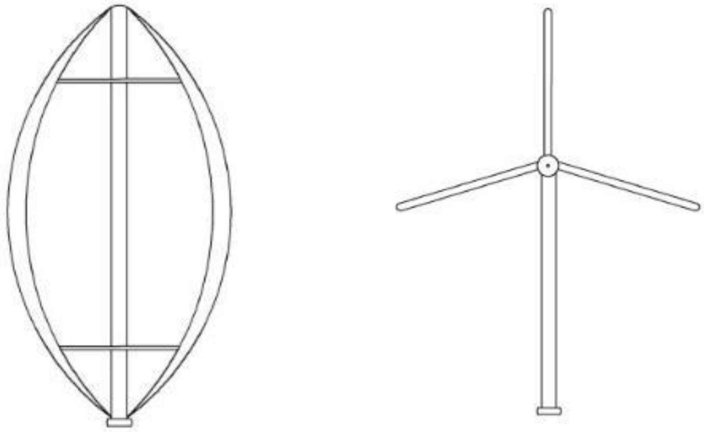

Figure 22: Vertical Axis Wind Turbines (VAWT) (left) and Horizontal Axis Wind Turbines (HAWT) (right)

VAWTs would typically be the preferred option for built-up urban environments, and could be installed on rooftops, at ground level or even for roadside applications where they are located to capture wind from passing vehicles. However, small-scale wind turbines are not capable of supplying large amounts of power due to the low wind speeds and limited space, as well as the unpredictability and turbulent nature of winds in built-up environments and ground level applications.

#### Economic considerations

Site-specific (rather than region-specific) wind data is required to calculate reasonably accurate energy production estimates, as turbulent wind behaviour in urban areas can show marked variability in wind speeds and patterns. The fluctuating character of urban wind energy generation means that it cannot be sized to cover historic baseload as with photovoltaic systems. Contrary to PV installations and solar power, especially COVID was seen as an influencing factor for the Vietnamese Government to extend the feed-in tariffs until 2021.

Without the ability to feed-in to the grid, BESS are necessary for the exploitation of wind resources, which are considered unaffordable in the Vietnamese context. Therefore, small-scale urban wind generation is deemed unfeasible at present, especially when compared with more competitive technologies such as photovoltaics.

### 3.1.3. Ground and Water

Due to the proximity of population centres to delta regions (high ground water level), cooling specific energy resources may also be found in various ground and surface water sources, with the exploitation of groundwater for domestic use beginning roughly 100 years ago (Le Luu, 2019). Dumping of untreated municipal and industrial wastewater and tropical/subtropical rain events mean surface water is highly contaminated and unpredictable(Le Luu, 2019), limiting its applicability as a cooling resource. In the Red River Delta, rural residents have switched from using surface water or shallow wells to using family tube-wells from the Holocene and Upper Pleistocene aquifers (Berg et al., 2001) (Figure 23). Similarly, in the Mekong Delta, wells for water supply units and industrial uses access groundwater at a depth of 100-250m, with 60% of wells accessing the Pleistocene aquifer (Le Luu, 2019). Shallow ground wells (<100m depth) are expected to yield a source temperature of between 25-28°C - lower than the average summer maximum air temperatures of typically 30-33°C (Yasukawa et al., 2009) (Figure 23).

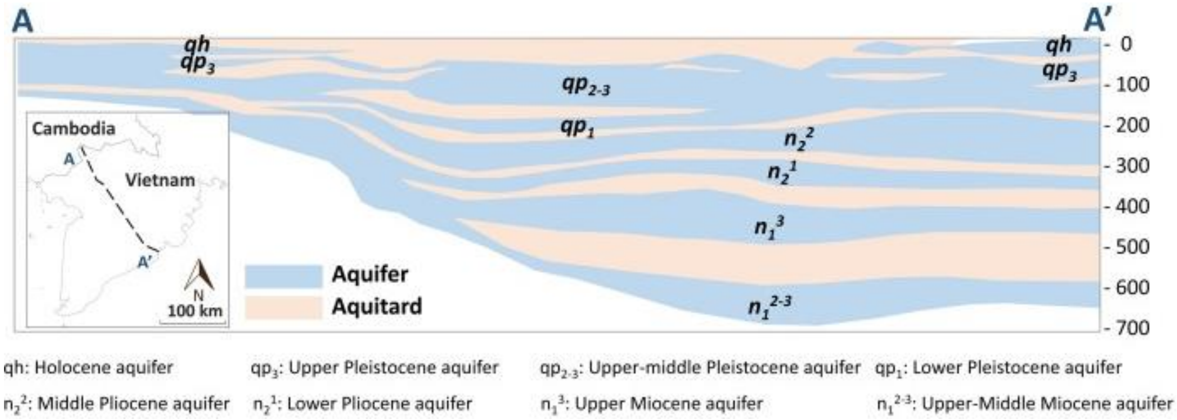


Figure 23: Hydrogeological profile of the Indochinese Peninsula (Lee et al., 2018)

While ground source and groundwater source heat pumps are technically feasible, high investment costs are expected to exclude small capacity and decentralised applications. The high land value of urban areas limits shallow ground heat exchangers and high capital, and regulatory hurdles of groundwater wells may only be attractive in industrial or high-end high-rise buildings, severely limiting the scope of their application. Other concerns for the sustained use of groundwater include the high levels of arsenic, decreasing groundwater levels and reductions in water (Le Luu, 2019).

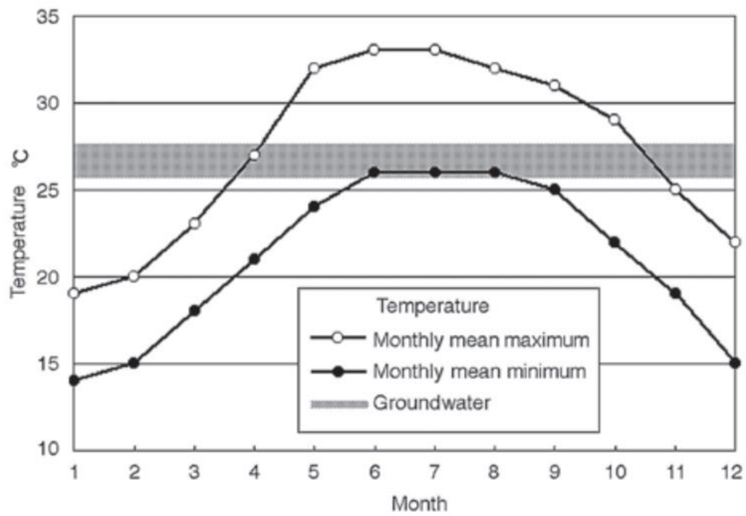


Figure 24: monthly change of atmospheric and groundwater temperature at depths of 20-50m in the Hanoi area (Yasukawa et al., 2009)

## 3.2 Reducing Cooling Demand

After having analysed the available sources for renewable energy, the following chapter will deal with the attempt to reduce initial cooling demand, in order to increase efficiency by not using additional energy for cooling.

### 3.2.1. Approach

Attempts to improve building performance are often based on previous experience or examples from literature. Such rules cover a wide range of building design aspects and are often transferred from one context and climate to another without critical evaluation. Similar assessments are often made when considering thermal comfort in buildings: Air temperatures setpoints are repurposed from other locations and standards and expected to ensure comfort without further investigation. Natural ventilation is frequently assumed to provide sufficient cooling in any climate. Arup's global design experience has repeatedly uncovered that such simplifications often result in suboptimal, if not detrimental results. The approach for this study utilises internationally recognised thermal simulation software and standardised thermal comfort models.

### Thermal simulation overview

Simulations for this study were performed with *EnergyPlus*, which is a globally recognised, open source, whole building energy (including hygrothermal) simulation program, developed and maintained by the US Department of Energy, and used by engineers, architects, and researchers (EnergyPlus, 2022). Weather files for both Hanoi and HCMC were used, as they account for a significant proportion of Vietnam's urban population. Furthermore, as they cover both dominant climate types for Vietnam, the findings from these cities can be generalised for other cities in similar climates.

Weather data was obtained from the *OneBuilding* project, which provides publicly available weather files for simulation (Climate.OneBuilding.Org, 2022). This data was statistically processed using historical records from 2007-2021, and thus represents the existing weather conditions well.

For both cities, two different building types were assessed:

- **Primarily Uncooled Building (PUB)** – buildings where air conditioning may be installed but is only in operation when conditions become unacceptably warm. These could be residential or lower-income retail, hospitality, and office buildings.

- **Primarily Cooled Building (PCB)** – buildings where air conditioners (partly with mechanical ventilation) are always in operation. These could be office, retail, hospitality, industry/factories or upmarket residential buildings.

Each building type has been modelled separately, with distinct building properties and performance metrics. The performance metrics represent two distinct optimisation cases (which have been analysed separately): the reduction of the heat gains to the building (minimisation of air conditioning operation for PUBs), and the minimisation of final energy consumption of cooling systems (for PCBs).

### Properties of the simulated buildings

The geometry for PUBs was selected to reflect a typical 50-60 m² urban residential apartment. It consists of a 7.5 m by 8 m space, split by a physical partition into a window zone and an interior zone. The aim of the analysis is to optimise the building envelope, and as such, the internal walls are modelled such that no heat transfer can occur across them (adiabatic); however, their thermal mass is considered. This is a reasonable approach, representing the case where an apartment is adjoined by other apartments with similar internal conditions.

The modelled geometry of PCBs is similar to PUBs, but in this case no physical walls are modelled (Figure 25). This represents an open plan office, where all adjacent spaces are air conditioned, and no heat transfer is therefore expected across these "virtual partitions". The focus of the analysis is to compare the impact of different building envelope measures to improve comfort and reduce energy consumption. The internal zones are largely not affected by the envelope, but were included to improve the accuracy of the perimeter zones. The internal zones are important in as much as they are a significant and variable thermal boundary condition to the perimeter zones.

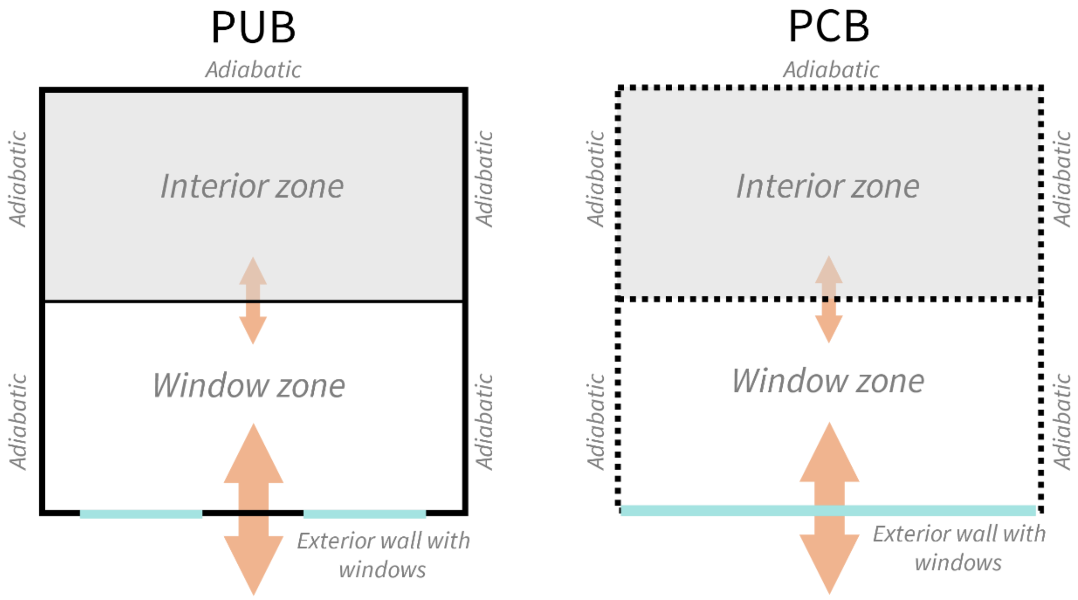


Figure 25: Plan view of the model geometry for the Primarily Uncooled Building (PUB) and Primarily Cooled Building (PCB)

For both building types, several properties were combined and varied in a parametric analysis. This analysis allows the impact of each property, or parameter, to be measured independent from all others. For the PUB & PCB types, the parameters shown in Table 2 were analysed (further information can be found in the Appendix (11.2 Energy Model Assumptions):

| Parameter | Variations (PUB) | Variations (PCB) |
|---|---|---|
| **Construction** | • Heavy (masonry) and uninsulated (no wall insulation) construction, without a dropped ceiling in the interior – (shorthand HU_NC)<br>• Heavy insulated construction without a ceiling – (shorthand HI_NC)<br>• Heavy insulated construction with a ceiling – (shorthand HI_WC)<br>• Lightweight insulated construction with a ceiling – (shorthand LI_WC) | • Heavy uninsulated construction – (shorthand HU)<br>• Heavy insulated construction – (shorthand HI)<br>• Heavy highly insulated construction – (shorthand HII)<br>• Lightweight insulated – (shorthand LI)<br>• Lightweight highly insulated – (shorthand LII)<br>Note: Because of lack of noticeable influence for PUB, the presence of dropped ceilings was not varied and all constructions are simulated to not have a dropped ceiling. |

| Parameter | Variations (PUB) | Variations (PCB) |
|---|---|---|
| **Glazing extent** | The impact of the window frame on the thermal behaviour is neglected<br>• 40% of the exterior wall is glazed (40% WWR)<br>• 80% WWR | The impact of the window frame on the thermal behaviour is neglected<br>• 40% WWR<br>• 100% WWR |
| **Solar shading approach** | Shading assumes that the shading measure is static and active all the time<br>• No shading - (shorthand SN)<br>• Internal reflective blind - (shorthand SB)<br>• External shading which allows 50% of solar radiation through - (shorthand S50)<br>• External horizontal slats - (shorthand SH)<br>• External louvers - (shorthand SL) | Shading assumes that the shading measure is static and active all the time<br>• No shading - (shorthand SN)<br>• Internal reflective blind - (shorthand SB)<br>• External horizontal slats - (shorthand SH)<br>• External louvers - (shorthand SL) |
| **Glazing type** | The impact of the window frame on the thermal behaviour is neglected<br>• Single glazing – (shorthand SG)<br>• Double glazing – (shorthand DG) | The impact of the window frame on the thermal behaviour is neglected<br>• Single glazing – (shorthand SG)<br>• Double glazing – (shorthand DG) |
| **Glazing performance** | All glazing was assumed to be simple clear glazing. | • Clear glazing – (shorthand SGC and DGC)<br>• Body tinted glazing – (shorthand SGT and DGT)<br>• Low-e coated glazing – (shorthand SGE and DGE) |
| **Night-time ventilation** | The Night-time ventilation is set to a constant value during the night<br>• 2 changes of air per hour, which can typically be achieved with natural ventilation – (2 ACH)<br>• changes of air per hour, which required mechanical ventilation – (4 ACH)<br>• 6 ACH<br>• 8 ACH | The Night-time ventilation is set to a constant value during the night<br>• No night-time ventilation (0 ACH)<br>• 6 ACH |

| Parameter | Variations (PUB) | Variations (PCB) |
|---|---|---|
| **Daytime ventilation** | • 0.5 ACH, which can be achieved by air infiltration into buildings when windows are mostly closed – (shorthand 0 ACH)<br>• 2 ACH, which can be achieved if windows are left open during the day. | Note: as this building type is typically mechanically ventilated according to national regulations, daytime ventilation was not varied. Daytime ventilation is done by the HVAC system, with outdoor air inflow of 7l/(person*s). |

Table 2: Analysed parameters

All building cases and parameter variations were modelled facing the 8 major orientations: North, North-West, West, South-West, South, South-East, East, and North-East. It is to be stated, that the actual achievable air change rate with natural ventilation is dependent on the geometry of the windows and the ambient conditions. In this study, the air change rates are assumed to be fixed to help generalise the findings. If for a given specific geometry the air change rate of 2 ACH cannot be reached with natural ventilation, mechanical ventilation is required.

For both building types, the interior storeys of a building – meaning all storeys excluding the ground level and the top storey – are depicted with the adiabatic roof and ground approach. To assess roof insulation performance, the best performing variations were selected and simulated with different levels of roof insulation together with dropping the assumption that the roof is adiabatic. This aims to depict the flat in the top storey of a building.

To assess the impact of ventilation heat recovery in air-conditioned buildings, the best performing PCB variations were selected and simulated with both sensible (dry) heat recovery (70% efficiency sensible heat recovery) and for enthalpy (wet) heat recovery (65% efficiency latent heat recovery). The heat/cooling is recovered from the exhaust air that is rejected from the HVAC system to the air that is taken in from the HVAC system.

Further information regarding the simulation work is provided in the Appendix (11.2 Energy Model Assumptions).

### Metric for the simulated buildings

The PUB type was assessed by calculating the percentage of comfortable hours in a typical year. The aim is to achieve as close to 100%, as this would mean that an air conditioner would become redundant.

Thermal comfort was measured using the Adaptive Thermal Comfort (ATC) model, which has been standardised (International Organization for Standardization, 2005; American Society of Heating and Ventilating Engineers, 2020). This model is suitable for naturally ventilated and occupant-controlled spaces, and considers occupant's psychological, physiological, and behavioural adaptation in determining acceptable upper temperatures (upper limits). The comparison with the ATC model is done using the operative temperature. The operative temperature is the mean value of the radiant temperature and the air temperature. Note, that the ATC does not include humidity in its thermal comfort analysis for the PUB types.

The ATC model also considers the cooling effect of elevated air speeds (produced e.g., by a ceiling or freestanding fan). As the use of fans for personal comfort is widespread in Vietnam, the comfort results have been calculated assuming access to such.

The PCB type was assessed purely on cooling demand, with percentage cooling demand used as the metric. The total annual cooling demand is compared to a "reference building" as a percentage, with lower results indicating a comparative reduction in cooling demand. (Positive percentages are undesirable, as this indicates higher cooling demands than in the "reference building".) Dehumidification demands are excluded (except for the heat recovery case) because these are only marginally affected by the building envelope design.

The "reference building" is assumed to face east and have a fully glazed exterior wall (100% window to wall ratio (WWR)) with no shading and double-glazed, tinted windows (DGT). No mechanical night-time ventilation is simulated. This is thought to reasonably simulate a corresponding building, such as an office building in one of the cities mentioned in the context of chapter 2.

### Summary

- A comparative analysis was done to determine which building properties have the greatest influence on maximizing thermally comfortable conditions for PUB and reducing cooling demand for PCB.
- The analysis was done using the internationally recognised *EnergyPlus* thermal simulation engine, and simulations were done for both Hanoi and HCMC. As these cities are based in subtropical and tropical climates respectively, the recommendation can be generalised for other cities in similar climates, covering much of the Vietnamese urban landscape.
- Two building types were assessed, Primarily Uncooled (PUB) and Primarily Cooled (PCB). These represent distinct optimisation cases and have differences in the building properties/parameters that are evaluated, as well as different performance metrics.
- PUB performance is measured by comfortable hours (%), in which the aim is to reach 100% if possible (In this case, air conditioning would become completely redundant for this building type.)
- Percentage comfortable hours are calculated by comparison of the perimeter zone operative temperature with the upper temperature limits determined by the Adaptive Thermal Comfort model, including the cooling effect of elevate air speed (achieved by e.g., a ceiling or free-standing fan).
- PCB performance is measured as cooling demand (%), where the aim is to achieve as low a percentage as possible. This metric is calculated relatively to a "reference building" reference value (It is also possible for results to be larger than 100%, in which case cooling demand exceeds the "reference building").

### 3.2.2. An introduction to the data

Through analysing all potentially significant combination of parameters, we have created a large simulation data set, providing hourly and annual data for 17,920 different cases across the two building types.

The body of data is very large, even when reduced to a single typical yearly metric per case. To represent this visual, the following approach has been used.

Figure 26 shows the annual performance of each simulated case and is represented as a single red "tick". To allow insight into the distribution of data, these ticks are all transparent, and as opacity of the red increases - the more cases are represented at that location.

To allow the general trend to be easily read, the mean and min/max values are plotted as a solid and dashed black line, respectively.

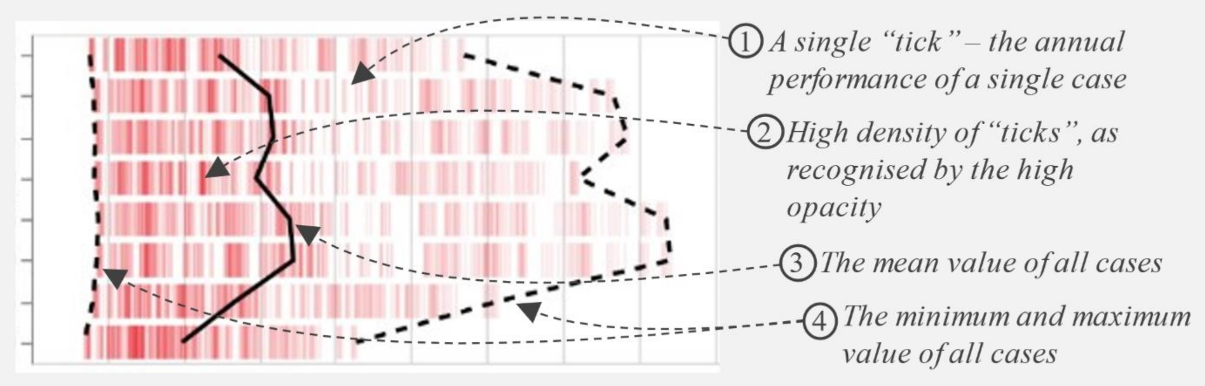


Figure 26: Overview of a tick plot

There are several patterns that can be identified from viewing the data sorted for location and orientation.

#### Location

- Conditions that lead to higher building operation temperatures are more common in HCMC than in Hanoi. This can also be seen in the tick plot and the higher minimum and average temperatures.
- In HCMC, ideally, spaces can ensure thermal comfort throughout the year, as indicated by the maximum values of the comfortable hours plot. This is, however, not feasible in Hanoi due to warm summer temperature spikes.
- When normalising the values of the cooling demand plot to a "reference building" in Hanoi, HCMC has noticeably higher cooling demand.

#### Orientation

The average values on both plots shown in Figure 27 and Figure 28, establish that orientation has a significant effect on both the PUB and PCB building types, simplified as follows:

- An orientation to north is most beneficial,
- Southern, north-eastern, and north-western orientations are still largely beneficial, and
- Eastern, south-eastern, south-western, and western orientation are most detrimental.

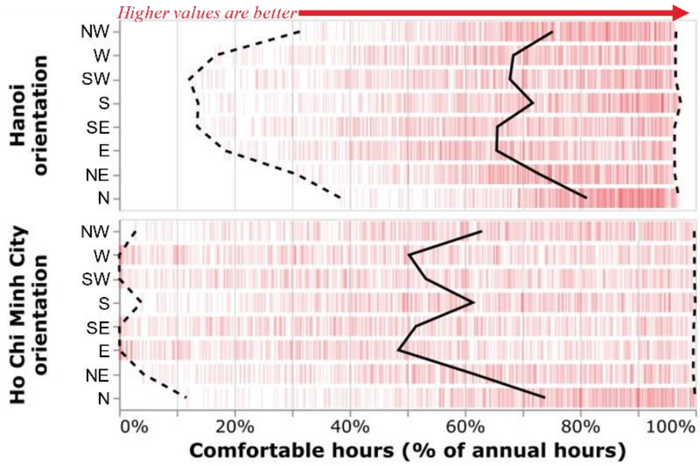


Figure 27: Uncooled thermal comfort performance by location and orientation

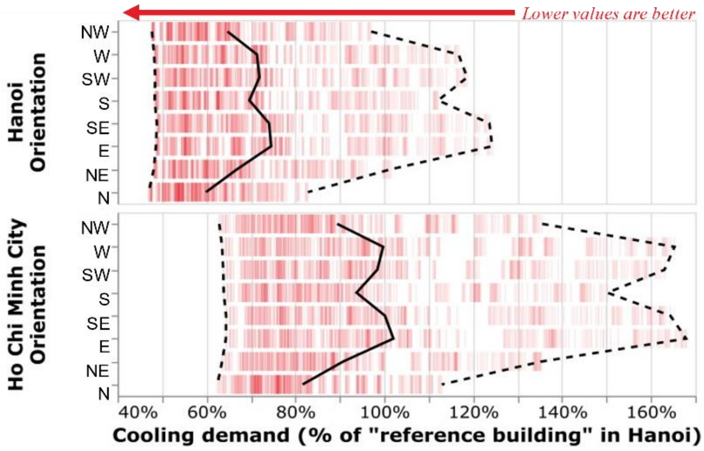


Figure 28: Cooling demand by location and orientation.

## Summary

- A tick plot is used to visualise the annual performance values of the simulated plots.
- Clear orientation impacts can be recognised which affect both PUB and PCB building types, with northern orientation being most favourable, followed by southern, south-western, and south-eastern orientations.

### 3.2.3. Hanoi

#### Primarily Uncooled Buildings (PUB)

Figure 29 shows the different parameters used in the study, sorted by the strength of their impact on the percentage of comfortable hours. The following trends can be distinguished:

- An effective shading strategy has the strongest effect, as heat from solar radiation is prevented from entering the building.
- Night ventilation also has a strong effect, as it allows the heat built up during the day to be removed, and cooler night air temperatures to be potentially stored in the thermal mass of the building. Higher night ventilation air change rates require mechanical ventilation (fan or ventilation system). Note, that all simulations assume a constant air change rate over the night regardless of internal and external conditions. This means, that summer temperatures in both cities might pose a problem, because the night air still retains a high temperature, making it hard to achieve cooling compared to lower winter temperatures.
- Construction has a noticeable effect, with heavy construction outperforming lightweight construction. Wall insulation has a mixed effect. The mean performance of HU_NC is noticeably better than HI_NC, but the maximum performance of HI_NC is slightly better than HU. A core dynamic at play here is the ability of the building to be cooled down at night, retain this coolness during the day, and release any build-up of heat as soon as conditions cool down. Another effect that is not visible in the results is that insulation of roof and walls might reduce the amount of radiative heating of the walls and roof during night-time.
- Window to Wall Ratio (WWR) and daytime ventilation both have a noticeable effect. Especially when shading is not possible, WWR has a strong effect.
- The different glazing parameters demonstrate that single glazing in PUB is somewhat more beneficial than double-glazing. This effect is largely due to the buildings improved ability to release heat built up during the day once conditions cool down in the afternoon or evening. A similar trend as for wall insulation is visible where the DG mean performance is significantly worse than the mean SG performance, but the maximum performance of DG is slightly better than SG's maximum performance.

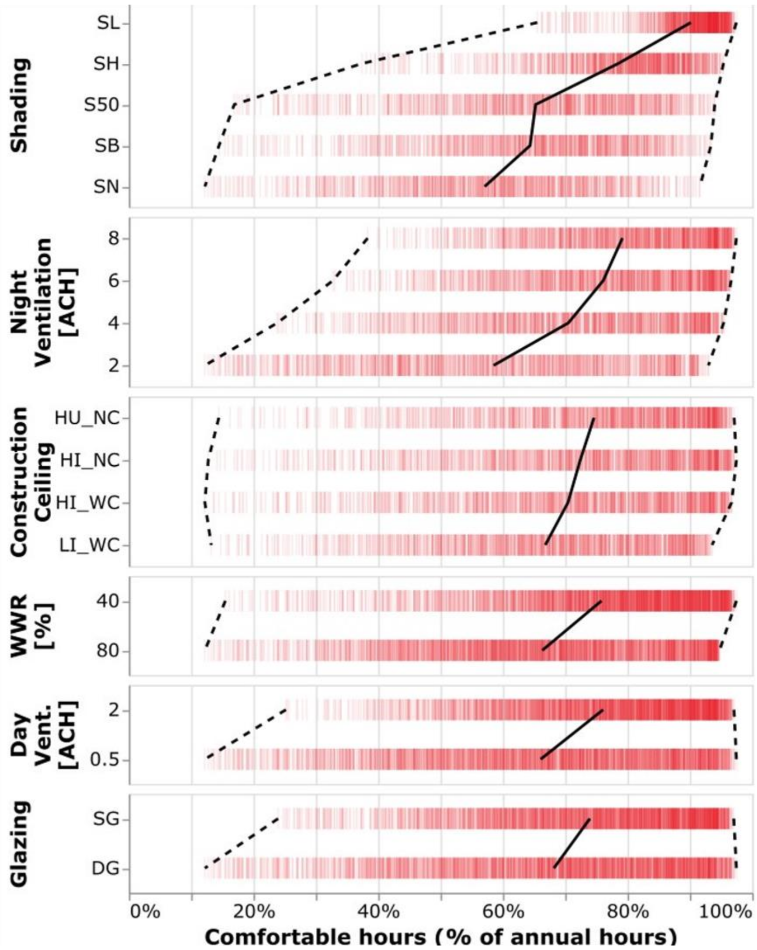


Figure 29: Tick plot of parameters, sorted by strength of influence on performance

From these results, different strategies emerge to keep PUB cool:

- Minimise the entry of solar radiation by effective shading and smaller windows,
- Maximise evening cooling through mechanical night ventilation, lack of insulation, and use of single glazed windows, and
- Maximize the thermal mass of the building to retain coolness throughout the day by opting for heavy (masonry and/or concrete) constructions.

The data set was further investigated using enquiries to solidify recommendations for a decision process. These were:

- Does the building have a heavy weight or lightweight construction?
- What extent of glazing is/will be present; approximately 40% or 80% WWR?
- What shading strategy can be accommodated; external louvers, internal reflective blinds, or none?

These parameter combinations are listed in Table 3 and the results are visualized in Figure 30. For each resulting setup, the effect of night-time ventilation is assessed and shown as a range (the range spans the results for all orientations). The range of night ventilation values is reduced to not overload the graphic. Only

2 ACH and 6 ACH is visualised where 2 ACH represents natural ventilation and 6 ACH represents mechanical ventilation.

| setup | Shading | window coverage | construction |
|---|---|---|---|
| 1 | Louvers | 40% | heavy, uninsulated |
| 2 | Blind | 40% | heavy, uninsulated |
| 3 | None | 40% | heavy, uninsulated |
| 4 | Louvers | 80% | heavy, uninsulated |
| 5 | Blind | 80% | heavy, uninsulated |
| 6 | None | 80% | heavy, uninsulated |
| 7 | Louvers | 40% | light, insulated |
| 8 | Blind | 40% | light, insulated |
| 9 | None | 40% | light, insulated |
| 10 | Louvers | 80% | light, insulated |
| 11 | Blind | 80% | light, insulated |
| 12 | None | 80% | light, insulated |

Table 3: Case setups for the comparison of uncooled buildings in Hanoi

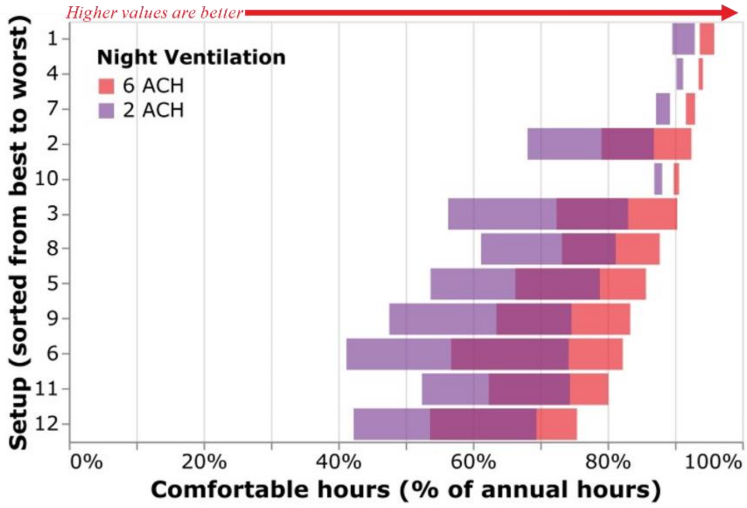


Figure 30: Performance ranges for the selected setups, setup numbering chosen to be consistent with the setups for HCMC

To enable this investigation, building properties with small comparative influence have been simplified as follows:

- Even though there is a high degree of air pollution, day ventilation is accepted to be 2 ACH – so the building is being naturally ventilated during the day.
- Glazing is accepted to be clear single glazing.

## Summary

- With setup 1, zone operative temperatures below ATC with elevated air speed can be reached for up to 96% of the year according to the data.
- Building properties that strongly influence thermal comfort performance are (in order of significance) solar shading, night ventilation rates, construction weight, and window size.
- It is generally beneficial to ensure good daytime natural ventilation, and to use single glazing rather than double-glazing.[1]

[1] For the discussion of the potential challenges of natural ventilation in Vietnam, please refer to p. 12.

### Primarily Cooled Buildings (PCB)

Figure 31 shows the different parameters used in the study, sorted by the strength of their impact on the cooling demand. The following trends can be distinguished:

- Effective shading again has the strongest effect, as heat from solar radiation is prevented from entering the building. The beneficial effects of internal blinds are much reduced, so that external shading becomes more critical.
- Window to Wall Ratio (WWR) has a strong effect.
- Glazing performance has a significant effect, with the use of a body tint or low-e coating both being beneficial. The specification of single or double glazing only has an understated effect.
- Night ventilation remain beneficial but is not as pronounced as in the PUB results.
- Building construction does not recognisably affect building performance. It is highlighted, that the simulation contains only limited amount of walls because of high glazing and because three of the four walls are treated as being adiabatic (see Chapter 3.2.1). For a building with a higher ratio of perimeter to internal area, this might change.

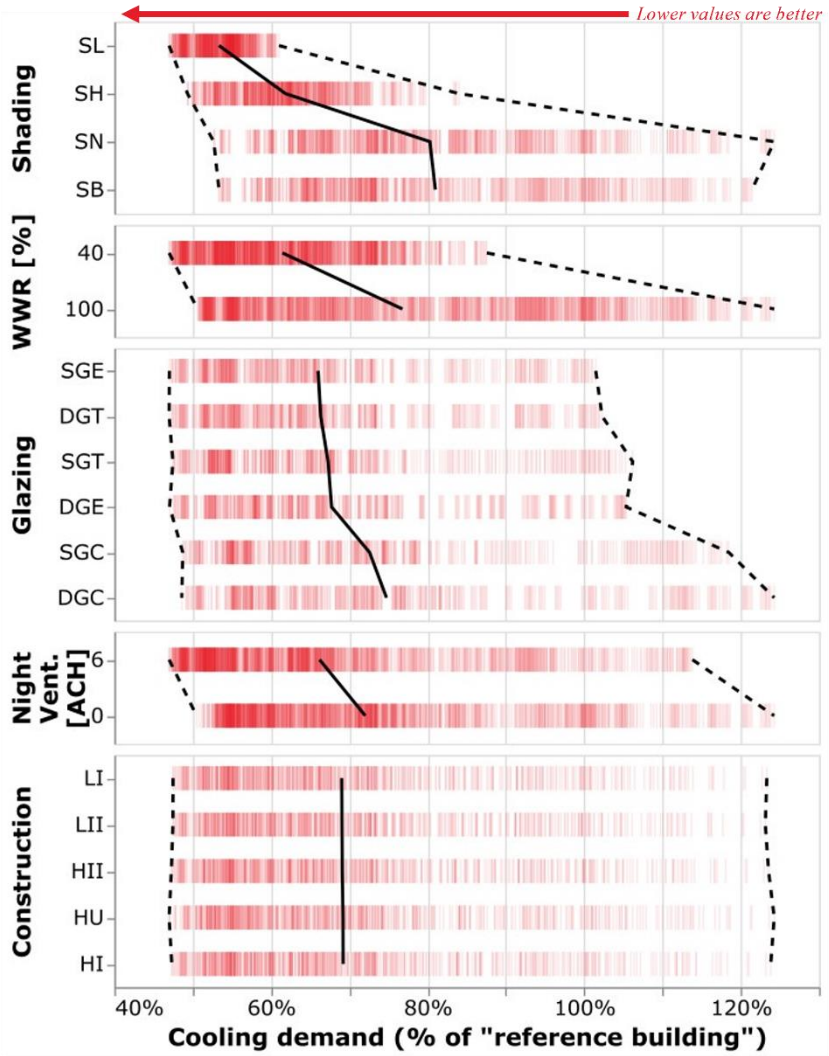


Figure 31: Tick plot of parameters, sorted by strength of influence on performance

Since the heat of the day is removed from the building by the cooling system, the dominant aim is to minimize the heat flow into the building during the day. Some heat gain does occur outside of operational hours, and properties (such as single glazing) allow this heat to be released overnight, instead of having to be cooled during the following day.

The following strategies are optimal for high performing PCB buildings:

- Minimise the entry of solar radiation by effective shading, smaller windows, and glazing performance (body tint or low-e coatings,
- Maximise evening cooling through mechanical night ventilation.

The construction type and insulation seem to have a very small impact on the cooling demand. This is since the conducted heat through the walls is comparatively insignificant against the window heat gains.

The data set was investigated according to enquiries to solidify recommendations for a decision process:

- What extent of glazing is/will be present, approximately 40% or 100% WWR?
- What shading strategy can be accommodated; external louvers, internal reflective blinds, or none?
- What glazing performance is specified (clear, tinted, or low-e)?

The parameter combinations are listed in Table 4 and the performance of the cases is shown in Figure 32. For each resulting setup, the effect of night-time ventilation is assessed and shown as a range (the range spans the results for all orientations).

| setup | window coverage | Shading | glazing |
|---|---|---|---|
| 1 | 40% | Louvers | double, tinted |
| 2 | 40% | Louvers | single, clear |
| 3 | 40% | None | double, tinted |
| 4 | 40% | None | single, clear |
| 5 | 100% | Louvers | double, tinted |
| 6 | 100% | Louvers | single, clear |
| 7 | 100% | None | double, tinted |
| 8 | 100% | None | single, clear |

Table 4: Case setups for the comparison of cooled buildings in Hanoi

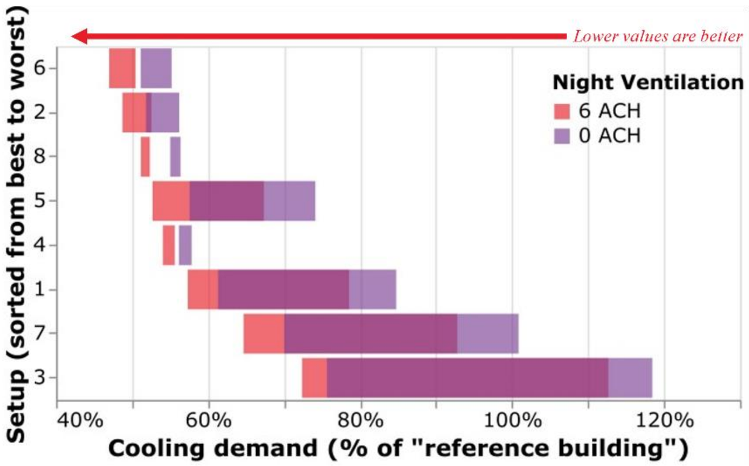


Figure 32: Performance ranges for the selected setups, setup numbering chosen to be consistent with the setups for HCMC

To enable this investigation, building properties with small comparative influence have been simplified as follows:

- Glazing is accepted to be single glazing.
- Construction weight is accepted to be heavy and uninsulated.

### Summary

- With an optimal design, cooling demand can be reduced to approximately 45% of that of the "reference building."
- Building properties that strongly influence thermal comfort performance are (in order of significance) window size and solar shading, as well as glazing performance.
- It is generally beneficial to ensure active night-time ventilation, whereas single or double-glazing and construction weight have a minimal effect.

### 3.2.4. Ho Chi Minh City

Most of the trends have been found to be similar for Hanoi and HCMC. As such, the analysis is presented here in an abbreviated version.

#### Primarily Uncooled Buildings (PUB)

Figure 33 shows the different parameters used in the study, sorted by the strength of their impact on performance. The following trends can be distinguished:

- An effective shading strategy has the strongest effect.
- Night ventilation has a strong significance. Higher night ventilation air change rates require mechanical ventilation. Note, that all simulations assume a constant air change rate over the night regardless of internal and external conditions.
- Construction, Window to Wall Ratio (WWR) and daytime ventilation all have noticeable effects.
- The different glazing parameters demonstrate that single glazing is somewhat more beneficial with regard to comfortable hours than double-glazing.

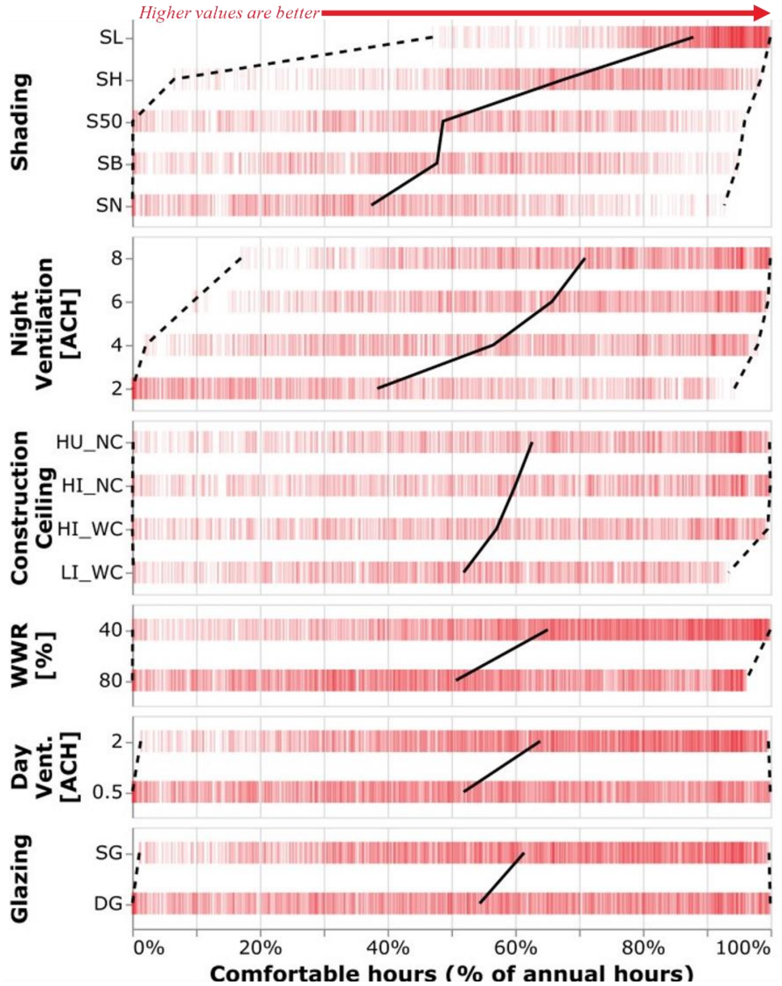


Figure 33: Tick plot of parameters, sorted by strength of influence on performance

From these results, different strategies emerge to keep primarily uncooled buildings cool:

- Minimise the entry of solar radiation by effective shading and smaller windows,

- Maximise evening cooling, through mechanical night ventilation, lack of insulation, use of single glazed windows,
- Maximize the thermal inertia of the building to retain coolness throughout the day by opting for heavy (masonry) constructions.

The data set was investigated according to a few enquiries to solidify recommendations for a decision process:

- Is the building heavy weight or lightweight construction?
- What extent of glazing is/will be present, approximately 40% or 80% WWR?
- What shading strategy can be accommodated; external louvers, internal reflective blinds, or none?

These parameter combinations are listed in Figure 34 and the results are visualized in Table 5. For each resulting setup, the effect of night-time ventilation is assessed and shown as a range (the range spans the results for all orientations). The range of night ventilation values is reduced to not overload the graphic. Only 2 ACH and 6 ACH is visualised where 2 ACH represents natural ventilation, and 6 ACH represents mechanical ventilation.

| setup | Shading | window coverage | construction |
|---|---|---|---|
| 1 | Louvers | 40% | heavy, uninsulated |
| 2 | Blind | 40% | heavy, uninsulated |
| 3 | None | 40% | heavy, uninsulated |
| 4 | Louvers | 80% | heavy, uninsulated |
| 5 | Blind | 80% | heavy, uninsulated |
| 6 | None | 80% | heavy, uninsulated |
| 7 | Louvers | 40% | light, insulated |
| 8 | Blind | 40% | light, insulated |
| 9 | None | 40% | light, insulated |
| 10 | Louvers | 80% | light, insulated |
| 11 | Blind | 80% | light, insulated |
| 12 | None | 80% | light, insulated |

Table 5: Case setups for the comparison of primarily uncooled buildings in HCMC (Arup, 2022)

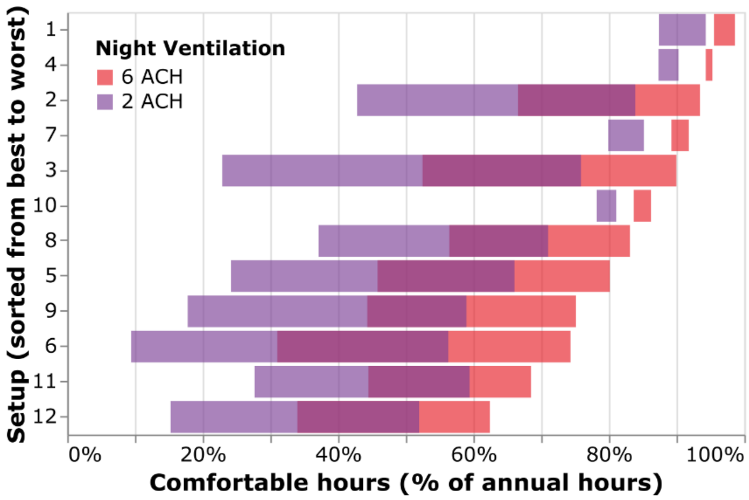


Figure 34: Performance ranges for the selected setups (Arup, 2022)

To enable this investigation, building properties with small comparative influence are simplified as follows:

- Day ventilation is accepted to be 2 ACH, so the building is being naturally ventilated during the day.
- Glazing is accepted to be clear single glazing.

### Summary

- With an optimal design, acceptable thermal comfort conditions can be reached for up to 98% of the year.
- Building properties that strongly influence thermal comfort performance are (in order of significance) solar shading, night ventilation rates, construction weight, and window size.
- It is generally beneficial to ensure good daytime natural ventilation, and choose specific single glazing rather than double-glazing.

### Primarily Cooled Buildings (PCB)

Figure 35 shows the different parameters used in the study, sorted by the strength of their impact on performance. The following trends can be distinguished:

- Effective shading again has a pronounced effect
- Window to Wall Ratio (WWR) has a strong effect
- Glazing performance has a clear effect
- Night ventilation remain beneficial
- Building construction does not recognisably affect building performance. It is highlighted, that the simulation contains only limited amount of walls because of high glazing and because three of the four walls are treated as being adiabatic (see Chapter 3.2.1). For a building with a higher ratio of perimeter to internal area, this might change.

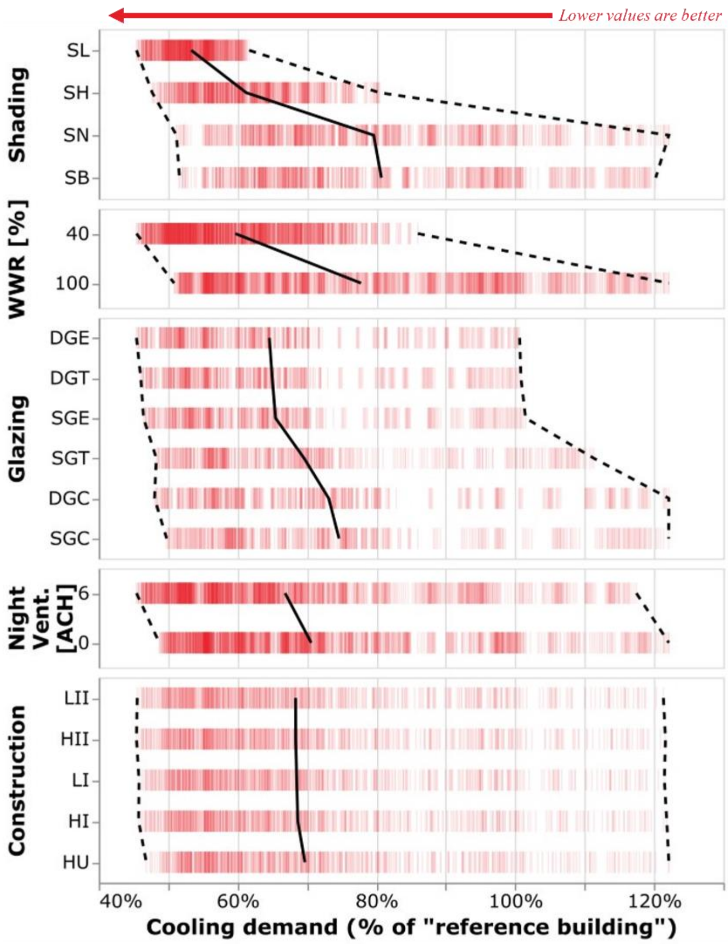


Figure 35: Tick plot of parameters, sorted by strength of influence on cooling demand (Arup, 2022)

These strategies are optimal for high performing primarily cooled buildings:

- Minimise the entry of solar radiation by effective shading, smaller windows, and glazing performance (body tint or low-e coatings),
- Maximise evening cooling, through mechanical night ventilation.

The construction type and insulation seem to have a very small impact on the cooling demand.

The results are very similar to those of Hanoi, but the performance is normalised against a “reference building” in HCMC. The overall trends are the same, but as shown in section 3.2.2, the scale of cooling demand in HCMC is larger than that of Hanoi.

The data set was investigated according to a few enquiries to solidify recommendations for a decision process:

- What extent of glazing is/will be present, approximately 40% or 100% WWR?
- What shading strategy can be accommodated; external louvers, internal reflective blinds, or none?
- What glazing performance is specified (clear, tinted, or low-e)?

These parameter combinations are listed in Table 6 and the performance of the cases shown in Figure 36. For each resulting setup, the effect of night-time ventilation is assessed and shown as a range (the range spans the results for all orientations).

To enable this investigation, building properties with small comparative influence were simplified as follows:

- Glazing is accepted to be single glazing.
- Construction weight is accepted to be heavy and uninsulated.

| setup | window coverage | Shading | glazing |
|---|---|---|---|
| 1 | 40% | Louvers | double, tinted |
| 2 | 40% | Louvers | single, clear |
| 3 | 40% | None | double, tinted |
| 4 | 40% | None | single, clear |
| 5 | 100% | Louvers | double, tinted |
| 6 | 100% | Louvers | single, clear |
| 7 | 100% | None | double, tinted |
| 8 | 100% | None | single, clear |

Table 6: Case setups for the comparison of primarily cooled buildings in HCMC (Arup, 2022)

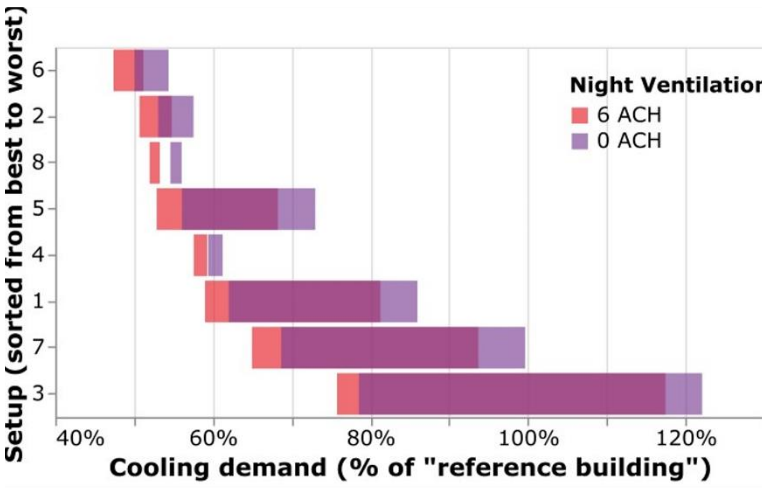


Figure 36: Performance ranges for the selected setups (Arup, 2022)

### Summary

- With an optimal design, cooling demand can be reduced to approximately 48% of that of the “reference building”.
- Building properties that strongly influence thermal comfort performance are (in order of significance) window size, solar shading, and glazing performance.
- It is generally beneficial to ensure active night-time ventilation, whereas single or double glazing and construction weight have a negligible effect.

### 3.2.5. Roof insulation

A further set of simulations were done to evaluate the influence of roof insulation.

The best performing setup from the previous study was selected (setup 1 for both the PUB and PCB results), as additional heat gain through the roof is expected be most noticeable in these cases.

For this analysis, the roofs now experience heat gain, and different levels of insulation are tested:

- Minimal insulation, modelled as only a concrete slab,
- R =1.0 $Km^2/W$ as per the national regulation (27.5mm of insulation with $\lambda$=0.04 W/(mK) and concrete slab),
- R =2.2 $Km^2/W$ (75mm of insulation with $\lambda$ = 0.04 W/(mK) and concrete slab),
- R =4.2 $km^2/W$ as required in Germany (155mm of insulation with $\lambda$=0.04 W/(mK) and concrete slab),
- Adiabatic, where no heat gain is modelled through the roof. This is the result from the previous set of simulations where a storey that is not the top storey is simulated. This is a reference to the maximum possible insulation level.

#### Primarily Uncooled Buildings (PUB) roof insulation

No insulation has a strong negative impact. There is then a dramatic improvement when an R-value of 1.0 is modelled. Performance further improves with an R-value of 2.2, but further increases to insulation see diminishing returns on performance improvements (Figure 37).

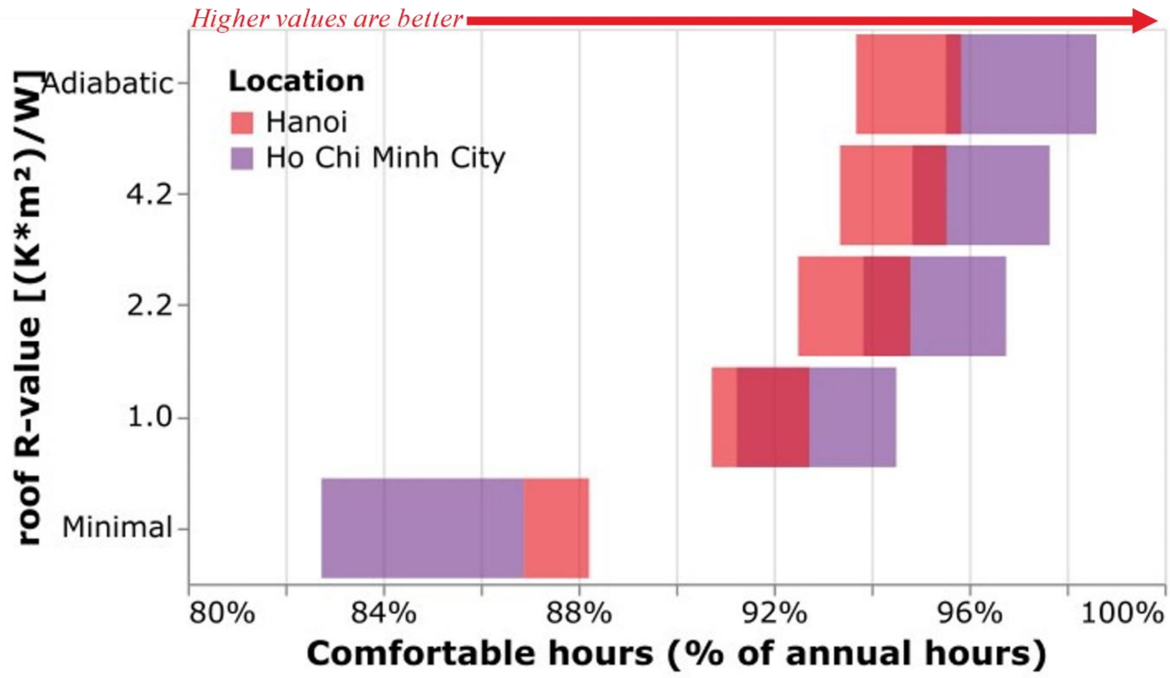


Figure 37: Roof insulation impact on PUB performance (Arup, 2022)

### Primarily Cooled Buildings (PCB) roof insulation

As for PUB types, no insulation severely limits a building's performance. Increasing insulation to 1.0 and 2.2 $Km^2/W$ produces large improvements, where after further insulation produces diminishing returns (Figure 38).

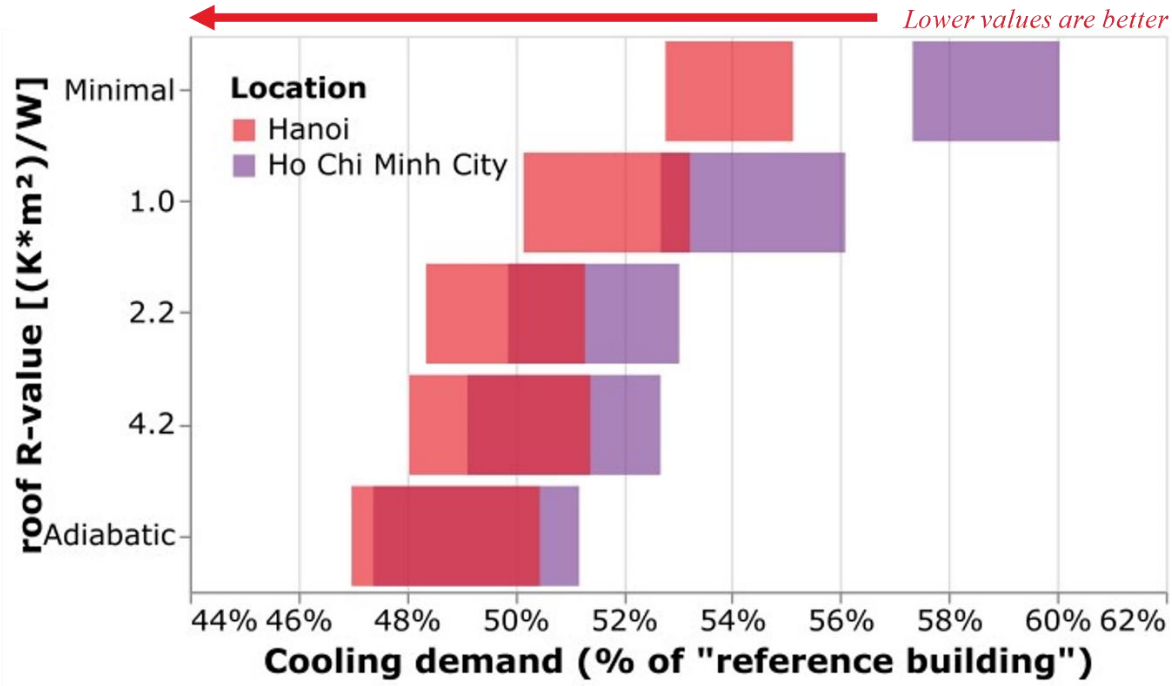


Figure 38: Roof insulation impact on PCB performance (Arup, 2022)

The results are very similar to those of Hanoi, but the performance is normalised against the "reference building" as defined in section 3.2.1 in HCMC. The overall trends are the same, but as shown in section 3.2.2, the scale of cooling demand in HCMC is larger than that of Hanoi.

### Summary

Small amounts of insulation result in significant performance improvements. Very high levels of insulation can further improve performance, but not as much. Ultimately, this is also a question of the economic rate of return for developers and inhabitants.

## 3.3 Efficient cooling

As with reducing cooling demand, it is helpful to distinguish between the Primarily Uncooled Buildings and Primarily Cooled Buildings building types. Different cooling approaches and technologies must be considered according to their building types. Furthermore, various approaches or technologies can be interlinked for better performance, where possible. Also, a combination of a PUB and a PCB in one building can be reasonable and lower energy consumption. In larger office buildings it has proven effective (Example: IBR Shenzhen) to combine uncooled public spaces with natural ventilation with closed and mechanically cooled office areas. As this was not part of the simulation, it will not be discussed in the following chapter.

### 3.3.1. Cooling approaches for Primarily Cooled and Uncooled Buildings

#### Mechanical night-time ventilation

By using mechanical ventilation designs the building interior can be flushed with cooler outdoor air, as soon at outdoor temperatures decrease below interior air temperatures (known as "free" cooling). Such installations are designed in a variety of ways and can be either centralised (one large installation for many spaces/tenant) or decentralised (an independent system for each tenant). It is essential that the design ensures that the outdoor air can realistically flush all interior spaces; otherwise, localised "hot spots" could remain.

The higher the desired ventilation rate, the larger and potentially noisier the ventilation components become (for example fans, ductwork, and grilles). For this reason, in addition to uncomfortable humidity levels, operation in commercial applications should ideally be done when the building is unoccupied. Such an approach consumes only a fraction of the electricity of air conditioning for the same space. In PUBs, free cooling could be controlled manually or with a simple timer; however, the greatest benefit is achieved with automatic electronic control. Automatic electronic controllers could ideally activate the ventilation when the outside air temperature falls 1-2 °C below the interior conditions and stop operation once a certain minimum temperature is reached, or outdoor temperatures increase above the interior air temperature. If designed well, a controller could ensure optimal night-time cooling, while avoiding the unnecessary operation (and energy consumption) of fans.

Our simulation results demonstrate that mechanised night ventilation is a more significant component for improvement. In theory, the fitment and correct maintenance of filters for mechanised ventilation could improve air quality. Several studies have proven their efficacy (e.g. Jones et. al 2021), however, filter systems require a regular exchange of components and continuous maintenance. The United States Environmental Protection Agency (EPA) (United States Environmental Protection Agency, 2022) provides a technical summary for the application of filters and air cleaners for residential air cleaning, in this case applicable to PUB as well as PCB. They provide an overview over filter or purifier systems as well as their general effectiveness and efficiency. Two types of systems stand out: furnace filters applied to HVAC installations, as well as standalone devices for home use (Figure 39). The latter are seen as in use by a lot of inhabitants of buildings, as pointed out above.

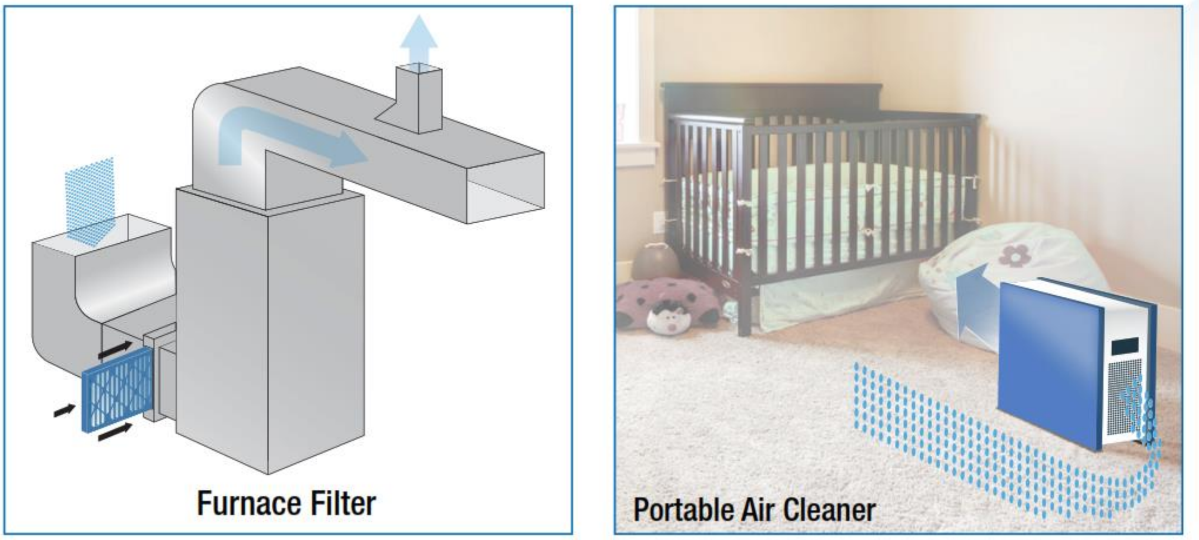


Figure 39: Types of filter systems (adapted from: United States Environmental Protection Agency, 2022, p. 14)

However, air cleaning and ventilation can only be seen as two of three strategies to reduce indoor air pollutants, among which the most important one is deemed source control. While the paper focuses mostly on indoor pollutants stemming from materials used, this can also be applied to sources outside of the building, in line with the general argument of this study.

### Shading

Shading has proven to be one of the most decisive factors in our simulation in order to reduce cooling demand. While the simulation relied on louvres (parameters shows in 12.2.3), shading is also possible via other options.

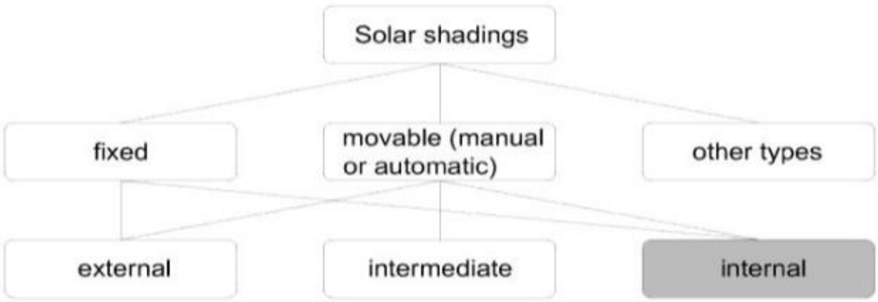


Figure 40: Solar shading systems for buildings: a possible classification (Bellia et. al. 2014, p. 311)

This includes building-internal as well as external solutions such as a roof overhang of buildings or plants (also see adiabatic cooling). For external shading, in addition to roof overhang, there are several additional options, as shown in Figure 41. The shading options and their necessity are heavily influenced by the orientation of the building (see. 3.2.1).

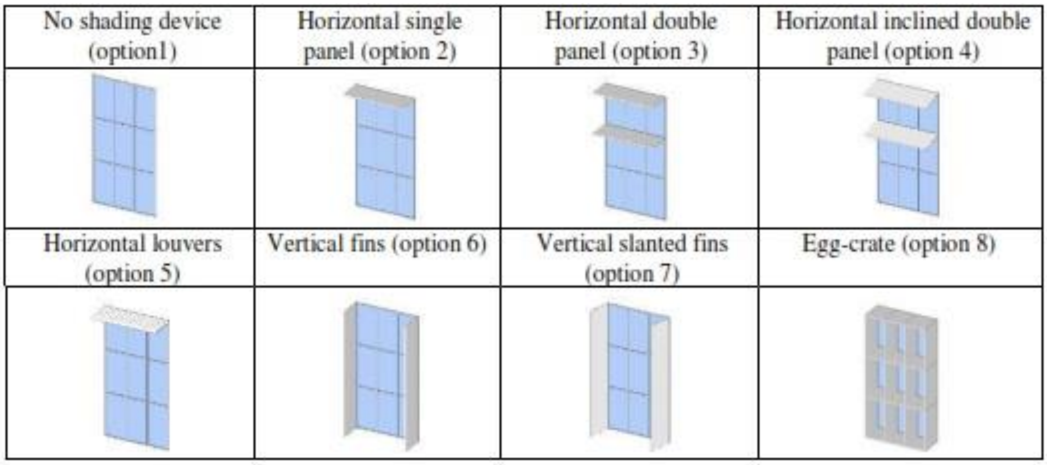


Figure 41: Shading strategies (adapted from: Shahdan et. al. 2018, p. 3-4)

### Adiabatic & Evaporative cooling

These technologies leverage the cooling potential that is realised when water is evaporated. The viability and efficiency of such systems depend heavily on the ability of the outside ambient air to absorb additional moisture. Evaporative cooling strategies employed in very humid climates (conditions with high dew point temperatures) only serve to moisten the environment, with a lower benefit for cooling purposes. While technically feasible in the dry seasons of monsoonal climates, the typical high humidity of the Vietnamese summer limits the viability of such systems during the *primary* cooling season. Therefore, only passive evaporative cooling strategies with low investment costs and little risk of legionella can be recommended (e.g., plants). These approaches were not considered in the simulations. From experience, the adiabatic cooling from plants is pretty small in comparison to e.g. shadows casted by the plants. Shading from plants is highly variable, so that it is normally not advised to rely on plant-based shading for reliable solar control.

### Vapour compression cooling

Vapour compression air conditioners are essentially heat pumps operated in reverse – moving heat from inside to outside using a refrigerant vapour compression cycle. The most common type of vapour compression air conditions are direct expansion (DX) split units, used throughout the world in small-and-medium capacity applications. The energy efficiency and environmental impact of such units can vary significantly, with cheaper units often using older, less efficient compressors and refrigerants (Figure 42). A key risk with such units, especially in low-income contexts, is the risk of poor installation and subsequent refrigerant leaks. Such leaks can be a health hazard and result in environmental damage due the high Ozone Depletion Potential (ODP) and Global Warming Potential (GWP) of refrigerants. Consequently, professional training and certification of air conditioning installers and contractors is recommended to prevent risks associated with leaks.

The ideal Coefficient of Performance (COP) of vapour compression heat pumps is dependent on the source (of heating or cooling) and supply temperature, with smaller temperature differentials improving theoretical performance. Considering the variability of ambient air as a source of cooling, the much more stable temperatures of ground and water sources can result in a marked increase in efficiency. However, a core prerequisite for such systems involves maintaining the source temperatures in an annual equilibrium, where any heat added to the ground must be removed within a one-year period. This can be done either through seasonal heating and cooling, which should be closely matched, or through cooling matched with another process that requires heat (e.g., industrial processes or large-scale domestic hot water). Vietnam's lack of significant heating season, bureaucratic processes (Ministry of Construction) and cost sensitivity limit the scope of such systems to larger developments.

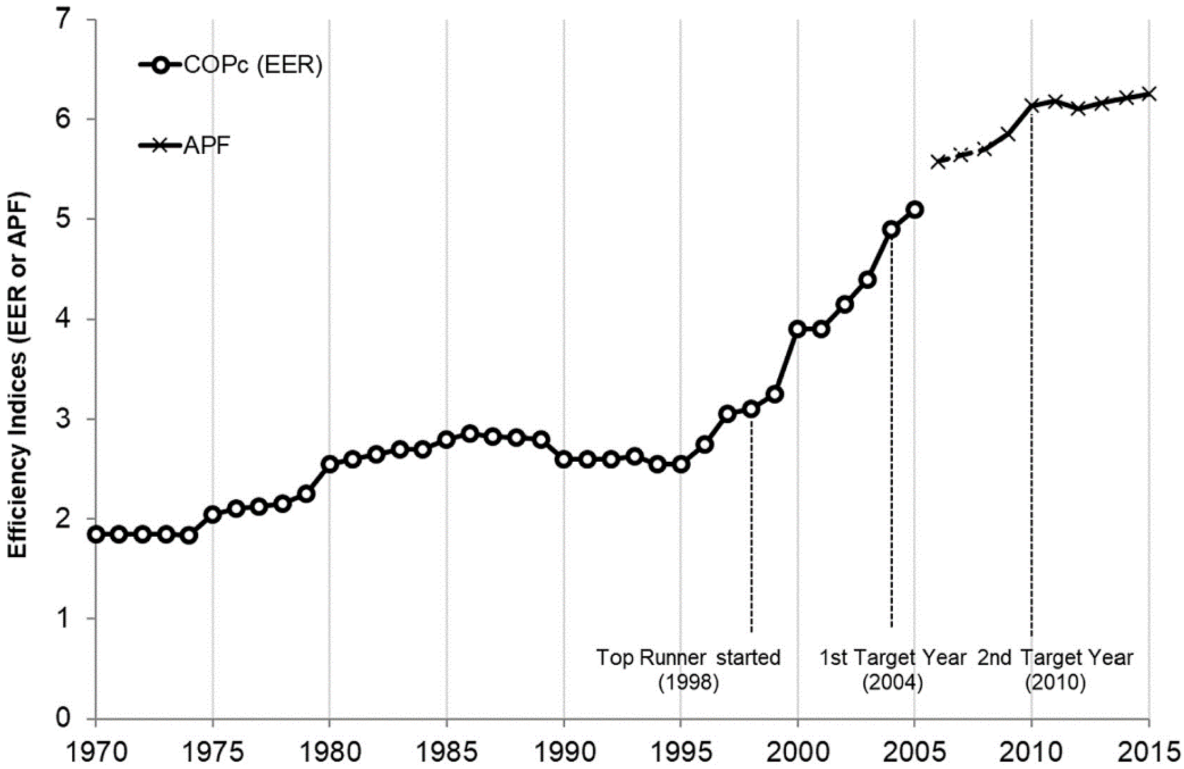


Figure 42: Trends in best-in-class energy efficient technologies for room air conditioners (Niharm and Shah, 2021);
COPc / EER: Coefficient of Performance / Energy Efficiency Ratio
APF: annual performance factor (APF)

### Refrigerants

Due to the flammability and toxicity of historical refrigerants, such as ammonia, chloromethane and sulphur dioxide (acid rain), less toxic and flammable halogenated hydrocarbons (chlorofluorocarbons (CFCs), hydrofluorocarbons (HFCs) and hydrochlorofluorocarbons (HCFCs)) were developed and exploited. However, in 1987 the Montreal Protocol called for a drastic reduction in CFCs, due to their powerful effect on ozone depletion in the atmosphere. Consequently, the exploitation of the less ozone destructive HFCs rose dramatically, with common examples including R-134a, R-404A, R-410A, R-125 and R-32. Unfortunately, Global Warming Potential (GWP) of these gases is considerable and "the probability of finding 'ideal', better-performing low-GWP fluids is minimal" (Domanski et al., 2017). Typically, there is a trade-off between toxicity, flammability, coefficient of performance, volumetric capacity and GWP.

Further low-GWP refrigerants are natural refrigerants, such as ammonia and CO2 which have an ODP of zero and GWP of <=1. Ammonia specifically has a growing adoption for chillers with its high refrigeration system efficiency and excellent thermodynamic properties. However, in some jurisdictions, ammonia-refrigerating systems are subject to legal regulations and standards because of personnel safety considerations due to its toxicity at high concentrations.

### 3.3.2. Cooling approaches for Primarily Uncooled Buildings

#### Natural Ventilation

Natural ventilation is a beneficial phenomenon where indoor ventilation is achieved by means of either buoyancy or wind driven pressure differentials (Figure 43). Passive and hybrid (combination of natural and mechanical) ventilation strategies capitalise on these natural forces; however, without adequate design work, ventilation rates can vary considerably. Typical rates of single-sided ventilation are considered as 2 to 5 air changes per hour (Aguilar et al. 2022) – enough to maintain indoor air quality. In the tropical climate zones, ambient air conditions do not often feature a marked reduction in night-time wet bulb temperatures (see Section 2.2 Climate and Climate Change). This results in higher ventilation rates necessary for thermal comfort, as outlined in the sections before. Reduced ventilation rates unintentionally caused by building modification (e.g., partially obstructed openings or insect nets to fitted to windows), poor design and occupant control (closing openings to privacy, noise, and security motivations); can often result in insufficient exhaust of the heat accumulated indoors.

#### Smog problem – air cleaning

Due to heavy air pollution in big cities natural ventilation bring lots of smog inside the rooms and creates health problems and uncomfortable living space. Ventilation systems with heat recovery and filters can solve this problem. However, there are arguments against this, as non-airtight building envelopes and the habit of leaving windows open might pose hindrances. Filter systems are also examined again above under 3.3.1.

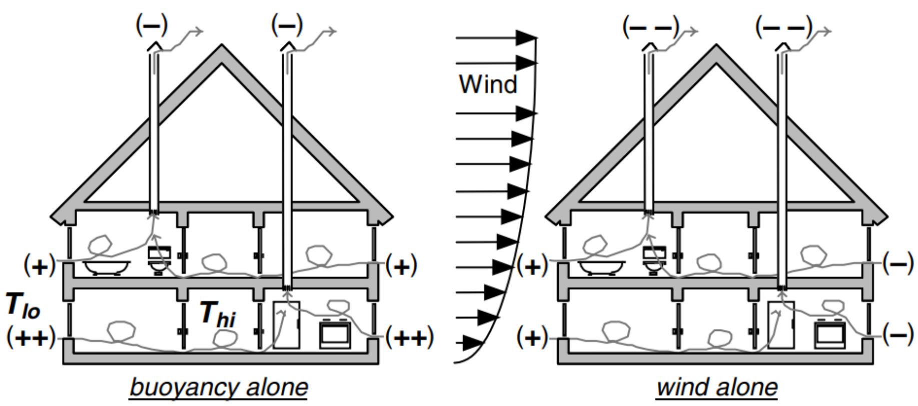


Figure 43: Positive (+) and negative (-) envelope pressures resulting from buoyancy alone and wind alone. Relative magnitude indicated by number of symbols (Axley, 2009).

#### Fans and elevated air speed

Elevated air speeds produce a cooling sensation, and this can be very beneficial to enhance occupant thermal comfort. This is quantified in the standardised thermal comfort models (American Society of Heating and Ventilating Engineers, 2020), and can increase the acceptable temperature limits for naturally ventilated spaces by 1.2 – 2.2 °C (Figure 44). Elevated air speeds can be achieved by using ceiling, wall-mounter, or free-standing fans, and are typically easily controlled by occupants – but may be uncomfortable at higher speeds (>3m/s). The PUB simulations results assume that occupants have access to such devices.

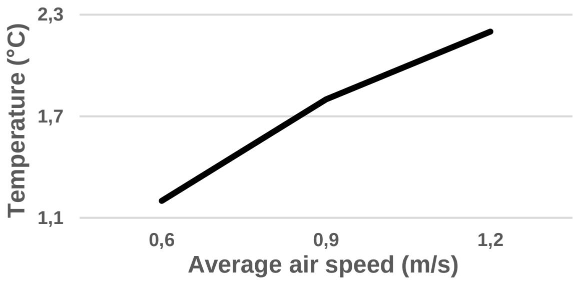


Figure 44: Increase in acceptable temperature limits due to elevated air speeds
(American Society of Heating and Ventilating Engineers, 2020)

#### Thermal Mass

Thermal mass is of importance because it increases the thermal inertia of the building. This thermal inertia strongly affects how heat gains act upon the interior: By introduction of thermal mass local (in terms of time) spikes in heat flux (e.g. through solar radiation during noon) can be buffered. Another important effect is the ability to evacuate the heat during the night because every Joule of thermal energy that is absorbed during the day needs to be rejected during the night (night ventilation is therefore vital). By comparison, lightweight buildings do not have enough thermal mass so the heat flux leads to a pronounced change in temperature throughout a 24h day. Insulation reduces the heat transfer to inside at daytime but it reduces the ability to reject heat during the night, furthermore this is also due to the amount of glazing modelled (in case of PCB). This essentially hinders the thermal mass from cooling down quickly enough, resulting in elevated temperatures in the following day. According to our data the effect of being able to get rid of the heat is greater than the effect of gaining additional heat. For PCBs, the effect of the thermal mass is considered not to be so significant, first due to the extent of glazing that was modelled, furthermore because of daytime active cooling.

### 3.3.3. Cooling Approaches for Primarily Cooled Buildings

#### Heat Recovery + Airtightness

Ventilation heat recovery systems recovers cooling and dehumidification from the exhausted air stream, and transfers this to the incoming outdoor air. Such systems typically come in two types:

- Sensible heat recovery, which exchanges only the “dry” component of cooling,
- Enthalpy heat recovery, which also recovers cooling energy spent to dehumidify outdoor air.

This has been simulated for the Primarily Cooled Building (PCB) type to assess the potential impact on cooling demand. The simulations indicate that while sensible heat recovery is advantageous, the use of enthalpy heat recovery is clearly preferable, and can lead to a significant reduction in cooling demand. Due to the large amount of energy required to cool, dehumidify and reheat air in conditioned buildings, the minimisation of infiltration is very important in decreasing energy loads. Infiltration of ambient air will not only increase the zone temperatures, but also diminish the impact of heat recovery devices.

#### Radiant cooling

Radiant cooling systems such as chilled (cooled) ceilings, or thermally activated concrete structures use the direct cooling benefit of colder surfaces on building occupants. Significant risks in high humidity locations are associated with moisture saturated air condensing on colder surfaces (lower or at the dew point), leading to wet surfaces and even indoor “rain” from radiant ceilings. Therefore, radiant cooling may only be used in a highly controlled environment where supply air has been previously desaturated and there is minimal chance of the introduction of outside, ambient air. These systems are often typically more expensive than air conditioning alternatives but may reduce relative energy consumption and increase thermal comfort in certain applications. Considering the high cost of such systems and the cost sensitivity of the Vietnamese market, these systems are deemed unfeasible at present for most applications, limiting their overall impact.

### Phase-change and thermo-active technologies

Like evaporative cooling, phase-change technologies rely on the large amounts of energy that can be “stored” in a medium due to latent heat capacity. The simplest example of such a system is ice-storage, where water is frozen at night, when outdoor conditions are cooler and equipment efficiencies improved. During the day, coolness is “extracted” from the ice melting to water and used to efficiently cool the building. These systems often add significant additional costs to HVAC designs and construction budgets as they typically require large volume of phase-change material. Furthermore, specialised contractors are often needed for installation and maintenance. Considering the high cost of such systems and the cost sensitivity of the Vietnamese market, these systems are deemed unfeasible at present.

### Ground source heat pumps (GSHP)

GSHPs utilise the relatively stable ground and ground water temperatures near the surface to realise high efficiency cooling and heating by means of water-source heat pumps. A core prerequisite for such systems is that the ground source temperature must be maintained with a yearly equilibrium, where any heat added to the ground must be removed again within a one-year period. This can be done either through seasonal heating and cooling, which should be closely matched, or through cooling matched with some process, which requires heat (e.g., industrial processes, or large-scale water heater). Vietnam’s tropical climates do not have winter periods, and even the subtropical winters are very modest, meaning that the annual heating demand would be insufficient to match the large cooling demand. Furthermore, the use of geothermal resources currently requires special permission from the National Department of Construction, adding significant additional application load and uncertainty in designing such systems. Considering both climate and regulatory complexity, GSHP are deemed unfeasible at present.

### Absorption cooling

Absorption cooling requires the input of a high-quality thermal source (typically at or above 90 °C) to generate cooling. Considering cheaper flat-panel solar thermal systems are incapable of reaching the required thermal quality, industrial waste heat is expected to be the only source for such cooling technologies. Furthermore, these systems are very expensive, require specialist contractors to install and maintain, and commonly use toxic chemicals (e.g., lithium bromide). Consequently, absorption cooling is deemed unfeasible at present in the Vietnamese market.

# 4. Recommendations

While chapter two outlined the basic framework in which the topic of cooling is addressed in Vietnam, chapter three showed three different approaches to the topic of renewable cooling: First, the availability of renewable energy for cooling devices was presented. Then, the possibility of an initial reduction of the demand for cooling was discussed. This was done with the help of a site-specific simulation, using different variables such as the building construction, insulation, window area and shading possibilities as well as the orientation of the building. Finally, various cooling options were presented, including technical options in particular, but also possible structural changes. These were also evaluated in the context of the framework, which was perceived as setting limits. In the following, suggestions will be made to enable efficient and sustainable cooling.

## 4.1 Renewable energy supply

Photovoltaic (PV) systems are an attractive solution to provide renewable energy supply in Vietnam. As outlined before, energy from renewable energy sources is needed to decrease the adverse effects of pollution stemming from fossil fuel powered energy generation. Compared to Wind or Ground and Water solutions, they are deemed efficient and effective when used for cooling. This is due to their technical feasibility, specifically their application in the urban context. Such installations are also financially attractive, subject to several considerations (Figure 45). BESS have an unfavourable payback period and should only be considered where energy security or autonomy motivations are relevant. Subject to favourable capex and operational costs, payback could be reached within the 25-year installation lifespan in Ho Chi Minh City. Under present conditions a reasonable payback period cannot be achieved in Hanoi. Due to the restriction on feed-in to the grid and high cost of BESS, PV installation should be sized to meet the building baseload demand. For existing buildings, this data should be available, although the lack of historical baseload demand information is problematic when it comes to the construction of new buildings. If data is available from a comparable building, this could be used to size a PV installation. Alternatively, it is advisable to prepare for a future installation once sufficient data becomes available (indicatively after 2 years). The financial viability is highly dependent on favourable capex and operational costs, and this should be assessed on a project-by-project basis. A detailed payback calculation should be done accordingly, ensuring that a payback period of 10-15 years is actually achievable.

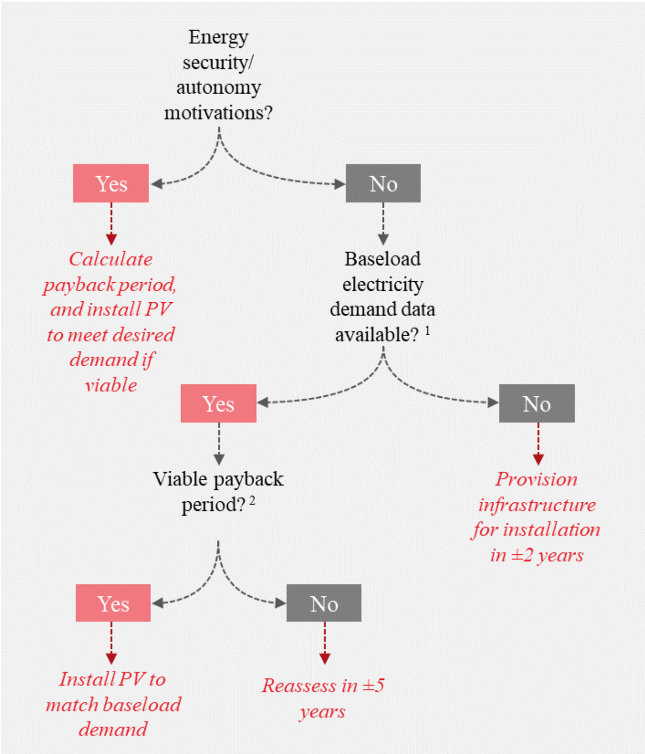


Figure 45: Decision tree for renewable energy supply (Arup, 2022)

Should an attractive payback period not be possible at present, it is advisable to reassess financial viability in the medium term, as the costs for PV installations continue to reduce.

1. Baseload demand data should be based on historic data, either of the building itself, or a comparable existing building (in the case of new builds).
2. Payback periods should be calculated using actual installation cost and operational costs, as unattractive payback periods are possible in Vietnam.

## 4.2 Reducing cooling demand

Reducing cooling demand is essential in reducing the corresponding electrical demand. A lower electrical demand is easier to meet with renewable supply.

### Primarily Uncooled Building (PUB) types

Buildings, which are not intended to be primarily mechanically cooled and ventilated, require appropriate strategies. Decision trees are provided for both Hanoi and HCMC (Figure 46 and Figure 47 respectively). These recommendations can also be generalised to be applied to other Vietnamese cities in either a subtropical or a tropical climate (using Hanoi and HCMC as a reference, respectively). The comparison of the two decision trees shows that buildings in HCMC are more sensitive to envelope performance, with optimal design choices having the potential to make the building comfortable for almost the whole year. However, bad design choices also have worse consequences in HCMC in comparison to Hanoi.

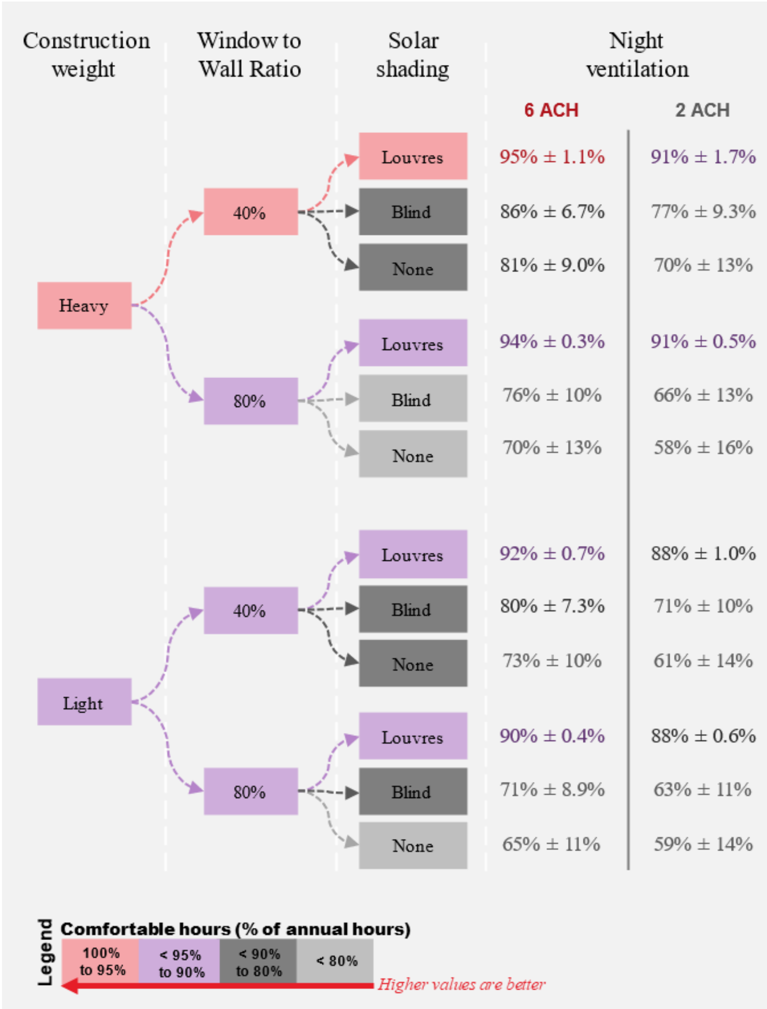


Figure 46: Decision tree for Primarily Uncooled Buildings in Hanoi

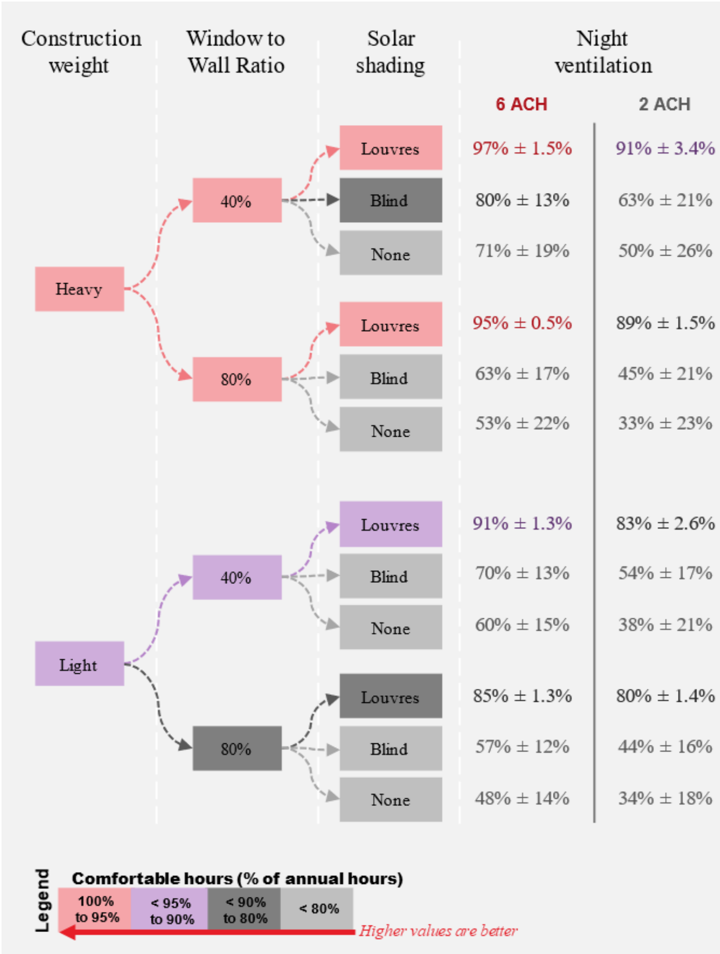


Figure 47: Decision tree for Primarily Uncooled Buildings in Ho Chi Minh City

Important parameters to choose are described in the following, and are similar for both cities:

- The construction weight has a noticeable impact as heavy weight (masonry & concrete) buildings can retain coolness from effective night-time cooling and resist rapid temperature increases.
- Window to wall ratio also has a strong effect as it decreases the amount of solar heat gain by reducing the extents of the windows.
- Solar shading is the parameter with the most prominent impact, affecting how much solar radiation can enter the interior. It is essential, that the solar shading measures be used during the day in cases where the shading is not automatically controlled.
- Night-time ventilation is an essential component of optimal thermal performance, with higher ventilation rates ensuring that heat is quickly exhausted, and building mass cooled down for the following day.
- The glazing type is recommended to be single glazing as it shows better mean behaviour than double-glazed.

## Primarily Cooled building (PCB) types

Decision trees are provided for both Hanoi and HCMC (refer to Figure 48 and Figure 49 respectively). As with PUBs, these recommendations can be generalised in order to apply to other Vietnamese cities.

Important parameters to choose are described in the following:

- Window to wall ratio also has a strong effect as it reduces the amount of solar heat gain by reducing the extents of the windows.
- Solar shading is the parameter with the most prominent impact, affecting how much solar radiation can enter the interior.
- Glazing performance has a significant impact, as high-performance glazing can significantly reduce the amount of solar heat gain during the day.

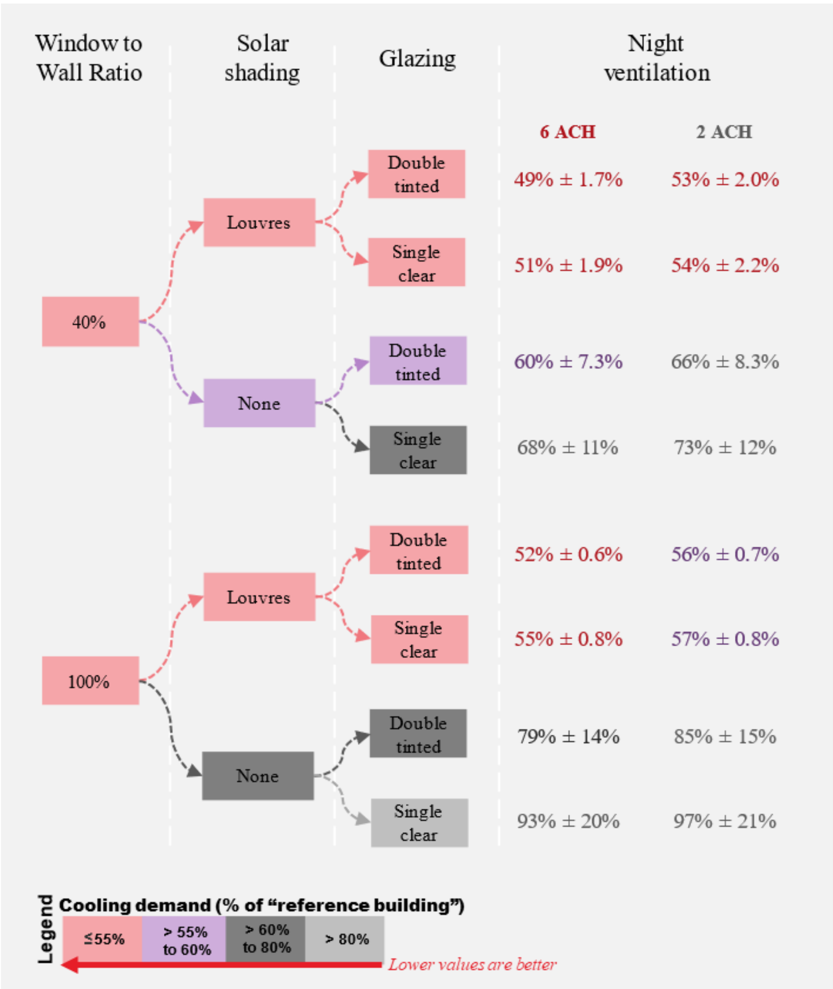


Figure 48: Decision tree for Primarily Cooled Buildings in Hanoi

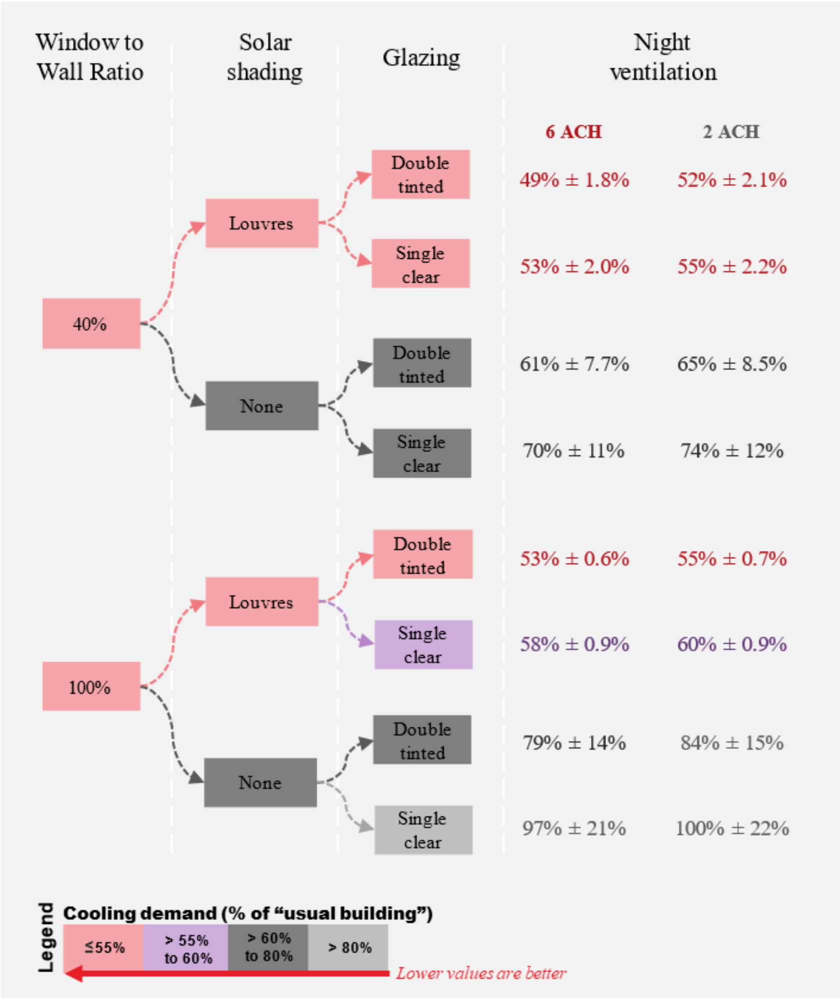


Figure 49: Decision tree for Primarily Cooled Buildings in Ho Chi Minh City

## 4.3 Efficient Cooling

Meeting the cooling demand as efficiently as possible is essential in reducing the corresponding electrical demand, which can then be met with renewable supply.

### Primarily Uncooled Building (PUB) types

Residential and lower-income retail, hospitality, and office buildings can potentially operate well without air conditioning, if the following recommendations are adhered to (Figure 50):

1. The building envelope must be optimised, as per the recommendation of the section 4.2.
2. Mechanical night-time ventilation should be installed. Such a system should achieve ~6 ACH and ensure that all interior spaces can effectively be flushed with cooler night-time outdoor air.
3. Occupants should be provided with direct control of natural ventilation and elevated air speed mechanisms, as this allows them to adapt their thermal environment, and tolerate higher temperatures.
4. Air conditioning should ideally not be installed but may be considered if frequent thermal complaints occur.

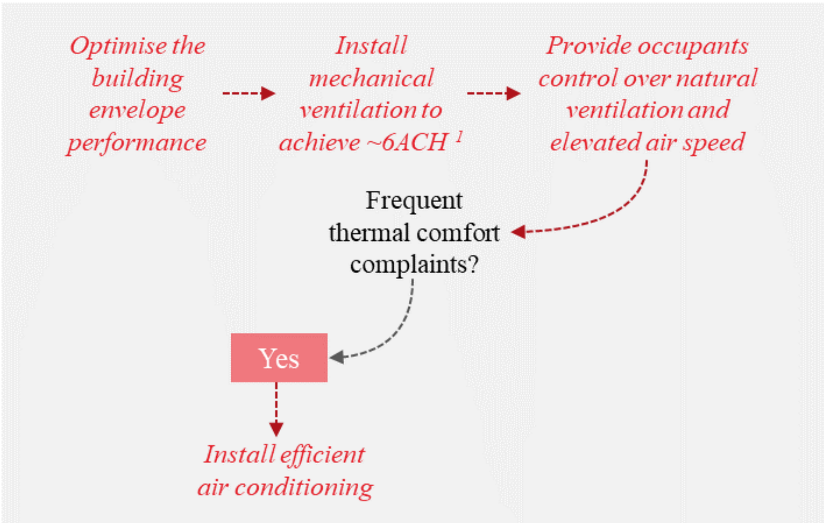


Figure 50: Decision tree for efficient cooling of Primarily Uncooled Buildings

### Primarily Cooled Building (PCB) types

Office, retail, and hospitality buildings, as well as upmarket residential buildings are expected to be air-conditioned. The electrical demand generated by cooling can be reduced as follows (Figure 51):

1. Specify enthalpy heat recovery for the ventilation system.
2. Incorporate night-time ventilation/Free Cooling in the ventilation systems design.
3. Specify highly efficient air conditioning equipment and systems.


Figure 51: Decision tree for efficient cooling of Primarily Cooled Buildings

# 5. Conclusion

The renewable cooling context of Vietnam shows great complexity, with rapidly changing social identity, population fluxes, climate and infrastructure. The opening of the once command-based economy has shown considerable growth in population, export and services industries and urban migration. However, modernisation has come at the expense of the local environment – with increasingly hotter and more polluted urban areas. Climate change is expected to further expand tropical conditions northward, resulting in considerable increases of cooling demand. Unfortunately, the most populous region of the Red River Delta is also located in the north, and its' electricity is expected to remain coal based in the short to medium term – showing a concerning feedback loop.

Vietnam has significant renewable energy potential that can be harnessed using, among other sources, photovoltaic (PV) installations. Indeed, the reduction of PV costs and temporary feed-in-tariff scheme has led to a massive boom in installed PV capacity, especially in the southern and central regions. However, the discontinuation of feed-in-tariffs due to grid instability issues has slowed PV expansion, forcing photovoltaic installers to carefully consider acceptable payback periods, as capital and operational costs related to PV and BESS can easily become financially restrictive. The future implementation timeline of rooftop renewable technology is dependent on governmental schemes and the delayed Power Development Plan for 2021-2030 (PDP-8).

Much can be done to avoid or drastically lower building cooling demand, for which different approaches are required based on the building type. The examined strategies show similar behaviour in HCMC and Hanoi due to the predominant cooling demand and shared hot and humid summers. Generally, HCMC shows more potential for reduction as the climate is more punishing for bad thermal design. The analysis has shown that there are certain hindrances to the integration of renewable energy for sustainable cooling.

For both PUBs and PCBs, an effective shading strategy is found to be the most dominant factor. Night ventilation is shown to be possibly a very important factor when the assumed air change rates can be implemented. PUBs call for a strategy to maximize the thermal mass of the building to resist heat fluxes during the day and maximize the heat flux out of the building during the night whereas PCB types mainly focus on minimizing heat flux into the building during the day. The thermal storage mass of the building helps to prevent the room temperatures from rising much during the day. It is nevertheless also important to minimize solar and internal loads, e.g. through shading and building orientation. It has been shown that low insulation of the roof leads to a significant reduction in cooling demand. With medium to high insulation, only a slight improvement compared to low insulation level is observed. Heat recovery, especially latent heat recovery, is a valuable strategy for saving energy in PCBs. Once the building envelope has been optimised, the remaining cooling demand can be met through efficient cooling approaches and technologies. The broad adoption of these three solutions would result in a large reduction in electricity consumption and the corresponding carbon emissions.

Furthermore, various supports from the Vietnamese government, such as financial benefits or subsidies, as well as an expansion of the infrastructure to be able to accommodate higher capacities of fluctuating renewable energies would be desirable. Overall, the potential for sustainable cooling in Vietnam is very high, in terms of both building construction and technical solutions. With this study, we hope to be able to provide an important building block for sustainable cooling solutions.

# 6. Figures

# 7. Tables

# 8. Abbreviations

| Acronym / Abbreviation | Expanded Name |
|---|---|
| ACH | Air changes per hour |
| ATC | Adaptive Thermal Comfort |
| Am | According to the Köppen Climate Classification,<br>A= temperature of coolest month 18°C or higher<br>m= precipitation in driest month less than 60 mm but equal to or greater than 100 – (r/25) |
| ASHRAE | American Society of Heating and Ventilating Engineers |
| BESS | Battery Energy Storage Systems |
| BPIV | Building Integrated Photovoltaic |
| COP | Coefficient of Performance |
| CCGT | combined cycle gas turbines |
| Cwa | According to the Köppen Climate Classification,<br>C= temperature of warmest month greater than or equal to 10 °C, and temperature of coldest month less than 18 °C but greater than –3 °C<br>w= precipitation in driest month of the winter half of the year less than one-tenth of the amount in the wettest month of the summer half<br>a= temperature of warmest month 22°C or above |
| Cwb | According to the Köppen Climate Classification,<br>C= temperature of warmest month greater than or equal to 10 °C, and temperature of coldest month less than 18 °C but greater than –3 °C<br>w= precipitation in driest month of the winter half of the year less than one-tenth of the amount in the wettest month of the summer half<br>b= temperature of each of four warmest months 10 °C or above but warmest month less than 22 °C |
| dena | Deutsche Energie-Agentur GmbH |
| DG | Double glazing |
| DGC | Double glazing, clear |
| DGE | Low-e coated double glazing |
| DGT | Body tinted double glazing |
| DX units | Direct Expansion Units |
| FIT | Feed-in-tariff |
| GFA | Gross Floor Area |
| GHI | Global Horizontal Irradiation, measured in W / $m^2$ |
| HAWT | Horizontal Axis Wind Turbines |
| HCMC | Ho Chi Minh City |
| HI | Heavy insulated construction |
| HI_WC | Heavy insulated construction without a ceiling |
| HII | Heavy highly insulated construction |
| HU | Heavy uninsulated construction |
| HU_NC | Heavy (masonry) and uninsulated (no wall insulation) construction |
| HVAC | Heating, Ventilation, Air Conditioning |
| LI | Lightweight insulated construction |
| LI_WC | Lightweight insulated construction with a ceiling |
| LII | Lightweight highly insulated |
| Low-e | Low emissivity |
| LPD | Lighting Power Density |

| Acronym / Abbreviation | Expanded Name |
|---|---|
| MOIT | Ministry of Industry and Trade |
| OTTV | Overall Thermal Transfer Value |
| PCB | Primary Cooled Building |
| PDP | Power Development Plan |
| PDP8 | Power Development Plan for period 2021-2030. |
| PUB | Primary Uncooled Building |
| PV | Photovoltaic |
| RH | Relative Humidity |
| S50 | External shading allowing 50% solar radiation through |
| SB | Internal reflective blind |
| SG | Single glazing |
| SGC | Single glazing, clear |
| SGE | Low-e coated single glazing |
| SGT | Body tinted single glazing |
| SHGC | Solar Heat Gain Coefficient |
| SL | External louvers |
| SN | No Shading |
| UHI | Urban Heat Island |
| VAWT | Vertical Axis Wind Turbines |
| VC | Vapour Compression |
| VRF | Variable Refrigerant Flow systems |
| WTGs | Wind Turbine Generators |
| WWR | Window to Wall Ratio |

# 9. Glossary

| Term | Definition |
|---|---|
| **Adaptive Thermal Comfort** | A theory and assessment methodology of experienced change in comfortable room temperature in response to changes in external air temperature. |
| **Adiabatic** | Adiabatic process is a closed system into which no heat enters or escapes the system. The process refers to internal energy variations in temperature that can be expanded or compressed through isothermal processes. |
| **Battery Energy Storage Systems** | Devices that enable energy from renewable sources such as solar, to be stored and then used later. |
| **Comfortable Hours** | Based on the comfort equation, comfortable hours are determined through complex equations and computer analysis of the heat balance between a human body and its environment. The calculation includes geographically and seasonally specific data regarding weather conditions. |
| **Cooling Demand** | Calculation of a building’s peak energy requirement capacity for cooling systems from multiple peaks over a period of time. |
| **Enthalpy** | Wet heat recovery - the sum of internal energy of the system plus the product of the pressure of the gas in the system and its volume. Enthalpy of the liquid phase at constant temperature remains constant for moderate pressures. |
| **Heat recovery** | The process of collecting and re-using heat that is generated from any process which would otherwise lose the heat. |
| **Load** | A component or portion of a circuit that consumes electrical power as opposed to the power source which produces power. Load also affects the performance of output voltage, currents, and amplifiers. |
| **Low-e** | Low emissivity refers to surface condition that emits low levels of radiant thermal (heat) energy. |
| **Low-e glass** | Glass that has been coated on one or more of its surfaces to reduce its emissivity. |
| **Photovoltaic Systems** | An electric power system designed to supply useable power from photovoltaics (also known as solar panels). |
| **Primarily Cooled Buildings** | Building where air conditioners (and mechanical ventilation) are always operations. These could be office, retail, hospitality, or upmarket residential buildings. The desired outcome is to reduce the heat gains to the building in such a way that cooling demand is minimised. |
| **Primarily Uncooled Buildings** | Buildings where air conditioning may be installed but is only operated when conditions become unacceptably warm. These could be residential, or lower-income retail, hospitality, and office buildings. The desired outcome is to reduce the number of hours where air conditioning is necessary to a minimum. |
| **Sensible heat recovery** | Dry heat recovery – Sensible heat is exchanged in an energy generation system affecting the temperature of one or more substances. The heat that is removed from or added to a system in which there is no change of state. |
| **Solar Heat Gain Coefficient** | Standard used to estimate energy and solar radiation that passes through glass relative to the amount of solar radiation hitting the glass. |
| **Thermal Comfort** | The condition of the mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation. |

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# 11. Appendix: Simulation details

## 11.1 Site & weather

The location of interest is Ho Chi Minh City and Hanoi in Vietnam. The examination is performed for both locations.

Weather data has been obtained from OneBuilding in an Energy Plus Weather (EPW) data format. The weather file contains weather data from 2007-2021 (Climate.OneBuilding.Org, 2022):

- Hanoi-Noi.Bai.Intl.AP,NVN,VNM,SRC-TMYx,488200,21.22100,105.8070,7.0,11.9.epw
- Ho.Chi.Minh-Tan.Son.Nhat.Intl.AP,SVN,VNM,SRC-TMYx,489000,10.81900,106.6520,7.0,10.1.epw

## 11.2 Energy Model Assumptions

### 11.2.1. Geometry

#### Primarily Uncooled Building (PUB)

For this simulation, a small multi-storey residence was modelled with 60m² living space and dimensions 7.5 m x 8 m with a height of 3.2m. For both building types, the interior storeys of a building – meaning all storeys excluding the ground level and the top storey – are depicted with the adiabatic roof and ground approach. To assess roof insulation performance, the best performing variations were selected and simulated with different levels of roof insulation together with dropping the assumption that the roof is adiabatic. This aims to depict the flat in the top storey of a building. All walls, except the front wall, are considered as adiabatic but their thermal mass is considered. Adiabatic in this context refers to the idealised assumption that no heat transfer occurs to the environment). WWR is simulated with 40 % and 80 %.

#### Primarily Cooled Building (PCB)

For this simulation, a section of an office was modelled with dimensions 7.5m x 8m with a height of 3.2m. All walls except the front wall are considered as adiabatic and their thermal mass is *neglected,* as a real office area is much bigger than this section. WWR is simulated with 40 % and 100 %.

#### Both PUB and PCB

The front wall's heat flux to the environment and thermal mass are considered. The zone that is facing away from the windows is an interior zone where the results are neglected due to the minimal influence on performance and thermal comfort. The results from the perimeter zone, bitt e next to the windows are post-processed. The orientation of the geometry is a parameter that is varied for 8 different directions North, North-East, East, South-East, South, South-West, West, North-West.

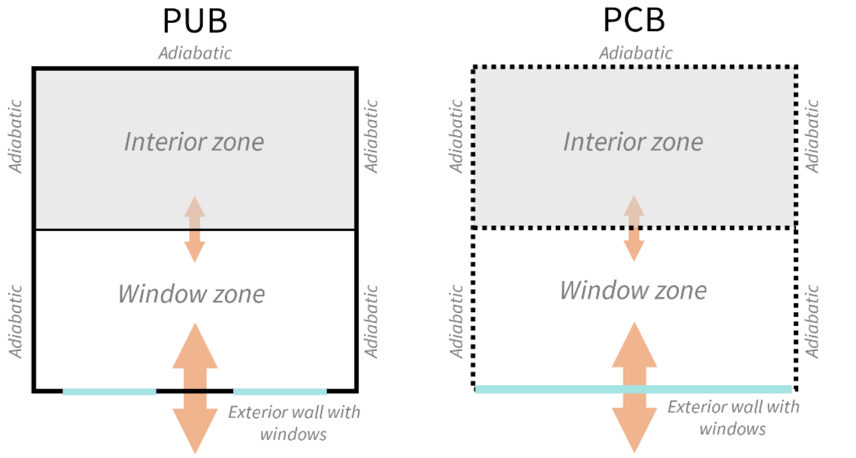


Figure 52: Plan view of the model geometry for the Primarily Uncooled Building (PUB) and Primarily Cooled Building (PCB)

Some parameters relate strongly to geometry, and must therefore be modelled explicitly, such as constructions and ceilings, shading strategies, glazing extent and glazing type. All other parameters are modified by code as part of a parametric simulation process. The modelled 3D geometry is visualised in Figure 54 for PUB and PCB cases, respectively, with floor plan outlined in red.

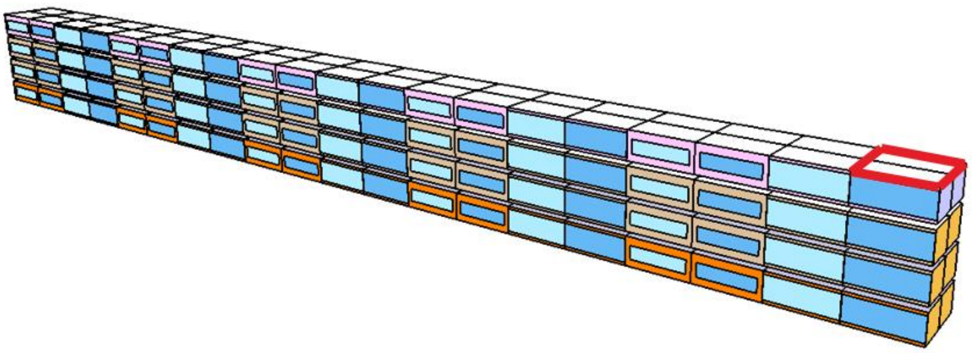

Figure 53: Primarily Uncooled Building 3D model

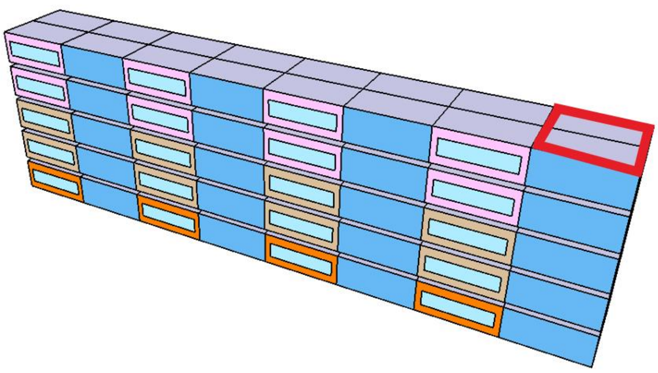

Figure 54: Primarily Cooling Building 3D model

### 11.2.2. Materials and construction

| | Heavy highly insulated | Heavy insulated | Heavy uninsulated | Lightweight highly insulated | Lightweight insulated |
|---|---|---|---|---|---|
| **Applied Cases** | PCB | PCB / PUB | PCB / PUB | PCB | PCB / PUB |
| **Layers from outside (first) to inside (last)** | 110 mm Expanded Polystyrene 100 mm Brickwork 10 mm Cement Plaster 100 mm Brickwork inner 13 mm Gypsum Plasterboard | 50 mm Expanded Polystyrene 100 mm Brickwork 10 mm Cement Plaster 100 mm Brickwork inner 13 mm Gypsum Plasterboard | 100 mm Brickwork 10 mm Cement Plaster 100 mm Brickwork inner 13 mm Gypsum Plaster | 120 mm Expanded Polystyrene 13mm Gypsum Plasterboard | 60 mm Expanded Polystyrene 13mm Gypsum Plasterboard |
| **R value [W/(m²*K)]** | 3.636 | 1.519 | 0.497 | 3.650 | 1.934 |
| **U value [W/(m²*K)]** | 0.275 | 0.519 | 2.013 | 0.274 | 0.517 |
| **Heat capacity [kJ/(m²*K)]** | 131.3 | 131.3 | 131.3 | 14.49 | 12.26 |

Table 7: Energy model wall construction parameters

| | Single glazing clear | Single glazing tinted | Single glazing low emission | Double glazing clear | Double glazing tinted | Double glazing low emission | Double glazing tinted, low emission |
|---|---|---|---|---|---|---|---|
| **Applied Cases** | PCB / PUB | PCB | PCB | PCB / PUB | PCB | PCB | PCB |
| **U-Value [W/(m²*K)]** | 5.818 / 5.778 | 5.809 | 3.262 | 2.689 / 2.665 | 2.687 | 1.673 | 1.672 |
| **SHGC [-]** | 0.819 / 0.818 | 0.615 | 0.515 | 0.704 / 0.703 | 0.490 | 0.453 | 0.428 |

Table 8: Energy model glazing parameters

To evaluate whether an internal ceiling has a noticeable impact on the results, two options are examined:

- the first option is to neglect the internal ceiling (considered for PCBs and PUBs), and
- the second is to assume a floating ceiling construction of gypsum board with a 300 mm air cavity (only considered for PUBs). Because of lack of noticeable influence for PUB, the presence of dropped ceilings was not varied and all constructions are simulated to not have a dropped ceiling.

### 11.2.3. Shading Strategies

| | No shading (SN) | Internal blinds (SB) | Louvers (SL) | Horizontal Louvers (SH) | Translucent Film (S50) |
|---|---|---|---|---|---|
| **Applied Cases** | PCB / PUB | PCB | PCB / PUB | PCB / PUB | PUB |
| **Description** | No shading | Internal applied Medium reflectivity slats | Externally applied Louvers at 45 ° Spaced 0.3 m apart | Externally applied Louvers at 0° Spaced 0.3 m apart | Externally applied 50% solar transmittance |

Table 9: Energy model shading strategies

### 11.2.4. Occupancy and loads

| | | Primarily Uncooled Building (PUB) | Primarily Cooled Building (PCB) |
|---|---|---|---|
| **Density** | **[m²/pers.]** | 15 | 10 |
| **Metabolism*** | **[W/pers.]** | 123 | 123 |
| **Factor**** | **[-]** | 0.9 | 0.9 |
| **Occupancy Schedule** | **[-]** | 07:00 – 18:00 at 50% density<br>18:00 – 07:00 at 100% density | 08:00 – 18:00 at 100% density<br>18:00 – 08:00 at 0% density |
| **Small Power Load** | **[W/m²]** | 2.5 | 20 |
| **Small Power Radiant Fraction** | **[%]** | 72 | 72 |
| **Small Power Schedule** | **[-]** | 07:00 – 22:00 at 100% load<br>22:00 – 07:00 at 50% load | 08:00 – 18:00 at 100% load<br>18:00 – 08:00 at 20% load |
| **Lighting Load** | **[W/m²]** | 2.5 | 11 |
| **Lighting Radiant Fraction** | **[%]** | 72 | 72 |
| **Lighting Schedule** | **[-]** | 07:00 – 22:00 at 100% load<br>22:00 – 07:00 at 50% load | 08:00 – 18:00 at 100% load<br>18:00 – 08:00 at 0% load |

* Occupant sensible and latent fractions calculated dynamically based on zone air temperatures.

**Metabolic rate is modified for gender/age with references values of 1.0 for men, 0.85 for women, and 0.75 for children

Table 10: Energy model occupancy and load assumptions

### 11.2.5. Ventilation

#### Primarily Uncooled Building (PUB)

As this study is aimed to optimize thermal comfort without active cooling, no HVAC system is applied. However, ventilation is also considered in two ways where the numeric values are measured in air changes per hour (ACH):

- Night-time ventilation: 2 ACH (simplified approximation of typical buoyancy driven natural ventilation), 4 ACH, 6 ACH, 8 ACH (>2 ACH assumed with forced ventilation)
- Daytime ventilation: 0.5 ACH (infiltration), 2 ACH (simplified approximation of typical buoyancy driven natural ventilation).

#### Primarily Cooled Building (PCB)

In this parametric study, an ideal HVAC system is implemented. The HVAC system's setpoints are 18 °C for heating and 24 °C for cooling. Mechanical ventilation is considered in two ways:

- Night-time ventilation: 0 ACH (no ventilation), 6ACH (forced ventilation)
- Daytime ventilation: outdoor air flow rate is set to 0.007 $m^3$/(person*s).

### 11.2.6. Simulation variants

Due to the exploding dimensionality of combinatorial optimisation, the best performing solutions from the parametric studies were given additional modifications (variants) to model areas of particular interest: roof insulation and heat recovery. The following describes the variants considered:

- *Default*: examines the influence of the different parameters on the results.
- *Roof insulation*: the roof is no longer adiabatic anymore and exposed to solar radiation. Different levels of insulation are introduced to compare their performance.

| | **Minimal insulation** | **Slight insulation** | **Moderate insulation** | **Heavy insulation** | **Number of parameters** |
|---|---|---|---|---|---|
| **Applied Cases** | PCB / PUB | PCB / PUB | PCB / PUB | PCB / PUB | PCB / PUB |
| **R-Value [($m^2$*K)/W]** | 0.3 | 1.0 | 2.2 | 4.2 | 4 / 4 |

Table 11: Energy model roof construction parameters

- *Heat Recovery:* This simulation is aimed to examine whether heat recovery is beneficial or not. The best performing building design is chosen and a heat recovery system is introduced.

| | **Sensible Heat Recovery** | **Latent Heat Recovery** | **Number of parameters** |
|---|---|---|---|
| **Applied Cases** | PCB | PCB | PCB / PUB |
| **Efficiency [%]** | 70% | 65% | 2 / 0 |

Table 12: Energy model heat recovery parameters

### 11.2.7. Parameter combinations

The parametric study is performed for all significant parameter combinations.

| | Possible values | Number of parameters (PUB / PCB) |
|---|---|---|
| **Location** | Hanoi, Ho Chi Minh City | 2 / 2 |
| **Orientation** | North, North-East, East, South-East, South, South-West, West, North-West | 8 / 8 |
| **Wall construction** | Heavy highly insulated, heavy insulated, heavy uninsulated, lightweight highly insulated, lightweight insulated | 3 / 5 |
| **Glazing** | Single glazing clear, single glazing tinted, single glazing low emission, double glazing clear, double glazing tinted, double glazing low emission, double glazing tinted low emission. | 2 / 7 |
| **Shading** | None, blind, louvres 45 °, louvres 0 °, 50 % shading | 4 / 4 |
| **Window to Wall ratio** | 40 %, 80 % / 40 %, 100 % | 2 / 2 |
| **Ceiling** | No ceiling, with ceiling* | 1* / 1 |
| **Night-time ventilation** | 0 ACH, 2 ACH, 4 ACH, 6 ACH, 8 ACH | 4 / 2 |
| **Day time ventilation** | 0 ACH, 0.5 ACH, 2 ACH | 2 / 1 |
| **Roof Insulation**** | Minimal insulation, slight insulation, moderate insulation, heavy insulation | 4 / 4 |
| **Heat Recovery**** | Sensible, latent | 0 / 2 |
| **Total** | | 8196 / 8966 |

* Ceiling only applied to heavy insulated building type in PUB case

** Parameters only introduced for best performing parameter combination

Table 13: Energy Model Parameters

### 11.2.8. Result variables

The result from each simulation is the percentage of total annual hours that the operative temperature is below the upper limits defined by the adaptive thermal comfort model (the 80% acceptability limits as per ASHRAE 55-2020) with elevated air speed (PUBs) and without elevated air speed (PCBs).

Reference building: for PCBs, the amount of sensible cooling (Hanoi at 9091 kWh/year and Ho Chi Minh City at 12498 kWh/year) over the whole year is normalised to the value for a usual office building in the respective city (assumed below):

| | |
|---|---|
| Orientation | 90 ° |
| Night Ventilation | 0 ACH |
| Glazing | Double Glazing Tinted |
| Construction | does not have any effect, but we chose heavy insulated |
| Shading | None |

| | |
|---|---|
| Window to Wall Ratio | 100% |

Note that the values are dependent on the area of the office building and are not expected cooling demand values, as they are very dependent on the assumptions. The relative sizes are, however, comparable. For the heat recovery case the total cooling is considered as enthalpy heat recovery recovers latent heat. Again, the values are normalised to the usual office building and for Hanoi, this resulted into 12298 kWh/year whereas the value for Ho Chi Minh City is 17148 kWh/year www.dena.de

German Energy Agency