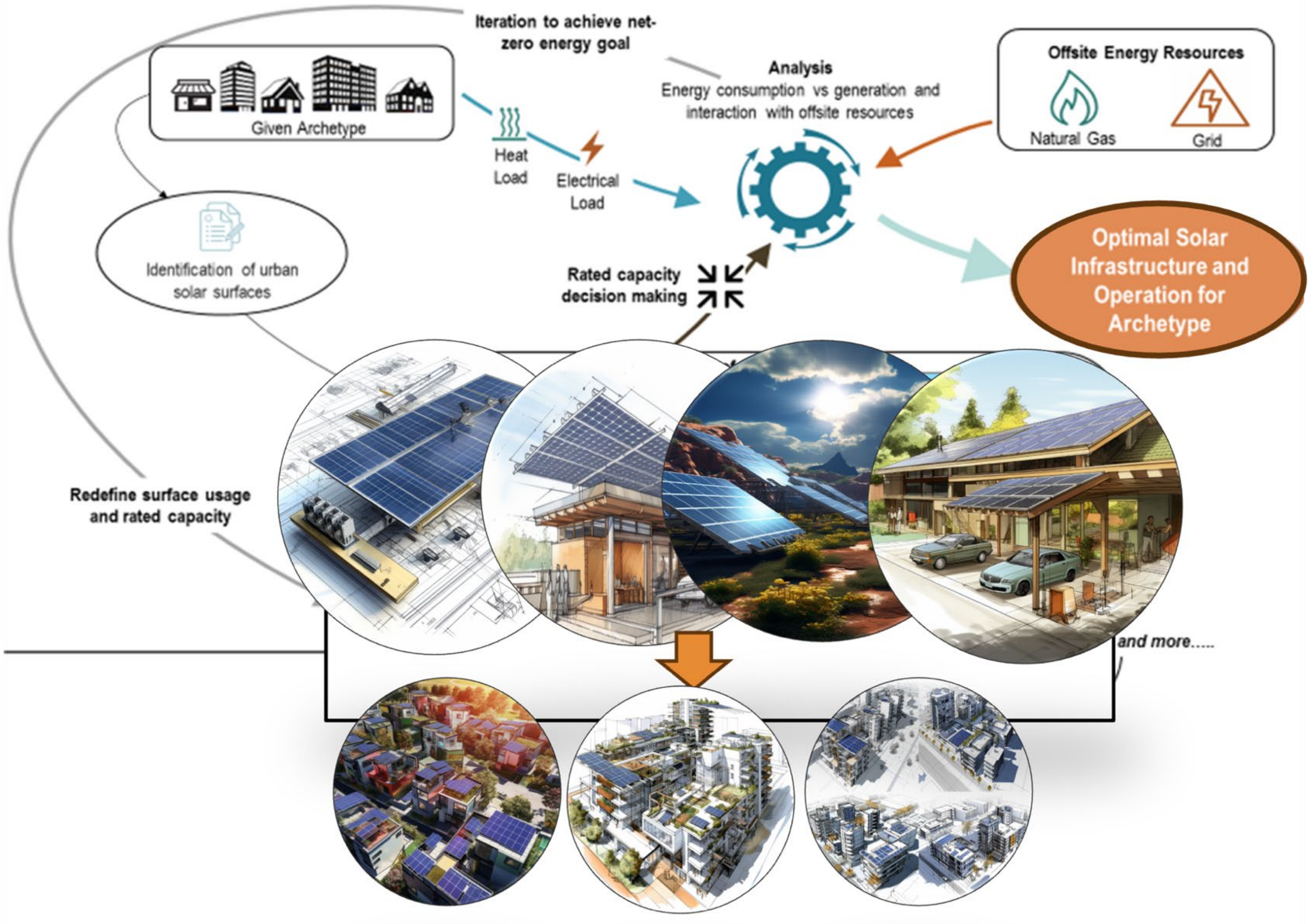
SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

Strategies for the Design of New and Existing High Energy Performance Solar Neighborhoods



IEA SHC TASK 63 | SOLAR NEIGHBORHOOD PLANNING

Technology Collaboration Programme
by iea

SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

Strategies for the Design of New and Existing High Energy Performance Solar Neighborhoods

This is a report from SHC Task 63: Solar Neighborhood Planning and work performed in Subtask A: Solar planning strategies and concepts

Editors: Caroline Hachem-Vermette, Kuljeet Singh Grewal, and Maria Wall

Authors: Caroline Hachem -Vermette, Kuljeet Singh Grewal, Gilles Desthieux, Javeriya Hasan, and Somil Yadav

Contributors: Alessia Boccalatte, Johannes Brozovsky, Silvia Croce, Ricardo D'Almeida; Matteo Formolli, Martina Giorio, Miljana Horvat, Olaf Bruun Jørgensen, Wolfgang Kampel; Karin Kappel, Jouri Kanters, Tobias Kristiansen, Rossana Paparella, Rafael Campamà Pizarro, Martin Thebault.

Date: May 2024

Report A1, DOI : 10.18777/ieashc-task63-2024-0003

Editors/Authors

Caroline Hachem-Vermette
Department of Building, Civil and Environmental Engineering
Gina Cody School of Engineering and Computer Science
Concordia University, Montreal, QC, Canada

Kuljeet Singh Grewal
Future Urban and Energy Lab for Sustainability (FUEL-S)
Faculty of Sustainable Design Engineering (FSDE)
University of Prince Edward Island, Charlottetown, PE, Canada

Maria Wall
Division of Energy and Building Design
Department of Building and Environmental Technology
Lund University, Lund, Sweden

Gilles Desthieux
Haute école du paysage d'ingénierie et d'architecture de Genève, (HEPIA)
University of Applied Sciences and Arts Western, Switzerland (HES-SO), Geneva, Switzerland

Javeriya Hasan
Department of Architectural Science
Toronto Metropolitan University (formerly Ryerson University), Toronto, Canada

Somil Yadav
Department of Building, Civil and Environmental Engineering
Gina Cody School of Engineering and Computer Science
Concordia University, Montreal, QC, Canada

Contributors

Alessia Boccalatte
LOCIE Laboratory
Université Savoie Mont Blanc, Le Bourget du Lac, France

Johannes Brozovsky,
Architecture, Materials and Structures
SINTEF Community, Trondheim, Norway

Silvia Croce
Eurac Research
Institute for Renewable Energy, Bolzano, Italy

Ricardo D'Almeida
School of Architecture, Planning and Landscape (SAPL)
University of Calgary, Calgary, AB, Canada

Matteo Formolli
Department of Architecture and Technology
Faculty of Architecture and Design
Norwegian University of Science and Technology (NTNU), Trondheim, Norway

Martina Giorio
Department of Civil, Environmental and Architectural Engineering
University of Padova, Padova, Italy

Miljana Horvat
Department of Architectural Science
Toronto Metropolitan University (formerly Ryerson University), Toronto, Canada

Olaf Bruun Jørgensen
Dansk Energi Management, Copenhagen, Denmark

Wolfgang Kampel
Multiconsult Norway AS
Department of Building Physics and Energy, Oslo, Norway

Karin Kappel
Solar City Denmark, Copenhagen, Denmark

Jouri Kanters
Division of Energy and Building Design
Department of Building and Environmental Technology
Lund University, Lund, Sweden

Tobias Kristiansen
Department of Civil and Environmental Engineering
Faculty of Engineering
Norwegian University of Science and Technology (NTNU), Trondheim, Norway

Rossana Paparella
Department of Civil, Environmental and Architectural Engineering
University of Padova, Padova, Italy

Rafael Campamà Pizarro
Energy and Building Design
Lund University, Lund, Sweden

Martin Thebault
LOCIE Laboratory
Université Savoie Mont Blanc, Le Bourget du Lac, France

Solar Heating and Cooling Technology Collaboration Programme (IEA SHC)

The Solar Heating and Cooling Technology Collaboration Programme was founded in 1977 as one of the first multilateral technology initiatives (*"*Implementing Agreements*"*) of the International Energy Agency.

Our mission is *To bring the latest solar heating and cooling research and information to the forefront of the global energy transition.*

IEA SHC members carry out cooperative research, development, demonstrations, and exchanges of information through Tasks (projects) on solar heating and cooling components and systems and their application to advance the deployment and research and development activities in the field of solar heating and cooling.

Our focus areas, with the associated Tasks in parenthesis, include:

- Solar Space Heating and Water Heating (Tasks 14, 19, 26, 44, 54, 69)
- Solar Cooling (Tasks 25, 38, 48, 53, 65)
- Solar Heat for Industrial and Agricultural Processes (Tasks 29, 33, 49, 62, 64)
- Solar District Heating (Tasks 7, 45, 55, 68)
- Solar Buildings/Architecture/Urban Planning (Tasks 8, 11, 12, 13, 20, 22, 23, 28, 37, 40, 41, 47, 51, 52, 56, 59, 63, 66)
- Solar Thermal & PV (Tasks 16, 35, 60)
- Daylighting/Lighting (Tasks 21, 31, 50, 61, 70)
- Materials/Components for Solar Heating and Cooling (Tasks 2, 3, 6, 10, 18, 27, 39)
- Standards, Certification, Test Methods and LCA/LCoH (Tasks 14, 24, 34, 43, 57, 71)
- Resource Assessment (Tasks 1, 4, 5, 9, 17, 36, 46)
- Storage of Solar Heat (Tasks 7, 32, 42, 58, 67)

In addition to our Task work, other activities of the IEA SHC include our:

- SHC Solar Academy
- *Solar Heat Worldwide*, annual statistics report
- SHC International Conference

Our members

Australia	France	Slovakia
Austria	Germany	South Africa
Belgium	International Solar Energy Society	Spain
Canada	Italy	Sweden
CCREEE	Netherlands	Switzerland
China	Norway	Türkiye
Denmark	Portugal	United Kingdom
EACREEE	RCREEE	
ECREEE	SACREEE	
European Commission	SICREEE	

For more information on the IEA SHC work, including many free publications, please visit www.iea-shc.org

Contents

List of Figures

List of Tables

Abbreviation

Abbreviation	Description
AH	Attached House
APSH	Annual Probable Sunlight Hours
ARCA	Architecture Comfort Environment
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BAPV	Building-Added PV
BIPV	Building Integrated Photovoltaic
BIPVT	Building Integrated Photovoltaic Thermal
BIST	Building Integrated Solar Thermal
BPV	Bio Photovoltaic
BREEAM	Building Research Establishment Environmental Assessment Methodology
CAD	Computer-Aided Design
CC	Commercial Development
CO2	Carbon Dioxide
COP	Coefficient Of Performance
CR	Commercial-Residential
DH	Detached House
DHW	Domestic Hot Water
EAHE	Earth Air Heat Exchangers
EPC	Energy Performance Certificates
EU	European Union
GIS,	Geographic Information System
ICC	Internation Code Council
INECP	10-Year National Energy and Climate Plan
ITACA	Italian Environmental Certification
LCA	Life Cycle Analysis
LEED	Leadership In Energy and Environmental Design
MU	Mixed Use
NECB	National Energy Code of Canada
NRC	National Research Council of Canada
NREL	National Renewable Energy Laboratory
NU	Neighborhood Unit
NZEB	Net Zero Energy Building
PNACC	National Climate Change Adaptation Plan
PV	Photovoltaic
SDG	Sustainable Development Goals
SHGC	Solar Heat Gain Coefficient
SINTEF	Foundation For Industrial and Technical Research (Norway)
SNACC	National Strategy of Adaptation to Climate Change
STC	Solar Thermal Collector
STPV	Semi-Transparent Photovoltaic
UHI	Urban Heat Island
USGBC	U.S. Green Building Council

1 Executive summary

This report provides a comprehensive overview of solar neighborhoods, including their definition, applications, standards, and regulations. It also outlines the methodology and tools used to develop archetype designs and analyses solar strategies at both building and neighborhood levels. The report presents selected archetypes from Canada, France, Italy, Norway, Sweden, and Switzerland and provides a decision-making tool for solar strategies. The target audience for this report includes architects, urban planners, policymakers, and anyone interested in sustainable and energy-oriented developments.

The second chapter introduces the concept of solar neighborhoods, emphasizing the global interest in integrating solar energy into urban areas. It defines solar neighborhoods as those maximizing solar access through passive and active strategies. The chapter highlights associated benefits, such as reduced energy consumption and contributions to sustainable development goals. It also discusses successful global examples and acknowledges challenges like geographical variations, regulatory differences, financial barriers, and community engagement.

Chapter 3 of the report discusses the conceptual foundation of neighborhood archetypes, defining them as original patterns serving as models for analyzing solar potential and sustainability. The development criteria for these archetypes are outlined, encompassing considerations such as construction period, climate, and spatial characteristics, providing a comprehensive framework for classification. The chapter also details the methodology for collecting neighborhood information using a developed matrix, emphasizing the importance of understanding effectiveness, functionality, and quality of life for residents in residential, commercial, and mixed-use neighborhoods. It provides a detailed analysis of selected archetypes from Canada, France, Italy, Norway, Sweden, and Switzerland, outlining specific criteria for their selection, characteristics such as climate and spatial features, and the integration of solar strategies. The neighborhoods studied exhibit diverse building types, land uses, and street layouts, reflecting a comprehensive exploration of solar potential and renovation measures in different geographical contexts. The study delineated theoretical neighborhood archetypes, including commercial, mixed-use, and sustainable configurations, based on an analysis of Canadian urban developments, emphasizing amenities within walking distance and employing the fused grid concept for sustainable land-use composition.

Chapter 4 outlines solar design principles and strategies at both building and neighborhood levels. It covers key passive solar concepts such as solar gain, storage, conservation of energy, distribution, control of heat gain, and explores various applications, including passive heating and cooling, solar-induced natural ventilation, and daylighting. The chapter also presents diverse passive technologies and shading devices, emphasizing the importance of integrating these strategies into building design to optimize energy efficiency and sustainability. It discusses neighborhood-level passive solar strategies, emphasizing the integration of building-level approaches with urban planning for capturing and controlling solar energy effectively. Key considerations include solar access protections through zoning regulations, the impact of urban design elements such as density and layout, and the role of factors like street orientation, planting, and reflective surfaces in optimizing solar potential and mitigating urban heat island effects. It also discusses various solar technologies for building-scale applications, including solar photovoltaic (PV) and solar thermal technologies. It covers different types of PV cells, such as monocrystalline, polycrystalline, thin-film, semi-transparent, translucent, and transparent cells, as well as bifacial solar panels and bio photovoltaic panels, along with air-based and water-based solar thermal collectors. The integration of these technologies into building envelopes, factors affecting their performance, and considerations for successful integration are also addressed in this chapter. Further, it explores diverse methods of integrating photovoltaic and solar thermal technologies into building design, covering roofs, facades, and various building components, while also addressing challenges and opportunities at the neighborhood level, and introducing innovative solutions such as solar carports and solar trees.

Chapter 5 discusses methods for analyzing solar neighborhood archetypes, including existing neighborhoods, a heritage archetype, and theoretical neighborhoods. The analysis involves energy consumption, generation, and simulation procedures using various tools, emphasizing the importance of comprehensive system analysis for accurate evaluations of a city's energy potential. Advanced models and tools are highlighted for assessing solar potential in urban areas, addressing challenges such as data quality and the need for precise 3D representation. The analysis of archetypes for energy performance and solar strategies involves detailed modeling and simulations, employing tools like SketchUp and EnergyPlus, with considerations for construction materials and regional building standards. In the case of Canadian neighborhoods, the study explores various solar strategies such as monocrystalline panels, tilted rooftops, and solar carports, assessing their feasibility based on factors like cost, efficiency, and power output. Meanwhile, the energy renovation of the Cité Carl Vogt neighborhood in Geneva showcases the intricate integration of solar solutions within a heritage context, addressing architectural constraints and utilizing a comprehensive database for solar potential assessment. Moreover, a comprehensive energy modeling approach for theoretical neighborhoods is discussed, involving pre-processing, cluster configuration setup, and post-processing steps. Solar strategies, including PV systems and solar thermal collectors are optimized using genetic algorithms to achieve an optimal mix of renewable energy sources. The study highlighted variations in energy consumption among diverse neighborhood archetypes and underscored the importance of additional land for effective implementation of solar technologies to achieve net-zero energy goals. The chapter also underscores the potential of renewable energy generation in mixed-use clusters through optimal combinations of diverse neighborhood units, emphasizing the importance of landscape solar designs and optimization methodologies for effective energy resource sharing while maximizing land utilization.

Chapter 6 of the report introduces a decision-making tool framework for solar strategies, emphasizing both passive and active approaches. The framework covers a comprehensive range of solar strategies and employs an adoption score methodology, assessing factors such as ease of implementation, cost, accessibility, environmental impact, and acceptance. The tool is developed through a pilot study involving experts, and it classifies and ranks various solar strategies based on defined criteria. The chapter includes sensitivity analyses for both existing and new neighborhoods, demonstrating the impact of varying weights on decision criteria. Practical applications for single and composite objectives in cold and very cold climates are presented, showcasing the prioritization of solar strategies. The chapter concludes with insights into the tool's early development stages, acknowledging limitations and outlining future research directions for refinement and expansion.

2 Background and Context

Solar energy application in new and existing neighborhoods is gaining worldwide interest in recent years, as cities, around the globe, are increasing their efforts to reduce their carbon footprint. To facilitate the widespread adoption of solar energy, it is crucial to establish innovative solar design strategies and concepts that can assist in the systematic integration of solar technologies within neighborhoods. Such design concepts and strategies should aim at optimizing the neighborhood and buildings design, to maximize the implementation of solar energy.

2.1 Definition of solar neighborhoods

Solar neighborhoods are neighborhoods that aim at maximizing solar access and utilization. These neighborhoods implement passive strategies including equatorial orientation, high performance windows, and adequate solar control, as well as active solar strategies such as solar collectors for electrical and heat generation. Both buildings and neighborhood outdoor area should be designed to maximize useful solar.

Solar neighborhoods are associated with a myriad of benefits such as enhancing passive heating and cooling in buildings and reduced overall energy consumption and can reduce the dependence of residents on fossil fuels and conventional energy grids. This shift towards solar energy not only promotes a more sustainable future but also contributes significantly to mitigating emissions and reducing energy vulnerabilities.

Implementation of solar strategies and technologies on a neighborhood scale yields a range of secondary benefits, including a substantial reduction in energy bills for consumers, which enhances energy affordability. New job opportunities can also be created within the renewable energy sector, contributing to low impact and green economy. Other benefits include stimulating research and innovation and contributing to the development of cutting-edge technologies and better quality of life due to greener and noise free energy generation. In addition, solar neighborhoods have the potential to contribute to several United Nations sustainable development goals (SDG) such as SDG 7 affordable and clean energy, SDG 8 decent work and economic growth, SDG 11 sustainable cities and communities, SDG12 responsible consumption and production, and SDG13 climate action.

2.2 Solar neighborhoods applications

The concept of solar neighborhoods is becoming more globally recognized, due to the benefits mentioned above, and to a growing knowledge base attributed to active research and practical advancements (Caroline Hachem-Vermette, 2020). One well-established principle in solar development involves the incorporation of passive solar strategies during the design of buildings and landscapes. Successful design and implementation of solar neighborhoods relies on a holistic approach that considers various design strategies at building and neighborhood levels. These design strategies include window location and size, building orientation, thermal mass use as well as active solar strategies such PV and solar thermal panels to generate electricity and thermal energy. These principles are thoroughly presented in chapter 3.

An example of sustainable neighborhood development is Masdar City in Abu Dhabi, United Arab Emirates, which employed a two-fold energy management approach (Sankaran and Chopra, 2020). This approach entailed reducing energy consumption through the implementation of globally proven energy-efficient techniques, along with efficient energy generation using innovatively redesigned PV panels to harness solar energy. The city is powered entirely by renewable energy resources, with a 10 MW solar array and a 1 MW rooftop solar array fulfilling 53% of the total energy consumption. Another notable solar neighborhood is the Fujisawa sustainable smart town (“Fujisawa Sustainable Smart Town:

planning for the next 100 years," n.d.) in Fujisawa City, Japan, sponsored by Panasonic. Spanning an area of 19 hectares and accommodating 1000 homes, this experimental town relies on rooftop solar systems with battery storage to meet 100% of the household energy requirements.

In the United States, the River Garden Apartments ("New Orleans Home To Largest Solar Neighborhood In SE | EarthTechling," n.d.) in Louisiana is one of the largest solar neighborhoods, encompassing eight blocks. This neighborhood comprises 89 residential apartments with a collective PV generation capacity of 420 kW. Similarly, Solterra EcoLuxury Apartments (Home Energy Systems, Inc., 2015) near San Diego, California, consists of 120 apartments equipped with PV panels installed on rooftops, carports, and the ground, generating an estimated 992 325 kWh of energy.

Drake Landing ("DLSC homes have stringent requirements: DLSC," n.d.) in Alberta, Canada, represents a solar community with 52 homes featuring 800 south-facing solar panels installed at a 45-degree tilt over the roofs of homes and garages. The community employs a district heating system to store abundant solar energy underground during the summer months and distribute it to each home for space heating needs in winter. Over 90% of the energy used for space heating comes from solar energy.

West5, London, Canada, presents a successful example of coupling passive and active solar strategies in a mixed-use community. Initially, a feasibility study was conducted to demonstrate the impact of various solar technologies and energy-efficient measures within this new urban development area. The findings and measures from this feasibility study were subsequently incorporated into the actual project. In addition to focusing on building envelopes, optimal orientation of the entire neighborhood, window placement, and thermal massing, photovoltaic (PV) systems were integrated into various urban elements, such as parking lots and shelters. West5 features a 1.7 MWp PV plant with an annual yield of 900 kWh/kWp as of 2021. Even without accounting for the carbon offset from rooftop PV, the project compensates for approximately 200 tons of CO2-equivalents per year.

In London, UK, BedZED ("BedZED - the UK's first major zero-carbon community – Bioregional," n.d.) is a mixed-use community with 100 homes, an office building, a college, and community buildings, constructed in 2002, incorporating various features such as solar PV generation, passive solar design, and natural ventilation. Further, drawing inspiration from BedZED, One Brighton ("One Brighton – One Planet Living® Leader – Bioregional," n.d.) is another sustainable solar community developed in the UK. It comprises two multi-story blocks housing 172 apartments, offices, a community space, and a café. The energy generation system relies on a combination of a biomass boiler, a photovoltaic array, and a communal energy distribution system. In India, the Perijanam Village Model ("India Times," n.d.) in Kerala exemplifies how solar neighborhoods can provide clean energy, reduce carbon emissions, and generate economic benefits. The integration of rooftop solar PV across 360 houses in this model reduced approximately 192 000 kilograms of carbon emissions while generating surplus electricity. In Switzerland, own-consumer communities become more and more systematic in the framework of new building and neighborhood development. Indeed, Federal subsidies cover about 30% of the investments. The Federal law on energy allows neighborhoods to share and mutualize solar energy production through the creation of microgrids (Swiss Federal Office of Energy SFOE, 2021).

The development of solar neighborhoods can be challenging due to the involvement of various factors related to climate, availability of sunlight, size and density of community, land usage, economic and social implications. Each neighborhood is unique in terms of location, land use, climate, and local regulations that can affect the implementation of solar strategies, therefore site-specific parameters should be critically evaluated (Armstrong, Brown, Davies, Whyatt and Potts, 2021). These parameters along with occupant energy use behavior and energy systems further govern the energy demand profiles that influence the adoption of solar strategies. Further, technological advancements and innovation in solar technologies also introduce several challenges in developing general strategies ensuring compatibility and scalability (Thakur et al., 2022). In terms of existing neighborhoods, the adoption of solar strategies can be crucial due to building design and infrastructure update needed for effective integration. For instance, grid connectivity of solar photovoltaic (PV) electricity generation may not be feasible due to utility infrastructure limitations (Denholm and Margolis, 2007). Financial barrier associated with significant upfront cost of solar installations, retrofits, energy storage systems, and grid connectivity (e.g., microgrid infrastructure) including their funding options can also affect the financial viability of solar neighborhoods (Rai, Reeves and Margolis, 2016). Moreover, regulatory and policy frameworks usually vary predominantly across various regions that can limit the development of general solar concepts and strategies (Abdmouleh, Alammari and Gastli, 2015). At last, community engagement and acceptance are also important in developing solar neighborhoods (Parkins, Rollins, Anders and Comeau, 2018). For example, personal dislikes related to aesthetic aspects of solar strategies can influence the acceptance of solar strategies.

2.3 Standards and regulations

This section provides an overview of two key aspects related to neighborhood planning. It first discusses the conventional approach to designing traditional neighborhoods, highlighting that energy and resource efficiency were not prioritized during their planning. Thereafter, an overview of regulations, standards, and codes pertaining to the design of solar and energy-efficient neighborhoods is discussed, which involves the integration of high energy performance criteria and solar energy technologies.

2.3.1 Traditional developments

This section explains the general approaches adopted in traditional neighborhoods that are planned and built using conventional planning processes. Additionally, relevant practices around regulations and common practices are briefly captured for various countries.

Canada (and North America): Canada's urban design regulations focus on shaping public urban spaces and the built environment, covering building placement, relationships to streets and the surrounding area, and building appearances. Canada's urban design regulations are primarily enforced at the municipal level, with various provinces deriving regulations related to land use, site planning, and building design. While many Canadian municipalities have design regulations in place, comprehensive urban design standards are lacking in many areas. These regulations primarily focus on building design, with limited attention to public spaces. Examples include zoning bylaws, policy statements, and heritage preservation policies are used in many Canadian municipalities to regulate urban design (Kumar, 2002). For example, the City of Toronto has zoning bylaws and design guidelines that govern building design and public spaces in the city for the provision of enhanced sunlight and view of the sky (City of Toronto, 2017).

Denmark: In Denmark, regulations for building design and urban planning are managed at the national, regional, and municipal levels (Dobravec, Matak, Sakulin and Krajačić, 2021). National legislation provides guidelines for regions and municipalities, allowing them to develop specific local plans. These local plans set rules and regulations for numerous parameters that influence solar and daylight utilization. For example, the Danish building code and regulations (Danish Housing and Planning Authority, 2018) provides guidelines for building and construction, and local plans at the municipal level specify rules and regulations for land use and building parameters. Climate considerations in Denmark are based on a dataset that considers temperature, humidity, wind, radiation, and other climate factors. Regulations cover aspects such as building height, distances between buildings, and energy supply.

Italy: Italy's urban planning and energy legislation follows a hierarchical structure, with national, regional, and municipal levels of regulation (Organisation for Economic Co-operation and Development, 2017). Territorial coordination plans, general regulatory plans, construction programs, and detailed execution plans are the main types of plans. Climate-related design in Italy focuses on aspects like sunlight exposure, shading, and passive solar strategies (Legambiente and CNAPPC, 2017). Building regulations vary depending on the municipality and may include parameters like building height, usable surface, window surface, and more.

Norway: Norway's regulations are governed by the Planning and Building Act and are administered at the national, county, and municipal levels (Plan-og bygningsloven, 2008). These regulations address safety against natural stresses, including floods, landslides, and wind. Norway's climate considerations vary based on regional differences in climate, and geographical correction factors are applied to building energy requirements (Ministry of Local Government and Modernization Norway, 2008). Regulations cover aspects like building height, distances between buildings, and roof angles.

Sweden: The national level in Sweden sets land-use legislation and guidelines for municipalities. At the regional level, County Administrative Boards represent the national government's interests and provide advice. Municipalities have three key responsibilities: creating land-use plans, providing housing through public housing companies, and establishing technical infrastructure for land development. Climate considerations are adjusted based on geographical differences, with stricter energy requirements in the south compared to the north. Regulations address aspects such as building height, ridge height, total building height, and roof inclination.

Switzerland: Swiss urban planning is tied to federal land use laws introduced in 1979 and revised in 2011. The revised law aims to limit new building areas and promote densification. Each canton creates its own regulations, causing variations. Cantons must create a master plan every 15 years, guiding local planning projects (Office of Urban Planning, 2021). Responsibilities for planning and building vary by canton, with Geneva having centralized authority. The planning process includes zone modifications, local master plans, local urban plans, and architectural projects, with approvals from the canton or municipality.

2.3.2 Sustainable and energy-oriented developments

This sub-section presents an overview of regulations, standards, and codes that are available and used in various countries to design sustainable solar energy and energy efficient oriented neighborhoods.

Canada: Canada encourages the implementation of solar energy and energy consumption reduction, primarily through financial incentives, tax credits, and grants. Various provinces and cities in Canada have introduced codes and standards related to energy efficiency, some of which are specific to particular regions. For instance, the city of Toronto's official plan emphasizes the provision of sunlight and views in new and existing buildings (City of Toronto, 2017). The Toronto Green Standard promotes the integration of active and solar technologies in building design. Canada has developed codes like the National Energy Code for Buildings (NECB) to improve energy efficiency and reduce greenhouse gas emissions (National Research Council Canada, 2022). The Pan Canadian Framework aims to achieve a net-zero energy-ready model national building code by 2030 (Government of Canada, 2018). Various sustainability-related design practices have emerged, driven by voluntary standards and certificates such as LEED for Neighborhood Development and ASHRAE/ICC/USGBC/IES Standard 189.1-2017 (Efficiency Canada, 2020; Ministry of Municipal Affairs and Housing, 2017).

Denmark: In Denmark, there are no specific standards or requirements for solar elements in urban planning, but there is a strong ambition among politicians, developers, and landowners to include solar solutions in new developments. Legislation concerning solar measures is included in the Danish building regulations (Danish Housing and Planning Authority, 2018). Specific regulations address energy demand, renovation classes, and indoor climate conditions, including thermal indoor climate and visual comfort (daylight). The Danish building code includes high-performance codes for new buildings, setting maximum specific energy demands for space heating, ventilation, domestic hot water, and electricity for building operation and lighting. The code also specifies limits on transmission loss per square meter of floor area based on the number of floors and heated floor area.

Italy: Italy has adopted a 10-year National Energy and Climate Plan (INECP) in line with European Union directives, aiming to achieve 30% of energy from renewable sources, reduce primary energy consumption by 43%, and cut greenhouse gas emissions by 38% by 2030 (Ministry of Economic Development, 2020). Italy has also adopted the National Strategy of Adaptation to Climate Change (SNACC) (Ministry of the Environment and Protection of Natural Resources and the Sea, 2015) and the National Climate Change Adaptation Plan (PNACC) (Ministry of the Environment and Protection of Natural Resources and the Sea, 2018) based on European documents like the EU Climate Change Adaptation Strategy. Italian cities focus more on mitigation than adaptation to climate change. Larger cities are required by national law to have energy plans to reduce consumption, leading to the adoption of mitigation plans and decarbonization strategies. Italy's INECP sets growth targets for solar energy, with goals of 28 550 MW by 2025 and 52 000 MW by 2030 (Ministry of Economic Development, 2020). It also introduced guidelines for energy performance certification of buildings, requiring the integration of renewable energy sources. Since July 2009, Italy mandates Energy Performance Certificates (EPCs) for new and existing properties (ENEA, 2020). These certificates provide information on a building's energy efficiency and performance. Italy offers tax deductions for energy-saving interventions and renewable energy installations, such as Ecobonus and Bonus Casa (Ministry of Economy and Finance, 2021). In 2020, a Superbonus program was introduced, providing deductions of up to 110% for specific energy efficiency interventions. Italy has various national and international voluntary certifications for energy efficiency and sustainability, including CasaClima (Agenzia CasaClima, 2021), Italian environmental certification (ITACA) (Istituto per l´Innovazione e Trasparenza degli Appalti e la Compatibilitá Ambientale, 2011), architecture comfort environment (ARCA) (habitech, 2021), LEED (Green Building Council Italia, 2009), BREEAM (BREEAM, n.d.), WELL (Standard, 2018), and PassivHaus (Moreno-Rangel, 2020).

Norway: Norway has building codes (TEK 17 (Direktoratet for byggkvalitet, 2017)) that consider daylight and sun conditions in building placements. There are specific requirements for daylight and views in residential units and restrictions on certain actions that negatively affect neighbouring properties. The Planning and Building Act governs the installation of solar cells, allowing some exceptions. Norway follows the Zero Emission Neighborhoods in Smart Cities Research Centre (ZEN) (FME ZEN, 2021) and Zero Emission Building Research Centre (ZEB) (ZEB, 2021) to develop guidelines for buildings and neighborhoods with no greenhouse gas emissions. There's also SINTEF's building research series that provides insights into planning and construction (SINTEF, 2011). Common practices in Norway include the design of photovoltaic systems on buildings, the use of water-based solar collectors, and the calculation of sun, shadow, and horizon conditions. Additionally, guidelines for sun protection and ensuring sufficient daylight in buildings are observed. There is a document by Solenergiklyngen Norge, offering advice and guidance for municipalities seeking to integrate solar energy (Solenergiklyngen Norge, 2020).

Sweden: Sweden's future deployment of solar energy concepts and their application is influenced by the municipality's authority to determine various aspects of the built environment, such as building heights, usage, and apartment proportions (The Swedish National Board of Housing; Building and Planning, 2016). Detailed development plans should consider the existing built environment, property rights, and potential shading impacts on solar energy systems. However, these plans cannot mandate the use of specific technologies, like photovoltaic/solar thermal systems, on buildings. The law is flexible to accommodate evolving technologies. Swedish national legal framework places energy efficiency requirements on buildings, allowing deductions for energy produced by solar systems. Solar energy installations on existing buildings may not always require building permits, but new buildings typically do.

Switzerland: Switzerland's energy transition is driven by the Swiss Energy Strategy 2050, which seeks to shift away from nuclear energy and increase the use of renewables (Swiss Federal Office of Energy SFOE, 2021). Solar power production on building roofs and facades is promoted, with federal subsidies covering a substantial portion of the investment costs. The economic model encourages own consumption of solar electricity, especially when combined with heat pump systems. The Swiss Association on Solar Energy provides guidelines for solar installations, and community-based consumption groups are encouraged. Switzerland has ambitious energy regulations at both the federal and cantonal levels, with a focus on energy efficiency and renewable energy sources (The Swiss Federal Office of Energy SFOE, 2019). Labels such as (Minergie, n.d.) and international standards like LEED are commonly used. Energy regulations in Geneva are particularly stringent. The Swiss solar market is growing, with a significant increase in installations in recent years. While solar systems are commonly installed on building roofs, they are also integrated into other surfaces like facades, quarries, and water bodies.

2.4 Methods and tools

To evaluate the feasibility of different solar strategy accounting various design aspects, several tools can be used. For instance, various municipalities publish solar potential maps that can be used to estimate solar intensity and energy generation, thus making informed decisions about solar strategies. A good example is the solar cadaster developed in the Greater Geneva that provides key performance indicators for potential installation on roofs for each building in the region (Canton of Geneva, 2022).

Further, such maps can be useful in identifying optimal tilt and orientation of solar installations for a given area. Site analysis tools can be also utilized for informed decisions regarding the design of buildings, building orientations, and landscape surface uses to exploit solar energy. Some such tools examples include Google Sunroof, PVWatt, solar energy prospector, and Solar APP+. Design guidelines and standards such as relevant building and solar installation codes can be referred to ensure maximum energy efficiency and energy harvesting selecting appropriate materials. For example, solar ready guidelines by National Renewable Energy Laboratory (NREL) can be used to make decisions for solar installations. Community engagement tools such as surveys can be used to assess the needs facilitating communication between community members, designers, and planners. Further zoning and land use regulations can also be used in deciding solar strategies as it may affect the neighborhood characteristics such as limit on building heights.

To encourage the adoption of solar neighborhoods and related strategies it is useful to create a database of neighborhood archetypes. A neighborhood archetype is considred to represent a foundational model of neighborhoods, developed through the classification of patterns and typologies, serving as a basis for analyzing solar potential and sustainability performance. It encompasses criteria such as street layout, building characteristics, building types, density and other spatial and geographic characteristics (see Chapter 2). For the new solar neighborhood planning such database can be used as a resource by the urban planners and designers. Additionally, neighborhood archetype databases can be used to promote best practices in designing solar neighborhoods by showcasing successfully implemented solar design principles and strategies. The tangible archetypes examples with effective solar strategies can help planners to generate innovative ideas and solar strategies can be adapted to suit specific contexts. These archetypes can serve as foundation of replication and scalability through documentation of design strategies and respective outcomes thus can be used as roadmap for similar neighborhoods. This will lead to significant savings in cost and time as planners can adapt the archetypes to achieve the goals of the project. Solar neighborhood archetypes will eventually result in the development of a network of sustainable neighborhoods that can be served as model for professionals. These archetypes can be also used for benchmarking by the planners to evaluate the effectiveness of specific solar design strategies. The neighborhood archetype database can also facilitate communication and collaboration among various stakeholders such as urban planners, designers, architects, and community members facilitating knowledge sharing. Policymakers can also draw insights from these archetypes to make informed decisions about adoption of solar strategies at a larger scale. Such archetype database will also serve as an effective tool to educate public, professionals, and students to raise awareness as well as preparing the future workforce.

2.5 Objectives and overview of the report

This report aims at presenting various solar concepts and strategies and their application in specific neighborhoods. To achieve this objective, the report discusses first the procedure in developing archetypes of neighborhoods, representative of existing practices, as well as theoretical neighborhoods that can serve as basis to study various advanced solar strategies (Chapter 3). The report includes archetypes from seven different countries from Europe and North America capturing residential, commercial and mixed-use neighborhood archetypes, in addition to the theoretical neighborhoods, developed based on various sustainable practices.

Extensive solar strategies and concepts, both passive and active, are summarized in the report (Chapter 4). The strategies and concepts enclosed in this report, are intended to serve as examples of possibilities, and not as absolute solutions. Hence various possibilities can be beneficial for specific designs (considering context, location, etc.). Selected analysis methods are provided to evaluate those archetypes, from energy performance point of view, and to determine the impact of various solar strategies on the performance. (Chapter 5). These methods include detailed simulation approaches, employing advanced simulation tools. Finally, a preliminary decision-making tool developed to assist in evaluating various designs according to specific criteria, is presented (Chapter 6). The decision-making framework can be employed to prioritize and select relevant solar strategies depending on archetypes as well as various planning objectives such as net-zero energy neighborhoods and reducing energy consumption.

3 Neighborhood archetypes designs

This part presents a definition of neighborhood archetypes, methods of collection of information for the selected archetypes, and an overview of all the archetypes presented in this Task by the contributing experts.

3.1 Archetype definition

The Archetype is widely defined as an “original pattern or model from which all things of the same kind are copied or on which they are based; a model or first form; prototype” (Dictionary.com, 2023). In this task, archetype represents a model of neighborhoods that serves as a basis for the analysis of solar potential and performance of similar neighborhoods. Archetypes can be developed based on patterns specification, to serve as ‘indicators of urban form’ against which ‘indicators of performance’ (e.g., different aspects of sustainability) can be tested (Marshall 2005, 2004).

There is a multitude of ways in which patterns may be specified and assembled in typologies (sets of types). There is no single right or wrong way of doing this, but such classification must be meaningful to the required task. For example, several research concentrated on street network and their patterns to classify neighborhoods. For example, Duany Plater-Zyberk & Co (Duany Plater-Zyberk & Co., 2014) presented various neighborhood patterns such as Savannah, Mariemont, Riverside, Nantucket, Washington, and Radburn. Street layout has a significant impact on the design of buildings around and along them, their orientation, and thus their potential to capture and utilize solar energy. On the other hand, a number of criteria are important to be considered in the design of archetypes to allow in depth analysis of energy and carbon footprint, such as:

- Being representative of the most repetitive patterns of neighborhoods
- Being representative of special cases such as neighborhoods developed with specific energy target
- Different other criteria that include building characteristics, street layout, density, or other spatial characteristics.

3.2 Development of archetypes criteria

A set of criteria of classification is presented in (Marshall and Gong, 2005). Table 1 gives a summary of the different kinds of potential objects of classification. It demonstrates the breadth of factors potentially involved. Some criteria that can be used in the classification of archetypes include year of construction, land use (residential, industrial, commercial, etc.); green space/open space; spatial distribution (location of land uses, jobs, etc.), mixture of spatial and physical form (compact, sprawl, location in settlement, etc.), physical form, pattern structure and topology (general shape, street layout, building type/form, neighborhood type, etc.).

Table 1: Key criteria of neighborhood archetype development

Category	Archetype selection criteria
Time /construction period	1961-1970
	1971-1980
	1981-1990
	1991-2000
	2001-2010
	2011-2020+

Climate /geographic location	Northern, hot Northern, moderate Northern, cold Equatorial Southern, hot Southern, moderate Southern, cold
Pattern/special case	Repetitive pattern Special development
Spatial characteristics	Type of neighborhood (new, retrofit) Land use (residential, mixed, etc.) Building type and characteristics (shape, use, height, etc.) Location of development (downtown, outskirt, etc.) Street layout

3.3 Method to collect neighborhood information

In the realm of neighborhood performance evaluation, this section explores an understanding of effectiveness, functionality, and quality of life, examining criteria for residential, commercial, and mixed-use environments.

3.3.1 Neighborhood performance

The evaluation of neighborhood performance encompasses a comprehensive assessment of its effectiveness, functionality, and quality of life for its residents. This assessment considers many factors determining a neighborhood's desirability as a residential, commercial, or mixed-use environment. Residential neighbourhoods' performance is commonly evaluated based on criteria such as housing quality, affordability, access to amenities (e.g., schools, parks, grocery stores), safety, and community engagement. Conversely, commercial neighborhoods are primarily designated for business and commercial activities, and thus their performance is typically measured in terms of economic viability, employment opportunities, foot traffic, and business resources. In the case of mixed neighborhoods that amalgamate residential and commercial zones with recreational facilities, performance evaluation is centered on factors such as commuting distances, walkability, and the creation of vibrant live-work-play environments. It is important to note that mixed-use and commercial neighborhoods offer a more diverse environment due to their multiple uses and activities and a higher level of accessibility compared to residential neighborhoods. However, residential neighborhoods often excel in providing their inhabitants with a superior quality of life.

The physical characteristics of a neighborhood, encompassing urban forms such as density, building height, and the composition of constructed elements, exert notable influences on the area's physical, spatial, social, and economic performances (Charley, 1969). The impact of high density and intensification on neighborhood performance reveals a complex interplay, with positive effects on economic sustainability but negative implications for environmental and social sustainability (Lin and Yang, 2006). In densely populated urban areas, the configuration of the neighborhood can significantly affect environmental performance, particularly due to the dynamic interconnections among buildings, including shading effects, longwave radiant heat exchange, solar reflection, and the urban heat island phenomenon. Researchers have investigated the relationship between urban block typology, energy consumption, and thermal comfort. Taleghani et al. (Taleghani, Tenpierik, Van Den Dobbelsteen and De Dear, 2013) explored the impact of urban block typology on energy consumption and thermal comfort, revealing that the surface-to-volume ratio plays a critical role as a geometric factor, with the courtyard model outperforming single and linear models in terms of energy efficiency and thermal comfort. Rode et al. (Rode, Keim, Robazza, Viejo and Schofield, 2014) concluded from their study on representative urban fabrics and archetypal forms that urban morphological factors can significantly influence heating energy efficiency, potentially leading to up to sixfold energy savings. They also observed that compact and tall building typologies exhibit higher energy efficiency than detached houses at the neighborhood scale. Vartholomaios (Vartholomaios, 2017) conducted a parametric study to evaluate the impact of urban form on residential energy consumption for heating and cooling, identifying compactness and south orientation as crucial factors in designing energy-efficient neighborhoods with lower energy demands. Sattrup and Strømann-Andersen (Sattrup and Strømann-Andersen, 2013) investigated the influence of urban block typology on building energy consumption and daylight autonomy, revealing that variations in block typology can account for a 16% variation in building energy consumption and a substantial 48% difference in daylight autonomy. Furthermore, the physical characteristics of a neighborhood are closely linked to its vibrancy, defined as the extent to which urban form supports the essential functions, biological requirements, and capabilities of its inhabitants (Lynch, 1984). A study conducted in Oslo, Norway, indicated that the location and distribution of commercial, public, and residential areas and the total population are key drivers of neighborhood vibrancy (Lang et al., 2022). Vibrant neighborhoods typically manifest in high-density, central urban areas with a notable concentration of diverse commercial and public buildings along main thoroughfares. In contrast, less vibrant neighborhoods tend to have limited-service facilities and are surrounded by single residential areas, large venues, green spaces, or vacant land. Further investigations were conducted to assess the impact of urban form on solar access and the potential for harnessing solar energy in neighborhoods.

The relationship between urban block typology, solar energy harvesting potential, and building energy use efficiency for the tropical high-density city was investigated in Singapore (Zhang et al., 2019). The findings revealed that different urban block typologies could result in a 200% increase in solar energy harvesting potential and a 25% reduction in building net energy use intensity under identical planning conditions and design assumptions. Among the typologies studied, courtyard and hybrid urban block designs consistently outperformed commonly used tower and slab blocks, demonstrating the greatest benefit from photovoltaic (PV) deployment in tropical regions. Compagnon et al. (Compagnon, 2004) used a case study approach to examine the impact of urban form on active and passive solar heating, PV electricity production, and daylighting potential. The results showed that the potential to harvest solar energy on building surfaces varies significantly with building layouts within the same urban context and under the same density. In a series of studies, Hachem et al. (Hachem, Athienitis and Fazio, 2011, 2012; Hachem, Fazio and Athienitis, 2013a) explored the design factors affecting solar energy collection potential in two-story residential units and neighborhood layouts. They analyzed various generic building typologies with convex and concave shapes arranged in different spatial configurations. The results indicated that the shape and orientation of buildings played a significant role in maximizing the peak generation potential of solar electricity, with specific building arrangements achieving up to a 50% increase. The key design factors to consider are the depth ratio and the number of shaded facades, the angle enclosed by the wings, and the distance between parallel rows of buildings. Furthermore, the heterogeneity of building layouts, including building height, footprint area, volume, footprint aspect ratio, and surface-to-volume ratio, also influenced carbon emissions and renewable energy generation at the neighborhood level (He et al., 2023). The study revealed that the heterogeneity of building height hindered carbon reduction efforts due to increased mutual shading on rooftops, resulting in reduced solar harvesting. On the other hand, carbon reduction through building façade solar energy collection could be improved by introducing heterogeneity in building shape, including variations in aspect ratio and surface-to-volume ratio.

3.3.2 Data collection for archetype development

A framework (termed Matrix) was developed to collect information related to neighborhood designs in various countries of Europe and North America (Canada). Different types of neighborhoods were selected ranging from simple residential neighborhoods to more complex mixed-use neighborhoods, composed of various types of buildings. Targeted neighborhood size is between 300m and 500m radius.

This size is considered a manageable size to conduct energy analysis, allowing detailed simulations, exploration of urban energy systems and their interaction [67].The main objectives of the developed matrix are:

- To define all parameters relevant/required to the design and analysis of solar neighborhoods, as well as energy efficient, low carbon neighborhoods.
- To collect information about neighborhood designs in various countries.
- To determine criteria of selection of archetypes from these neighborhoods.
- To determine the assumptions that will be employed in the archetypes and overall depth of simulation of these archetypes.

The matrix is a spreadsheet that allows input data of neighborhoods' characteristics, divided into five general categories: (A) type of neighborhood, (B) neighborhood building structure and passive design, (C) solar energy generation, (D) energy systems, (E) miscellaneous information, and (F) simulation outputs. In every category, several items are listed to collect information of different types of neighborhood archetypes, such as: street layout, green areas, density indicators, building type, block design, usage type, roof design, façade characteristics, geometry, shading devices, and others. These archetypes are then simulated, and their energy performance is compared.

Filling data into the matrix is a process that should be thoroughly considered. Different tools can be used to fill the matrix, including mapping software such as Google Earth, Open Street Map, ArcGIS, and others that will combine with 3D modeling software, like SketchUp, AutoCAD, Rhino, and others to develop a model of each neighborhood. With a 3D model in place, essential data to generate an energy model can be extracted from it, like floor and rooftop areas, shading analysis, window to wall ratio, and much more. A possible variation of around 5% is expected when generating geometries out of real buildings geometric data.

Some other data that are not extractable from the model (mentioned above) needs to be addressed, like demographics for instance. Reliable data sources, such as census and regional building codes are also alternatives that can be exploited. Further, these data can be used for energy simulation and accordingly suitable solar strategies can be implemented. The flowchart shown in Figure 1 illustrates the overall process of utilizing the proposed matrix for archetype data collection. In Figure 2 the developed matrix for archetype data collection is presented. Section A, B and C of the matrix are related to neighborhood configuration features, building topography features, and detailing of solar systems, respectively. These three sections are intended to help the user in deciding criteria for archetype development based on various characteristics such as land use, street layout, spatial design, etc. Further, the data collected can be useful for geometric modeling (i.e., neighborhood building information modeling) of archetypes using modeling software like SketchUp upon the detailed information extraction using various tools such as Google Earth and OpenStreet Maps. Sections D and E of the matrix are respectively related to details of energy systems (i.e., heating and cooling systems, domestic hot water – DHW systems, etc.) and other information (i.e., other loads such as lighting, appliances, internal gains, etc. as well as information about set points and desired simulation output parameters). Sections D and E play a vital role in energy modeling of archetypes leading to simulation of neighborhood archetypes in order to assess the energy performance. Moreover, based on energy demand profiles, an informed decision making of solar strategies can be facilitated.

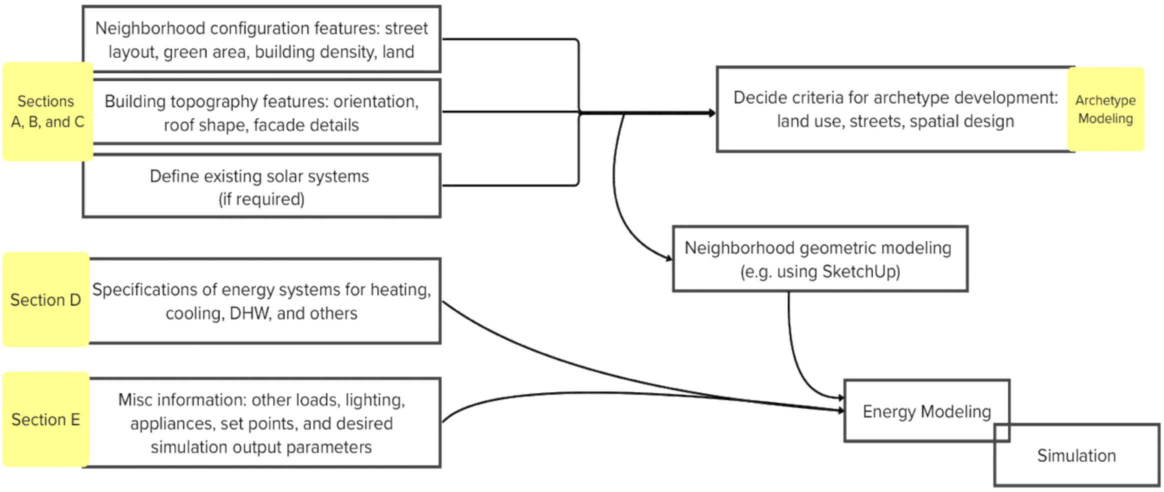


Figure 1: Workflow of collecting data using proposed matrix and its utilization for neighborhood archetype energy modeling

Archetype Matrix Exercise

Name of Participant:	Institute	Country	Location (Lat - Long; Altitude)

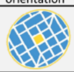
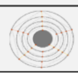
Climate zone	Degree days

** Please feel free to add below each table if something is missing*

(A) TYPE OF NEIGHBORHOOD CHARACTERISTICS

A0. General neighborhood information	Radius (m)	Total area (ha)

A1. Type of Neighborhood	Existing	New	Infill	Residential	Mixed use	Urban	Rural
Response (*tick*)							

A2. Street layout	Street to land ratio (*specify*)	Average street width (m)	Conventional grid	Conv grid- diff orientation	Radial	Curvilinear loop	Cul de sac conventional
							
Response (*tick*)							

A3. Green areas	Type of green areas			Type of vegetation			Green area to land ratio (*specify*)
Description	Parks	Open space - around buildings	Other (*specify*)	Trees	Green landscape	Other (*specify*)	
Response (*tick*)							
m² per type of green area							

A4. Density indicators	Distance between buildings		Floor to area ratio (FAR)	Residential population (per)	Residential intensity (household/ha)	Number of households	Persons per household	Other type of density indictor (*specify*)
Description	N-S axis	E-W axis						
Response (*specify in m*)								

(B) NEIGHBORHOOD BUILDING STRUCTURE AND PASSIVE DESIGN ELEMENTS

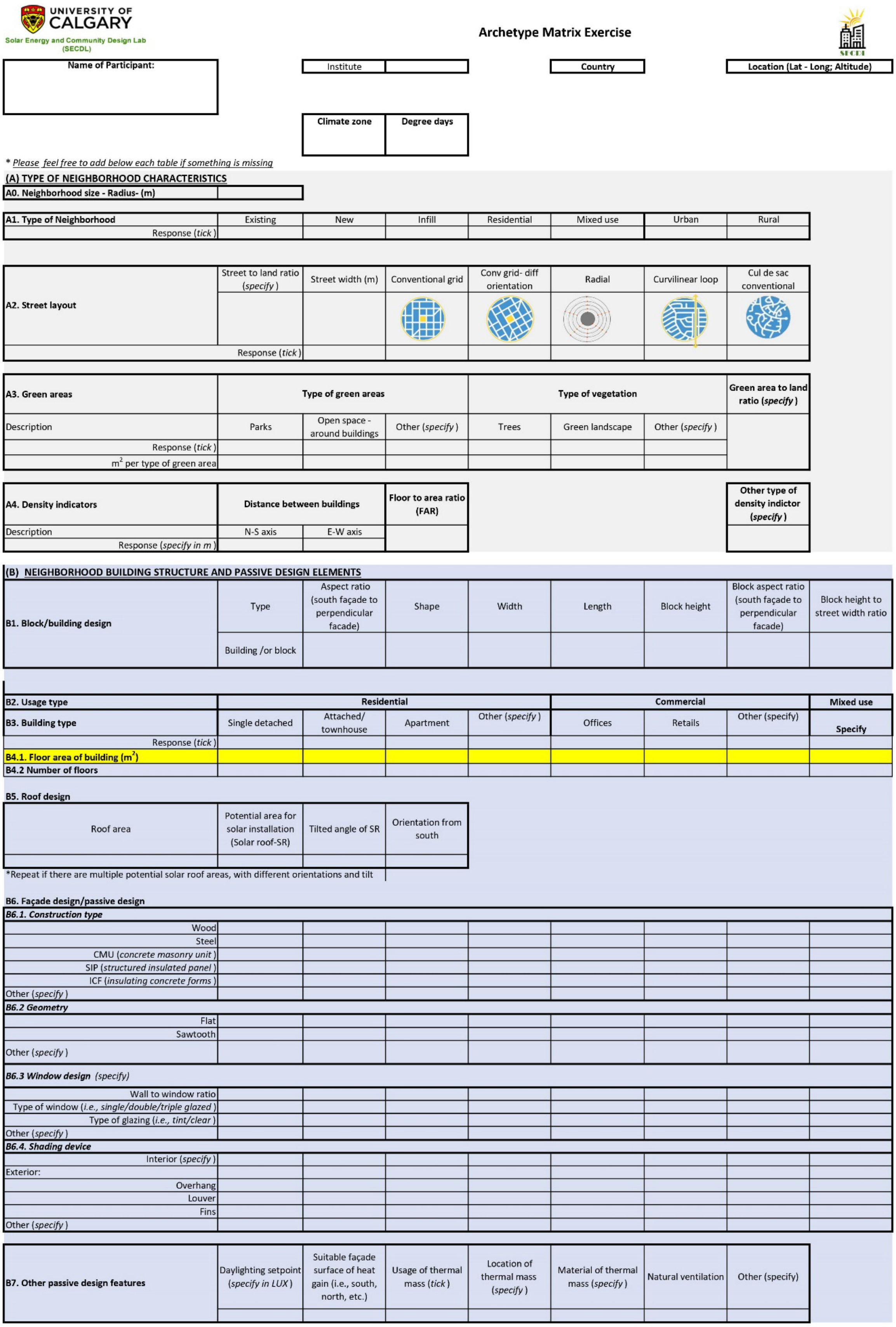
B1. Block/building design	Type	Aspect ratio (south façade to perpendicular facade)	Shape	Width (m)	Length (m)	Block height (m)	Block aspect ratio (south façade to perpendicular facade)	Block height to street width ratio
	Building /or block							

B2. Usage type	Residential				Commercial			Mixed use
B3. Building type	Single detached	Attached/ townhouse	Apartment	Other (*specify*)	Offices	Retails	Other (specify)	Specify
Response (*tick*)								
B4.1. Floor area of building (m²/building)								
B4.2 Number of floors (or storey)								
B4.3 % of given total use to total land area								-
B4.4 Total area of each use (m²)								-
B4.5 Number of units								
B5. Roof design								
Roof area								
Potential area for solar installation (Solar roof-SR)								
Tilt angle of SR								
Orientation from south								

**Repeat if there are multiple potential solar roof areas, with different orientations and tilt*

B6. Façade design/passive design

	Single detached	Attached/ townhouse	Apartment	Other (*specify*)	Offices	Retails	Other (specify)	Other (specify)
B6.1. Construction type								
Wood								
Steel								
CMU (*concrete masonry unit*)								
SIP (*structured insulated panel*)								
ICF (*insulating concrete forms*)								
Other (*specify*)								
B6.2 Geometry								
Flat								
Sawtooth								
Other (*specify*)								
North façade area (m²)								
North window to wall ratio 0-10%								
11-30%								
31-50%								
>50%								
South façade area (m²)								
South window to wall ratio 0-10%								
11-30%								
31-50%								
>50%								



UNIVERSITY OF CALGARY
Solar Energy and Community Design Lab (SECDL)

Archetype Matrix Exercise

Name of Participant:	Institute		Country	Location (Lat - Long; Altitude)
	Climate zone	Degree days		

* *Please feel free to add below each table if something is missing*

(A) TYPE OF NEIGHBORHOOD CHARACTERISTICS

A0. Neighborhood size - Radius- (m)	

A1. Type of Neighborhood	Existing	New	Infill	Residential	Mixed use	Urban	Rural
Response (*tick*)							

A2. Street layout	Street to land ratio (*specify*)	Street width (m)	Conventional grid	Conv grid- diff orientation	Radial	Curvilinear loop	Cul de sac conventional
		Response (*tick*)					

A3. Green areas	Type of green areas			Type of vegetation			Green area to land ratio (*specify*)
Description	Parks	Open space - around buildings	Other (*specify*)	Trees	Green landscape	Other (*specify*)	
Response (*tick*)							
m^2 per type of green area							

A4. Density indicators	Distance between buildings		Floor to area ratio (FAR)	Other type of density indictor (*specify*)
Description	N-S axis	E-W axis		
Response (*specify in m*)				

(B) NEIGHBORHOOD BUILDING STRUCTURE AND PASSIVE DESIGN ELEMENTS

B1. Block/building design	Type	Aspect ratio (south façade to perpendicular facade)	Shape	Width	Length	Block height	Block aspect ratio (south façade to perpendicular facade)	Block height to street width ratio
	Building /or block							

B2. Usage type	Residential				Commercial			Mixed use
B3. Building type	Single detached	Attached/ townhouse	Apartment	Other (*specify*)	Offices	Retails	Other (specify)	Specify
Response (*tick*)								
B4.1. Floor area of building (m^2)								
B4.2 Number of floors								

B5. Roof design

Roof area	Potential area for solar installation (Solar roof-SR)	Tilted angle of SR	Orientation from south

*Repeat if there are multiple potential solar roof areas, with different orientations and tilt

B6. Façade design/passive design

B6.1. Construction type
Wood
Steel
CMU (*concrete masonry unit*)
SIP (*structured insulated panel*)
ICF (*insulating concrete forms*)
Other (*specify*)
B6.2 Geometry
Flat
Sawtooth
Other (*specify*)
B6.3 Window design (*specify*)
Wall to window ratio
Type of window (*i.e., single/double/triple glazed*)
Type of glazing (*i.e., tint/clear*)
Other (*specify*)
B6.4. Shading device
Interior (*specify*)
Exterior:
Overhang
Louver
Fins
Other (*specify*)

B7. Other passive design features	Daylighting setpoint (*specify in LUX*)	Suitable façade surface of heat gain (i.e., south, north, etc.)	Usage of thermal mass (*tick*)	Location of thermal mass (*specify*)	Material of thermal mass (*specify*)	Natural ventilation	Other (specify)

Figure 2: Illustration of various parts of the matrix

As mentioned above, the matrix can be used to collect useful information to carry on detailed urban - scale energy simulations, and to explore different types of technologies including the integration of active solar strategies (i.e., PV panels and solar thermal collectors) as well as useful in the assessment of passive solar strategies. Figure 3 illustrates the use of various parts of the matrix, at different stages of a neighborhood study. It also presents potential sources of information that can be employed to fill in the matrix of a specific neighborhood. For instance, tools like Google Earth and OpenStreet maps can provide some general information about the street width, building plans, building elevations etc. Data can be then input (or exported) into drawing software, that allows to have more precise information, especially geometry related (such as area of facades and roofs, roof inclinations, and others) to input into the matrix. Other information, for instance related to construction types and demographic information, can be obtained from published datasets from local governmental authorities.

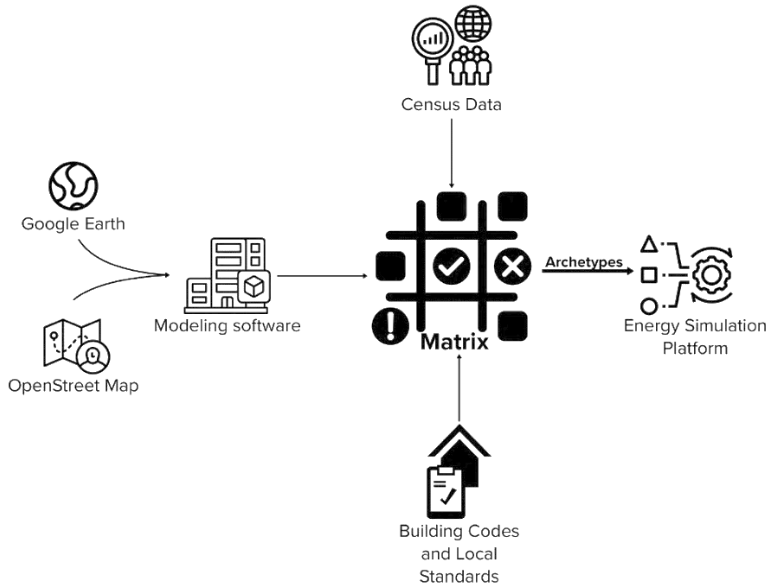


Figure 3: Potential sources of information to feed into the matrix

3.4 Archetypes selected for analysis

In this section, we delve into a comprehensive exploration of archetypes curated by experts, examining the specific criteria guiding their selection. Initially, we provide a succinct overview of the archetypes presented by each country, followed by a comprehensive summary encompassing all archetypes, complete with a detailed table outlining their main characteristics.

3.4.1 Canadian archetypes

A total of 12 neighborhoods in different provinces are selected as a case study for each layout representative of urban patterns in Canada. The neighborhoods analyzed are from various Canadian provinces such as British Columbia, Alberta, Manitoba, Ontario, and Quebec. These five provinces together accounted for around 87% of the total Canadian population. Figure 4 shows aerial views of the selected area of seven neighborhoods considered in the archetype's selection.

Figure 4: Aerial views of seven neighborhoods such as (a) Toronto – East York, (b) Vancouver – Mount Pleasant, (c) Calgary – Parkdale, (d) Richmond – Brighouse, (e) Calgary – Saddle Ridge, (f) Winnipeg – Glendale, and (g) Montreal – Mount Royal

- Toronto – East York (Figure 4a): The selected area analyzed in this study comprises 44 dwellings, of which 100% are classified as detached houses. The average area is 115 m^2 per household, and the total floor area is around 5059 m^2. The average population is 2.2 people per dwelling, and the primary heating system source used is Natural Gas.

- Vancouver – Mount Pleasant (Figure 4b): The selected cluster of dwellings comprises 19% of detached houses and 81% of apartments, totaling an amount of 163 dwellings: 31 detached houses and 132 apartments. The total floor area is around 16 615 m^2, averaging 102 m^2 per household. The average population per household is 2.6, and the main heating system source is natural gas, followed by electricity. The following image shows the area selected to be analyzed.

- Calgary – Parkdale (Figure 4c): The area included in this study presents 25 dwellings, of which 17 are detached houses (68%), and eight are attached houses (32%). The total floor area of those households is 3 449 m², averaging 138 m² per house. The average population is 2.2 people per household, and the main heating system source is natural gas.

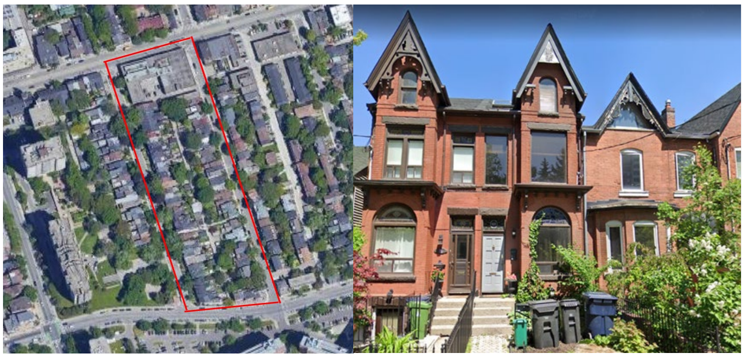
- Richmond – Brighouse (Figure 4d). The selected region is composed of 44 detached houses, which is the only building type present in the area. The total floor area is 10 100 m², and the average area per dwelling is 229 m². The average population of Brighouse is 2.6 persons per household, and the main heating system source is natural gas, followed by electricity.

- Calgary – Saddle Ridge (Figure 4e). The area selected for this study comprises 54 dwellings, of which 26 are detached houses (48%), and 28 are attached houses (52%). The total floor area is 8 895 m², and the average area of a household is 165 m². The average population per household is 4.1, and the main heating system source is natural gas.

- Winnipeg – Glendale (Figure 4f). The area selected for this study comprises 24 dwellings, all being categorized as detached houses. The total floor area is 6.986 m², and the average area of a household is 291 m². The average population per household is 2.2, and the main heating system source is natural gas.

- Montreal – Mount Royal (Figure 4g). The selected area has 40 dwellings, of which 36 of them are detached houses (90%), and four are attached houses (10%). The total floor area is 13 875 m², and the average area per dwelling is around 347 m². The average population per household is 2.3 people, and the primary heating system source is electricity.

Further, several neighborhoods are particularly studied focusing the work on Eastern Canada. For this purpose, in Toronto, five neighborhoods, Cabbage Town, Downtown, Richmond Hill, St. James Town, and North of 401, are selected for investigating the neighborhood forms, geometry, and solar energy potential. All neighborhoods are characterized by temperate mild summer and extreme minimum temperature varying from -29ºC to -26ºC. The detailed description for each neighborhood is as below.



(a)

(b)

(c)

(d)

Figure 5: Five neighborhoods studied in Eastern Canada such as (a) Cabbage Town, (b) Richmond Hill, (c) Downtown, (d) north of 401

- Cabbage Town (Figure 5a): It is a residential neighborhood covering an area of 2.64 ha with a radius of 148.08 m. The streets are laid out in conventional grid-different orientations and are 20 m wide. The major form of vegetation in the neighborhood is trees. The residential intensity in the neighborhood is 23.86 per/ha, and there are 63 households with 2 persons per household. The building type in the neighborhood is the attached townhouse, each with a floor area of 338 m^2 and 2 floors. For interior shading, curtains are used, and porches provide exterior shading. These townhouses employ furnaces and boilers for heating systems, central air conditioning, and ceiling fan as cooling systems. The domestic hot water supply is based on gas.

- Richmond Hill (Figure 5b): This residential neighborhood is spread over 6.75 ha. The street width is 13 m, and the layout is Cul de sac conventional. The neighborhood has 44 207 m^2 of green area with a green area-to-land ratio of 0.66. The distance between the buildings is 3 m along the N-S axis and 38 m along the E-W axis. The residential intensity is 8 households per ha, with 2.35 persons per household. The neighborhood has 54 single detached houses, each having a floor area of 711 m^2 and two floors. The shape of houses is rectangular, and they are developed in a block pattern. These homes have furnaces and boilers for heating, central air conditioning, and ceiling fans for cooling. Gas is used to provide household hot water.

- Downtown (Figure 5c): It is a mixed-use neighborhood having an area of 3.9 ha with a radius of 86.4 m. The streets follow a conventional grid pattern and are 21.20 m wide. The open green area is mostly in the form of green spaces around buildings. The buildings are 26 m apart on the N-S axis and 44 m on the E-W axis. The neighborhood has a residential intensity of 56.9 households/ha with 1.70 people per household. The floor area occupied by the eight office buildings is 78 532 m^2, and these buildings are 30 stories high. The construction of buildings is in-situ reinforced concrete, with a window wall ratio of 40 %. The windows are double-glazed and tinted, and the application of curtain walls into the façade is common. However, these buildings have no interior and exterior shading provisions. On the contrary, the solar roof potential for this neighborhood block is high as there is a degree of randomness in the heights of adjacent buildings (a mix of high-rise and mid-rise).

- North of 401 (Figure 5d): It is a rural residential neighborhood that is not densely populated, spanning an area of 6.43 hectares. The layout of the streets follows the conventional cul-de-sac pattern and has a width of 10 meters. The neighborhood has approximately 44 847 square meters of green spaces, primarily consisting of trees and green landscapes. The buildings in the neighborhood are positioned at intervals of 30 meters along the north-south axis and 6.80 meters along the east-west axis. The residential density is measured at 4.82 households per hectare, and each household typically consists of 2.46 individuals. The primary residential building type in the neighborhood is a two-story, detached house with a floor area of 343 m², while other structures within the block are single-story. The windows in the buildings have a varying window-to-wall ratio, ranging from 11% to 30%, and they are made of clear double or triple-glazed glass. Interior shading is provided through the use of Venetian blinds. For heating purposes, the buildings utilize a combination of furnaces, boilers, and air-source heat pumps with a coefficient of performance (COP) of 3. Cooling is achieved through central air conditioning systems and ceiling fans. As for the domestic hot water supply, it is based on gas.

3.4.2 Danish archetypes

The Danish archetypes are described below.

- ***New Urban Quarters – Årslev:*** Proposal for an existing open field farming area which is transformed into a new urban development in an open and light structure. The area is divided in three individual structures organized in a village like lay-out. The total area is ≈ 200.000 m² and have a total floor area of ≈ 53.320 m². Roads, path-ways and parking constitutes to ≈ 27.100 m² and recreative areas are ≈ 146.820 m² corresponding to a building plot ratio of ≈ 27 %. The area incorporates 94 single family houses, 262 row-houses, 86 youth housings, 94 senior homes. The area includes ≈ 1.000 parking lots. The area holds a potential for implementing 21.000 m² PV-modules corresponding to 2.900 MWh_e situated on ≈ 70 % of the roof area.
- ***Tage Hansens Gade - Århus:*** Proposal for transformation of existing buildings worthy of preservation in an old hospital facility into a new modern and relatively dense urban quarter including some demoliton and construction of new buildings in the heart of Århus (Denmarks second largest city). The total area is ≈ 67.000 m² and have a total floor area of ≈ 101.500 m² corresponding to a building plot ratio of ≈ 150 %. This includes ≈ 7.500 m² for retail, daycare center, culture facilities, etc. The area incorporates ≈ 60 student housings, ≈ 67 public housing homes, ≈ 670 privately owned row houses and apartmentsrental apartments and 41.000 m² for public housing (incl. 110 nursing homes) 3.000 m² for retail, cafe's etc., 14.800 m² for public school incl. indoor sport facalities and 2.200 m² for daycare centers. The area is planned for ≈ 480 parking lots. The area holds a potential for implementing 6.400 m² PV-modules corresponding to 900 MWh_e situated on ≈ 50 % of the roof area.
- ***New Urban Quarters - Vejland Quarters:*** Proposal for an existing open field area in central Copenhagen to be developed into a new relatively dense urban housing area. The area is organised in a dynamic and organic structure with one large central ring road for main traffic. The total area is ≈ 181.000 m² and have a total floor area of ≈ 219,000 m² corresponding to a building plot ratio of ≈ 120 %. Recreative areas are ≈ 6.300 m². The area is surrounded with several km² of public green areas. The area incorporates 192 student housings, 390 community housing homes, 1.118 private rental apartments and 41.000 m² for public housing (incl. 110 nursing homes) 3.000 m² for retail, cafe's etc., 14.800 m² for public school incl. indoor sport facilities and 2.200 m² for daycare centers. The area is planned for ≈ 900 parking lots. The area holds a potential for implementing 37.500 m² PV-modules corresponding to 5.250 MWh_e situated on ≈ 75 % of the roof area.

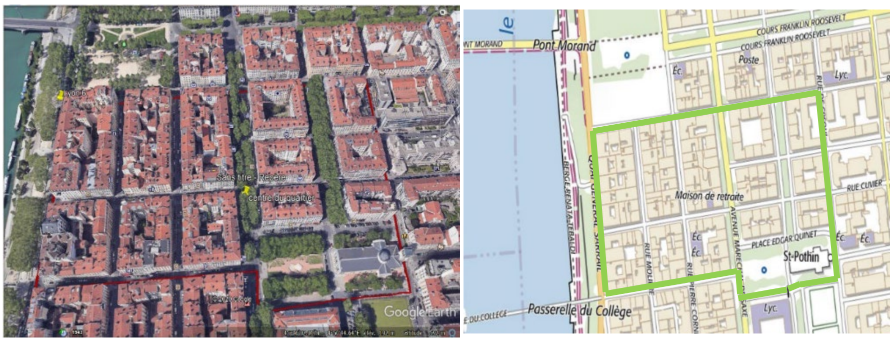
3.4.3 French archetypes

In France, as presented in Figure 6 two neighborhoods are selected in the city of Lyon (i) Confluence and (ii) 6th Arrondissement. Confluence was developed recently under a European program called Renaissance, and energy efficiency measures such as building integrated solar systems were incorporated into the neighborhood since the planning phase. On the other hand, the 6th Arrondissement is an old district consisting of apartment blocks, representing the typical neighborhood design and architecture of Lyon.

Figure 6: Satellite view of two selected neighborhoods in France (source Google Earth)

- Confluence (Figure 7a): This mixed-use urban neighborhood consists of Lot A, Lot B, and Lot C developed with a conventional grid-type street layout. Each Lot hosts a cluster of rectangular-shaped buildings with 6 to 10 floors exclusively as apartments, and the ground floor is used as shops, restaurants, and offices. The neighborhood has 21 buildings, each with a floor area of 571 m^2. The neighborhood has 671 households with an average population of 2 people per household.
- 6th Arrondissement (Figure 7b)**:** The studied area includes 13 blocks having 6 stories tall buildings, mostly apartments. There are 141 buildings, each with a floor area of 313 m^2, street width is 15.1 m, and layout is conventional grid. The total number of households in the area is 1230, and the average population is 2 people per household.

(a)



(b)

Figure 7: Visual representations of two neighborhoods analyzed in France (a) Confluence, and (b) 6th Arrondissement

3.4.4 Italian archetypes

In Bolzano city, Italy, two neighborhoods (Sinfonia district & South industrial area) are selected, and in Trento city, one neighborhood (Stardust) is selected, as a case study, based on existing building typology. Detailed information about neighborhood locations is presented in Figure 8. The Sinfonia district neighborhood consists of two social housing blocks refurbished with innovative technologies, such as PV, solar thermal and building integrated solar thermal (BIST). The South industrial neighborhood is prone to the urban heat island effect and high air pollution, forcing competition between green and PV roofs. BIPV and geothermal water-to-water heat pumps are employed in the Stardust neighborhood to achieve Net zero energy building (NZEB) status.

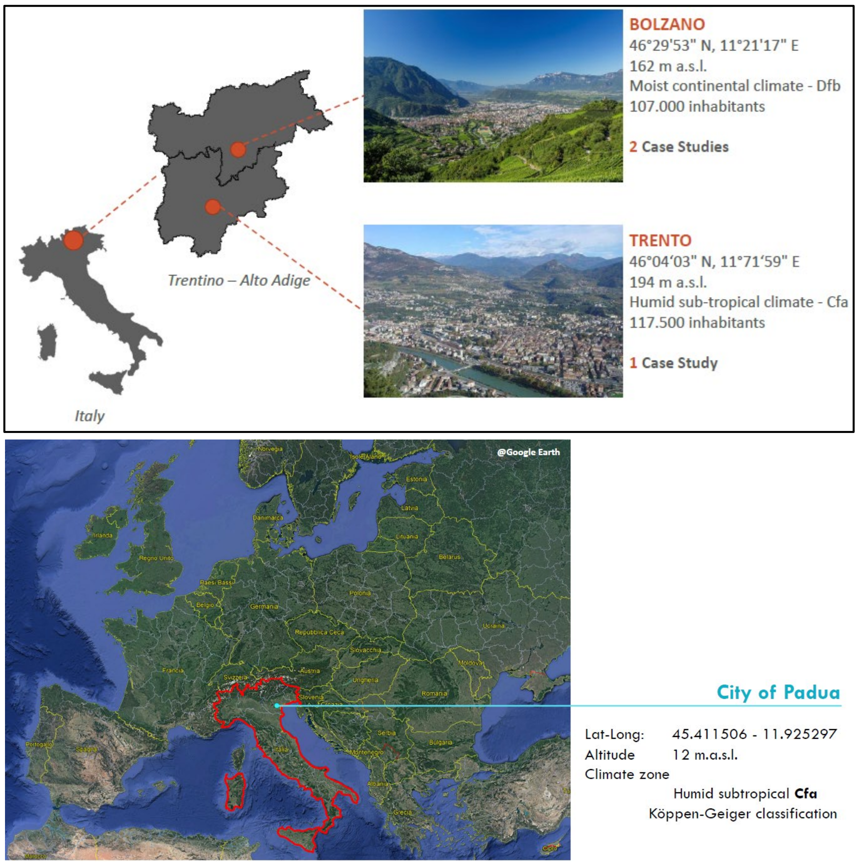


Figure 8: Location of neighborhoods selected in Italy in (a) Bolzano and Trento as well as (b) in Padua

- Sinfonia district (Figure 9a): It is a residential neighborhood covering 2.41 ha, and the building blocks were constructed in the 60s and 70s. The streets are 9 m wide with a conventional grid-type layout. The Brescia building in this neighborhood has a floor area of 9 400 m^2 and incorporates 106 apartments. 80 PV modules and 218 m^2 of solar thermal system are installed on the roof, and the south façade of the building has 155 m^2 of integrated PV.

(d)

Figure 9: Various studied neighborhood archetypes in Italy (a) Sinfonia district, (b) South industrial area, (c) Stardust, and (d) North Padua

- South industrial area (Figure 9b): It is a mixed-used industrial neighborhood spanning 100 ha, consisting of retail, offices, and residential spaces. The streets are laid in a conventional grid-type layout with a width of 18.5m and an orientation of 17.5 degrees N/NE. The distinguishing feature of this neighborhood is a high percentage of sealed soil, leading to a greater urban heat island effect and high traffic levels causing pollution. The electricity needs of the industries conflict with citizens' need for improved thermal comfort and air quality; hence, this situation poses a competition between solar active roof systems and green roofs.
- Stardust (Figure 9c): This social housing site consists of 14 identical towers with a common green space, and this entire neighborhood covers an area of 30.2 ha. The street has a curvilinear loop pattern with an average street width of 10.2 m. The three towers in this neighborhood are retrofitted for net zero. The NZEB measures include BIPV, improved thermal

insulation, optimized shading, and geothermal water-to-water heat pumps. The building towers are rectangular shaped and have 13 floors.

- North Padua (Figure 9d): This mixed-use neighborhood covers an area of 101 ha, of which the buildings occupy 39 percent. The streets are 19 m wide and follow a conventional grid pattern. This neighborhood contains 12 blocks having rectangular or trapeze shapes. There are 459 units, of which 23 are single detached houses, 160 are offices, and 136 are industrial units. The heights of buildings vary from 6 to 40 m. The neighborhood has 6 090 m^2 of south-oriented PV panels with 30 degrees tilt, and about 144 323 m^2 of PV area is proposed for future expansion.

3.4.5 Norwegian archetypes

NTNU campus at Gloshaugen is selected as a study area (Figure 10) for Norway. The campus covers 33.9 ha of the area that is under redevelopment to become a zero-energy neighborhood. Under redevelopment, 40 m^2 of the existing building will be refurbished, and 90 m^2 of new building will be developed. The total floor area of buildings is 30 976 $m^{2,}$ which are 3 to 13 floors high. The residential intensity in the neighborhood is 553.2 people per ha. The neighborhood has green areas in the form of parks, open spaces around buildings, and sports fields. The streets follow a curvilinear pattern and are 6.5 m wide. Further, the campus has 100 m^2 of façade integrated PV facing southeast, 92 m^2 of roof integrated PV with 42 degrees tilt facing south, and 6.5 m^2 of solar thermal collectors facing south with 42 degrees tilt. The campus also hosts the ZEB living laboratory, ZEB test cell laboratory, and ZEB Flexilab.

Figure 10: Details of NTNU campus archetype and example buildings involved

3.4.6 Swedish archetypes

In Sweden, Malmo Kungsgatan is selected as a study area. Malmo Kungsgatan (Figure 11) is a mixed-use urban neighborhood with residential apartments and schools with large rectangular courtyards, developed before 1960.

There are 6 130 residential units four floors high and 2 five-floor high schools covering 5 397 m^2. The total neighborhood area is 28.3 ha, and streets are laid out in a conventional grid-type layout. The regular street width is 15 m, and the main street width is 30 m. This neighborhood has 3 046 households with a residential intensity of 216.6 people per ha.

Figure 11: Aerial view of Malmo Kungsgatan mixed-use neighborhood in Sweden

3.4.7 Swiss archetypes

Cite Carl Vogt, Geneva neighborhood is selected as a study area for Switzerland as shown in Figure 12. This 2.2-hectare mixed-used urban neighborhood has 14 social residential buildings, structured into 5 blocks, of 32 m height, oriented towards NW-SE, and retail stores are available on the ground floor. Each of the 14 residential units has 8 floors having an area of 328 m^2. For retail, there are 7 units with a floor area of 300 m^2. The neighborhood has three street layouts, i.e., conventional-grid, conventional-grid different orientations, and curvilinear loop, with a street width of 10 m. There are 482 households (868 inhabitants) with a population intensity of 1.8 people per household. The total roof area represents about 4 500 m², which represents, according to the solar cadaster of the Greater Geneva a potential of about 500 kWp for solar PV as shown in Figure 13. A global renovation of the 5 units is underway (from 2018 to 2024) as presented in Figure 14. As the buildings are heritage protected, the insulation of facades is limited in order to preserve some architectural features. PV solar panels have been installed on some parts of the roofs totalizing a power of 210 kWp (see Figure 15). The neighborhood initially heated by fuel has been connected by the district heating network supplied 80% by a heat pump (using the lake as cold source) and 20% by gas, which considerably reduces the carbon footprint comparing to the initial situation.

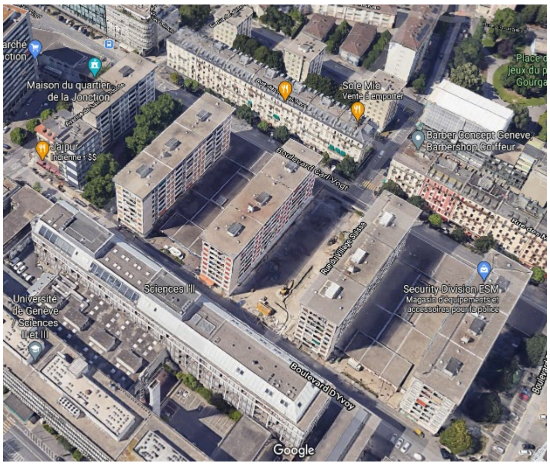


Figure 12: Aerial view of Cite Carl Vogt mixed-use neighborhood in Switzerland (©Google)

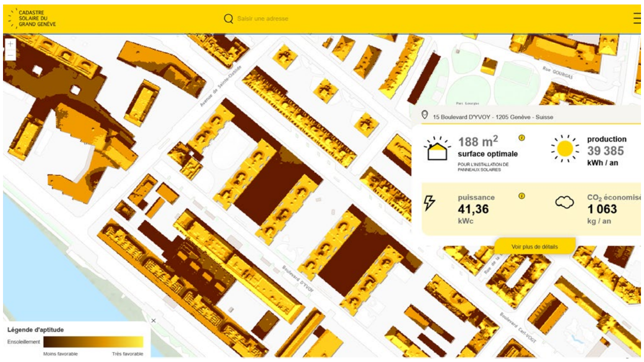


Figure 13: Extract of the Geneva Solar Cadaster of the studied neighborhood (©https://apps.sitg-lab.ch/solaire/)

Figure 14: Mock-up of the renovation project (©Hospice General)

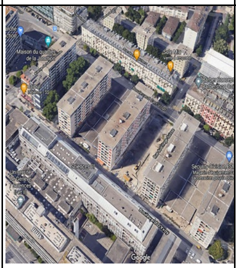
Figure 15: Solar panel installation on one of the roofs (©YellowPrint)

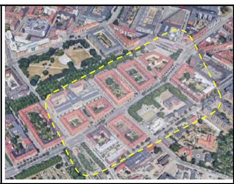
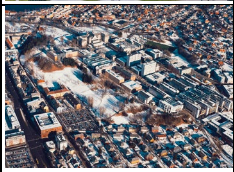
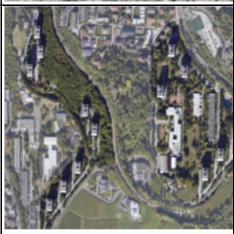
3.5 Summary of archetypes and their main characteristics

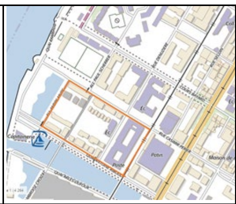
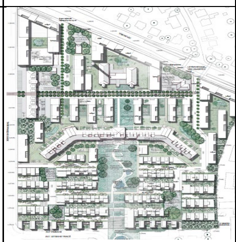
Table 2 lists Canada (North America) and European countries and their criteria for selecting buildings for solar potential and renovation measures. Switzerland and Norway both prioritize repetitive neighborhood patterns and buildings with specific characteristics or construction periods, as well as solar potential. Archetypes from Sweden focus on representative buildings, grouping buildings by year and type, and proposed renovation measures. For Italy, archetypes of typical Italian districts with encompassing solar strategies and available data are presented. The expert from France focused on social diversity, local energy production, and innovative solutions for energy needs, with a focus on already installed solar systems. However, Danish experts selected buildings for new urban developments, both in rural and existing urban areas. Their selection also included the reuse of existing buildings, such as transforming an old hospital into a new urban quarter. For Canadian archetypes list, it prioritizes repetitive neighborhood patterns and buildings with specific characteristics such as street layout, density, and construction period, as well as special cases that demonstrate potential for solar energy. Based on this, below are six key criteria for selecting archetypes:

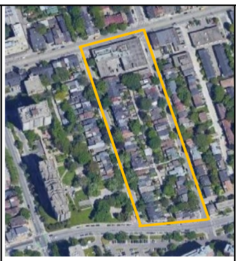
- Repetitive neighborhood patterns under various land usages (i.e., residential, commercial, or mixed-use)
- Specific neighborhood characteristics such as street layout, density, and construction period
- Solar potential, solar strategies, and renovation measures
- Availability of data

Table 2: Summary of studied neighborhoods in various countries

Country	**Criteria of selection**	**Area of Archetypes**	**Schematic**	**Type of neighborhood**	**Existing solar-related strategies**
Switzerland	- Representative of typical blocks of existing residential buildings of the period 1960 – 1980. - Special case: social housings and heritage constraints - Global energy project and approach (solar, renovation, fuel switch) with social and heritage issues	Cité Carl Vogt, Geneva		Existing residential use with shops on the ground floor	- Active solar strategy with Solar PV panels - Connection to DH network for heating and cooling - Building retrofitting with consideration of heritage constraints

Sweden	- Representative buildings - Buildings grouped by year (1960-2005) and building typology - Proposed renovated measures - Conventional grid street layout	Malmö Kungsgatan		Existing mixed-use (residential + school)	- PV installation (proposed) - Passive design optimization
		Lund Rådhusrätten		Existing residential use	
Norway	- Most repetitive patterns of neighborhoods - Special cases, that demonstrate some solar potential - Building characteristics, street layout, density, or other spatial characteristics - Climatic zone and geolocation - Period of construction - Conventional grid – different orientation	NTNU Trondheim		Existing institutional use	- Active and passive solar strategies - HVAC solutions in mutual interaction with people - Innovative materials
Italy	- Representative of typical Italian districts - Encompassing solar strategies - Availability of data	Bolzano, Sinfonia District		Existing residential district	-PV and ST on roofs, - BIST on the south facade - Connection to DH network
		Bolzano, South industrial area		Existing mixed-use: industrial, retail, offices, tertiary, residential	- Solar active systems - Competition between solar active systems and green on roofs
		Stardust		Existing residential district	NZEB retrofitting of 3 towers. - Construction of technological floor with BIPV - Improved building envelopes - Optimized shading - Free cooling solutions - Geothermal water-to-water heat pumps - Connection to the district heating network with heat waste recovery from the supermarket
		Area zip North, Padua		Existing industrial district	Solar systems are already installed on different buildings

France	Solar systems already installed, focusing on social diversity, local energies, and innovating solution for energy needs	Confluence		Existing mixed-use	- Solar systems are already installed on different buildings
	An old district composed of apartment blocks, which can be considered as typical from Lyon by its design and architecture.	District in the 6th arrondissement of Lyon		Existing residential district	
Denmark	- New urban development including sustainable solutions. - All buildings must be based on wood constructions	Copenhagen New Urban Quaters		New mixed-use: 3.400 apartments + schools, kindergartens	- 75% of roof area is suited for PV panels - Good daylight access
	- New sustainable urban development in rural areas. Must achieve DGNB-Gold certification	Årslev New Urban Quarters		New residential: 600 apartments. In total ≈ 53.000 m². Up to 3 storeys.	- 70 % of roof area suited for PV (May cover energy demand of 665 homes) - 76 % of ground floor has good daylight access - attractive outdoor accommodation conditions
	- Existing urban area - Partly re-use of existing building (Transformation of old hospital into new urban quarter)	Århus Transformation		Existing Transformation of existing buildings and construction of new residential: 800 apartments. In total ≈ 92.000 m². Up to 7 storeys.	- 90 % of roof area suited for PV - 98 % of ground floor has good daylight access
Canada	- Most repetitive patterns of neighborhoods - Special cases, that demonstrate some solar potential - Building characteristics, street layout, density, or other spatial characteristics - Period of construction	Downtown Toronto		Existing mixed use: Commercial/residential neighborhood	- Active PV is not suitable (due to presence of equipment and other auxiliaries on roofs) - Overshadowing of building restrict passive opportunities
		Richmond Hill (Toronto)		Existing residential neighborhood	- Active and passive solar - District heating (proposed in study)

		Cabbage Town (Toronto)		Existing residential neighborhood	- Active and passive solar
		North of 401 (Toronto)		Existing residential neighborhood	- Active and passive solar
		Saddlestone (Calgary)		Existing residential neighborhood	N/A
	- Most repetitive patterns of neighborhoods - Special cases, that demonstrate some solar potential - Building characteristics, street layout, density, or other spatial characteristics	Parkdale (Calgary)		Existing residential neighborhood	N/A
		Richmond – Brighouse		Existing residential neighborhood	N/A
		Winnipeg – Glendale		Existing mixed-use neighborhood	N/A
		Montreal – Mount Royal		Existing residential neighborhood	N/A
		Vancouver – Mount Pleasant		Existing mixed-use neighborhood	N/A
		Toronto – East York		Existing mixed-use neighborhood	N/A

3.6 Overview of main characteristics

In the above presented neighborhoods in various countries, the selection criteria may vary. For instance, the characteristics of the neighborhoods can be categorized in terms of climate and spatial characteristics as presented in Table 3

Table 3: Climate and spatial characteristics of various archetypes in different countries

Neighborhood name	Climate characteristics					Spatial characteristics										
	Climate					Type of Neighborhood		Location		Land Use		Street Layout				
	Tropical	Arid	Temperate	Continental	Cold	Existing	New	Urban	Rural	Residential	Mixed	Conventional grid	Conv grid- diff orientation	Radial	Curvilinear loop	Cul de sac conv.
Canada																
Downtown					•	•		•			•	•				
Richmond Hill					•	•				•					•	
Cabbage Town					•	•				•		•				
North of 401					•	•			•	•		•				
Fairfield Park					•	•					•	•				
Saddle Town					•	•				•		•				
Parkdale					•	•				•			•			
Bridlewood					•	•				•						•
Arbor Creek					•	•				•		•	•			
Denmark																
Vejland Quarters			•				•	•			•			•		
Tage Hansens			•				•		•	•				•		
Årslev			•				•		•	•				•		
France																
Confluence, Lyon city			•			•		•			•	•				
6th Arrondissement			•			•		•			•	•				
Italy																
Sinfonia district			•			•		•		•		•				
Bolzano south industrial			•			•		•			•		•			
Stardust			•			•		•		•					•	
North Padua			•			•		•			•	•				
Norway																
NTNU campus					•	•		•			•		•			
Sweden																
Malmö Kungsgatan					•	•		•			•	•				
Lund Rådhusrätten					•	•				•		•				
Switzerland																
Cite Carl Vogt			•			•		•		•		•				

(i) Climate

In the six European countries (Denmark, France, Italy, Sweden, Switzerland, and Norway), most neighborhoods fall under the Continental and Temperate climate zones according to the Köppen classification. Continental climates are characterized by significant temperature variations between seasons, featuring cold winters and warm to hot summers. On the other hand, Temperate climates exhibit moderate temperatures, distinct seasons, and a variety of precipitation patterns. Norway is an exception, as its neighborhoods fall under the polar climate zone due to its high latitude. In the case of Canada, the climate classification is based on plant hardiness zones, with most Canadian neighborhoods falling under zone 5a.

(ii) Spatial Characteristics

- Type of neighborhood/location: The areas selected for implementing solar strategies predominantly consist of existing neighborhoods. These neighborhoods are refurbished or retrofitted with innovative technologies such as PV (Photovoltaic), solar thermal, and BIST (building integrated solar technologies). In France, the Confluence residential neighborhood, developed as part of the European Renaissance program, has integrated energy efficiency measures, including building integrated solar systems right from the planning phase. However, it is worth noting that Denmark is currently exploring the potential for integrating solar strategies in new neighborhoods.
- Land use: In European countries, both residential and mixed neighborhoods primarily consist of apartment units housed in multistorey buildings. However, in Canada, residential neighborhoods mainly comprise detached and attached housing units. Detached housing units account for over 70 percent of the total housing in most neighborhoods, except Vancouver and Saddle Ridge. In Vancouver, detached houses make up 19 percent of the total housing, while in Saddle Ridge, they account for 48 percent.
- Street layout: The predominant street layout in most European countries is the conventional grid with different orientations. This is followed by the conventional grid layout and curvilinear loop layout. However, in Canada, a few neighborhoods also utilize the cul-de-sac conventional street layout.

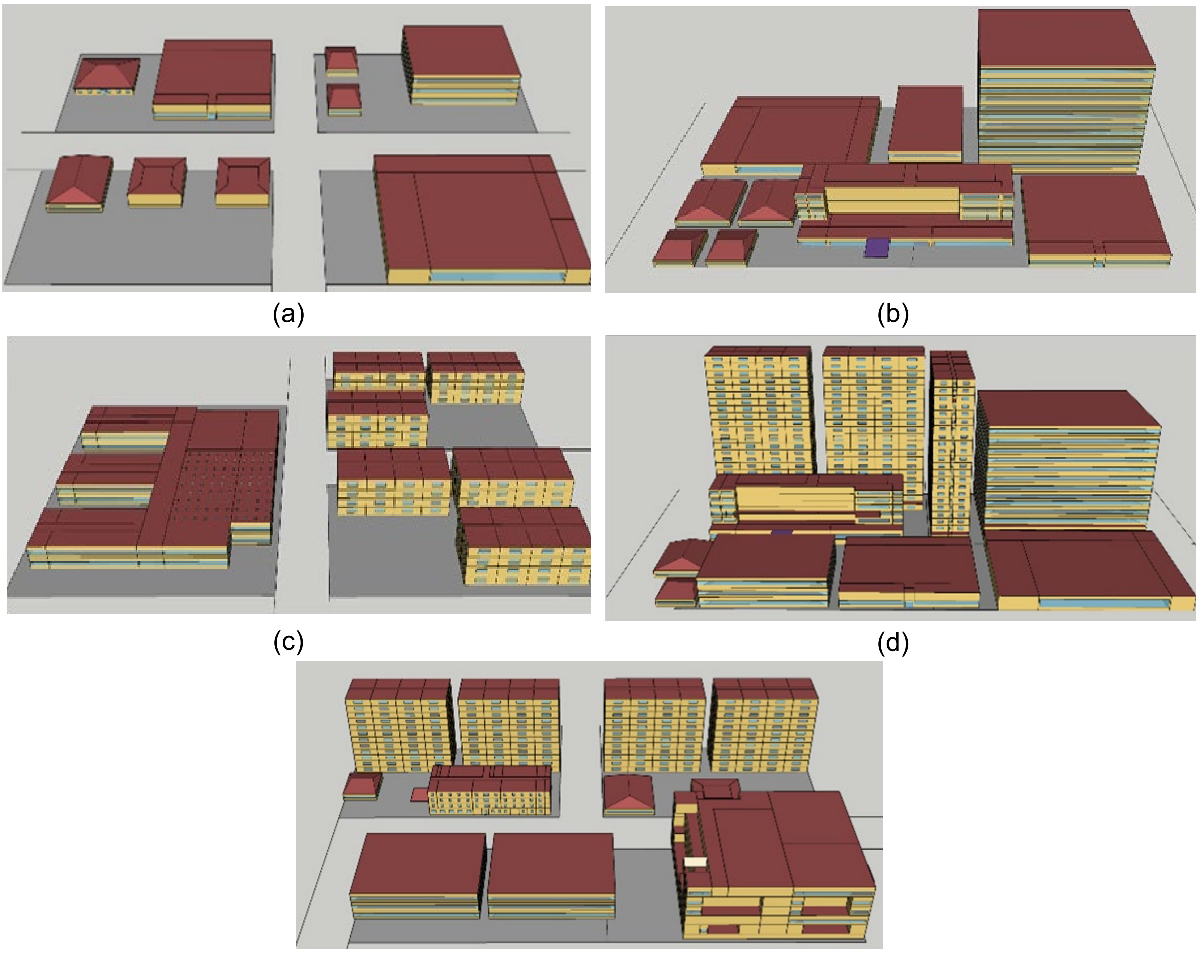
3.7 Theoretical neighborhood archetypes

A dozen clusters of buildings are designed to represent commonly built cluster types, in Canada. To develop these archetypes of building clusters, a survey was conducted employing ARCGIS Pro, in five major Canadian cities, that looked at various street networks and combination of building types within different urban developments. Several street networks are commonly found, including grid network, curvilinear, and *cul-de-sac* confirming various literature, as shown above.

For the study of theoretical neighborhoods, the grid street network is adopted, since the survey shows that this layout is employed for the development of all types of clusters, while others are used in specific types of development (e.g., cul-de-sac is mostly used in residential clusters). The developed archetypes are presented in Figure 16. The designed clusters range from all residential, low density to high density commercial and mixed-use developments. All clusters assume the same built area of 20 000 m^2 (~5 acres). The street area (~34% of the total built area) is not considered within this built area. The land area occupied by commercial buildings varies from 0% (all residential) to about 75% (high density mixed-use and special development). Two mixed use communities - MU4 and MU5, are designed assuming a central business district within the urban development (in MU4) and a special development that includes a hospital and some mid-density residential (in MU5). The design of both cases aims at accommodating various type of usages expected in such developments, within the specified land area. Although theoretical residential communities are also designed and analyzed as part of this study, they are not included in this report. The selected neighborhoods are intended to complement the models developed from existing patterns presented above.

Below is a summary of the five patterns of mixed use included in this report.

- CC1: is a low-density commercial development containing a supermarket, a large retail complex and 2 small standalone retails, 2 fast restaurants, a full restaurant, a small office, and a medium office.
- CC2: similar to CC1, this neighborhood contains only commercial buildings, but with higher density. It consists of a large office.
- e and a medium office, a large retail complex, a supermarket, a large hotel, a full restaurant, and a fast restaurant.
- MU2: contains 6 low rise apartment buildings (of 3 floors) and a secondary school.
- MU3: is highly mixed neighborhood including residential and commercial buildings, representing models of downtown core urban areas. It includes a large office, a medium office, a large retail complex, a supermarket, a large hotel, a full restaurant, a fast restaurant, and 3 apartment buildings (20 floors each).
- MU4: represents a special type of development that includes a hospital, a small hotel, 4 apartment buildings (10 floors each), a small retail, 2 medium offices, a full restaurant, and a fast restaurant.



(a) (b) (c) (d) (e)

Figure 16: Various theoretical archetypes developed using analysis of existing Canadian neighborhoods (a) CC1, (b) CC2, (c) MU2, (d) MU4, and (e) MU5 (taken from (Hachem-Vermette and Singh, 2022a)**)**

3.7.1 Sustainable archetypes

Six archetypes of neighborhood units (NU) are designed, ranging from low density, residential dominant, to highly mixed-use units. All neighborhood units are designed to have diverse amenities in a walking distance (less than 250 m in the NU itself). The area of the neighborhood unit is 20 000 m² (around 5 acres). A summary of each of the neighborhood units is presented below. The neighborhood units are illustrated in Figure 17.

- *Core cluster archetype (CR)*: consists of relatively low density of 8 units per acres (u/a), and includes residential buildings composed of detached and attached houses; and amenities such as small retail, a small office, a fast restaurant, and a full restaurant.
- *Residential/institutional archetype (CR/I):* consisting of primary or secondary school and different other types of buildings. Two variations are designed:
  - CR/I (V1): this archetype has a residential density of around 17 u/a. It is composed of attached houses and medium-rise apartment buildings, a primary school, small office, convenience store, and 2 restaurants.
  - CR/I (V2): This is a higher density neighborhood of 32 u/a, containing mid-rise apartment buildings, a secondary school, 2 offices (small and medium sizes), 2 restaurants and a convenience store.
- *Residential/commercial archetype (MU-S)*: This archetype has similar residential density to CR/I (V2) of 32 u/a, but with higher commercial density. It includes 5 mid-rise apartment buildings (of 4-floors each), a medium office, a large retail, a supermarket, 4 restaurants, and a small hotel.
- *Commercial/institutional archetype*: This archetype of neighborhood units consist of a concentrated business district that include a special type of building such as large hotel or a hospital. Two variations are designed:
  - MU-P(V1): comprising a medium office, a small hotel, a hospital, 4 restaurants (2 full, and 2 fast restaurants), a small retail and 4 apartment buildings of 15 floors each. The residential density of this neighborhood is 96 u/a.
  - MU-P(V2): containing a large office, a large hotel, 4 restaurants (2 full, and 2 fast restaurants), a large retail and 4 apartment buildings of 20 floors each. This neighborhood has a residential density of 128u/a.

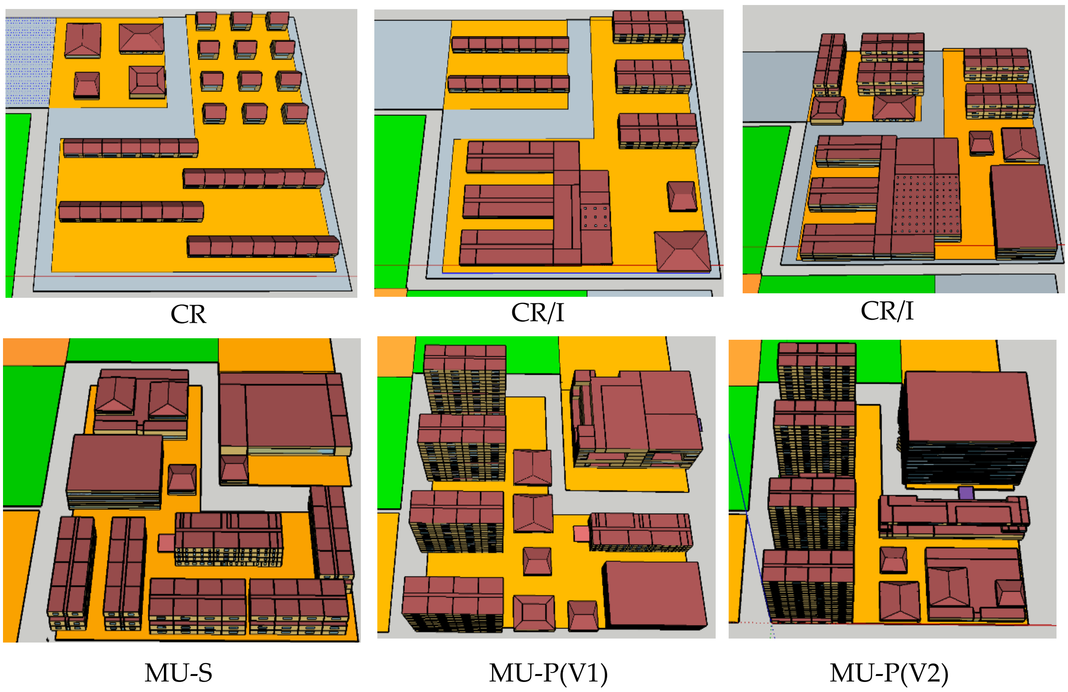


Figure 17: Configurations of NUs (CR, CR/I(V1), CR/I(V2), MU-S, MU-P(V1) and MU-P(V2)) (taken from (Hachem-Vermette and Singh, 2022a)**)**

Neighborhood units are created with the aim of blending the idea of green open spaces with the inclusion of a variety of essential amenities to ensure a comfortable living environment while also providing local employment opportunities to cut down the emissions related to transportation. To further support the idea of sustainability, each neighborhood unit is intended to incorporate retail facilities, office spaces, restaurants, and various institutional buildings like schools and hospitals.

The land-use composition is rooted in the fused grid concept, which encompasses several sustainability principles. The fused grid is built upon an underlying orthogonal grid, though it doesn't necessarily adhere to a uniform grid pattern. Lot dimensions can vary based on the type and size of buildings. Blocks designated for large structures, such as apartments or commercial complexes, may have different dimensions compared to those allocated for single-family homes. The fused grid adopts a modular design, creating neighborhoods with a central focus and boundaries, with each module covering approximately 40 acres.

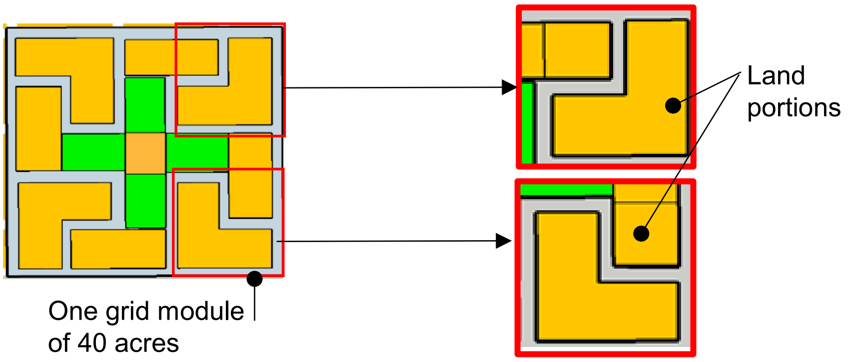


Figure 18: Representation of fused grid module with 8 units per acres density (taken from (Hachem-Vermette and Singh, 2022a)**)**

The neighborhood design is based on 1/8th of a fused grid module, which is equivalent to 5 acres as presented in Figure 18. This specific neighborhood size is chosen to facilitate an in-depth examination of building and urban-scale energy systems, as well as to explore potential combinations of these neighborhood units (NUs) within the entirety of the fused grid modules.

4 Solar Strategies

This section presents a discussion of existing solar strategies and offers the basis for a decision-making tool (presented in section 5). The discussion presents first an overview of various existing solar strategies, passive and active, on building and neighborhood levels. It highlights those strategies that are commonly applied.

4.1 Passive solar strategies and concepts at building level

This section presents various existing solar technologies, passive and active and examples of potential application of some of these technologies and strategies to selected archetypes.

4.1.1 Passive principles

Passive solar design application relies on several principles and building design considerations. These principles can be modified according to the location and climatic conditions. A successful implementation of passive solar design requires the simultaneous application of five main principles (Erdman, Douglas and Marr, 1969), presented below.

- Solar Gain: getting sufficient solar radiation inside buildings, for space heating and daylighting.
- Storage: storing some of the solar energy captured inside the building, to keep it warm during colder hours, and to avoid overheating during the day by reducing the temperature swing.
- Conservation of energy: Preserving energy by preventing heat transfer across the building envelope.
- Distribution: transferring solar heat collected in one area of the building to other areas that lack direct exposure to solar radiation.
- Control of heat gain: Employing architectural techniques like shading to govern the influx of solar heat when not required, such as during the summer months.

4.1.1.1 Selected Applications

The primary passive design applications are centered around the regulation of building temperatures, for heating and cooling, and the introduction of natural light. Passive design predominantly depends on an integrated design of building elements and materials. For instance, in the context of passive heating, architectural elements such as windows, walls, floors, and roofs should be designed to gather, retain, and evenly disperse heat within the interior environment. These very same architectural features also play a role in naturally cooling the indoor space.

Passive solar design can substantially diminish the scale of mechanical heating systems and the amount of fossil fuels needed to attain comfortable indoor temperatures in cold regions.

The applications surveyed in this section relate primarily to residential buildings, but the main principles apply also to commercial buildings.

4.1.1.2 Passive Heating

Passive solar heating offers an economical approach to supply space heating to buildings. It is particularly well-suited for residential buildings. A well planned passive solar building can fulfil from 45% to 100% of its heating needs during sunny winter days, even in cold climates (American Society of Heating Refrigerating and Air-conditioning Engineers Inc (ASHRAE), 2007).

Provisions for passive solar heating applications, particularly those related to the orientation of the building and window locations do not significantly affect the initial cost, when included in early design decisions. Moreover, the operational cost savings achieved by passive solar design can outweigh the additional cost in building upgrading, such as added insulation and advanced glazing materials.

Incorporating strategies for passive solar heating, particularly those pertaining to building orientation and window placement, might have a marginal impact on initial expenses when integrated during the initial design phase. Furthermore, the cost savings in operational expenses resulting from passive solar design can outweigh additional upfront expenditures for building enhancements, like increased insulation and high-performance glazing materials. There exist three primary approaches for capturing heat within a building, detailed as follows.

- Direct heat gain: Direct gain is the simplest method of gaining heat from solar energy, relying mainly on near equatorial facing glazing. Equatorial facing windows (south facing in the northern hemisphere), admit solar radiation to the interior space, where it is converted into thermal energy.
- Indirect gain: element, which is subsequently utilized to naturally heat designated areas through convection and radiation. Unlike the direct gain method where solar radiation directly enters the interior space, the indirect gain approach involves channeling solely the solar heat gain (longwave radiation) into the interior via a thermal mass. A typical application consists of Trombe Wall (discussed below).
- Isolated gain: is a design strategy where thermal gain is gathered and stored in a separate location from the area intended for heating. Adequate ventilation plays a critical role in this passive solar heat gain technique, enabling the efficient dispersion of heat to specific sections within the building.

4.1.1.3 Passive cooling

Passive cooling employs natural methods to dissipate heat from building indoor space either into the atmosphere and surrounding sky or into the ground beneath the building. Embracing passive cooling tactics contributes significantly to diminishing energy consumption and peak demand. Various passive cooling methodologies yield immediate advantages, including promoting natural airflow, and facilitating direct evaporative cooling. Additionally, alternate approaches center around entrapping heat within the building's thermal mass, subsequently releasing it to the environment as needed (Geetha and R Velraj, 2012).

Natural cooling relies on many of the principles and techniques applied in passive solar heating. Managing the surplus solar heat gain from equatorial windows is one the primary and most effective methods to reduce cooling loads in buildings. Methods employed to prevent heat loss during the heating period, such as high level of insulation, retard heat gain during the cooling period. Thermal mass such as masonry walls and concrete floors, absorb heat when the indoor temperature is higher than the temperature of the mass, and delay rise of the indoor temperature. The thermal mass passively releases the heat absorbed, during the night as the outdoor temperature drops below the temperature of the mass. To increase the efficiency of the mass, and allow it to cool down, it should be exposed to the outdoor air (e.g. by nighttime ventilation).

4.1.1.4 Solar induced natural ventilation

Natural ventilation is an efficient passive cooling strategy. Adequate ventilation is vital for to maintain good indoor air quality. Natural ventilation can be employed to ventilate and cool the building as long as the outdoor air is cooler than the indoor air. Operable windows can be an integral part of current constructions dominated by large, glazed façades. Current practices often do not allow opening of windows, particularly in office buildings, eliminating thus potential utilization of natural ventilation to supply fresh air to indoor spaces. Solar radiation can be used to enhance airflow, allowing efficient natural ventilation. One approach employs the Trombe wall concept discussed below but vented to the outside (Figure 19). Solar radiation striking the mass of the Trombe wall will heat the air in the space between glass and wall, causing this air to rise quickly and escape, drawing thus cooler outdoor air into the building.

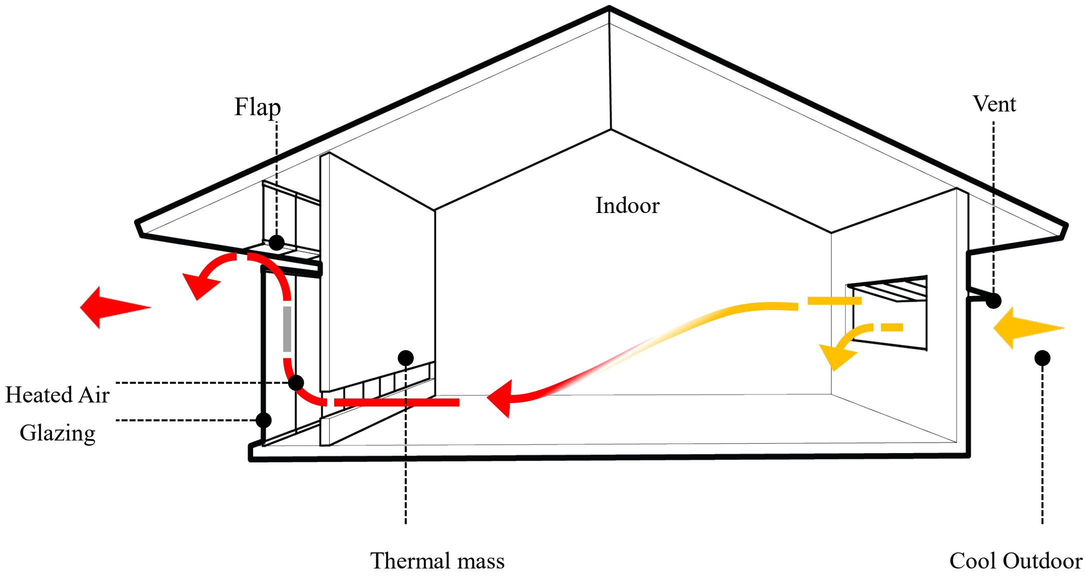


Figure 19: Use of Trombe wall in a cooling mode (Hachem-Vermette, 2020)

Another technique consists of solar chimneys. These chimneys are constructed with seasonal dampers. During winter, they channel heated air into the building's interior space, while in summer, they expel this air to the outside, thereby creating a flow of cooler outdoor air through the building to provide ventilation (Figure 20).

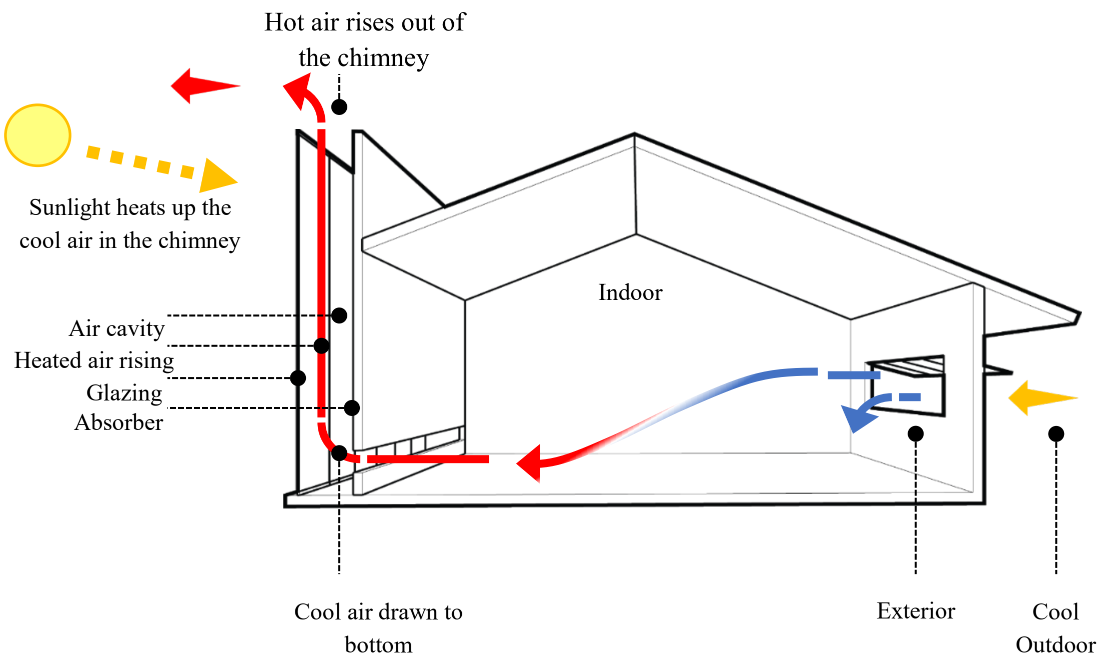


Figure 20: Illustration of the concept of solar chimney, (Hachem-Vermette, 2020)

4.1.1.5 Heat mitigation strategies

A key approach in passive cooling involves mitigating heat gain in a building due to both solar radiation and outdoor conditions. Multiple methods can be employed to curtail solar heat build-up during periods of cooling. Effective strategies consist of preventing direct solar gain through windows and skylights, minimizing heat absorption by the building's external surfaces, and constraining the re-emission and reflection of heat from the surroundings. Controlling solar radiation methods are briefly presented in the following.

4.1.1.6 Window shading

Shading equatorial-facing windows can be achieved employing horizontal overhangs or awnings. Another option is utilizing a trellis adorned with deciduous plants. Managing solar radiation on east and west orientations, however, presents a greater challenge compared to equatorial-facing orientations and necessitates a distinct strategy. In these cases, vertical shading proves to be a more fitting solution.

4.1.1.7 Use of vegetation

Deciduous trees can be employed to mitigate summer direct solar radiation, on the lower floors of a building. Vegetation can be employed in special designs of facades, as for example in a double skin façade to replicate the same effect, in multistory buildings. Planting vegetation to cover the ground reduces ground reflection and can assist in keeping the earth surface cooler preventing re-radiation.

4.1.1.8 Daylighting

Effective daylight management is an energy-efficient strategy that depends on solar radiation accessibility. This strategy incorporates diverse technologies and architectural design methods. Daylighting not only enhances the quality of light in a space but also reduces the reliance on artificial lighting. Research demonstrates that daylight has a beneficial influence on human well-being, satisfaction, performance, and productivity (Nazzal, 2005). However, it's imperative to regulate the amount of daylight within a space to ensure visual comfort (Tabet, K.A.; Sharples, 1990). Thoughtful daylighting design should be integrated during the initial architectural planning of a building to attain an optimal balance of quality and quantity of illumination.

Numerous design elements influence the efficacy of daylighting, including the geometrical configuration of the facades and the interior space and window dimensions, location, and orientation (Lechner, 2001). Some design considerations overlap with what is required for passive heating and cooling of the space. Daylight can be admitted to buildings through several strategies, including basic windows, advanced windows and glazing, and top lighting.

4.1.1.9 Basic windows

This approach is the most widely employed strategy. Windows equipped with clear glazing admit a significant amount of natural light into a space. Nonetheless, the intensity of illumination is greatest near the window and decreases rapidly, potentially becoming inadequate for common visual tasks. Incorporating windows on two walls, particularly on opposing sides of a single area, proves instrumental in augmenting the light level in indoor areas farther from the windows. A drawback of these window configurations is their susceptibility to be a source of glare and excessive brightness due to direct solar radiation. Mounting widows at increased height can mitigate these issues, simultaneously enhancing the depth to which natural light permeates the indoor space.

4.1.1.10 Advanced windows

Advanced window technologies can be employed to modify the quality and quantity of daylighting. These strategies include the use of devices to reflect light into the building for deeper penetration of daylight. For instance, light shelves offer an efficient method that allows increasing the daylit zone, by reflecting light onto the ceiling and then into the space (Figure 21).

While light shelves are most effective on equatorial-facing orientations, alternative methods must be devised for other orientations to optimize daylight diffusion. Another effective approach for reflecting light onto the ceiling entails the application of reflecting venetian blinds. Dynamic systems, designed to adapt to fluctuating daylight and sunlight conditions are more effective than static systems such as light shelves. Other strategies used to maximize daylighting consist of adopting advanced glazing types. These however should be designed to balance between lighting design and controlling of heat loss/gain.

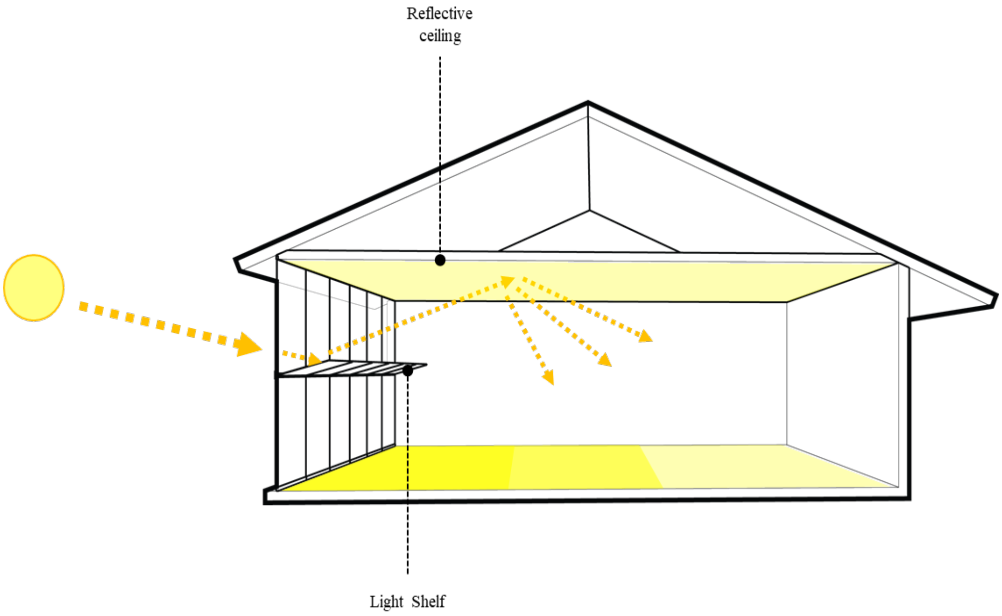


Figure 21: Illustration of light shelf principle, (Hachem-Vermette, 2020)

4.1.1.11 Top lighting

In addition to conventional windows, daylight can be admitted into buildings through top lighting mechanisms, such as clerestories and skylights. Clerestories are vertical windows located at roof level, while Skylights involve openings within a roof. Skylights may be either horizontal or pitched and can be seamlessly integrated within a sawtooth structure. An effective shading device should be installed along large skylights to curtail nocturnal heat loss and minimize heat accumulation during cooling phases.

The advantages of top lighting include enhanced illumination over a large area, and more even distribution of light. This type of daylighting is however restricted to the top floor of a building.

4.1.2 Building design and its impact

Passive solar design and architectural design are closely intertwined. A comprehensive approach to design is crucial, to integrate various design elements from the initial phases. This entails factoring in key aspects such as the building's site context, its physical configuration, and envelope specifications encompassing both opaque and glazed components.

Cost considerations form an integral part of the design process. While passive solar features can add up to 15% to design and construction costs (Chan, Riffat and Zhu, 2010), this initial cost is offset by significant reduction in building operational cost.

4.1.2.1 Building site setting

The site selected and the siting of the building relative to its surroundings have substantial impact on solar access. Optimal solar exposure during cold seasons relies on a site selection that minimizes potential obstructions, emanating from adjacent trees, landscape and buildings.

The proximity of the site to water bodies, hills, or the exposure to wind affects a building's passive heating and cooling capabilities. These factors should be considered during the architectural design phase to optimize the building's thermal performance.

4.1.2.2 Orientation

The building should be oriented with the long axis running east-west, ensuring its most extensive façade is directed equatorially (south in the northern hemisphere). This is because east- and west-facing buildings could encounter issues like excessive heating in cooling seasons, diminished heat gain during heating seasons, and notable fluctuations in terms of radiation and daylighting.

4.1.2.3 Building shape

4.1.2.3.1 General geometry

Numerous design considerations come into play when optimizing building geometry for effective solar capture. While a rectangular layout with dominant equatorial-facing façade is typically considered energy-efficient, non-rectangular configurations, especially self-shading forms like L shapes, offer greater architectural and solar design versatility. However, their efficient design hinges on various factors, including the placement and size of the shading portions. Such issues should be considered at early design stages.

4.1.2.3.2 Building layout and interior space

The layout, form and design of various zones in a building significantly contribute to passive solar design and the effective utilization of solar energy. The layout of the interior space should be such that daily activities align with the sun's trajectory throughout the day. This synchronization enables capturing solar heat gain during human active periods, thereby diminishing the requirement for additional heating.

The internal layout of the building should facilitate the natural flow of heat from one space to another. This objective can be accomplished through diverse architectural designs and concepts, including open interior layouts and the implementation of apertures to encourage air circulation between different levels and between north and south zones.

4.1.2.4 Building envelope

This section presents an overview of the main components of the building envelope design and their impact on capture of solar radiation.

4.1.2.4.1 Overall envelope

Building envelopes, including walls and roof, have a significant role in passive solar design. High energy performance building envelopes can substantially curtail the energy demand for space heating by 30% to 85% (Rémi Charron and Athienitis, 2006). High performance building envelopes should specifically target the mitigation of heat transfer, primarily attributable to inadequate insulation, thermal bridges, and air infiltration. Significant improvement to the building envelope can be achieved through highly insulated walls and windows (including frames), and improved air tightness. Window characteristics and their effects on heat loss and are detailed below.

4.1.2.4.2 Glazing

Windows have substantial impact on passive heat regulation. They contribute to both heat loss and solar heat gain dynamics. Heat loss emanates from both the glazing and the framing of windows (M. Arasteh, 1986; Winkelmann, n.d.) . Highly insulated windows (low U-value), including glazing and frame, should be selected as a fundamental step in promoting energy efficiency.

Equatorial facing windows design should achieve a balance among several factors: low U-value for the glazing, high solar heat gain coefficient (SHGC), and ensuring a high visible transmittance. This balance is key to optimize net energy gains, effective daylighting, and satisfactory visibility levels. SHGC represents the relative portions of solar radiation transmitted into the indoor space, including direct radiation and absorbed radiation (by the glazing and subsequently released to the indoor space. SHGC is employed as a metric to measure a glazing's capability to transmit solar gains. The glazing area on the south façade, for optimal solar performance, depends on building characteristics, thermal control systems and local climate (Remi Charron and Athienitis, 2006a).

4.1.2.4.3 Shading devices

Shading devices are essential elements to achieve a balanced solar efficiency of a building's envelope. Appropriate solar shading devices can regulate indoor illumination, minimize glare, manage solar heat gains, and concurrently lower energy needs for both heating and lighting (Laouadi, 2009). Shading devices are divided into two main categories, static and dynamic. Static devices are simple and can be efficient in blocking excessive solar radiation, but they have limited capability of controlling solar gains. Retractable awnings on the other hand, enable the reduction by up to 80% of summer solar gains (A. K. Athienitis and M. Santamouri, 2002).

Dynamic shading has greater capacity for managing and adapting solar heat gains based on specific requirements. Extensive studies have examined the potential energy savings associated with manually or mechanically operated dynamic shading mechanisms, encompassing internal blinds among other options (A. K. Athienitis and M. Santamouri, 2002; Foster and Oreszczyn, n.d.; Laouadi, 2009; Tzempelikos and Athienitis, 2007).

Exterior insulated roll-shutters are effective under Northern climate conditions. Roll-shutters can reduce heating load, by allowing solar heat gain when it is needed, while blocking radiation in the cooling period, as well as improve thermal conditions near windows (Laouadi, 2009).

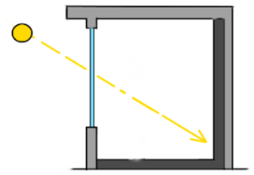
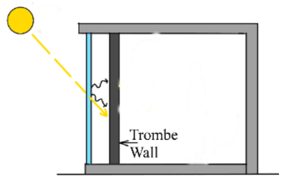
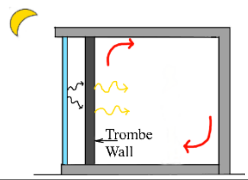
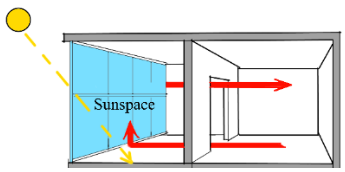
4.1.2.4.4 Window location

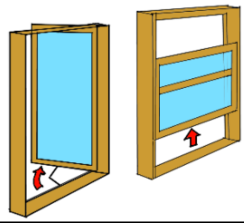
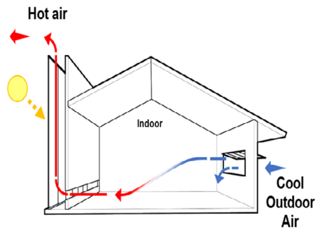
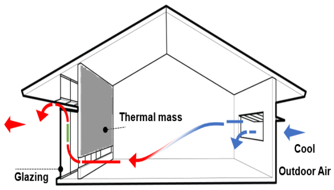
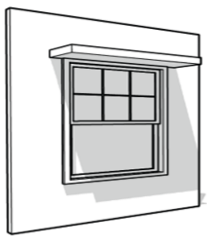
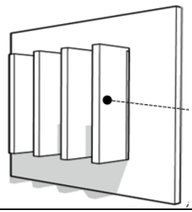
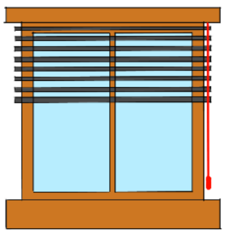
In the northern hemisphere, regardless of the specific climatic zone, south windows are optimal to facilitate solar heat gain during the winter period. North windows contribute significantly to heat loss, while presenting reduced potential for useful solar gain in winter. East and west windows predominantly admit solar radiation in the summer, increasing thus cooling loads, while in winter they are conductive to heat loss. However, non-south facing windows still serve non-energy related functions, such as daylighting and view (Geetha and Ramalingam Velraj, 2012).

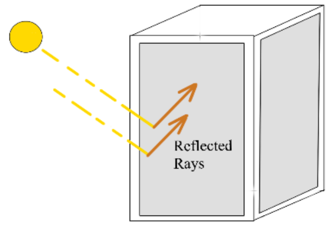
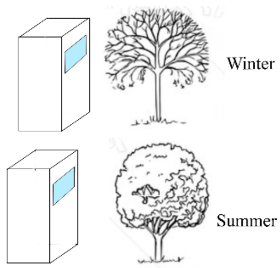
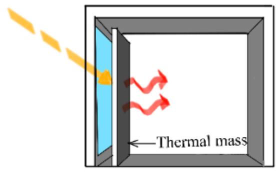
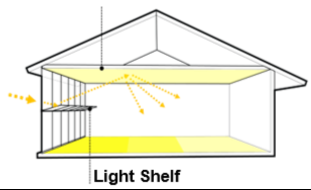
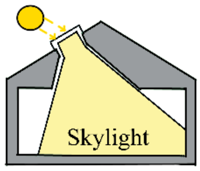
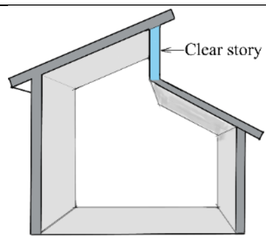
4.1.3 Selected passive technologies

Table 4 summarizes selected passive strategies presented in the sections above, and their main characteristics.

Table 4: Summary of passive solar strategies

		STRATEGY	DESCRIPTION	TECHNOLOGY	ILLUSTRATION
Objective	Passive Heating	**Direct Gain**	Admits solar radiation to the interior space, where it is converted into thermal energy.	**Windows & glazing** • Equatorial-facing glazing employs the greenhouse effect.	
		Indirect Gain	This approach involves channeling the solar heat gain (longwave radiation) into the interior via a thermal mass.	**Trombe Wall** • Thermal mass consists of a wall just inside the south face glazing. • Absorbs heat during daytime and releases heat during nighttime. • Time lag can be adjusted by altering thermal mass.	 
		Isolate Gain	In this design strategy, thermal gain is gathered and stored in a separate location from the area intended for heating. Here, adequate ventilation plays a critical role.	**Sunspace** • Designed to collect heat for the main part of a building and serve as a secondary living area. • Also known as Solarium or Sunroom.	

	Passive Cooling	**Heat Dissipation/ Natural ventilation**	Natural ventilation can ventilate and cool the building as long as the outdoor air is cooler than the indoor air. In addition, solar radiation can be used to enhance airflow, allowing efficient natural ventilation.	**Operable windows** • Helps to increase the ventilation in a particular area. • There are different operable window types, such as Casement and Slider.	
				Solar chimneys • These chimneys are constructed with seasonal dampers. • In summer, they expel hot indoor air to the outside, thereby creating a flow of cooler outdoor air through the building to provide ventilation.	
				Ventilated Trombe Wall • Solar radiation striking the mass of the Trombe wall heats the air in the space between the glass and wall, causing this air to rise quickly and escape, thus drawing cooler outdoor air into the building.	
		Heat Prevention	It involves mitigating heat gain in a building due to both solar radiation and outdoor conditions. It also includes minimizing heat absorption by the building's external surfaces and constraining the re-emission and reflection of heat from the surroundings.	**Fixed Window Shading Devices** • **Overhangs:** Horizontal fixed overhangs effectively obstruct high-angle solar radiation while permitting low-angle solar radiation to penetrate the indoor space.	 Standard horizontal overhang
				• **Vertical Fins** It shields low-angle direct sunlight coming from the eastern & western orientations of a building.	
				Moveable Window Shading Devices • **Venetian Blinds** It consists of horizontal slats that are suspended on ladder cords. The slat's angle can be adjusted to allow more or less sunlight into the interior space.	

				Reflective building envelope • When sunlight strikes a reflective surface, a substantial portion of the solar radiation is bounced back into the atmosphere rather than being absorbed.	
				Use of Vegetation • Cooling loads can be reduced by strategically planting trees. Deciduous trees allow for winter's sun and block summer's sun.	
		Heat Modulation	During daylight hours, the solar heat is absorbed by thermal mass, which is gradually released at night, contributing to reduced temperature swings within the enclosed space.	**Thermal mass envelope** • Utilizing thermal mass for reducing swing in the indoor temperature.	
	Daylighting	**Solar radiation accessibility**	This strategy incorporates diverse technologies and architectural design methods to improve solar access. Some design considerations overlap with the strategies required for passive heating and cooling of the space.	**Light Shelves** • Light shelves offer an efficient method that increases the daylit zone by reflecting light onto the ceiling and then into the space.	
				Skylights • Skylights involve openings within a roof. Skylights may be horizontal or pitched and seamlessly integrated within a sawtooth structure.	
				Clearstories • These are vertical windows located at the roof level.	

4.1.3.1 Shading devices

A large range of designs of solar mechanisms can be adopted to accommodate architectural and functional objectives (G. Franta and K. Anstead, 1994; L. Edwards and P. Torcellini, 2002). For instance, window materials with various optical characteristics are commonly employed to control the amount of solar radiation admitted to the indoor space. These materials include tinted glass, reflective glass, and more sophisticated solar technologies like semi-transparent photovoltaic (PV) modules.

Concerning shading devices themselves, a summary of various types of shading devices and their applications is presented below.

4.1.3.2 Fixed shading devices

Fixed shadings include devices such as overhangs, vertical fins, canopies, balconies, protruded window frames, egg-crate louver, and others. This category of shading systems is static, not allowing for adjustment to respond to variations of climatic conditions and building requirements.

The architectural configurations of fixed shading devices, involving factors such as tilt angle and dimensions, are usually determined according to the sun incidence angle during the summer solstice. Shape and materials, including colors of fixed shading devices can be creatively explored to achieve a range of architectural visual effects.

4.1.3.2.1 Horizontal overhangs

Fixed horizontal overhangs effectively obstruct high-angle solar radiation while permitting low angle solar radiation to penetrate the indoor space. This type of shading device is mostly advantageous for south facing windows in northern climate, allowing useful heat gain during the heating period, while mitigating the risk of excessive overheating in summer.

Determining the optimal depth of the overhang relies on factors like the window's height and the intended extent of shading. Horizontal overhangs can be designed in diverse ways to achieve various outcomes. For instance, they can be tailored to diminish overhang depth or selectively permit diffused radiation. Figure 22 presents some horizontal overhang design options.

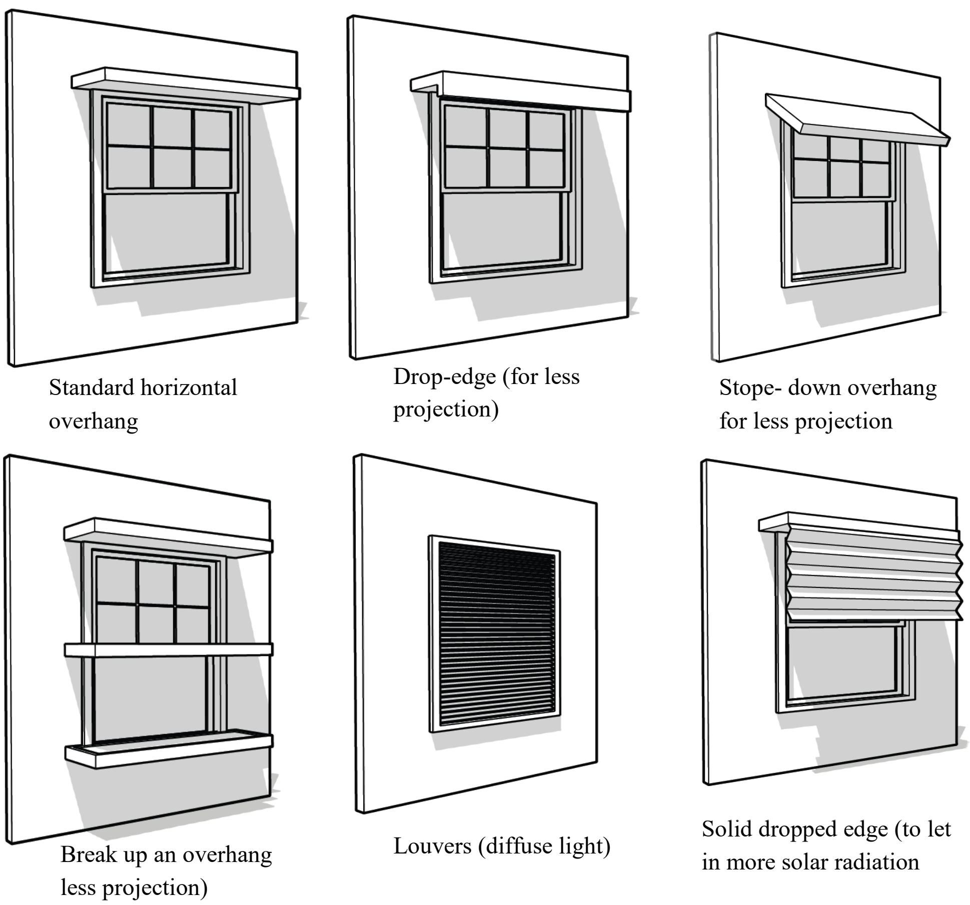


Figure 22: Illustration of different overhang designs (Hachem-Vermette, 2020)

4.1.3.2.2 Fixed vertical fins

Shielding low-angle direct sunlight, common on the eastern and western orientations of a building, poses a greater challenge. In such scenarios, vertical elements prove more effective compared to horizontal shading components (Figure 23). It is important to note, though, that while vertical fins can provide more efficient shade on east and west facades, this efficiency may prompt reduced natural daylight and compromised views.

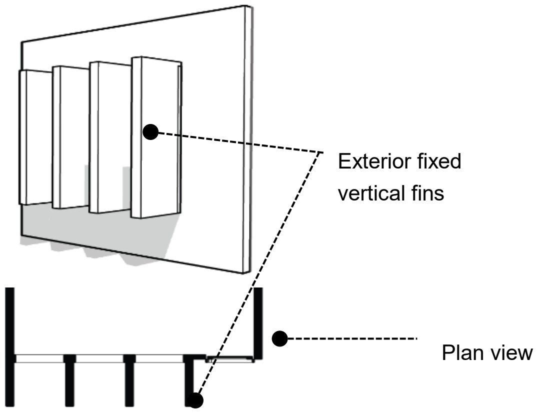


Figure 23: Representation of vertical fins, (Hachem-Vermette, 2020)

4.1.3.2.3 Hybrid horizontal and vertical fins

A hybrid shading solution that combines both vertical and horizontal shading elements can also be designed (Figure 23). Such elements couple the properties of horizontal overhangs – suitable for south windows - and of vertical fins which are more appropriate for east/west windows. This compound shading mechanism can be applied to windows of diverse orientations, offering similar advantages across the board. This type of shading device may however create a challenge in terms of integration with the architectural design as well as optimal view to the exterior.

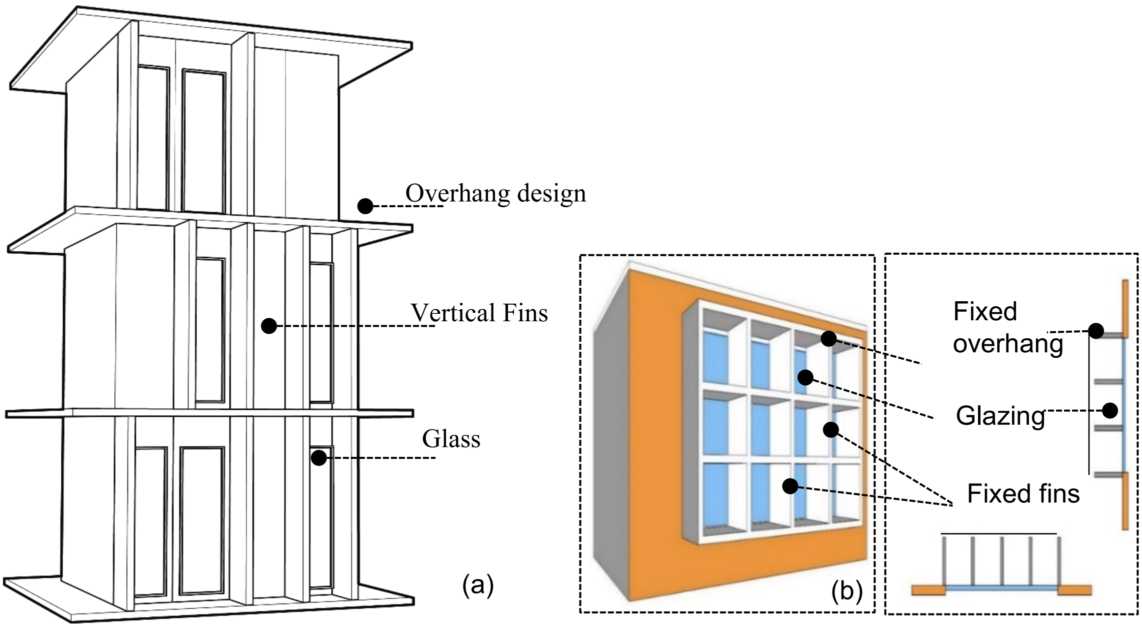


Figure 23: An example of hybrid horizontal and vertical shading (a) on a full floor level (within a multistory building), (b) on a window level, (Hachem-Vermette, 2020)

4.1.3.2.4 Mobile shading

Mobile shading devices encompasses a diverse array of devices including shutters, venetian blinds, roller blinds, and curtains. Mobile shading offers the advantage of easy adjustment to fulfil the needs \of the indoor space, such as indoor temperature and illuminance levels. This type of shading systems can result in significant improvement in the energy consumption of buildings, for annual heating and cooling as compared to fixed systems. Mobile shading devices can be operated either manually or through mechanical control mechanisms.

4.1.3.2.5 Interior Shading Devices

Interior shading devices are typically more cost-effective and offer greater controllability compared to external devices. Although interior shading solutions effectively manage direct sunlight and minimize glare, they are they are limited in their ability to control passive heat gain. This limitation arises because solar radiation that enters through the window heats both the interior shade and the surrounding indoor air. Internal shadings are commonly employed to provide privacy and thermal comfort while granting occupants the flexibility to regulate the amount of solar radiation entering the space.

A diverse array of interior shading options exists, including roller shades, venetian blinds and drapery. More advanced alternatives consist of blinds situated between the panes of an insulated glazing unit (in multi-pane window). The degree of natural light and passive solar heat admitted into indoor spaces is significantly affected by the shading material and their location with respect to the glazing (between the windowpanes or on the interior side of the window).

4.1.3.2.6 Motorized Shading Systems

Motorized shading systems are gaining considerable attention, particularly in commercial buildings and buildings featuring extensive glazing. The growing interest in motorized shading systems stems from their capacity to enhance energy efficiency while improving the thermal comfort of the indoor environment. These types of shades are operated employing motors typically integrated into the roller tube or head rail of the shading mechanism. Automation of motorized shadings needs to consider balancing energy management requirements, human comfort in terms of temperature and visual conditions, and functional tasks.

4.1.3.2.7 Mobile insulation

As discussed above, heat loss and gain through windows can be significant and may have significant impact on the building's energy requirements. Heat transfer occurs through the window frames, the glass itself, and any gaps around the window frames (infiltration). One strategy to mitigate this heat loss is the implementation of movable insulated panels that can be placed over the windows during critical periods. This approach proves particularly beneficial for buildings with large extents of glass.

Numerous creative methods can be employed to design moveable insulation. For instance, they can involve panels sliding along tracks covering the glazed areas. Moveable insulation can be controlled manually or mechanically. Additionally, these systems can be equipped with sensors that enable automatic activation based on factors such as indoor temperature set-point, illumination level as well as building occupancy.

4.1.3.3 Selected building envelope technologies

4.1.3.3.1 Reflective building envelope

Using highly reflective building envelopes is an effective cooling measure in buildings, primarily aimed at reducing solar heat gain and decreasing cooling loads. When sunlight strikes a reflective surface, a substantial portion of the solar radiation is bounced back into the atmosphere rather than being absorbed. Several research studies have demonstrated the efficacy of reflective surfaces in maintaining cooler building surfaces and preventing heat transfer into the interior. Givoni and Hoffman ('Barukh and 'Hoffman, 1968) observed that buildings with white-colored walls in Israel were approximately 3 °C cooler in summer compared to those painted grey. Synnefa et al. (Synnefa, Santamouris and Livada, 2006a) found that using reflective coatings on concrete tiles reduced surface temperatures by 4 °C during hot summer and 2 °C at night. Simpson and McPherson (Simpson, buildings and 1997, 1997) used 1/4 scale model buildings in Arizona and found that white roofs (0.75 albedo) were up to 20 °C cooler than grey (0.30 albedo) or silver (0.50 albedo) and up to 30 °C cooler than brown (~0.10 albedo) roofs. Akbari et al. (Akbari, Gartland and Konopacki, 1998) reported a 7.2 °C drop in roof temperature on hot summer afternoons by increasing the roof reflectance of commercial buildings in California from 20% to 60%. Implementing highly reflective building materials helps minimize the absorption of solar energy, thus reducing the urban heat island effect as well. It is worth mentioning that both reflectance and emissivity should be considered in surface selection to ensure effective temperature reduction and heat gain prevention.

4.1.3.3.2 High-performance materials

Building envelope insulation is pivotal in achieving energy efficiency and creating a comfortable indoor environment. In fact, the building envelope is responsible for approximately 50-60% of the total heat gain or loss in a building (Ascione, Bianco, Mauro and Napolitano, 2019; Causone, Pietrobon, Pagliano and Erba, 2017; Meng et al., 2018). Different insulation materials are available and classified as conventional, state-of-the-art, and sustainable based on thermal conductivity, as shown in Table 5. In literature, (Abu-Jdayil, Mourad, Hittini, Hassan and Hameedi, 2019) have examined insulation materials and found that state-of-the-art insulations exhibit the lowest thermal conductivity among the three categories. However, these materials have a higher life cycle cost than conventional alternatives. The selection of optimum insulation depends on regional climate conditions; cooling-load-dominated regions benefit from walls with lower thermal resistance, while heating-load-dominated regions find walls with higher thermal resistance more cost-effective. While highly insulated and airtight buildings offer energy efficiency advantages, they may present challenges such as an increased risk of overheating and peak cooling demands during hot summer periods. Hence, careful selection and design of insulation is crucial. In humid regions, in addition to thermal performance, insulator hygroscopic properties are important to control indoor relative humidity effectively. Insulation's acoustic, and fire retardancy properties should also be considered to keep noise pollution and fire hazards in check. Factors like operational energy, embodied energy, life cycle costs, and occupant comfort must be taken into account to make informed decisions for insulations that optimize the overall performance of the building envelope (Kumar, Alam, Zou, … and 2020, n.d.). Furthermore, high-performance windows incorporating advanced glazing technologies, such as low-emissivity (low-E) coatings, gas fills (e.g., argon or krypton), and multiple glazing layers, also help to improve thermal insulation and reduce heat loss or gain.

Table 5: Classification of building insulation materials (Kumar et al., n.d.).

BUILDING INSULATION MATERIALS				
CONVENTIONAL			STATE-OF-THE-ART	SUSTAINABLE
	Inorganic	Organic	• Closed-cell foam	• Bio-Insulation Material
Fibrous	• Material Wool	• Cork	• Aerogel	• Agricultural Waste
Cellular	• Foam Glass • Calcium Silicate • Perlite • Vermiculate	• Cellulose • Bio-insulation materials	• Transparent • Reflective Multi-foil • Vacuum	• Sheep Wool • Recycled Insulation Materials

4.1.3.3.3 Thermal mass envelope: Trombe wall system

Trombe walls, characterized by their thick construction and dark-colored coating on the sun-exposed face, are an innovative passive architectural feature used to harness solar energy (Sergei, Shen and Jiang, 2020). During daylight hours, these walls absorb solar heat, which is gradually released during the night, contributing to maintaining thermal comfort within the enclosed space. Integrating Trombe walls in buildings may offer significant energy efficiency benefits, particularly in cold climates, by reducing the heating demand (Hu, He, Ji and Zhang, 2017; Omrany, GhaffarianHoseini, GhaffarianHoseini, Raahemifar and Tookey, 2016; Zeng, Zhao and Wang, 2021). Research conducted by Bojic et al. (Bojić, Johannes and Kuznik, 2014) demonstrated that buildings equipped with Trombe walls in Lyon, France, could achieve energy savings of approximately 20% compared to buildings without such walls. To enhance heating performance, a transparent glazing layer is incorporated as the outer covering of the Trombe wall, creating a greenhouse effect. Here, heat transfer within the room occurs primarily through conduction. However, such traditional Trombe walls have limitations, such as inadequate heat storage control and low thermal resistance. These challenges have been addressed by the development of ventilated Trombe wall systems, which include mechanisms for controlling the supply of stored heat according to demand (Zalewski, Lassue, Duthoit and Butez, 2002). Ventilated Trombe walls facilitate heat transfer through both conduction and convection. To adapt Trombe walls to specific climatic conditions, various modifications can be implemented, such as incorporating double/triple glazing (Kundakci Koyunbaba and Yilmaz, 2012), integrating semi-transparent/opaque photovoltaic elements on the exposed face (Yadav, Hachem-Vermette, Eranki and Panda, 2023), and utilizing air ducts in supply, ventilation, or curtain modes (Abdullah, Attulla, Ahmed and Algburi, 2022). These adjustments optimize the performance and suitability of Trombe walls in different environments.

An exemplary illustration of a Trombe wall implementation can be observed in the National Renewable Energy Laboratory (NREL) visitors center (“Building: A better Trombe wall - Google Scholar,” n.d.), as depicted in Figure 24. This specific Trombe wall design employs a zigzag pattern to mitigate excessive heat gain and glare during daylight hours. The undulating Trombe wall comprises three distinct sections, with one section facing south and the remaining two sections angled inward in a “V” shape. Positioned on one side of the “V” is a window facing southeast, which serves the dual purpose of providing natural light and facilitating direct heat gain during the morning hours when rapid heating is most necessary. On the other side of the “V,” a Trombe wall is present, acting as a storage medium for the captured solar energy from the hot afternoon sun. This stored heat is subsequently released and distributed during the evening hours. Additionally, exterior overhangs are incorporated to shield the Trombe wall from intense summer sunlight, effectively controlling solar heat gain.

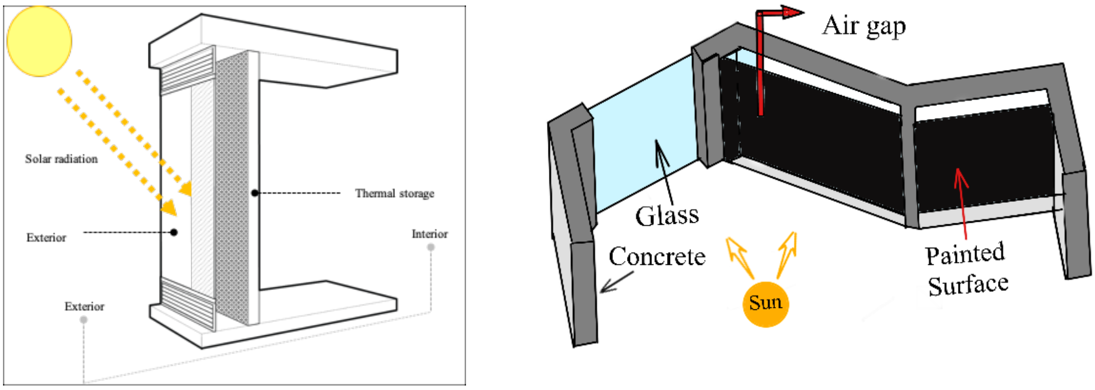


Figure 24: A zig-zag Trombe wall

4.1.3.3.4 Other technologies: Earth air heat exchanger

Earth Air Heat Exchangers (EAHE) are a viable solution for reducing buildings’ heating and cooling loads. These systems consist of buried pipe networks strategically placed at optimal depths within the ground, where the temperature remains relatively constant throughout the year. When coupled with buildings, EAHE exploits this constant ground temperature as a heat source for heating during winter and as a heat sink for cooling during summer. Various design characteristics, including the number of pipes, length, and depth, influence the efficiency of EAHE systems. Real-life applications of EAHE have demonstrated their effectiveness in reducing discomfort hours and improving energy efficiency. For instance, in Belgium, a building with a surface area of approximately 2 000 m² integrated EAHE with two concrete pipes measuring 80 cm in internal diameter and 40 m in length. These pipes were buried at depths of 3 and 5 m, respectively, resulting in a 30% reduction in discomfort during the summer (Breesch, Bossaer and Janssens, 2005). Another successful application can be observed in a commercial building near Zurich, Switzerland. In this case, EAHE was implemented with 43 parallel high-density pipes, each measuring 23 m long and buried at a depth of 6 m. The system was activated during summer when the outdoor air temperature exceeded 22°C, providing approximately one-third of the total cooling demand for the building (Elements, 2009). Similar positive results have been reported in Germany (Badescu, Energy and 2011, n.d.), Norway, Italy (Grosso, Ventilation and 2008, 2008), and Greece (Santamouris, Buildings and 2013, n.d.), further highlighting the effectiveness of EAHE in reducing the heating and cooling demands of buildings.

4.2 Neighborhood level passive solar strategies

Passive solar strategies at the neighborhood and urban scale encompass the integration of diverse building-level passive approaches previously explored, combined with fundamental urban planning strategies. These broader-scale strategies are founded on a comprehensive perspective that considers the interplay between buildings, open spaces, and the surrounding natural environment. The overarching objective is to capture and control solar energy effectively, thereby enhancing comfort levels, reducing energy usage, and promoting the development of sustainable and environmentally friendly living environments. Figure 25 illustrate the main parameters that affect the design of solar neighborhoods, contributing to achieving net- zero energy status.

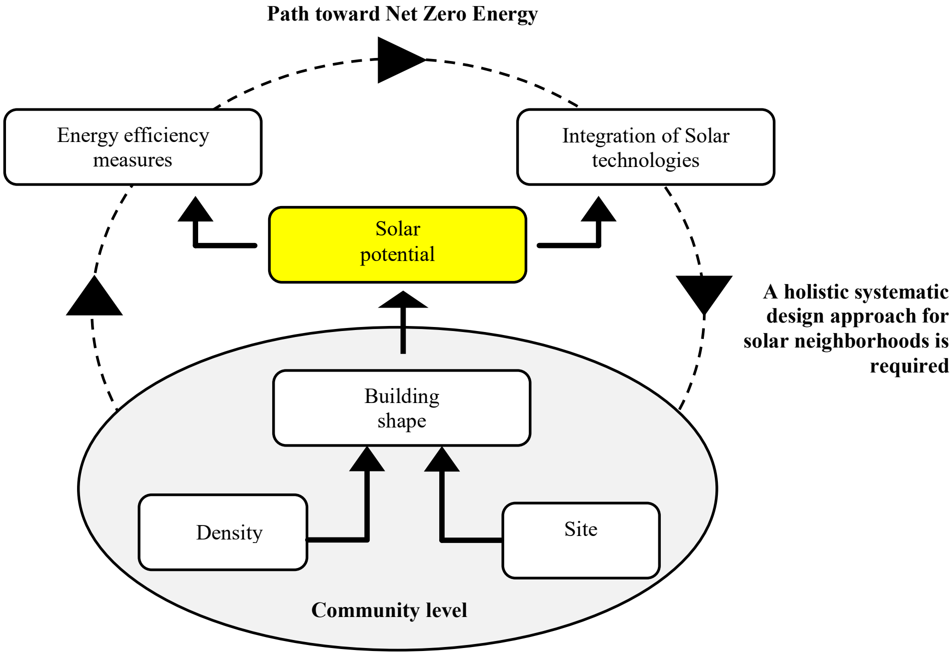


Figure 25: Various neighborhood parameters affecting the design of solar neighborhoods, (Hachem-Vermette, 2020)

4.2.1 Solar access

Incorporation of solar access and passive solar principles in the design of new neighborhoods results in multitude of benefits. Such benefits are associated with increased passive heating, cooling and daylighting potential, which reduce the overall energy consumption of the neighborhood.

Solar access can be significantly affected by the shape and height of buildings and their spacing, in urban context. Mixed-use neighborhoods, for instance, incorporate various types of buildings with different heights and layouts, and therefore require thorough design effort to ensure an optimal level of solar radiation. Solar access is widely considered in academic research. Numerous methods are proposed for measuring solar radiation in urban settings, along with strategies for managing it. Evaluating the solar potential of neighborhoods typically involve the utilization of diverse simulation and modeling tools (Baker et al., 2022). These tools are instrumental for assessing local solar resources and their capacity. Such assessments are especially valuable in the pre-planning and installation phases of solar technologies. They enable an understanding of potential challenges, including shading from nearby buildings, and facilitate the estimation of anticipated electrical generation from different structures and neighborhood surfaces. These tools often include Geographic Information Systems (GIS), solar radiation models, and 3D modelling software.

Solar access considerations are increasingly integrated into urban planning and zoning regulations. Some cities have implemented solar access decrees to ensure that new developments do not excessively shade neighboring properties. Data sources, such as local climate data, geographical information, and building characteristics, are essential for accurate solar potential assessments. The impact of major design parameters on solar access and energy performance of buildings in neighborhoods is reviewed below.

4.2.1.1 Solar Access Protections

Solar access zoning ensures that forthcoming constructions do not shade adjacent properties during specified daily timeframes. This concept, originally proposed by Ralph Knowles (R L Knowles, 1981), establishes a “solar envelope,” which delineates the largest permissible volume on a site that meets solar access criteria for neighboring structures. In the American legal system, three avenues exist for allocating and protecting solar rights: formal agreements (contracts) among landowners, government-backed regulations (e.g., permit systems or zoning ordinances), and rights assigned by the courts through legal settlements. Solar rights protections exhibit considerable variation across the United States, with a predominant focus on safeguarding installed solar collectors. At least 39 states have statutes that touch upon solar access in some form. Many of these statutes establish a legal framework for solar access rights, while a select few actively protect these rights (Bronin, n.d.). Regarding zoning ordinances (*City of Boulder Solar Access Guide City of Boulder Planning and Development Services Center*, n.d.; Kensek and Henkhaus, n.d.), one type employs adjustable setback and height restrictions to limit a building's shadow. Typically, a set of equations and tables are employed to calculate the precise setback and height requirements, considering factors like lot dimensions, orientation, and slope. Conversely, another type of zoning ordinance indirectly controls building height by constraining shadow length. This generally necessitates a shadow analysis for specific days, often during the winter solstice and at particular time of day. Furthermore, most regulations employed around the world for safeguarding solar access can be grouped into three main categories:

- Type 1: These are ordinances that stipulate specific hours or a particular time during the day when solar access is required. Examples include the cities of Boulder and Ashland in the United States.
- Type 2: These ordinances specify a set quantity of hours during the day when solar access is mandated. Countries like the Czech Republic, Slovenia, Poland, Slovakia, Germany, and China have implemented such regulations.
- Type 3: These regulations demand a certain ratio or percentage of the actual amount of direct solar access during the day. For instance, the United Kingdom and Estonia have enacted ordinances falling into this category.

Table 6 briefly overview some regulations implemented in different countries (De Luca and Dogan, 2019).

Table 6: Solar access regulation implemented in different countries

Country	Regulation	Definition	Type
US (Boulder, CO)	Solar Access Guide. Section 9-9-17, BRC 1981(City of Boulder 1981)	New buildings cannot cast shadows on surrounding facades above the shadow line, the height of which is different depending on the Solar Access Area (Area I 12 ft, Area II 25 ft, Area III no shadow line) between 10:00 and 14:00 on 21.12.	**1**
Germany	Regulation DIN 5034-1 (German Institute for Standardization 1999)	In a dwelling, at least one window needs to receive a minimum of 1 hour of direct sunlight on 17.01 and 4 hours on 21.03 and 21.09.	**2**
China	Code of Urban Residential Areas Planning &Design - Construction standard No. 542(Ministry of Construction of China 1993; Geng et al. 2012)	The standard for residential buildings requires minimum insolation hours, 2 and 3 on the "Great Cold Day" (20.01) and 1 on the winter solstice, depending on the size of the city (metropolitan, medium, and small) and in which climate zone it is located.	**2**
UK	BS 8206-2:2008. Lighting for buildings. Code of practice for daylighting (BSI 2008)	A room window should receive at least 25% of the Annual Probable Sunlight Hours (APSH) during the year. 5% of the required direct sunlight should be accessed during autumn and winter from 21.09 to 21.03.	**3**

4.2.2 Impact of urban design

Various urban design elements can have substantial impact on the microclimates of urban areas, including access to daylight, accessibility to natural daylight, the availability and intensity of solar radiation, the characteristics of wind flow (for potential implementation in natural ventilation), and local temperature. These microclimates in turn can affect the effective implementation of passive design principles, particularly when considered at the neighborhood scale. Some of the main factors that typically govern typical neighborhood design include building types and size, density of development and layout of streets. Solar neighborhoods, designed for harnessing of passive solar energy (along with active methods as discussed later), necessitates the consideration of supplementary variables. These factors as building geometry, roof shapes, the positioning of buildings along streets, and the. configuration to accommodate the desired population density, which might involve attached units, rows, or apartments.

Research has identified a set of parameters that enable the quantification of the urban layout's design and its impact on the solar access of buildings within this layout. These parameters consist of distance between buildings, building site coverage, complexity of building form, and variations in building height (Chatzipoulka, Compagnon and Nikolopoulou, 2016). Each of the identified neighborhood parameters has its own benefits and drawbacks. For instance, a higher density can lead to a reduction in energy consumption per capita (Steemers, 2003a), but it can also diminish solar access. Additionally, the size and shape of a site, along with the arrangement of streets within that site, can impact the orientation of buildings and consequently their ability to harness solar radiation effectively (Ralph L Knowles, 1981).

In addition, air pollution and noise which negatively impact the built environment, are strongly dependent on urban form. Urban environment with poor air quality and/or high noise level affects the potential of implementing natural ventilation in buildings (Ratti, Baker and Steemers, 2005a), increasing thus the dependence on mechanical systems. Below is a summary of the main influencing parameters of the neighborhoods, and a discussion on their impact on solar access and overall solar potential.

4.2.2.1 Density

Urban density refers to the magnitude of the ratio of the total built area to the area of a specific site. The adverse impact of increased building density on solar potential, including access to daylight have been extensively emphasized in academic literature. This includes the documented correlation between density and the energy performance of buildings (e.g., (Van Esch, Looman and de Bruin-Hordijk, 2012; Sanaieian, Tenpierik, Van Den Linden, Seraj and Shemrani, 2014; Steemers, 2003b; Strømann-Andersen and Sattrup, 2011)). Beyond its influence on building performance, increased density can also have consequences on the urban microclimate and outdoor human thermal comfort (Chatzipoulka, Nikolopoulou and Watkins, 2015).

Nonetheless, it's critical to note that numerous studies link increased urban density with enhanced environmental sustainability, particularly at urban scale (Jabareen, 2006). In regions with temperate and cold climates where optimizing solar access is of paramount importance, researchers and urban planners seek to mitigate the negative effects of increased density through the deliberate manipulation of urban layout (Kristl and Krainer, 2001). For instance, for a given density, the level of solar radiation can be managed through a combination of site coverage and building heights (Lee, Lee and Lee, 2016). Increasing the spacing between buildings allows for improved solar access to individual structures, consequently augmenting their potential for passive heating and daylighting. This approach simultaneously enhances solar availability at ground level.

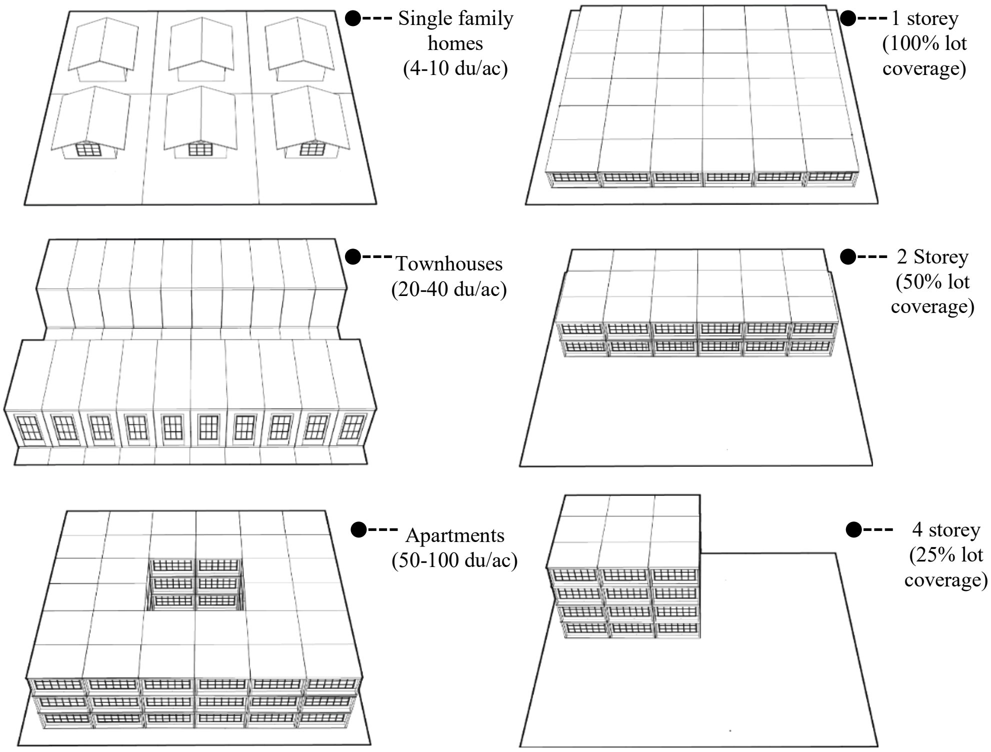


Figure 26: Building density illustrations for various building archetypes, (Hachem-Vermette, 2020)

Generally, two distinct methods are commonly utilized to quantify density within urban planning, *population density* or *building unit density* and *compactness.* Building density typically pertains to the planning aspect of a neighborhood, while compactness characterizes the physical architectural facet. Population density considers both the size and type of residential units. For instance, single-family houses tend to have larger floor areas compared to urban multifamily dwellings, resulting in lower building density in suburban areas (Ewing and Rong, 2008; Kaza, 2010). Figure 26 presents an example of building density associated with various types of residential buildings, and the relative lot area utilized. Building density can be measured employing different methods including the plan area density defined as the ratio of built area to the total lot area (Zhang et al., 2018), and the frontal area density which is the ratio of the windward-facing facade area to the building area (Ratti et al., 2005a).

Floor area ratio (FAR), defined as the ratio of a building's total floor area to the land area it occupies, is another density parameter that plays a role in influencing renewable energy resources at the urban level. It should be noted however that FAR alone doesn't account for the height or shape of buildings, nor does it consider the open spaces between them (Ratti et al., 2005a). These factors, which are related to density, have a substantial impact on energy performance. Therefore, additional indicators are needed to be considered in conjunction with FAR to effectively plan urban energy systems, particularly in the context of designing and integrating renewable energy technologies.

Assessing the exact impact of density on the energy performance of urban areas is a complex task as it depends strongly on the context of these urban areas, on their unique characteristics as well as on many other interrelated factors. Determining density impact has raised some controversy in the literature. For instance, there is a divergence of opinion regarding the effect of density on energy consumption by buildings, and the magnitude of the effect. Some empirical studies found no significant increase in energy use at higher density (Ko and Radke, 2014). Conversely, other sources in the literature argue that greater building density leads to higher night-time urban air temperature, increasing the urban heat island effect. This, in turn may increase cooling loads and decrease, often not significantly, the heating load of buildings (Li, Song and Kaza, 2018). The multifaceted and context-dependent nature of density's effect on energy performance emphasizes the need for comprehensive and location-specific assessments that consider the complex interaction of urban and architectural variables. Effects of density on solar access and energy performance and means of mitigating them are illustrated below.

4.2.2.2 Mutual shading effects

Distance between buildings plays a key role in creating mutual shading between these buildings. This distance should be determined as a function of several factors such as the height of these buildings, and any imposed constraints such as urban density and the intended functionality of the buildings (e.g., their types and uses). An example of the impact of various building heights on solar access is presented below. The example is based on a theoretical study that that systematically explores the impact of building heights and distances on solar irradiation (Hachem, Athienitis and Fazio, 2014; Hachem-Vermette, 2015).

Figure 27 and Figure 28 present the shading effects on solar radiation and on heating load, respectively. Figure 27 depicts the impact of shading by a 9-story building on solar radiation incident on the south façade of a building of similar height, positioned to the north, at varying distances between the two buildings. Solar radiation is significantly reduced when the distance between buildings is reduced. This effect is especially critical on the lower floors of the shaded buildings.

Understanding the impact of incident radiation provides valuable insights into the potential for passive heat gain and energy generation when incorporating photovoltaic (PV) systems into the facades of these shaded buildings. In essence, it helps estimate the solar energy potential and the feasibility of renewable energy integration in such urban configurations. Active strategies are further discussed in sub-section 4.3.

Figure 28 illustrates the impact on the heating load of shading a 9-story building by another building varies depending on the height and distance of the shading building to the south. The heating load increases as the distance between the buildings decreases and as the height of the shading building increases. In other words, buildings positioned closer together and taller structures that cast shadows on the 9-story building result in higher heating loads, as they block sunlight and reduce passive solar heating potential. The effects discussed above are expected to be amplified in case where other adjacent buildings cast shade from other directions, in addition to this studied effect.

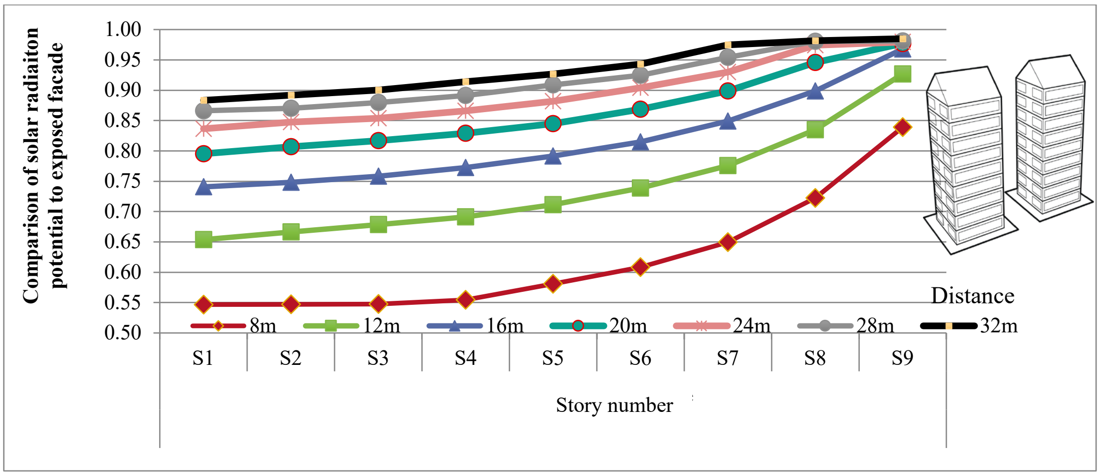


Figure 27: Mutual shading of two identical buildings 9 stories high; shading building is on the south of the shaded building (Hachem-Vermette, 2020)

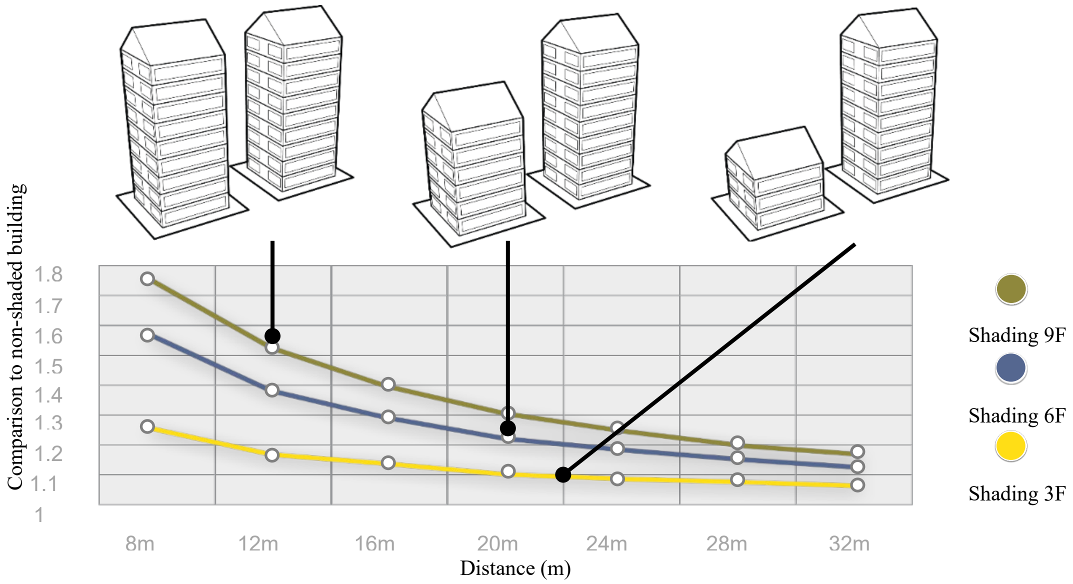


Figure 28: Comparison of average heating load in 9-story buildings, with different shading scenarios (Hachem-Vermette, 2020)

4.2.2.3 Neighborhood layout

Urban layout encompasses how the built structures are spatially distributed within a site, encompassing both horizontal and vertical arrangements. The design and positioning of buildings relative to roads have a substantial impact on the performance of small-scale neighborhoods, particularly when the orientation of the primary facade of these buildings significantly deviates from south.

The layout of a neighborhood is the result of a multitude of interconnected factors. These include the positioning of buildings on the site, the arrangement of these buildings in terms of their height and volume, the configuration of streets, the proportion of public green spaces, and various other considerations. Importantly, the neighborhood layout can exert a substantial influence on the solar access of both buildings and open public areas within the neighborhood. Figure 29 provides an example illustrating two different neighborhood layouts created by the arrangement of buildings on the site and their configurations. These layouts can impact the degree of shading between buildings, consequently affecting the solar radiation potential on rooftops and building facades.

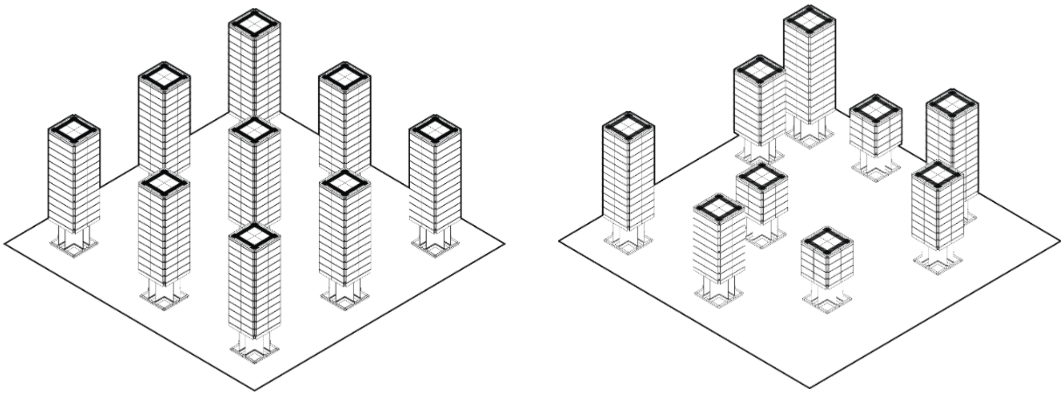


Figure 29: Examples of different horizontal and vertical building layouts (Hachem-Vermette, 2020)

Below is a discussion of the main factors that affect the performance of a neighborhood, particularly in terms of capture and utilization of solar energy.

4.2.2.4 Street Layout

The arrangement of streets within a neighborhood or urban area plays a crucial role in determining the orientation of buildings along them, often influencing the configurations of these buildings. The positioning of buildings on a site, the spacing between buildings, and the orientation of their facades all have a substantial impact on the quantity of solar radiation received by these buildings. In northern latitudes, it is typically considered optimal to orient a building (with the primary facade facing) within approximately 30 degrees to the east or west of true south. This orientation helps maximize the solar access of the building, allowing for more efficient utilization of solar energy (Hachem, Fazio and Athienitis, 2013b; Littlefair, 2000).

Research focused on solar neighborhoods suggest that streets should be oriented in general along the east-west axis. This orientation provides the opportunity to design buildings with prominent south-facing facades, as buildings in urban settings are typically aligned with the streets. However, the effectiveness of this approach can be compromised when streets are not optimally laid out in the east-west direction. In such cases, the solar access of buildings may be negatively impacted. To mitigate the impact of neighborhood layout on average annual solar radiation, specific design considerations should be taken into account. For example, a comparative study assessing the annual solar radiation potential of square, radial, and hexagonal neighborhood layouts indicates that the square layout outperforms the radial and hexagonal layouts by approximately 3%. This reduced impact on solar access is achieved by enhancing the orientation of the primary facades and roofs of all buildings within the optimal range of 30 degrees east to 30 degrees west from the south (Hachem-Vermette and Singh, 2019).

In practical terms, this means that buildings can be designed to achieve a balance between the ideal orientation for solar access and the required orientation imposed by the direction of streets or other layout constraints. This approach helps optimize solar access while accommodating the specific characteristics of the neighborhood layout. Hourly solar radiation patterns during specific periods of the year reveal certain advantages of the circular neighborhood pattern. This advantage arises from the greater variation in building surface orientations within such a layout. This variation can be advantageous in achieving a broader spread in the timing of peak electricity generation when solar PV technologies are integrated into these surfaces. Figure 30 illustrates the solar radiation levels on buildings within various neighborhood layouts on four different days of the year.

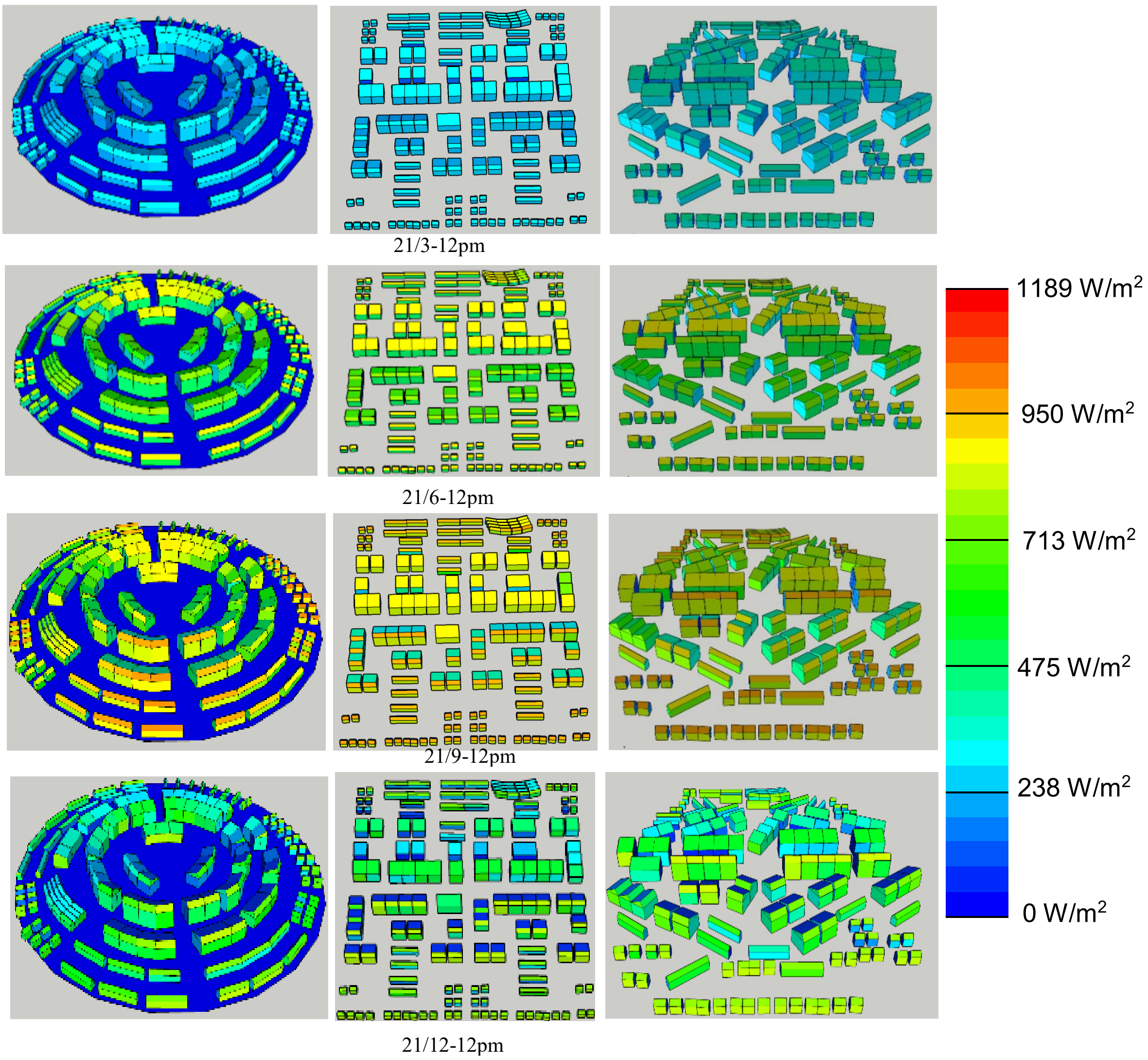


Figure 30: Solar energy analysis for various neighborhood layouts on across various sessions (Hachem-Vermette, 2020)

4.2.2.5 Planting and surface coverage

Diverse research methods, encompassing both experimentation and simulations, have consistently shown the substantial impact of trees on reducing cooling loads, and in some instances, heating loads, within urban environments. Strategies such as open space planning, tree planting, and altering surface coverage play a crucial role in shaping the urban microclimate. They particularly affect factors such as solar access and the urban heat island effect, which has emerged as a pressing concern in urban areas due to its influence on temperature and energy demands.

The strategically selected tree species can effectively control solar access (Lin, Meyers and Csiro, n.d.). For instance, selecting deciduous trees that provide shade during hot periods but shed their leaves in the winter can help counterbalance potential increases in heating demand in urban areas. Figure 31 provides a diagram summarizing the recommended tree types for each orientation of the building to optimize their energy and microclimate benefits.

Additionally, reducing exposed surface area through various measures such as reduced lot sizes, and increasing tree canopy cover is recommended to reduce urban heat island effects.

It was demonstrated in a study by Parker et al. (Journal and 1987, n.d.) that the walls of the concrete-block house with shrubs were -4 to -2°C cooler than uncovered walls during periods of direct sunlight. In addition, vegetation employed as green roofs or vertical gardens acts as an extra layer of insulation that minimizes heat transfer through the building's envelope, resulting in reduced heat gain. The heat flow through the building roofs in summer can be reduced by approximately 80% via green roofs, and green roofs are reported to consume less energy in the range of 2.2–16.7% than traditional roofs during summertime (Besir and Cuce, 2018). Furthermore, evapotranspiration, whereby vegetation releases water vapor into the surrounding air, significantly lowers temperatures near a building. Beyond its immediate benefits for individual buildings, vegetation can also address broader urban challenges. Vegetation actively contributes to mitigating the urban heat island effect, a phenomenon characterized by higher temperatures in urban areas due to the prevalence of heat-absorbing materials like concrete and asphalt. Moreover, the presence of vegetation in urban environments leads to improvements in air quality as well.

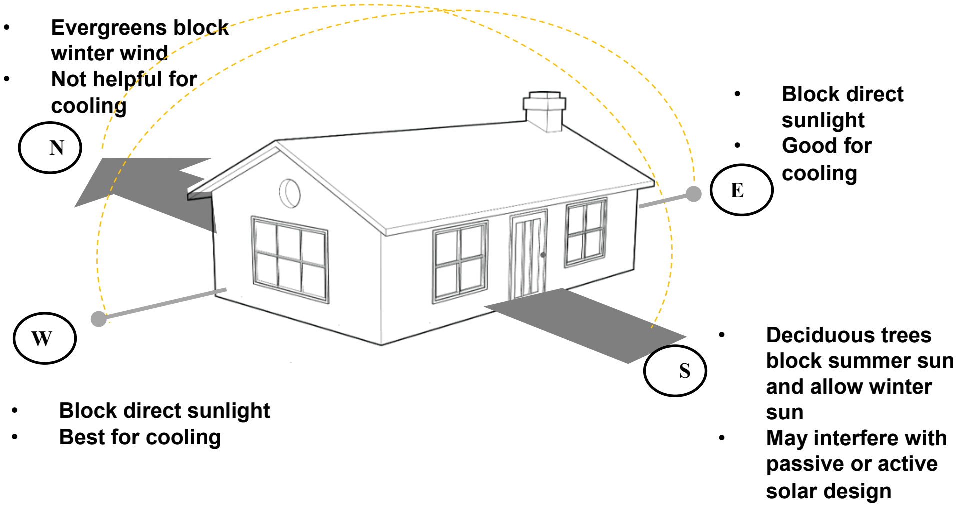


Figure 31: Optimal tree types corresponding to various building orientations (Hachem-Vermette, 2020)

4.2.2.6 Reflective surfaces

Urban Heat Islands (UHIs) refer to the phenomenon where urban areas experience higher temperatures compared to their surrounding suburban and rural areas. The influence of pavements on the formation of UHIs holds significant importance due to their extensive coverage within urban landscapes, encompassing approximately 40% of urban land, including around 75-80% of road surfaces (Qin, 2015). During the construction of pavements, natural vegetation is replaced with materials such as bitumen and concrete, which possess properties like heat absorption, thermal conductivity, and high heat retention. Consequently, these dark and thermally retentive pavements contribute to elevated surface temperatures, ultimately fostering the development of heat islands within cities. Reducing pavement surface temperatures can substantially mitigate UHI in cities grappling with elevated urban temperatures. The most widely adopted and effective method for mitigating the urban heat island effect is using reflective pavements. This approach entails resurfacing conventional roadways with materials that possess a higher albedo (lighter color), thereby increasing solar reflectance and reducing surface temperatures. Various techniques, including chip seals, slurry seals, white high-reflective paints, infrared-reflective colored paints, micro-surfacing, and roller compacting with light-colored aggregates and/or emulsified polymer resins, can be employed to enhance the reflective properties of pavements. Table 7 briefly describes these measures and their impact on pavement thermal performance (Croce, Hachem-Vermette, Formolli and Vettorato, 2022).

Table 7: Technological trends in reflective pavements (Santamouris, 2013)

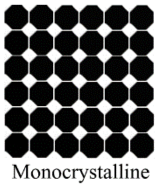
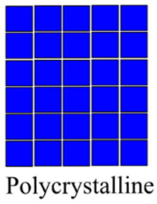
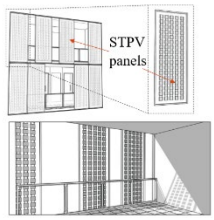
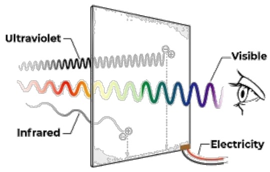
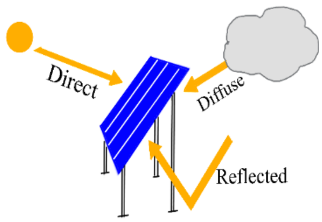
	Albedo Enhancement Technique	Description	Final Albedo Achieved	Thermal benefits
ASPHALT PAVEMENTS	**Infrared reflective colored paints on the pavement surface**	Application of dark infrared reflective paint with hollow ceramic particles.	0.50	Daily surface temperature was reduced by 8–15 K and by 2 K during the night (Van Bijsterveld and De Bondt, 2002).
		Application of five thin reflective layers of different colors using infrared reflective pigments.	0.27–0.55	Daily surface temperature was reduced by 16–24 K and by 2 K during the night (Synnefa et al., 2011).
	Heat-reflecting paint to cover aggregates	Application of reflecting paint to cover all aggregates.	0.46–0. 57	Reduce daily surface temperature of the pavement by 10.2–18.8 K (Boriboonsomsin and Reza, 2007).
		Application of reflecting paint to cover the surface aggregates.	0.25–0.6	Reduction of the daily surface temperature of the pavement by 6.8–20 K (Kawakami, 2008).
CONCRETE PAVEMENT	**Color-changing paints**	Application of eleven thermochromic colors.	Colored: 0.51–0.78 Colorless: 0.71–0.81	Daily surface temperature reduced by 5.4–10 K (Karlessi, Santamouris, Apostolakis, Synnefa and Livada, 2009).
		Application of ten infrared reflective paints of different colors.	0.27–0.70	Daily surface temperature under hot summer conditions was reduced by 2–10 K (Kondo, Ogasawara and Kanamori, 2008).
	Reflective colored paints	Application of 14 high-reflectivity white paints on the surface of concrete tiles.	0.80–0.90	Daily surface temperature of a white concrete pavement under hot summer conditions was reduced by 4 K and by 2 K during the night (Synnefa, Santamouris and Livada, 2006b).
		Application of white paints based on the use of calcium hydroxide placed on the surface of concrete tiles.	0.76	Daily surface temperature under hot summer conditions was reduced by 1–5 K and by 1 K during the night (Levinson et al., n.d.).

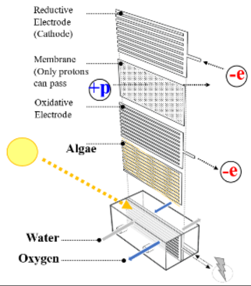
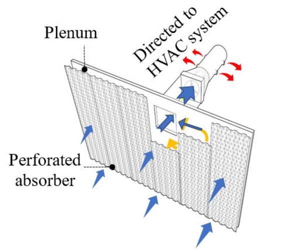
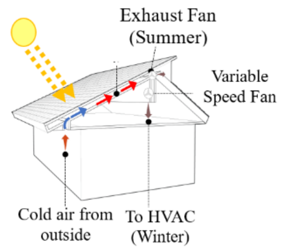
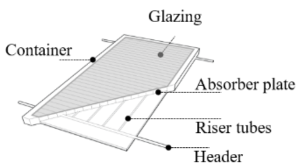
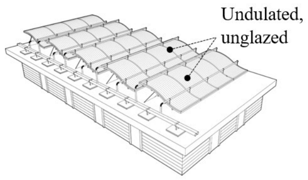
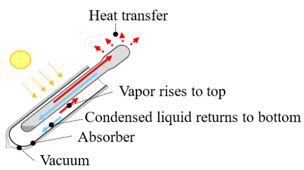
4.3 Active solar on building scale

4.3.1 Review of main solar technologies

Table 8 presents a summary of active strategies, their applications, and their main characteristics.

Table 8: Summary of solar technologies

	Strategy	Description	Application	Illustration
SOLAR PV	**Monocrystalline Cells**	Mono-crystalline silicon PV cells have a homogenous solid color ranging from blue to black, and their efficiency varies between 15 and 26.1%.	• Tilted rooftops with good solar orientation and free of shading. • Ground mounted.	
	Poly-crystalline Cells	The most common color of polycrystalline cells is blue or silver grey. Lower efficiency (13 to 23.3 %) than mono-crystalline cells.	• Tilted rooftops with good solar orientation and free of shading. • Ground mounted.	
	Thin-film Cells	It is usually produced from amorphous-based silicon (a-Si), Cadmium Telluride (CdTe), and Copper Indium Diselenide (CuISn2, CIS). Efficiency of a-Si is 5-14 %, and CIGS is 23.4 %.	• It can be bent into malleable shapes, offering more integration flexibility within the building envelope.	
	Semi-transparent PV	Semi-transparent PV is typically created using transparent glass panels with crystalline silicon PV cells or perforated silicon wafers. Ethylene Vinyl Acetate (EVA) film is often used for encapsulation.	• Offer an attractive solution to substitute the large extent of glazing in a building.	
	Translucent and Transparent PV	Thin film transparent PV cells are made by depositing a photoactive film on conductive oxide glass like Fluorine-Doped Tin Oxide (FTO). Transparency depends on factors like film thickness, deposition method, and materials.	• It can be utilized in window glazing and other applications where daylighting is desirable.	
	Bifacial Solar Panels	Bifacial panels are solar modules that can produce energy from the front and the backside of the panel. The backside generates power from the reflection of light that hits surrounding surfaces. It can generate over 30% more energy than a conventional module.	• Snow-covered regions. • Solar carports and canopies. • Floating solar	

	Bio Photovoltaic Panels (BPV)	BPV technology exploits natural photosynthesis to transform light into electrical energy.	• Application into real-life situations has yet to be demonstrated.	
SOLAR THERMAL	**Air-based collector systems**	The absorber collects solar radiation then the thermal energy is transferred to the working fluid. These can be classified into Glazed and Unglazed collectors.	• Air-based thermal collectors primarily preheat air for ventilation or space heating. • Solar collectors are typically mounted on building facades to allow optimal solar exposure during winter when the sun is at a lower altitude.	
SOLAR THERMAL	**Building Integrated Hybrid Photovoltaic /thermal systems**	Hybrid photovoltaic/thermal systems (PV/T) combine PV modules and heat extraction devices to produce simultaneously power and heat. Heat extraction from the PV rear surface is usually achieved using the circulation of a fluid (air or water) with low inlet temperature.	• It is exploited for space heating and hot water applications, and it cools the PV modules, thus increasing the total energy output of the system. • Applied to roof and facades.	
SOLAR THERMAL	**Water based collectors**	Water-based thermal collectors allow easy storage of solar gains and are suitable both for domestic hot water production and space heating. The medium of this type of collector consists mainly of water charged with glycol in variable percentages to avoid freezing, depending on climatic zones.	**Flat-plate collectors** • Flat-plate solar collectors are usually installed in fixed positions (i.e., tilt and orientation angles). • These can be classified as glazed and unglazed collectors.	
			Unglazed plastic collectors • The absorber typically uses UV-resistant black material, but it's not insulated, leading to heat loss, especially in windy and cold conditions.	
SOLAR THERMAL	**Evacuated tubes collectors**	It comprises many transparent glass tubes attached to a header pipe. Each of these tubes comprises two concentric tubes - an outer tube and an inner tube, with evacuated space between them.	• Evacuated tube collectors can be employed for various applications, including domestic hot water for residential use, space heating, and industrial applications.	

4.3.1.1 Monocrystalline Solar Panels

Mono-crystalline silicon PV cells have a homogenous solid color that ranges generally from blue to black. Monocrystalline cells typically have dimensions around 10 x 10 cm and are approximately 350 microns thick. Their efficiency ranges between 15 and 26.1% (Osterwald et al., 2023; Razykov et al., 2011). The form of the monocrystalline cells depends on the cutting methods, and how much of the cylindrical mono-crystal bar is sliced away. Three common cell shapes are obtained: circular, semicircular, and square. While the circular shape is the least expensive, it is not frequently used in PV modules because it is space-inefficient when cells are placed adjacent to each other within the modules. An interesting application of monocrystalline cells can be achieved within a semi-transparent PV system (see below), particularly for building integration, as discussed further below (Pearsall, 2016).

A wide range of colors is available for PV cells, but these colored options typically come with lower efficiency and higher costs. For example, certain colors like magenta or gold can result in a loss of up to 20% in efficiency when compared to conventional PV modules (Reijenga TH and Kaan HF, 2011). Colored PV cells present a solution for better integration of PV panels into building facades. Colors can be chosen to match the hues of various building materials used within the same structure, as well as those of surrounding buildings. Technical solutions for all components associated with colored PV, including glass, polymers, and the PV-active layers, are currently available and under development (Eder et al., 2019). These advancements aim to make colored PV an increasingly viable and aesthetically pleasing option for building integration.

4.3.1.2 Poly-crystalline cells

Poly-crystalline cells are produced using silicon material similar to what is used for mono-crystalline cells. The key difference lies in the manufacturing process, where the raw silicon material is melted and then cast into a mold. This mold is subsequently cooled and cut into square wafers. Controlled heating and cooling are applied to enable the cast block to cool uniformly in one direction. During this cooling process, the material crystallizes in an imperfect manner, resulting in random crystal boundaries (Ramalingam and Indulkar, 2017).

The controlled technique of solidification aims at maximizing homogeneous silicon crystals, increasing thus the potential efficiency of this type of cells, which is inherently lower than that of the mono-crystalline cells.

The most common color of polycrystalline cells is blue, or silver grey. Polycrystalline cells have an efficiency ranging between 13% and 23.3% (Osterwald et al., 2023; Petter Jelle, Breivik and Drolsum Røkenes, 2012). Although the usual dimensions of the cells are similar to that of the monocrystalline, there is a current trend to increase the size of these cells to improve the efficiency and reduce the cost of production.

4.3.1.3 Thin-film cells

Thin-film PV modules are created usually from amorphous-based silicon (a-Si), as well as other base materials such as Cadmium Telluride (CdTe) and Copper Indium Diselenide (CuISn2, CIS) (Aberle, 2009).

The thin-film technology employs a single or multiple thin layers of photoactive semiconductor material, to manufacture solar cells. During this process, semiconductor photovoltaic materials are deposited onto a low-cost supporting substrate, which can be a large sheet of glass, metal, or plastic. Typically, less than a micron (0.001mm) thickness of semiconductor material is sufficient to convert sunlight. This thickness is thus 100-1000 times thinner than the crystalline silicon wafer. The reduction in material compared to crystalline solar cells results in lower costs, which is a key advantage of these types of solar cells. Another advantage is that the production unit is not limited to the size of a wafer, as is the case with crystalline cells, but can be tailored to any required dimension and shape, depending on the size of the substrate (Aberle, 2009; Poullikkas, 2010).

Thin film PV presents a number of unique advantages, compared to crystalline PV. It better utilizes diffuse solar radiation, performs well in low light conditions, is less sensitive to increase of temperature and less sensitive to shading. From architectural perspective, thin-film PV can be molded into flexible shapes, providing greater integration flexibility within the building envelope (Petter Jelle et al., 2012). A disadvantage of thin-film PV is a toxic manufacturing process, which negatively impact the environment [16]. This is in addition to the lower electric output. For instance, amorphous silicon based thin-film cells have efficiencies of 5-14%, and this efficiency diminishes during the first 6-12 months. CIGS currently offer 22.1% and 23.4% of cell efficacies, respectively [83].

4.3.1.4 Semi-transparent PV

Semi-transparent PV (STPV) can offer an appealing alternative to substitute the large extent of traditional glazing in a building (see Figure 32). Semi-transparent PV is usually achieved by encapsulating PV modules between two panes of highly transparent glass, or by perforating the silicon wafer. Crystalline silicon PV cells are commonly employed in STPV systems, while Ethylene Vinyl Acetate (EVA) film is widely selected to encapsulate the PV cells (Skandalos and Karamanis, 2015). The level of transparency in STPV panels is achieved by adjusting the spacing between the PV solar cells. A greater degree of transparency can be attained by increasing the distance between the PV cells. In other words, the transparency of the panel is directly proportional to the spacing between the cells (Heinstein, Ballif and Perret-Aebi, 2013).

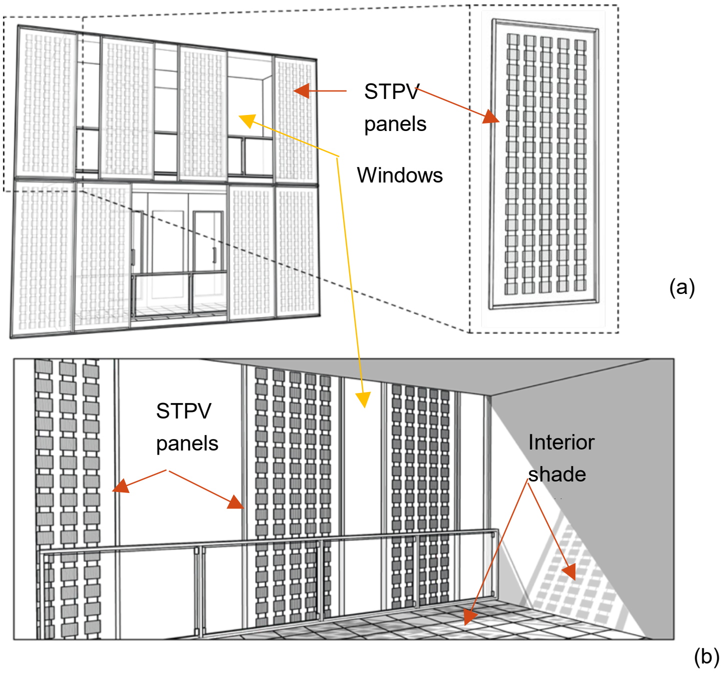


Figure 32: illustration of an STPV panel installed within a glazed façade, and the shading effect it has on the interior space (Hachem-Vermette, 2020).

STPV should be designed to balance between several factors, including electricity generation, glazing transparency, heat gain, daylighting, and the view to the outside. Increasing the proportion of PV cells in a semi-transparent PV module compared to the transparent glazing area has advantages such as higher electricity generation and reduced solar heat gain. However, this approach can limit daylighting and obstruct the view to the exterior (Miyazaki, Akisawa and Kashiwagi, 2005). In addition, the opaque cells will create a pattern of shadow in the building interior space that corresponds to the PV cells pattern of the STPV. This consideration should be carefully integrated into the interior space design, taking into account the requirements for solar heat gain and daylighting.

4.3.1.5 Translucent and Transparent PV

Translucent and transparent PV cells are highly desirable for numerous applications in buildings and are currently the focus of extensive research efforts. Research on such technologies is attracting a lot of attention. Various technologies and manufacturing processes are being employed to develop translucent/transparent PV products. For example, thin-film PV, as mentioned earlier, can be adapted to create transparent PV cells using different techniques. One such method involves depositing the photoactive film onto a conductive oxide glass like Fluorine-Doped Tin Oxide (FTO) (Husain, Hasan, Shafie, Hamidon and Pandey, 2018). The level of transparency of these thin-film transparent PV cells depends on various factors, including film thickness, deposition method, and the materials utilized in the process.

Other types of translucent solar cells are produced by creating evenly distributed microscopic holes through the mono-crystalline or polycrystalline silicon wafers, allowing some light to go through them. The holes can be created by a milling process or by laser cut. The efficiency of these cells depends on the methods of producing the holes, varying between 10% for the milled structure and 13% for the laser cut structure. The appearance and colors of these translucent cells derives from the original monocrystalline or polycrystalline wafers (Boxwell, 2009).

A promising emerging technology in the field of transparent solar cells is the transparent luminescent solar concentrator (LSC). This technology involves a transparent substrate, often made of materials like glass, with narrow PV cells positioned at the substrate's edge. Within the transparent substrate, fluorescent dye is either embedded or applied as a coating. The role of the fluorescent dye is to absorb incoming light, which is subsequently propagated through the material by total internal reflection until it reaches the PV cells located at the substrate's edge (Husain et al., 2018; Zhao, Meek, Levine and Lunt, 2014). Currently, transparent LSC technology can achieve an efficiency of around 1%.

4.3.1.6 Bifacial Solar Panels

Bifacial solar panels can generate energy not only from their front side but also from the backside (refer Figure 33). The rear side of these panels generates power from the reflection of sunlight that strikes nearby surfaces. The effectiveness of this energy generation depends on the reflectivity rate, often referred to as albedo. Bifacial solar panels have the potential to produce more than 30% additional energy compared to conventional solar modules. Additionally, frameless panels experience reduced potential-induced degradation (PID) [Pickerel, 2018a] (Pickerel, 2018).

These solar modules can only be installed into mounted structures, and they need special care when installing the frameless type because the clamp usually features a rubber guard to protect the glass so that overtightening bolts does not damage the glass structure of the panels.

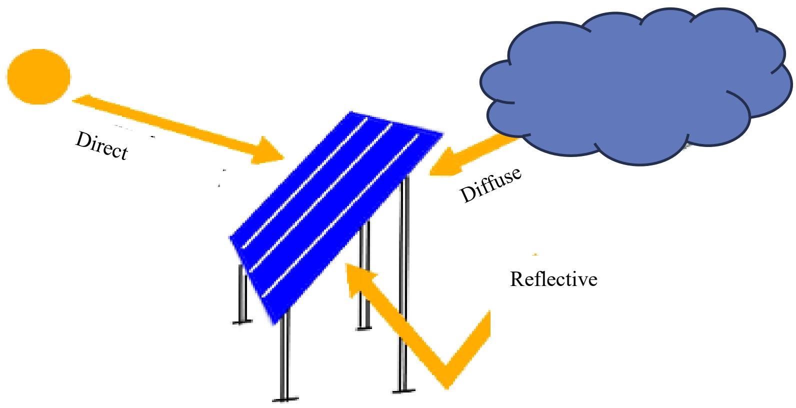


Figure 33: Bifacial solar panel and its working

4.3.1.7 Biophotovoltaic Panels (BPV)

Another advancing technology for solar energy harvesting is based on synthetic materials, known as biophotovoltaic panels (BPV). Biophotovoltaics represents a growing area of research within microbial fuel cell studies. This innovative BPV technology exploits natural photosynthesis to convert sunlight into electrical energy (Bradley, Bombelli, Rowden and Howe, 2012; McCormick et al., 2011). During this process, incident light is utilized by oxygenic biomass to facilitate the splitting of water molecules, resulting in the release of electrons. Liberated electrons are then captured through an anode to generate electricity (Tschörtner, Lai and Krömer, 2019). BPV, as a nano-bio material, involves the fusion of metal nanostructures and photosynthetic biomolecules, such as proteins. Figure 34 provides an illustration of the BPV technology.

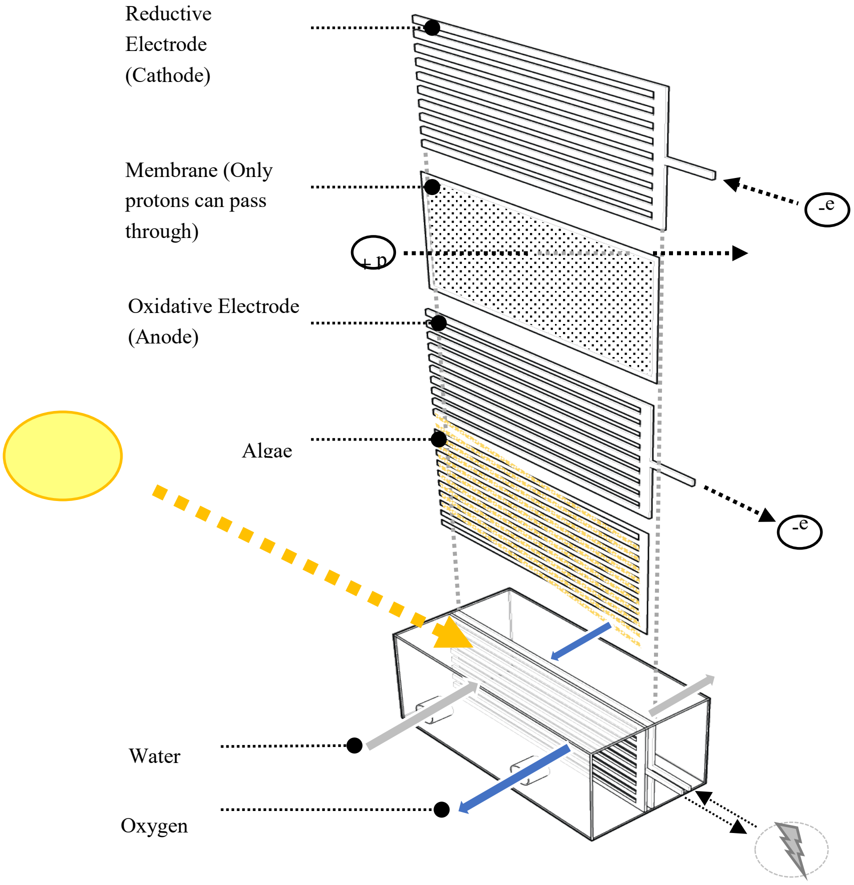


Figure 34: Schematic diagram of biophotovoltaic device (Hachem-Vermette, 2020)

The electrical efficiency of BPV technology is currently limited, and its associated cost remains prohibitively high for practical applications. BPV research is still in its early stages, and enhancing various factors may assist in increasing the viability of this technology. Numerous factors influencing the performance of BPVs must be identified and optimized. For instance, experimental studies on BPVs have highlighted their reliance on artificial light sources to maintain constant illumination. Real-world applications are yet to demonstrate how these systems perform under variable light intensities (Tschörtner et al., 2019). Other crucial factors that demand further research include biomass generation, the development of optimal growth methods for this biomass, and the impact of temperature variations (daily and seasonal) on their growth rate.

4.3.2 Review of main solar thermal collectors technologies

Solar thermal collectors absorb solar irradiation as thermal energy, which is then transferred to the solar collector working fluid (air, water or oil). The collected heat can be directly utilized within buildings for purposes like providing domestic hot water and space heating or to charge a thermal storage tank. Thermal storage can be used to supply heat when needed, especially during periods when there is no solar radiation, such as at night or on cloudy days.

Various types of collectors exist, depending on the intended applications and the technologies involved, including the medium used to transport the absorbed thermal energy.

4.3.2.1 Air-based collector systems

Air-based thermal collectors are primary used to preheat air for ventilation or for space heating. Solar thermal collectors are often installed on the building's façade near the fresh air inlets (Buker and Riffat, 2015). In addition, the vertical position of the collectors is more efficient during the heating season, as vertical inclination is advantageous for capturing sunlight at low solar angles.

The basic component of an air-based thermal collector is the absorber, which captures solar radiation. The thermal energy is then transferred to the working fluid (air in this case). The heated air is ducted directly to the indoor space or to the building's mechanical system for further processing, to achieve the desired temperature.

Air-based thermal collectors can be classified into two main types: Glazed collectors and unglazed collectors. These are briefly summarized below.

4.3.2.2 Glazed collectors

Glazed collectors consist of several components, including a transparent glass sheet, a dark-colored absorber plate, and insulated side and back panels, to reduce heat loss to the environment. The recirculating collector type is the most widely used for space heating applications (Kalogirou, 2004). In this system, indoor air is typically ducted into the collector, where it gains heat from the absorber plate through conduction. Subsequently, this heated air is channeled back into the building. It can be used either for direct space heating or to provide preheated air for the building's mechanical system.

4.3.2.3 Unglazed collectors

Unglazed collectors primarily consist of an absorber without any glass cover, making them fully exposed to the outdoor environment. In this type of collector, air either passes across the absorber or through it (in the case of transpired collectors), where it absorbs heat. Unglazed collectors are typically used for preheating ventilation air in various types of buildings, including commercial and industrial buildings.

A special type of unglazed collectors, termed Transpired Collectors, can be obtained by utilizing a perforated plate, to collect heat (Shukla, Nkwetta, Cho, Stevenson and Jones, 2012). These solar collectors are typically installed on building facades to maximize solar exposure during the winter months when the sun is at lower altitude. An air cavity is designed behind the collectors to provide a channel to the outdoor air, passing through the perforated exterior absorber (see Figure 35). A large number of micro-perforations allows the heated layer of ambient air, which is in contact with the exterior surface of the plate to be drawn into the air cavity. This preheated air is then directed to the ventilation system for distribution within the indoor space. Figure 35 presents an example of a perforated collectors, linked to an air conditioning system.

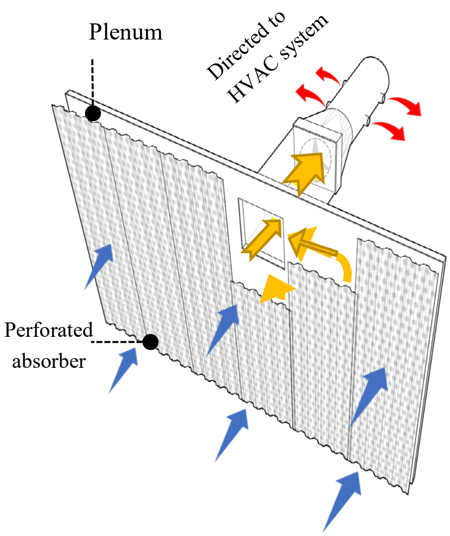


Figure 35: Air based perforated collector system (Hachem-Vermette, 2020)

4.3.2.4 Building Integrated hybrid photovoltaic /thermal systems(Korbinian Kramer et al., 2020)

Hybrid photovoltaic/thermal systems (PV/T) combine PV modules and heat extraction devices enabling the simultaneous production of electricity and heat to produce simultaneously power and heat

(Tripanagnostopoulos, Tzavellas, Zoulia and Chortatou, 2001). Typically, these systems involve the circulation of a fluid (such as air or water) with a low initial temperature to extract heat from the rear surface of the PV modules. This extracted thermal energy serves two primary purposes. It is utilized for space heating and hot water applications, and it cools the PV modules, which enhances their overall energy output (Remi Charron and Athienitis, 2006b).

The combined electrical and thermal energy output of the PV/T systems depends on various factors including the amount of solar energy received, ambient temperature, wind speed, and the method of heat extraction. In areas where there is a significant demand for space heating, air-based PV/T systems can be especially beneficial and cost-effective (Tripanagnostopoulos et al., 2001). The comparison between the performance of hybrid PV/T collectors and more traditional PV systems indicate that PV/T systems can achieve increased energy conversion efficiency with potential cost benefits (Tian and Zhao, 2013). Figure 36 presents examples of BIPV/T applied to a roof, in a residential building and to a vertical surface.

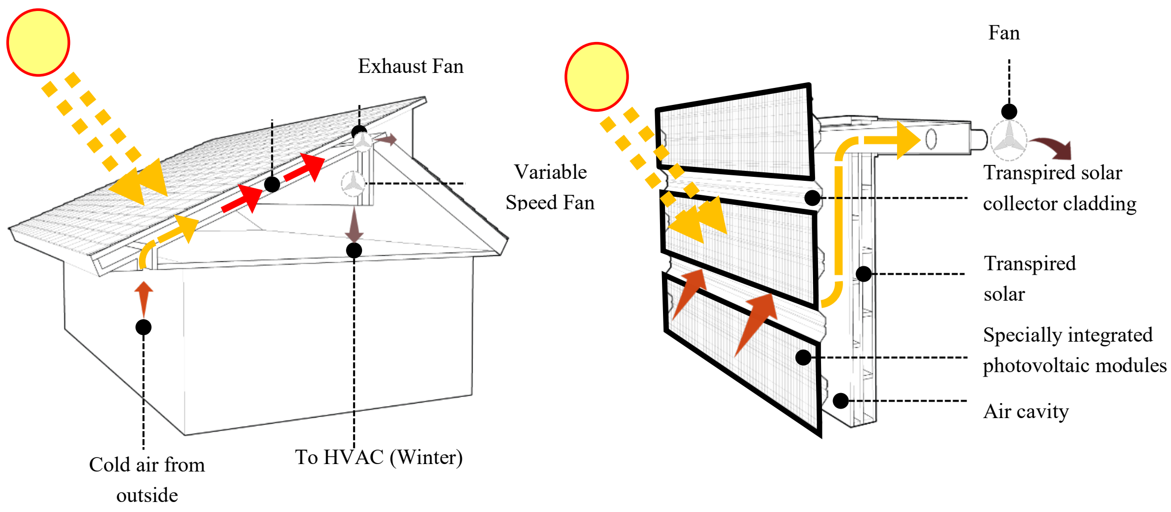


Figure 36: Examples of BIPVT systems applied to (a) roof, (b) vertical façade (Hachem-Vermette, 2020)

4.3.2.5 Water based collectors

Water based thermal collectors are effective for storing solar heat and are suitable for both domestic hot water production and space heating. These collectors typically use water charged with glycol in variable percentages to avoid freezing, depending on climatic zones. The high thermal capacity of water enables efficient heat exchange with both the absorber and the storage system. The collected solar thermal energy can be stored in insulated water tanks and used when needed. There are four main types of water-based solar collectors, categorized based on their technology: glazed flat plate collectors, unglazed flat plate collectors, unglazed plastic collectors, and evacuated tube collectors (Probst and Roecker, 2011a).

4.3.2.5.1 Flat-plate collectors

Flat-plate solar collectors are usually mounted in fixed positions (i.e., tilt and orientation angles). An appropriate orientation is crucial for optimal performance of the system. A variety of flat plate collector can be distinguished, as discussed in the following.

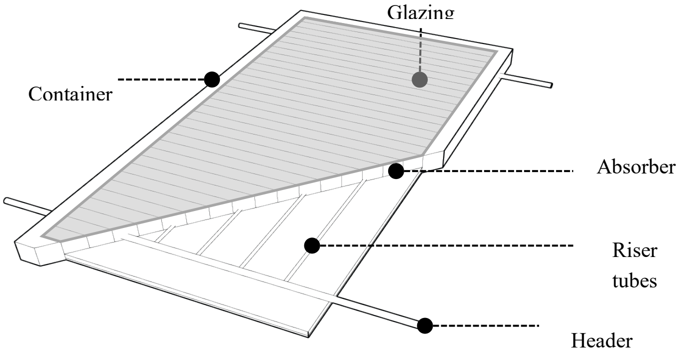


Figure 37: Illustration of a basic, water based, flat plate collector (Hachem-Vermette, 2020)

4.3.2.5.2 Glazed flat plate collectors

Glazed flat plate collectors are widely used for domestic hot water and space heating applications. The main components include external glazing, absorber plates, insulation layers, and recuperating tubes filled with heat transfer fluid (water). Glazing is a crucial aspect of these collectors' design, and it must be selected to maximize the absorption of solar radiation while minimizing heat loss from the absorber plate.

Flat plate collectors can employ single or multiple sheets of glass in their design. While the absorber plate's surface is typically black to enhance the absorption of thermal solar energy, there are commercially available color-coated absorbers that offer greater flexibility in design and integration with building architecture (Mills, 2004). To prevent the solar collector system from overheating, efficient transfer of the absorbed heat to the working fluid is essential (Slaman and Griessen, 2009). Figure 37 provides a schematic illustration of a basic flat plate collector.

4.3.2.5.3 Unglazed flat plate collectors

Unglazed flat plate collectors involve less technical complexity than other types of collectors such as glazed or evacuated tubes collectors (see below) but are not as widely used (Tripanagnostopoulos et al., 2001). They consist of fewer layers than the glazed absorber, primarily including the absorber, which is a dark-colored metal plate, and a hydraulic circuit that collects heat from the back of the absorber. The hydraulic circuit is insulated by a back insulation, to reduce heat loss to the environment. Unglazed flat plate collectors can be used for swimming pools, for low temperature space heating systems, and for DHW pre-heating (Figure 38).

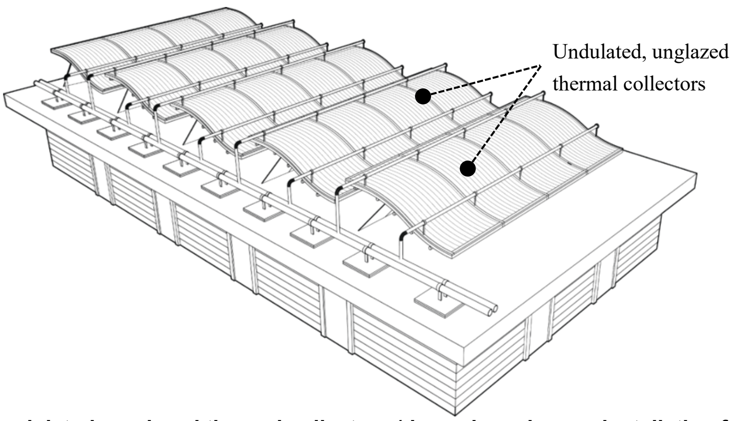


Figure 38: Example of an undulated, unglazed thermal collectors (drawn based on an installation for a swimming pool, Freibad Ilanz, Switzerland (Hachem-Vermette, 2020)

4.3.2.5.4 *Unglazed plastic collectors*

Plastic collectors are another variant of flat plate thermal collectors, consisting usually of black plastic or rubber, specially treated to resist ultraviolet radiation. The collectors are not insulated, and thus a significant amount of the absorbed heat is lost to the outdoor environment, particularly under windy, cold conditions. On the other hand, they can capture heat during the night under hot and windy conditions. Plastic unglazed collectors are mostly useful to heat swimming pools due to their low working temperatures (Probst and Roecker, 2011a).

4.3.2.5.5 Evacuated tubes collectors

Evacuated-tubes collectors comprise a series of transparent glass tubes connected to a header pipe. Each of these tubes is composed of two concentric tubes - an outer tube and an inner tube, with evacuated space between them (Abd-Elhady, Nasreldin and Elsheikh, 2018). The inner and outer tubes are sealed together at their ends. The vacuum space act as highly effective insulating layer, to reduce heat loss from the inner tube, increasing thus the energy conversion efficiency (Tang, Li, Zhong and Lan, 2006). The inner tube is coated with high absorptivity and low emissivity selective coating material, which allows to absorb incident solar radiation. The collected heat is then transferred to the medium inside the inner tube (Shah and Furbo, 2004), and then to a heat exchanger, located transversely at the edge the evacuated tubes, through various methods (e.g. employing heat pipe, see Figure 39).

The tubular shape of the individual evacuated tubes maximizes the capture of solar radiation, at various sun angles. This tube design enhances the overall efficiency of this thermal collector type, as compared to flat plate collectors. Evacuated tube collectors can be employed for a wide range of applications, including domestic hot water for residential use, space heating, and various industrial applications.

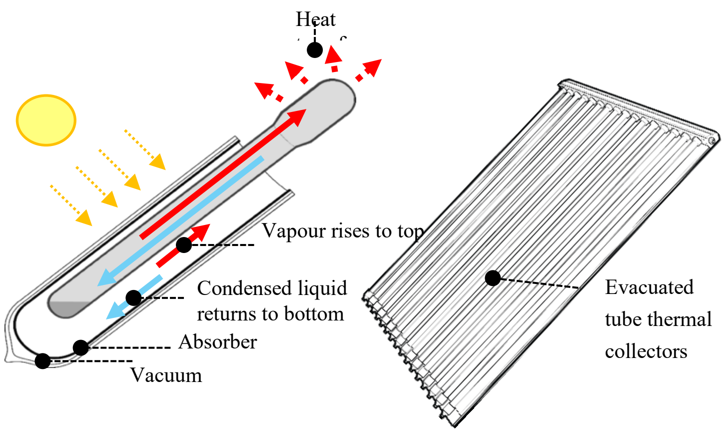


Figure 39: Evacuated tubes thermal collectors, (a) section of an individual tube, (b) sketch of the thermal collector (Hachem-Vermette, 2020)

4.3.3 Applications of PV technologies

PV technologies in buildings can be applied in two primary forms: complete integration, where PV panels are seamlessly incorporated into the building envelope, including roofs and facades, and added elements, where PV panels are added to the building envelope as separate components.

Building-Added PV (BAPV) involves installing PV panels on top of existing finished surfaces of a building, without integrating them into the building envelope. In contrast, Building-Integrated PV (BIPV) involves the seamless integration of PV modules into the functional and aesthetic aspects of the building envelope. Building-Integrated Photovoltaic Thermal (BIPVT) is a hybrid system that combines PV and solar thermal collector technologies to produce both thermal and electrical energy. These approaches can be applied in various building applications, which will be discussed in the following section.

Translucent and transparent PV are starting to attract considerable attention in view of their application into windows, to allow daylighting and solar radiation into the interior space, while generating some electricity.

4.3.3.1 Factors affecting performance

The efficiency of a PV system is primarily determined by the type of PV cells used and the efficiencies of the various components within the system. Weather conditions, including the level of solar irradiation and temperature, also have a significant impact on system efficiency. For instance, cloudy conditions with limited direct solar radiation can lead to substantial reductions in power generation.

Below are the main factors that affect the performance and the electrical output of the PV system.

- The daily and seasonal variations in solar radiation.
- Geographical location affecting the solar radiation availability at the specific location.
- Tilt angle of the solar panels.
- Azimuth angle, which refers to the orientation with respect to due south (in the northern hemisphere).
- Shadow that may be cast over the PV panels, from neighboring buildings, trees or other obstacles.
- Increase of temperature of the PV modules negatively impact the electrical efficiency of the module.

4.3.3.2 Integration of PV in the Building Envelope

The primary purpose of integrating PV panels into the building envelope is to create a synergistic relationship between architectural design, functionality, and renewable energy generation (Skea, van Diemen, Hannon, Gazis and Rhodes, 2019). The integration process typically involves replacing conventional cladding or roofing materials with photovoltaic modules. Although this concept has been promoted for some time, it is not yet widely implemented. This is mainly because the process of integration poses significant planning and architectural challenges. However, advancements in technology and growing awareness of both PV and building systems are contributing to increased deployment of Building-Integrated Photovoltaics (BIPV).

Building-Integrated Photovoltaics (BIPV) has the potential to replace various parts of the building envelope. Roof surfaces, with specific tilt angles optimized for the location, are ideal for PV module installation due to the high levels of solar irradiation they receive throughout the year. Facades also offer extensive application possibilities, especially in tall buildings located in northern regions where the sun's angle is relatively low throughout the year, particularly during the winter months. As buildings increase in height, the ratio of facade surface area to roof surface area also grows. Additionally, commercial buildings, including multi-story structures, often have limited roof space available due to the presence of various facilities and equipment like HVAC systems. This limitation makes integrating PV systems into facades especially appealing, particularly in high-density urban areas. The availability of thin-film PV technology further facilitates practical and efficient integration into facade surfaces.

The successful integration of PV systems into architectural designs necessitates careful consideration of various factors. These factors include color, pattern, size, weather resistance, wind resistance, durability, maintenance requirements, safety (including fire resistance, electrical safety, and structural stability), and overall cost (Roberts and Guariento, n.d.).

Building-integrated photovoltaic (BIPV) systems present advantages in terms of cost-effectiveness and visual appeal when compared to add-on PV systems (BAPV), by incorporating photovoltaic modules into building components, such as roofing, cladding, and glass. In instances where BIPV materials replace conventional construction materials in new building projects, the savings that would have been expended on procuring and installing traditional materials can be channeled into the cost of the photovoltaic system.

4.3.3.3 Aspects of Integration

To achieve a successful integration of PV systems into the building envelope, a comprehensive approach that encompasses architectural, functional, and technical aspects is essential. A summary of these considerations is presented below.

- Architectural/aesthetic integration: Several methods of architectural integration have been identified (Schoen, Prasad, Ruoss, Eiffert and Sørensen, 2001). These encompass neutral integration, where the system does not alter the building’s appearance, or prominent integration, where the BIPV system stands out as a distinct feature of the overall building design. An important criterion of a good architectural integration is the overall coordination with the design of the building (Probst and Roecker, 2012; Wall et al., 2012).

- Functional Integration: Solar collectors can be designed to fulfil multiple functions beyond energy generation. This can involve their incorporation into passive solar design elements like awnings and light shelves (see below), as well as their use as roofing and facade cladding materials (Keoleian and Lewis, 2003).
- Technical integration: This pertains to the incorporation of PV systems into the building's technical systems, encompassing structural, mechanical, and electrical systems. For instance, integrating a BIPV/T system with the building's HVAC (Heating, Ventilation, and Air Conditioning) system can lead to energy savings by preheating intake fresh air. Electrical integration encompasses considerations like voltage and current requirements, wiring methodologies, and interfacing with the utility grid.

A building envelope incorporating BIPV systems must be designed to prevent water infiltration, establish an effective weather seal, and manage thermal transfer. Additionally, these BIPV systems should be structurally robust to withstand the typical stresses experienced by a conventional building envelope, including those arising from thermal expansion.

4.3.3.4 Methods of Integration

Photovoltaic modules are usually integrated in three different parts of the envelope: the roof, facades, or in building components, such as balcony railings, sunshades, and sunscreens (Reijenga TH and Kaan HF, 2011). BIPV systems can cover a part or the total area of roofs or facades, depending on the design and energy generation requirements.

4.3.3.4.1 Roofs

There is a growing interest in integrating PV systems into roofs, particularly in residential or low-rise buildings, as this location offers an ideal exposure to solar radiation. Commercially available BIPV products can replace some traditional roof claddings like tiles, shingles, and slates (see Figure 40). These BIPV products are designed to seamlessly match existing building materials and are therefore compatible with common construction methods. For instance, small-scale PV components like PV shingles and tiles have been developed to allow flexible integration within the roof, making them suitable for use in various designs and building types, including retrofitting existing structures.

Prefabricated roofing systems (insulated panels) with integrated thin film laminates are gaining traction. These PV sandwiches constitute complete PV systems that comprise PV modules with mounting and interface components. Often, these products include dummy elements designed for aesthetic integration, particularly for roofs that are highly visible or have irregular shapes. Figure 40 presents various examples of PV integration within the roof design. PV can be installed in a saw-toothed roof structure, in a simple gable roof design, covering the total south facing roof area or a part of the roof surface. Further, semi-transparent PV panels can be also incorporated within skylight design (Figure 40). Employing PV modules as roof covering reduces the amount of building materials required compared to add-on PV panels, this not only enhances the sustainability of buildings but also reduces the costs associated with additional structural support systems.

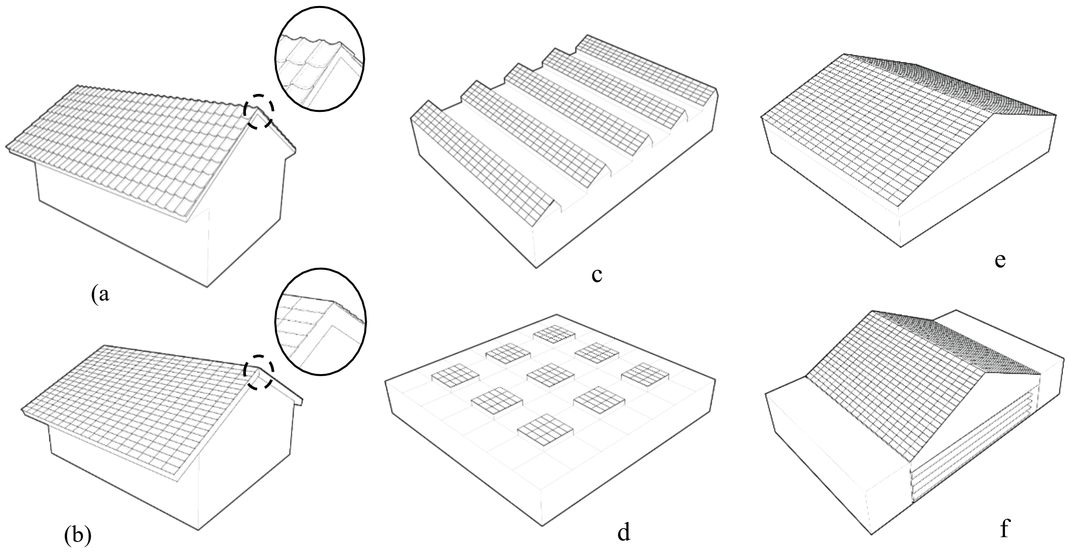


Figure 40: Schematic illustration of types of PV roofing products, (a) Shingle, (b) PV tiles; c-f Illustration of the integration of PV in various types of roofs (Hachem-Vermette, 2020)

4.3.3.5 Façades

PV systems can serve as a substitute for or a supplement to the external layer of facades, either as a cladding component or by replacing the entire facade system, including elements like curtain walls, opaque sections, or translucent materials. When PV is used as external cladding, the back is usually ventilated, to avoid overheating of the panels, which can otherwise reduce the electrical efficiency of the system. The heated air generated in this process can be utilized for space or water heating.

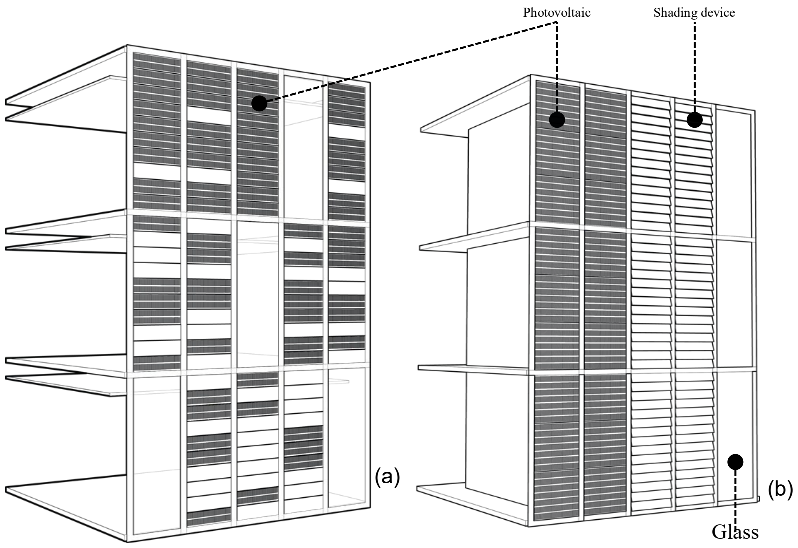


Figure 41: Application PV panels as (a) cladding elements (b) as window shutters (Hachem-Vermette, 2020)

In addition, PV can be integrated into the glazing, or replace it under appropriate solar exposure conditions. Semi-transparent PV glazing prevents direct sunlight from entering the interior space, reducing cooling loads and glare (see above-Semi-transparent PV section). In addition, PV can be integrated within daylighting and shading devices, to provide multiple benefits. Examples of incorporating PV panels within the façade and façade components are presented in Figure 41 and Figure 42.

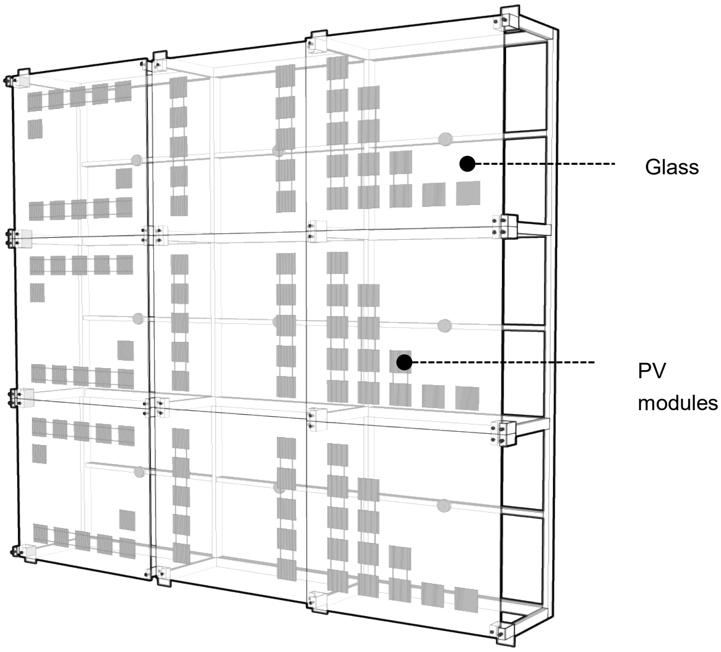


Figure 42: Schematic presentation of an example of integration of PV modules within a glazing system (Hachem-Vermette, 2020)

The electricity generation potential of PV integrated within facades is typically lower than that of PV installed on the roof, especially during the summer. This limitation can be mitigated by designing facades or facade elements that are tilted outward compared to the vertical axis. In such designs, PV panels can be used as external components that serve various functions, including shading devices, spandrels, or balcony parapets. Figure 43shows examples of BIPV systems as window shutters and awnings.

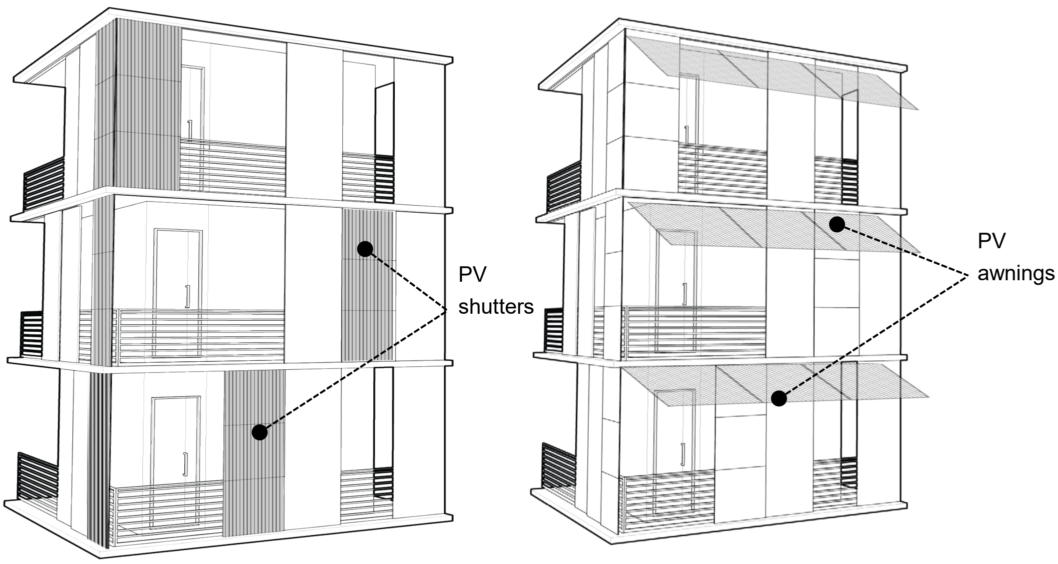


Figure 43: Application of PV panels as (a) window shutters, (b) Solar awnings (Hachem-Vermette, 2020)

4.3.4 Integration of solar thermal collectors in buildings

The criteria for integrating solar thermal collectors (STC) into buildings share some similarities with those used for PV systems integration, but there are also some notable differences. Similar to BIPV, integrating solar thermal collector systems into buildings requires addressing technical constraints related to the specific solar thermal technology, while fulfilling various architectural functions (such as cladding). These factors are critical for ensuring effective and aesthetically pleasing integration of solar thermal collectors into the building envelope.

Due to the large dimensions and complexity of their modules, thermal collectors are less flexible than PV systems, and the options of available products are restricted, making the integration of STC in the building envelope face several hurdles. Unlike PV modules, the integration of different types of STC modules is affected by the large variations in their characteristics (Probst and Roecker, 2011b).

- The energy transfer medium (air, water, etc.)
- The materials employed for the collector (plastic, metal, glass, etc.)
- The form of the collector (flat plate, multilayer flat plates, vacuum tubes)

The main methods of integration of STC in buildings are summarized below.

- Roof integration. Flat-plate collectors can be obtained in various sizes, which presents an opportunity for optimal integration in roof surfaces.
- Facade integration. Façade integrated solar thermal collectors are gaining more popularity, as solar irradiation can be exploited even during winter due to lower sun altitude, corresponding thus to higher space heating requirement. Installing STC on façades can be especially beneficial when roof space is insufficient or unsuitably oriented. While the dark color of thermal collectors may be a drawback for façade integration, collectors' color can be modified through coloring of the glass sheet covering the absorbers.
- Other integration possibilities. Solar thermal collectors can be employed to fulfil different other functions, as for example sun screening components or balcony railing. Evacuated tubes can particularly present an interesting design for balcony railings and vertical sunscreen. Figure 44 presents a schematic illustration of such application.

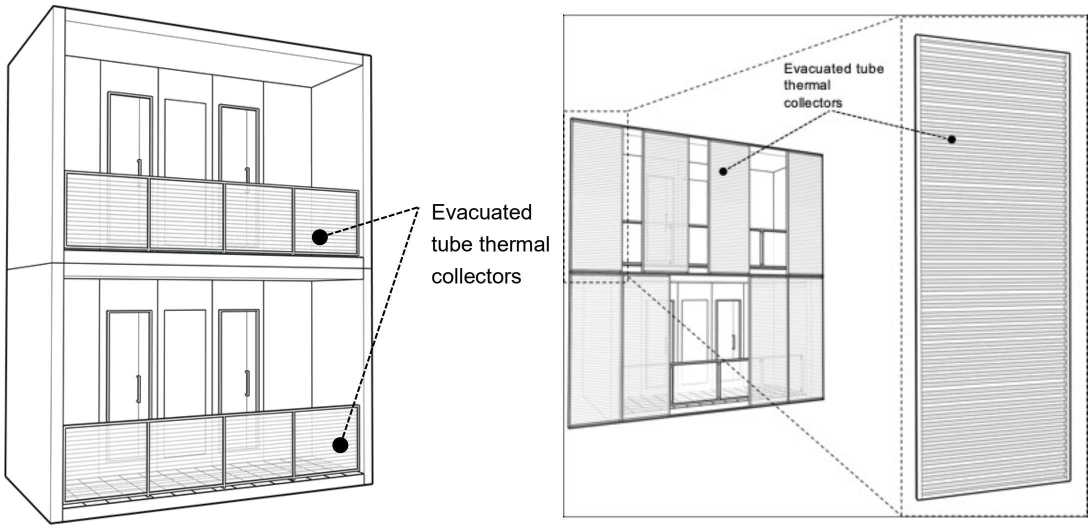


Figure 44: Illustration of the application of evacuated tubes thermal collectors, (a) as balcony railings, (b) as window shutters (Hachem-Vermette, 2020).

4.4 Neighborhood level active solar strategies

4.4.1 Green and spatial areas

The outdoor spaces in and around buildings can be strategically designed and planned to maximize the integration of photovoltaic (PV) and solar thermal collectors, particularly in high-performance, resilient neighborhoods. This solar strategy integration presents new challenges and opportunities in designing public open areas and landscapes within built environments (Figure 45a). One of the key challenges in this endeavor is the selection of suitable public spaces that offer optimal solar potential while avoiding shading from adjacent buildings. On the other side, integrating solar collector structures within public landscapes presents an opportunity to enhance the outdoor thermal comfort of the built environment. For instance, PV structures can serve dual purposes as shading devices and energy generators within urban landscapes (as illustrated in Figure 45b and c).

The public open areas within proposed neighborhoods can be thoughtfully designed to facilitate the seamless integration of landscape standalone structures. Such integrated designs can enhance the social appeal of these areas and effectively manage the balance between shaded and sunlit zones. Furthermore, these designs can be harmoniously combined with other initiatives to improve outdoor thermal comfort. In the urban landscape, urban green infrastructure, like public parks, is crucial, providing a broad spectrum of social, health, and well-being benefits (Lloyd and Auld, 2003). For instance, during the COVID-19 pandemic, public open areas played a crucial role in alleviating the stress and anxiety of urban residents who were compelled to forgo many of their usual social activities (Xie, Luo, Furuya and Sun, 2020). These public green spaces also serve as an inviting ground for innovation, advocating for sustainable materials and practices that mitigate environmental impacts while promoting a sustainable economy.

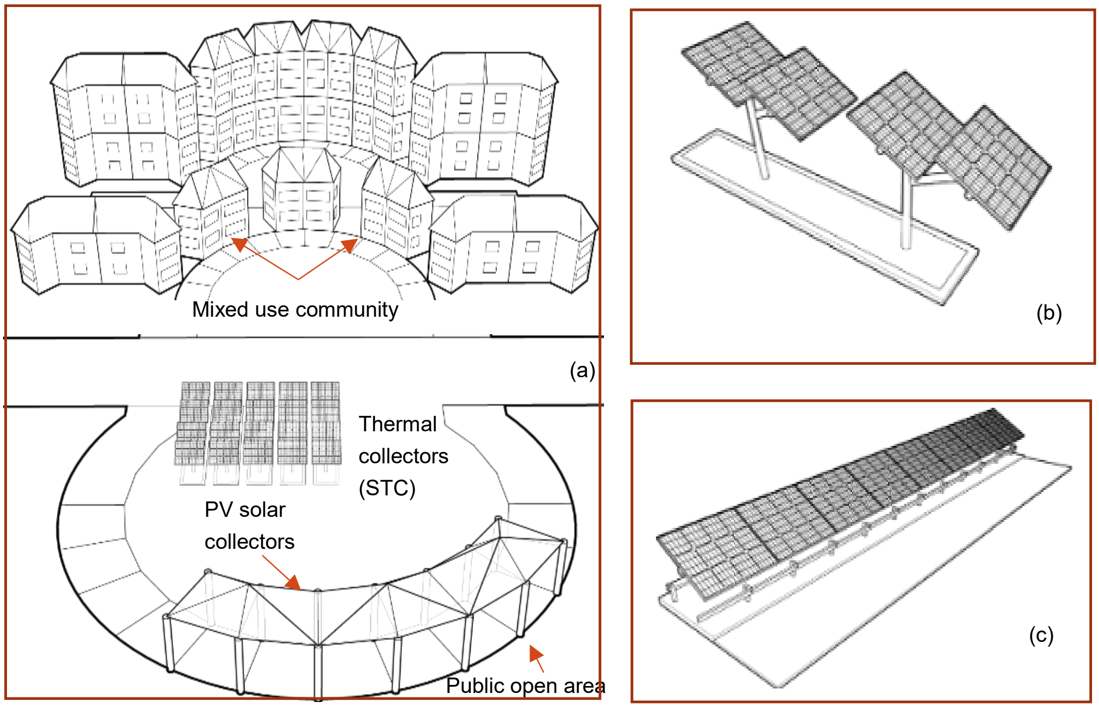


Figure 45: Balancing solar challenges and opportunities in built environments (a) Mixed use community with PV and STC integration in public areas, (b) PV as parking structure, (c) PV on street borders (Hachem-Vermette, 2020).

Additionally, the design of landscape elements can be both versatile and creative, allowing for the reduction of required land space. Consider the concept of meticulously designed double-height solar landscape structures incorporating PV panels (Hachem-Vermette, 2021). This approach demonstrates the potential to reduce land usage by up to 50% while generating a comparable amount of electricity. Stacking multiple levels of PV or solar thermal collector plates on top of each other expands available areas for solar technology integration. It presents significant potential for incorporating renewable energy sources within urban environments, where land can be scarce and expensive. Furthermore, these standalone landscape structures offer an aesthetically pleasing design opportunity, minimizing the visual intrusion of PV and solar thermal collector structures on the landscape. In summary, integrating solar technologies within public open areas and landscapes within urban settings presents a unique and multifaceted opportunity to enhance sustainability, outdoor comfort, and the overall quality of urban life. Careful planning and creative design can address challenges and promote the harmonious coexistence of renewable energy solutions with the urban environment.

4.4.2 Solar carports

When the available rooftop space is insufficient to accommodate an adequate number of panels to meet the building's energy requirements, an alternative solution involves the utilization of Solar Carports within the parking area. This approach can be further optimized by integrating bifacial solar panels to enhance performance and considering the application of a highly reflective surface on the ground to boost system efficiency.

Different from retrofitting panels onto existing carport structures, solar carports consist of overhead canopies designed to cover parking lots (Richardson, 2021). Functionally, they resemble ground-mounted systems, with the key distinction being their elevated positioning. However, this structural design offers greater efficiency compared to conventional ground-mounted systems. Since solar carports are typically installed in parking areas, they do not demand additional space, as they are integrated into an area's primary use. It is worth noting, however, that the installation cost per kWp per square meter for carports is notably higher due to the tall steel structures involved.

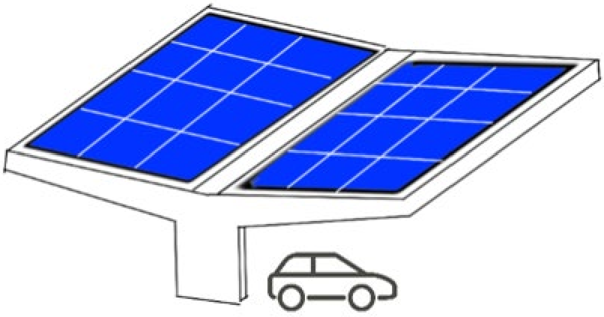


Figure 46: Implementation of solar carport

4.4.3 Solar trees

The concept of solar streetlights can be integrated into this study as an addition to solar tree design. Traditional solar mounts often introduce unwelcome visual clutter in recreational settings when considering their integration into green landscapes. Leveraging space to enhance energy performance can be a complex endeavor. Solar trees, however, offer a distinct design approach that, while not exceptionally efficient, can serve its purpose to harness solar energy in an aesthetically pleasing and space-efficient manner if employed thoughtfully.

Solar trees are steel structures designed to resemble trees, each equipped with solar panels at the end of their branches (see Figure 47). These structures offer considerable design flexibility and provide an excellent solution for integrating a solar system into public spaces. Like solar streetlights, this system can incorporate a built-in battery, serving as a lighting fixture and potentially equipped with microinverters. Furthermore, it can be linked to a nearby grid to supply power to specific buildings and infrastructure, thereby contributing to their energy efficiency.

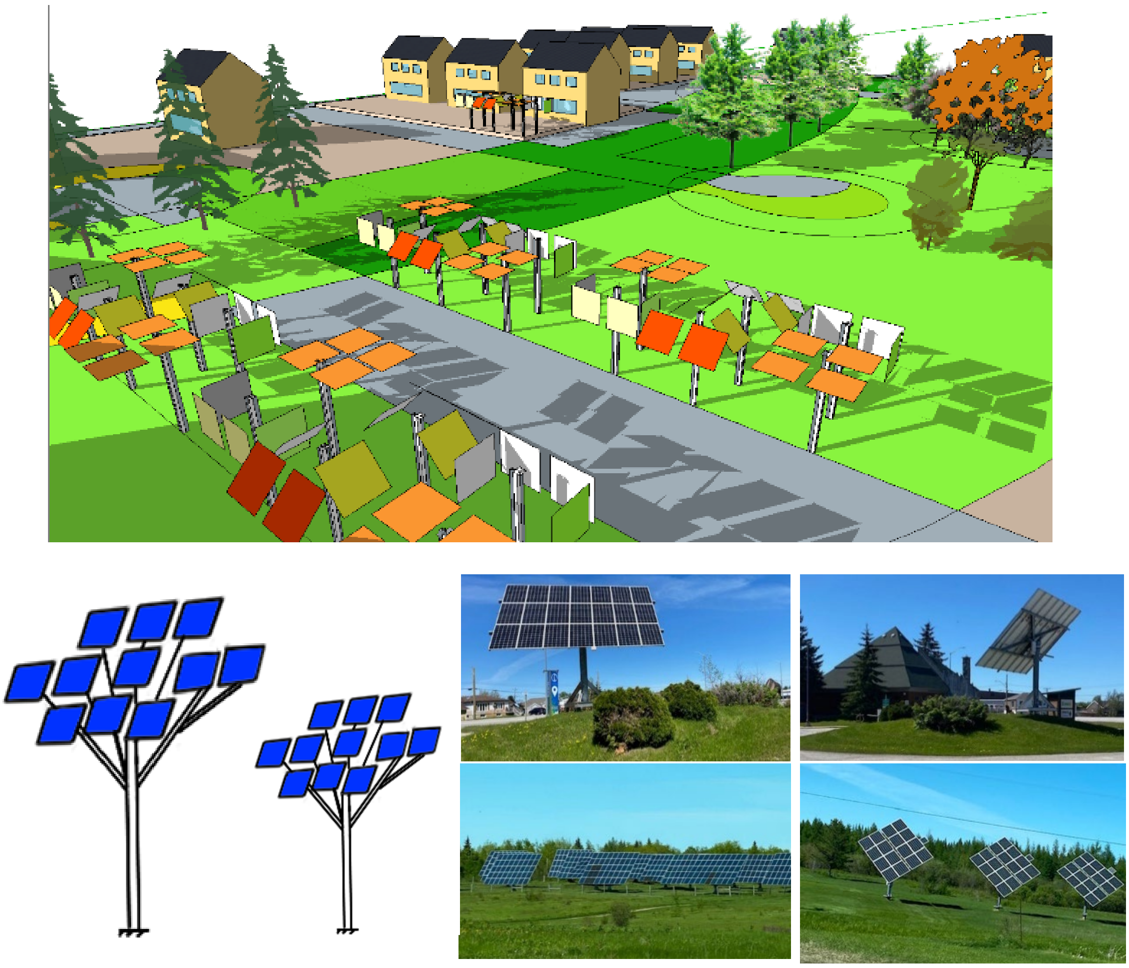


Figure 47: Integration of solar trees in built environment (Photos by C. Hachem-Vermette)

5 Analysis of solar neighborhood archetypes

This chapter presents a discussion of methods to analyze neighborhood performance, including energy consumption and energy generation. The impacts of some solar strategies and concepts (presented in detail in Chapter 4) are analyzed, in specific archetypes of neighborhoods. This section presents simulation procedures, for three main categories of archetypes: existing neighborhoods (from Canadian cities), a heritage archetype (Geneva, Switzerland) and theoretical neighborhoods.

5.1 Methods of analysis of neighborhoods

Research into the energy performance and solar potential of neighborhoods involve typically the utilization of various simulation and modelling tools. Modeling urban areas provides the advantage of incorporating various levels of complexity, characterizing the built environment, such as climatic conditions, location, and buildings and urban aspects. Modeling local solar resources and their potential is especially advantageous prior to planning and installing solar technologies. It assists in comprehending potential challenges such as shading cast by neighboring structures, as well as estimation of expected energy output of various buildings and neighborhood surfaces.

Energy modelling should be able to evaluate different energy options that might be applied inside urban areas, in addition to predicting solar potential and how it is impacted by neighborhood design elements. These prospects include micro grid applications, thermal storage options, district energy systems for heating and cooling, and more. Urban energy modeling ought to be flexible enough to incorporate various urban design variables, if not all of them. Examples of energy modeling tools include CitySim (Robinson et al., 2009), SynCity (Keirstead, Samsatli and Shah, 2010), IDEAS (Baetens et al., 2012), City Energy Analyst (CEA) (Fonseca, Nguyen, Schlueter and Marechal, 2016), and Urbanopt (Polly et al., 2016). CitySim (Robinson et al., 2009) provides hourly models encompassing building thermal behavior, urban radiation, occupant behavior, HVAC, and energy conversion systems. It can also incorporate energy generation from solar thermal, photovoltaic (PV), and wind technologies. SynCity utilizes publicly available annual energy data to produce accurate building specific synthetic data for energy demand profiles using supervised machine learning (Roth, Martin, Miller and Jain, 2020). Another tool, IDEAS (Baetens et al., 2012), developed at KU Leuven, enables simultaneous transient simulation of thermal and electrical systems at building and feeder levels. Utilizing the Modelica IDEAS Library, it integrates models of all district energy system components into a unified simulation environment, accounting for factors like energy storage, building-integrated photovoltaics (BIPV), and heat pumps (HP). Similarly, CEA (Fonseca et al., 2016), developed at ETH Zurich and École Polytechnique Fédérale de Lausanne (EPFL) serves as an urban simulation engine, aiming to optimize building energy systems and assess energy efficiency strategies at neighborhood and district scales. It is programmed in Python and functions as an extension of ArcGIS software and includes several calculation modules operating on an hourly basis. These modules cover demand, resource potential, systems technology, supply system optimization, decision-making, and spatiotemporal analysis. While CEA can simulate district thermal networks and considers factors such as heat pumps (HP), combined heat and power (CHP), photovoltaic (PV), and solar thermal systems, it does not simulate the electrical grid.

In general, the majority of current modeling techniques primarily focus on assessing the energy demand of individual buildings, often overlooking essential elements such as urban design, energy systems, storage, and potential energy exchanges. However, experts emphasize that a comprehensive system analysis is crucial for accurately gauging a city's true potential for energy savings [6]. These capabilities play a pivotal role in comprehending the effects of various solar strategies. Tools designed to model energy performance, encompassing aspects like solar access, daylighting, and energy consumption, are continually evolving. The ongoing efforts aim to enhance the accuracy and flexibility of these models while reducing computation time and the complexity of data input and output. This advancement is expected to encourage more professionals to utilize simulation tools for evaluating the influence of urban planning and building designs on specific energy indicators, particularly during the early stages of design.

5.1.1 Solar potential in urban areas

Modeling solar radiation in urban areas presents various advantages in strategically planning the integration of solar technologies within building and urban surfaces, allowing to optimize their energy output. To achieve such benefits, the model should be able to perform the following tasks:

1. Conducting accurate computation of solar radiation within the built environment, taking into considerations various climatic conditions and geographic data that can affect solar irradiance intensity.
2. Identifying various building and urban surfaces suitable for the integration of solar technologies and determining their orientation and tilt angle; and
3. Computation of solar radiation incident on specific surfaces and surroundings that may shade, taking into account their tilt and orientation angles [8].

This section provides an overview of approaches employed to assess solar access in urban areas. These methods encompass techniques to minimize mutual shading by buildings and to determine isolation or shading in a specific urban area. Such methods employ several tools to address some of the tasks described above.

5.1.1.1 Solar Irradiance computation

Advancements in solar irradiation computation models are ongoing. Initially, techniques focused on 2D models of specific surfaces, primarily rooftops within individual buildings. However, these models lacked the capability to represent complete 3D urban scenarios. With increased computational capacity and the continual evolution of modeling techniques, more comprehensive models are now feasible, taking into consideration various urban settings and complexities. Urban solar modeling employs a range of tools, from those suitable for small-scale urban models (e.g., computer-aided design (CAD) software) to macro-scale models based on geographical information system (GIS) tools, capable of processing extensive data sets. GIS data has been utilized to map insulated and shaded areas within a development, providing valuable insights for design decision-making.

An in-depth assessment of solar potential, taking into consideration both physical and geographical factors, necessitates a sequence of crucial steps. The initial stage involves collecting relevant information about surfaces and their surroundings using a digital surface model (DSM). This data can be acquired through diverse methods, such as aerial or satellite imagery, light detection and ranging (LiDAR) technology, and photogrammetry. Solar radiation models come in various forms, encompassing empirical models as well as computational models. More complex models are necessary in urban settings, which are defined by large regions and 3D phenomena, in order to create linkages between 3D urban structures and calculations that rely on physically based solar radiation formulas.

Many advanced models have been created in recent years, with a special emphasis on determining solar potential in urban settings. A number of these models are combined into "all-in-one" tools, which are software packages that include design interfaces, 3D object representations, and modules for sun radiation. Further, CAD plugin-based 3D modeling software may receive plugins from other applications that can perform radiation analysis, which allows flexibility of application in both non-urban and urban environment evaluations. Autodesk Ecotect analysis is one prominent instance. Among the most sophisticated models for projecting the physical potential of solar resources over the vast expanse of urban areas are GIS-based systems. The results of radiation algorithms applied to surface data are represented in these models primarily through the use of geographic information systems (GIS). GIS tools to determine solar irradiation include tools such as GRASS GIS, ArcGIS, SimStadt, CitySim, and Ladybug (Giannelli, León-Sánchez and Agugiaro, 2022). Ladybug and CitySim are recommended for precise neighborhood-scale solar irradiance assessment due to their comparable accuracy, common features like support for CityGML and GUI, despite Ladybug having a steeper initial learning curve (Giannelli et al., 2022). Other tools for assessingClick or tap here to enter text.Click or tap here to enter text. solar potential in urban settings include V.Sun (Hofierka and Zlocha, 2012) and SOL (Catita et al., 2014), which provide evaluations for any place on rooftops, grounds, or facades. The limitations of the current models and tools, though sophisticated, need to be addressed. Improving the quality of data is essential, as is fine-tuning the more detailed modeling of energy conversion and diffuse radiation. Achieving precise 3D representation and carrying out exhaustive model validation are also crucial components. When such characteristics are not included in basic models, the results can deviate significantly from actual values.

Additional challenges facing solar irradiation modelling and their accuracy, are caused by the characteristics of the modelled surfaces, their tilt angles and orientation (of an individual building or block of buildings). Basic models that do not capture such characteristics can produce results significantly different from the actual values.

5.1.1.2 Concepts and models for evaluating solar access

Several investigations have been conducted over the past few decades in an attempt to create comparatively straightforward models that could be used to assess an urban area's solar access without the need for rather involved simulations, as previously mentioned. For instance, Czachura et al. (Czachura, Gentile, Kanters and Wall, 2022) suggested potential performance indicators for evaluating indoor and outdoor solar access at the neighborhood scale. The suggested indicators for solar access evaluation include view skyline factor, solar vector fraction, average sun hours factor, and radiation distribution factor. Formolli et al. (Formolli, Kleiven and Lobaccaro, 2023) proposed solar envelope volume, buildable floor area, number of units, building distance, building layout, and building morphology, as well as solar technologies potential to evaluate solar access. The objective functions and design options studied regarding these factors varied. For example, some works seeking to maximize the sum of minimum direct sunlight hours at the 1st floor, while others aimed to minimize deviation from compliance with national daylight standards (Formolli et al., 2023).

Establishing models to specify the maximum height of a building that is permitted in order to prevent it from overshadowing its surroundings is one example of such an endeavor. A well-known strategy, known as the solar envelope, was created to guarantee that every building in a community has access to the sun (Knowles and Berry, 1980). The term solar envelope refers to a theoretical geometric surface that delineates the maximum heights of proposed or existing structures within a development, with the intention of preventing them from significantly shading existing buildings (Knowles and Berry, 1980). The solar envelope model was modified to define maximum heights of new/proposed structures that allow for a predetermined mean annual horizontal irradiance (W/m2) for existing buildings.

Furthermore, the concept of solar volume for determining the urban fabric (Capeluto and Shaviv, 2001) was proposed to determine solar access and rights within the built environment. This volume is made up of two parts: the solar rights envelope, which is the upper limit on building heights/positions where they do not infringe on the solar rights of neighbouring buildings, and the solar collection envelope, which is the lowest locations for solar collectors/windows that will still receive sunlight in the winter. These envelopes, which are based on predetermined solar access values (typically 4 hours of sunlight during the Winter solstice), and usually not account light intensity or angle of incidence, and the effect on building energy consumption is dependent on a variety of factors, including building construction and climate.

The ray tracing program RADIANCE, which simulates irradiation on façades, is one of the simulation programs used for investigating solar access of buildings within urban contexts (Sarralde, Quinn, Wiesmann and Steemers, 2015; Tian, Loonen, Bognár and Hensen, 2022). In some cases, digital elevation models (DEMs) are also used to determine the effect of urban texture on building energy consumption. These DEM models are primarily image-based and were used instead of detailed numerical simulations of radiation exchange (Ratti, Baker and Steemers, 2005b).

5.1.2 Energy performance

Several studies are focusing on developing specific modeling procedures to analyze urban energy performance. Top-down and bottom-up methods are commonly used to model urban scale energy consumption [64]. Building clusters are viewed as an energy sink in top-down methods. This method treats the entire studied building cluster or neighborhood as a single entity. As a result, the neighborhood provides a general energy demand profile without taking into account the energy characteristics of specific buildings within it. Buildings are treated as black boxes in this approach, and thus cannot provide information on the environmental impact of building design options, such as the use of various passive design strategies and technologies at the individual building level. This method's underlying models are based on statistical data and economic schemes. Building performance simulations can be utilized to model sets of buildings that are representative of real-world practices in bottom-up modeling. These models make it possible to comprehend how building design, including retrofitting strategies (for already-existing buildings), affects energy usage.

The predictive reliability of simulation tools, which are used to analyze the actual energy performance of buildings and neighborhoods, is sometimes questioned because they are primarily dependent on a number of assumptions and statistical data. One major factor influencing a building's energy performance is its occupants' actions, which can lead to a large difference between the building's actual performance and its modelled performance. Therefore, rather than being a measure of performance in absolute terms, simulation models should be viewed as analytical tools that enable the extraction of relative comparison results.

To examine how energy-efficient urban areas are, two methods are used. Models emulating actual urban design morphologies are used in the first method. When the examined morphologies cannot serve as widely accepted models of urban development, these cases typically have limited potential to generalize the results. Urban morphology optimization and sensitivity analyses can be carried out with ease using the second approach, which is based on simplified urban morphological archetypes that are easily parameterized. This approach's main flaw is its potential to depict fanciful urban design shapes. The pavilion archetype which includes variations in shape for high-rise buildings, courtyard arrangements, row houses, and urban street canyons is the one that is evaluated the most frequently.

The most extensively studied urban morphology parameters fall into one of three categories: (i) a specific building, (ii) the building form alone, and (iii) the morphological patterns of an entire neighborhood. These are explained as follows:

(i) Building-specific parameters, such as the ratio of passive to non-passive floor area, building orientation, wall surface area, and envelope area to floor area ratio. The space of the floor next to the equatorial façade that has a total width roughly twice the interior height (measured from floor to ceiling) is known as the passive solar floor area. The penetration of solar radiation is estimated using this technique [86].

(ii) The morphological surroundings of a specific building are determined by various parameters: the obstruction angle, which is the smallest angle with the horizontal under which the sky can be seen from the lower edge of a vantage point, usually an opening in a building [80]; the urban horizon angle, which combines the building's orientation with the elevation of the sun based on latitude [86]; the sky view factor, which is the ratio of radiation received or emitted by a planar surface to the radiation received or emitted by the entire hemispheric environment; and the building's height to width, or H/W ratio.

(iii) Characteristics of an entire neighborhood’s morphological patterns, such as the typology (including heights) of building clusters and the site coverage (defined as the area of a site occupied by buildings or structures for human occupancy).

Many tools are developed to calculate the heating demand of buildings in particular neighborhoods using simplified algorithms (Hao, Xie, Zhang and Liu, 2023). Additionally, more comprehensive tools for estimating different energy-related components, like daylighting and operational energy, are being developed. These tools are based on sophisticated energy simulation engines, like EnergyPlus and Radiance/Daysim (Reinhart, Dogan, Jakubiec, Rakha and Sang, 2013). Furthermore, to estimate hourly energy demands at the neighborhood level urban building energy models based on GIS (Geographic Information System) can be deployed (Ferrari, Zagarella, Caputo and Dall’O’, 2021). Moreover, a number of currently available tools offer precise models for technologies like geothermal heat pumps and solar thermal collectors. As an example, a feasibility study of zero-energy homes with solar hot water, energy-efficient heating systems, and renewable electricity is conducted using EnergyPlus and TRNSYS (Zahedi, Seraji, Borzuei, Moosavian and Ahmadi, 2022). Still, there are limitations when it comes to simulating novel technologies or the interactions between various equipment components.

5.2 Analysis methods of archetypes

Several analysis methods including modeling and simulation can be employed to understand the energy performance of a neighborhood, and to assess the feasibility of implementation of solar strategies and concepts. These methods may vary according to the type of neighborhoods and to their phase of development whether they are existing or in the planning phase. Figure 48 illustrates an example of phases employed in a specific method to analyze archetypes of existing neighborhoods. It starts with the identification of distinct neighborhood patterns, followed by data collection employing various GIS tools, and then, assuming specific construction materials, energy simulations are conducted to determine energy consumption as well as the potential of various solar strategies. In the following subsection, some examples of analysis of the energy performance and solar strategies of existing neighborhoods and theoretical neighborhoods are discussed, including the method illustrated in Figure 48.

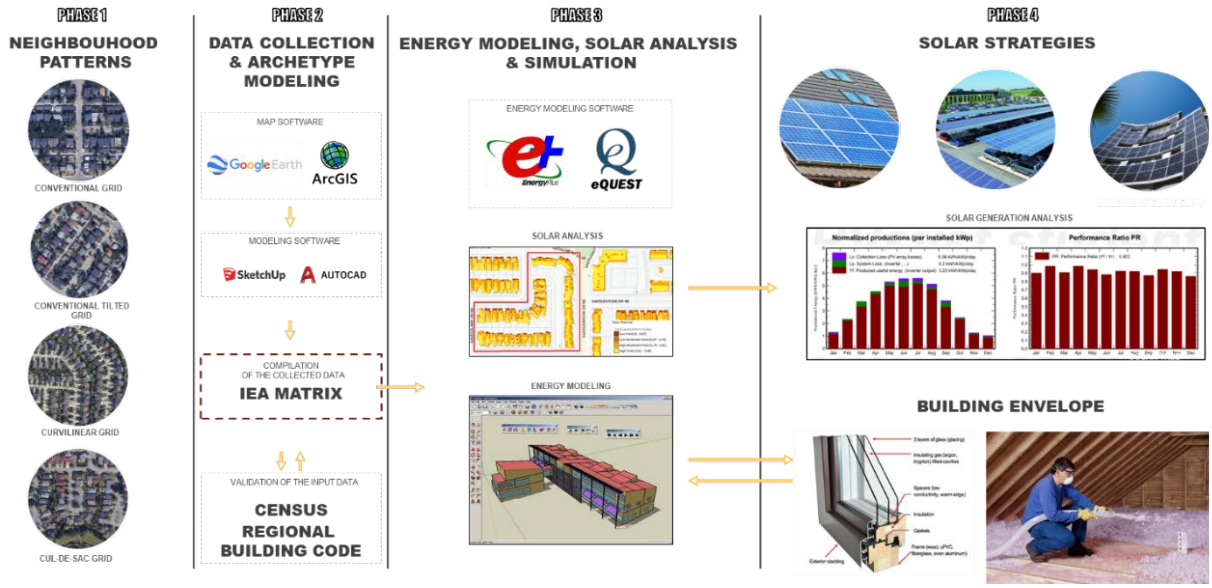


Figure 48: Overall modeling and simulation process of archetype analysis

5.2.1 Selected archetypes of existing neighborhoods -Canadian

The models presented in this section are developed based on Canadian archetypes, that mostly feature low density residential buildings (houses and low-rise multistorey buildings). These archetypes are quite common in Canada and other areas of North America, and the analysis of their performance is relatively easy to handle as compared to larger, higher density neighborhoods. In addition, it is easier to obtain and compile performance data for such neighborhoods (e.g., in a baseline), to allow comparison of results, and assessment of impact of various solar strategies and technologies.

5.2.1.1 Energy modeling of existing neighborhoods

The first step of the presented analysis method of the archetypes of existing neighborhoods consists of creating a geometrical model of these neighborhoods. This is done employing SketchUp in conjunction with an extension - Euclid. This extension uses SketchUp's modelling platform to transfer energy data input from the 3D model into an energy model compatible with EnergyPlus, employed to run energy simulations. Measurements used in the 3D modelling of the neighborhood buildings are based on satellite images. Moreover, Google Street view, and 3D models from Google Earth are utilized to model the buildings' rooftops as accurately as possible. Once the geometrical model is completed in SketchUp, an IDF file is generated and input into EnergyPlus.

All assumptions of energy simulations for the examples presented below are based on data from the census from Statistics Canada [24], government agencies (Department of Energy - DOE, 2004), and ASHRAE Handbook – Fundamentals [25]. Additional assumptions are as follows:

1. Construction materials are selected based on the standards used in the Canadian building industry (see below). All the analysed Canadian neighborhoods, presented in this section, use the same materials for comparison purposes.
2. For the standard construction, commonly employed materials are considered, like insulated wood frame walls, plywood floors, asphalt shingle roof coated with OSB boards, double pane glazing, and others.
3. The household size is determined using the community profile of each neighborhood provided by the Canada Census 2016 [24].
4. Heating, Ventilation, and Air Conditioning systems (HVAC) are selected based on the location of the neighborhood, according to NRCan baseline (for Canadian archetypes). Common heating systems employed in North American houses are assumed in this study.

Material selection: The standard energy simulation employs default construction materials available in EnergyPlus. The fenestration is based on the typical fenestration characteristics chart available in the ASHRAE Handbook Fundamentals (ASHRAE, 2017). The type of window assumed for the energy simulations are double glazing layers with operable aluminum frame for the conventional construction simulation and triple layered low-e, low-solar glazing with operable aluminum frame for the high-performance simulation.

When simulating a high-performance version of the neighborhoods, materials are selected to reduce the energy demand and increase the efficiency of the buildings. This includes insulated concrete forms poured into thick pieces of foam to reduce thermal bridging in the wall system, and triple pane glazed windows. The simulation of the neighborhoods is followed by a comparison to a baseline designed and modelled according to the national database [26], and validated based on the energy consumption per area and end-use (kWh/m²/year). The development of the baseline is described below.

5.2.1.2 Development of the baseline

A baseline is established for each building type to facilitate the comparison of energy efficiency measures and assess the impact of implementing solar strategies. The baseline is developed using the Natural Resources Canada energy use database [26], which include the average energy use based on building types, building use, and heating and cooling systems, associated with each province. Energy simulations are performed to estimate the energy demand of each of the selected neighborhoods and results were validated against the established baselines. These models are then systematically modified to reduce the overall energy consumption and to implement various solar strategies. The study focuses on the reduction of heating loads by altering the materials of the building envelope. Energy consumption of the neighborhoods is compared to energy generation to determine the feasibility of achieving a net-zero energy status.

Three baseline models are built for each province for this study, based on the following building types: single detached houses, single attached houses, and apartment buildings. The end-uses evaluated in the simulations include space heating, water heating, appliances, and lighting. Whilst all these end-uses contribute to the overall energy demand of buildings, the simulations focused on measures to minimize space heating demand since it is the most significant energy end-use in Canadian residences and other similar cold climates. Because cooling systems are less commonly used in Canada in residential buildings, space cooling systems are not taken into consideration.

Table 9: NRCan database - end-use energy consumption (Natural Resources Canada, 2019)

kWh/m²/year	British Columbia				
	Space Heating	*Water Heating*	*Appliances*	*Lighting*	*Space Cooling*
Single Detached	91.71	28.95	22.93	8.52	1.47
Single Attached	65.27	36.43	28.08	5.31	1.52
Apartments	45.37	43.78	34.62	4.38	0.80
kWh/m²/year	**Alberta**				

	Space Heating	*Water Heating*	*Appliances*	*Lighting*	*Space Cooling*
Single Detached	197.31	50.57	25.28	8.71	0.51
Single Attached	98.51	44.37	23.07	5.32	0.00
Apartments	117.41	47.25	25.77	2.15	0.00
kWh/m²/year			**Manitoba**		
	Space Heating	*Water Heating*	*Appliances*	*Lighting*	*Space Cooling*
Single Detached	148.95	39.14	38.05	9.78	11.42
Single Attached	115.74	28.94	34.72	5.79	0.00
Apartments	87.06	35.24	39.39	4.15	6.22
kWh/m²/year			**Ontario**		
	Space Heating	*Water Heating*	*Appliances*	*Lighting*	*Space Cooling*
Single Detached	144.23	36.00	19.39	6.71	10.49
Single Attached	117.49	39.09	22.27	4.80	6.55
Apartments	93.81	47.08	27.45	2.08	3.30
kWh/m²/year			**Quebec**		
	Space Heating	*Water Heating*	*Appliances*	*Lighting*	*Space Cooling*
Single Detached	178.41	12.59	33.01	10.60	4.97
Single Attached	117.24	31.31	35.97	9.33	4.66
Apartments	101.41	27.06	37.17	4.67	1.40

5.2.1.3 Solar strategies simulations

This section presents an overview of specific strategies suggested to improve the energy performance of the presented existing archetypes. The strategies proposed for these neighborhoods concentrate mostly on various types of PV modules, as well as on the methods of integration within the buildings and neighborhood surfaces. The type of PV includes monocrystalline and bifacial panels. The type of installation includes building integration in differently oriented roofs, and mounts on flat rooftops; neighborhood integration includes solar carports, and solar trees. The type of PV technologies and method of integration is largely affected by the energy demand of specific neighborhoods, and the PV size required to achieve net-zero energy status. Table 10 shows the pros and cons of each selected solar strategy used in the study of these low-density residential archetypes.

Table 10: Neighborhood level solar strategies, pros and cons

Monocrystalline			
Strategy	*Description*	*Pros*	*Cons*
Tilted Rooftops	Installation of solar panels on top of tilted rooftops to capture sufficient solar energy for effective system operation and energy production	Cheap cost of installation, good performance	Might suffer shading from surrounding rooftops and other environmental elements
East-west Mount	Installation of solar panel rows with lower tilting facing east-west	Higher percentage of area usage in flat rooftops, easy access of the modules for maintenance	Lower energy generation performance due to the orientation of the solar panels
Bifacial			

Strategy	*Description*	*Pros*	*Cons*
Flat rooftops/Ground Mount	Installation of solar panel rows in a ground mount using ballasts on top of flat roofs	Higher energy generation performance, lower mutual shading	Lower percentage of area usage in flat rooftops
Solar Carport	Installation of solar panels on parking shelters	Use of the parking area as a source of renewable energy generation	Expensive structure, difficult installation, and connection to the grid (usually requires trenching through concrete)
BIPV	Installation of solar panels as elements of buildings	Use of building elements to install solar panels and produce extra energy	Needs custom mounting, usually having a lower generation performance
Solar Trees	Installation of solar panels in mounting structure resembling a tree	Good alternative for solar application in green areas, aesthetical appealing	Custom mounting, solar system usually far from grid connection

The solar strategies presented above are simulated employing PVSyst (Mermoud, 2022). Prior to running these simulations, a shading analysis is carried out employing SketchUp in order to ensure that solar systems are not shaded, to understand the impact of the surroundings before designing solar strategies for each neighborhood. The shading analysis is used to recognize some of the environmental elements, like trees, other buildings, or different parts of the roof, that may shade the PV system. Figure 49 presents an example of extracting the geometry from the existing neighborhoods and specifying the most available surfaces for a basic scenario, where PV is installed on the roofs. The assumptions used in the simulation of the solar strategies include the following:

1. No solar system can have an azimuth of over 90 degrees (NE/NW orientation).
2. Albedo value for asphalt is 0.15 and is considered for bifacial modules installed on solar carports.
3. Albedo value for white painted concrete is 0.9 and is considered for bifacial modules installed on top of flat rooftops.
4. Albedo value for green grass ranges from 0.2 to 0.4, so the value 0.25 is considered for solar trees.
5. No system should receive more than 3 hours of shading per day.
6. The Ground Cover Ratio for Ground Mount PV systems is 0.66.

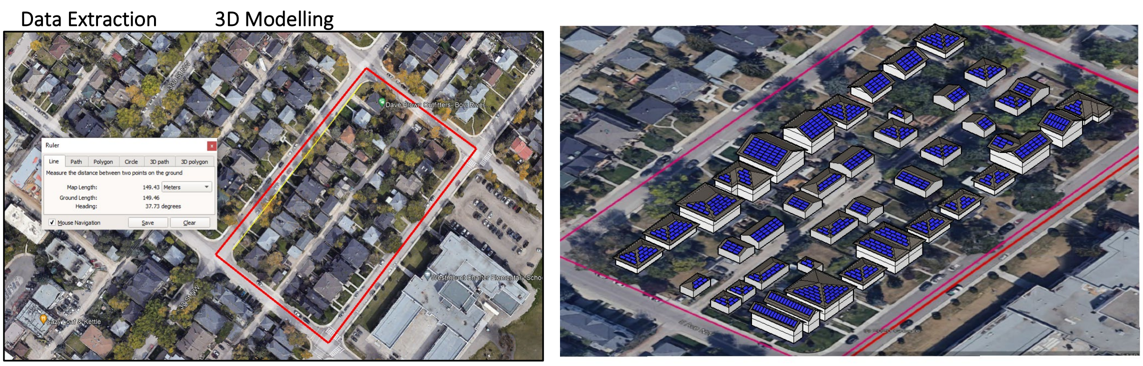


Figure 49: Example of data extraction and measurements using Google Earth and identifying suitable surfaces for PV installations

5.2.2 Solar strategies implementation rationale

To evaluate the benefits and drawbacks of each solar strategy when applied in various situations, a simplified qualitative method is developed, as presented in Table 11. The outcome is assessed based on comparative performance among the various strategies. The criteria employed in evaluating these strategies, namely implementation cost, assembly difficulty, efficiency, power-to-area ratio, and power output are briefly explained below. As mentioned above, this strategy aiming to classify and prioritize some designs, is a simple method based on a number of assumptions. Criteria and assumptions can be modified to reflect various changes including technological advances, market variations and other considerations. Each of the evaluation criteria is briefly introduced below.

Table 11: Solar strategy application decision making matrix

	Implementation Cost	*Assembly Difficulty*	*Efficiency*	*Power to Area Ratio*	*Power Output*
Flat Rooftop – South Oriented					
Ground Mount	Medium	Medium	High	Low	Medium
E-W Mount	Medium	Medium	Low	High	High
Flat Rooftop – SW/SE Oriented					
	Implementation Cost	*Assembly Difficulty*	*Efficiency*	*Power to Area Ratio*	*Power Output*
Ground Mount	Medium	Medium	High	Low	Medium
E-W Mount	N/A	N/A	N/A	N/A	N/A
Tilted Rooftop					
	Implementation Cost	Assembly Difficulty	Efficiency	Power to Area Ratio	Power Output
Monocrystalline	Low	Easy	High	High	High
Polycrystalline	Low	Easy	Medium	High	Medium
Bifacial	N/A	N/A	N/A	N/A	N/A

5.2.2.1 Implementation cost

The cost of implementing solar technologies plays a key role in the decision-making process. Given the tilt angle of rooftops, the expense associated with installing solar panels is relatively lower compared to alternative installation methods. As the structures required for installing solar systems on tilted rooftops are more cost-effective than other alternatives, monocrystalline and polycrystalline configurations are categorized as having a "low" cost, while bifacial configurations are categorized as having a "medium" cost. When considering the installation of solar systems in flat roofs, the costs can fluctuate based on the design, primarily due to the requirement for elevated ground mount structures for spacing and tilting the modules. Assuming an additional cost associated with these structures, systems necessitating a ground mount are also classified as having a "medium" cost factor. Alternative approaches for implementing solar systems, such as solar carports in parking lots, solar trees, and Building Integrated Photovoltaics (BIPV) using solar panels as integral building elements, typically involve custom designs, structure manufacturing, and the need for specialized labor during installation. Consequently, these strategies are categorized as having a "high" cost factor in the implementation rationale.

5.2.2.2 Assembly difficulty

Following the same approach as the cost factor, the ease of assembly is a key consideration when selecting an optimal solar strategy. Installing solar panels on tilted rooftops stands out as the most common approach, featuring standard clamps and an anchoring system that facilitates a swift and straightforward process. Therefore, it is rated as "easy." Ground mounts, on the other hand, involve the assembly of ground structures, anchoring into the slab, and waterproofing, requiring more materials and meticulous attention in the assembly phase. As a result, ground mounts are categorized as "medium" in terms of assembly complexity. Conversely, custom designs such as carports, solar trees, and Building Integrated Photovoltaics (BIPV) typically demand more time for installation, assembly, and design due to the intricate nature of the structures. Moreover, these custom designs often necessitate specialized labor, earning them a "hard" rating in the assembly factor.

5.2.2.3 Efficiency

Efficiency is gauged by the capacity to convert sunlight into usable energy. In this study, the assessment of efficiency extends beyond the individual solar panels to encompass the entire system, considering factors such as orientation, shading, tilting, and soiling.

Despite using modules with identical efficiency in simulations, variations in PV cell performance exist. For instance, monocrystalline and bifacial modules, with the same area and power (kWp), demonstrate different performances. Bifacial modules can generate energy from both the front and rear surfaces, potentially surpassing the output of a monocrystalline module with equivalent generating capacity. On tilted rooftops, the high purity of silicon used in the manufacturing process renders monocrystalline modules highly efficient, earning them a "high" rating. Polycrystalline modules, with a lower efficiency than monocrystalline, are rated as "medium." Bifacial modules are not applicable on tilted rooftops, as their rear surface lacks a reflecting surface, negating their advantage over similar technologies.

On flat surfaces, ground-mounted systems outperform east-west mounts due to array orientation and optimized tilting, earning them a "high" efficiency rating. East and west mounts, with less favorable orientation, are consequently rated as having "low" efficiency. In instances where custom designs like carports, solar trees, and Building Integrated Photovoltaics (BIPV) are the only viable options for implementation in certain environments, there is an assumption of flexibility to choose the technology that best suits the determined circumstances, irrespective of system efficiency. Solar carports typically demonstrate "high" efficiency, though this may be impacted if nearby buildings cast shadows on the parking area.

The performance of BIPV systems is heavily contingent on the method of implementation, including the tilt angle of the surface used for PV system integration. Consequently, each proposed BIPV system in the study should undergo separate evaluation and simulation, and its efficiency is not included in this solar strategy implementation rationale. Solar trees are assumed to have a "high" efficiency since they can be positioned in areas with no shading. However, it is important to note that the albedo from grass, or the reflectivity of sunlight, is low, which could influence the overall efficiency of solar trees in specific contexts.

5.2.2.4 Power to area ratio

This category factors in the amount of solar power that can be installed in a specific area, see Figure 50. Ground mounts employed on flat rooftops exhibit better efficiency; however, they require more spacing due to mutual shading, resulting in a lower power per area ratio compared to east-west mounts. Figure 50 provides a visual representation of the number of solar panels suitable for a 100 m² area. Following the comparison, the east-west mount is rated as "high," while the ground mount is rated as "low."

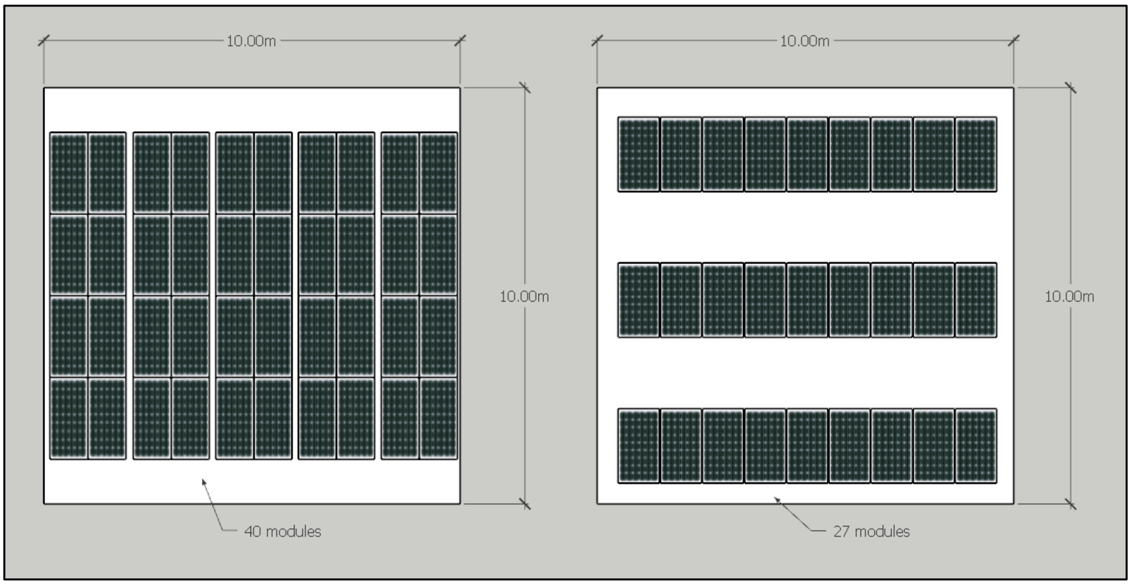


Figure 50: Power to area ratio comparison: (a) east-west mount and (b) ground mount

5.2.2.5 Power output

The simulation and comparison of the efficiency and power output of various photovoltaic (PV) technologies are conducted using PVSyst. Subsequently, the power-to-area ratio is established by configuring each approach for the rooftops in different neighborhoods employing SketchUp. It is concluded that, for tilted rooftops, monocrystalline technology exhibits superior energy generation and is consequently classified as "high." For flat rooftops, the east-west mount has a slightly better power output, even though its efficiency is lower.

5.2.3 Unique archetypes: Cité Carl Vogt (Switzerland)

This neighborhood archetype -Cité Carl Vogt neighborhood, consists of 5 apartment buildings with 450 social housing units (6 600 square meters of floor space) and ground-floor shops. The Hospice Général (the main social housing provider in Geneva) is the sole owner.

Energy renovation of the Cité Carl Vogt neighborhood took place from 2018 to 2023. The goal of the renovation project was to improve the quality of the buildings and apartments in various aspects, including comfort, energy efficiency, and deterioration, ultimately increasing the property's value. This project is complex and involves several challenges, including energy transition (improving the building envelope and increasing the use of renewable energy sources, including solar energy and a lake water heating system), social aspects (support for tenants), economic considerations (financing the renovations), and heritage preservation (cataloging the entire complex, Honegger architecture).

In Geneva, building projects can rely on a comprehensive database managed by the SITG (Geneva Land Information System, available at https://ge.ch/sitg/). This database offers a wealth of valuable information, including details on building ground and floor areas, type of use, number of floors and height, measured heat index (kWh/m2/y), heating systems, period of construction, solar potential based on the solar cadaster, and more. Additionally, it provides spatial information regarding heritage constraints and protection, as exemplified in the case of Cité Carl Vogt, as illustrated Figure 51.

Figure 51: Information of heritage constraint on the Cité Carl Vogt (source: SITG)

The buildings were subject to an architectural census (the census distinguishes 4 levels: exceptional, interesting, of secondary interest, of no interest). As shown in Figure 52 the buildings studied are considered as 'interesting' from a heritage point of view, and therefore require protection measures, limiting external insulation in particular.

Regarding the solar potential of this archetype, the 5 buildings offer approximately 4 000 square meters of roof space, which corresponds to a potential of about 740 kWp (kilowatt peak). However, as seen in Figure 54, the rooftops are heavily cluttered with technical equipment (elevator shafts, ducts, pipes, structures). Therefore, only 210 kWp of solar panels could be installed on the buildings.

The technical specifications of the solar installation are as follows:

Number of plants:	13 (1 plant per entrance)
Orientation:	dome structure 130° southeast, 310° northwest
Inclination:	10°
Number of modules:	687
Total surface area:	1 140 m^2
Module performance:	305 Wp/module (185 Wp/m^2)
Total installed power	210 kWp

The layout of the solar system can be designed by tools like PVSyst®, that also provides technical specifications on efficiency and energy production.

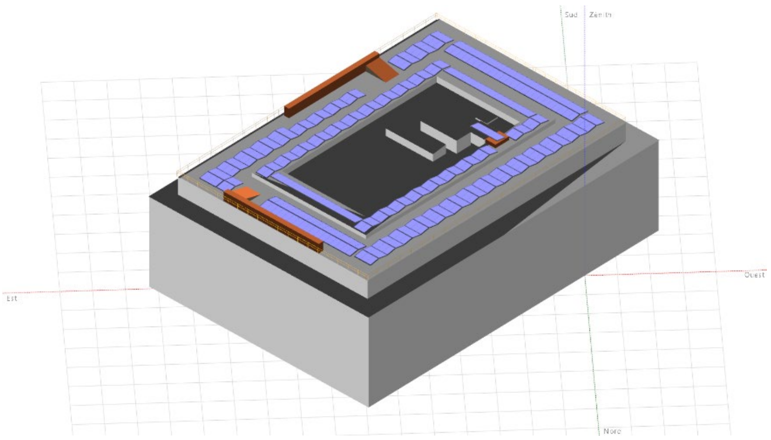


Figure 52: Example of solar system layout using PVSyst® (source: Amstein+Walthert Geneva)

The solar power is solely used to supply the common areas of the building (lighting, ventilation, heating), but not the residential units. There are plans to eventually supply the ground-floor businesses with solar power as well. To carry out the solar installation, Hospice Général received assistance from Yellowprint (Photovoltaic management), which managed the entire project from conception to implementation. Ongoing support during the operational phase is provided to optimize the installation and self-consumption over time, based on evolving needs.

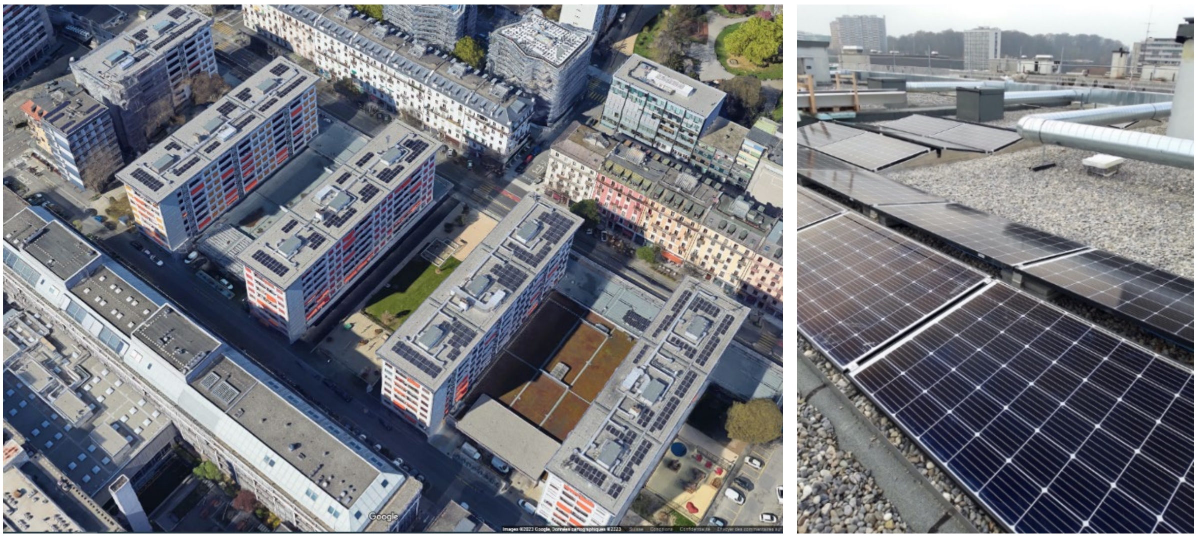


Figure 53: Aerial image of the solar installation on the roof (left), detailed view of the installation with obstacles (right) (source: Hospice General)

5.2.4 Modeling of theoretical archetypes

A number of theoretical neighborhoods are developed to analyze the impact of various solar concepts and technologies in new settings. Figure 54 shows the workflow of new archetype energy modeling merging various individual building models. The workflow can be subdivided into three main steps: pre-processing, cluster configuration setup and post processing. Energy modeling of individual buildings in cluster is carried out using EnergyPlus and SketchUp. The work is divided into various stages to facilitate the work and prevent errors due to merging individual building models into a larger neighborhood model.

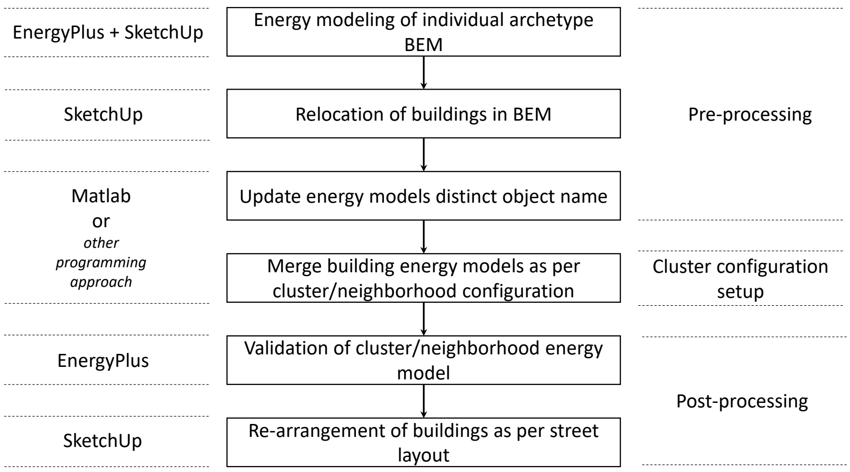


Figure 54: Workflow of energy modeling of neighborhoods (taken from (Singh and Hachem-Vermette, 2022)**)**

After pre-processing, the archetype configuration setup process can be applied by merging individual building energy models (EnergyPlus intermediate data format, IDF files) according to a specific cluster or neighborhood configuration. In this work, a Matlab code is employed although other programming approach such as Python, R, C/C++ can achieve similar objective. The clusterenergy model is then validated by comparing the results to the results of sum of used individual building energy models.

The procedure for merging separate building energy models (BEMs) into a collective archetype energy model is shown in Figure 5. First, the process collects file names from a designated directory or folder. This folder contains all of the BEM-IDF files for the buildings (individual building energy model) that need to be a part of the cluster model. All files with the.idf extension is listed in an array of file paths for IDF files that is created. The file information array (FIA) is the name given to this array. The primary IDF is chosen to be the first IDF file (IDF (1)) in the FIA. Next, the IDF file path array index (N = 2) is used by the algorithm to import the second IDF file, or the Nth IDF. In both the main IDF (1) and the Nth IDF, the algorithm finds the indexes of the first objects under the "Schedules" and "UtilityCost:Tariff" classes. The IDFs are segmented into three sections: below UtilityCost:Tariff, above Schedules, and Schedules to UtilityCost:Tariff. This segmentation is predicated on the same classes found in different IDF files. Certain classes/objects, such as "Schedules" and "UtilityCost:Tariff," are taken to be the same in every IDF.

Following segmentation, a subroutine creates unique class object name and index (UCONI) arrays for each of the two IDFs. In a given IDF, UCONI gathers all unique classes (like materials, construction, and building surfaces) along with their initial indexes. By looking for the term "!- Name" in the Schedules to UtilityCost:Tariff section of the IDF, the algorithm finds these indexes. The UCONI array is then obtained by sorting all object names and their matching indexes and removing duplicates. Counting the elements in the UCONI array yields the number of classes in the Nth IDF. These classes should be combined into the main IDF (1) since they each contain several objects. Iterating through each class, the procedure entails automatically copying and pasting the objects from the Nth IDF into designated areas of the main IDF (1). Between the sections above and below the insert index, the Nth IDF's objects from each class are combined to form the main IDF (1). The resulting main IDF (1) is updated if the requirement for the total number of classes in the Nth IDF to be merged (i = number of class objects in Nth IDF) is satisfied. This process is carried out by the algorithm until the predetermined number of IDFs have been merged. Any redundant "Sizing Parameters" objects are eliminated from the updated main IDF (1) after all merging is finished. The last main IDF (1) is then written by the algorithm to a text file in the.idf format. A modified version of IDF (1) is used as the archetype energy model.

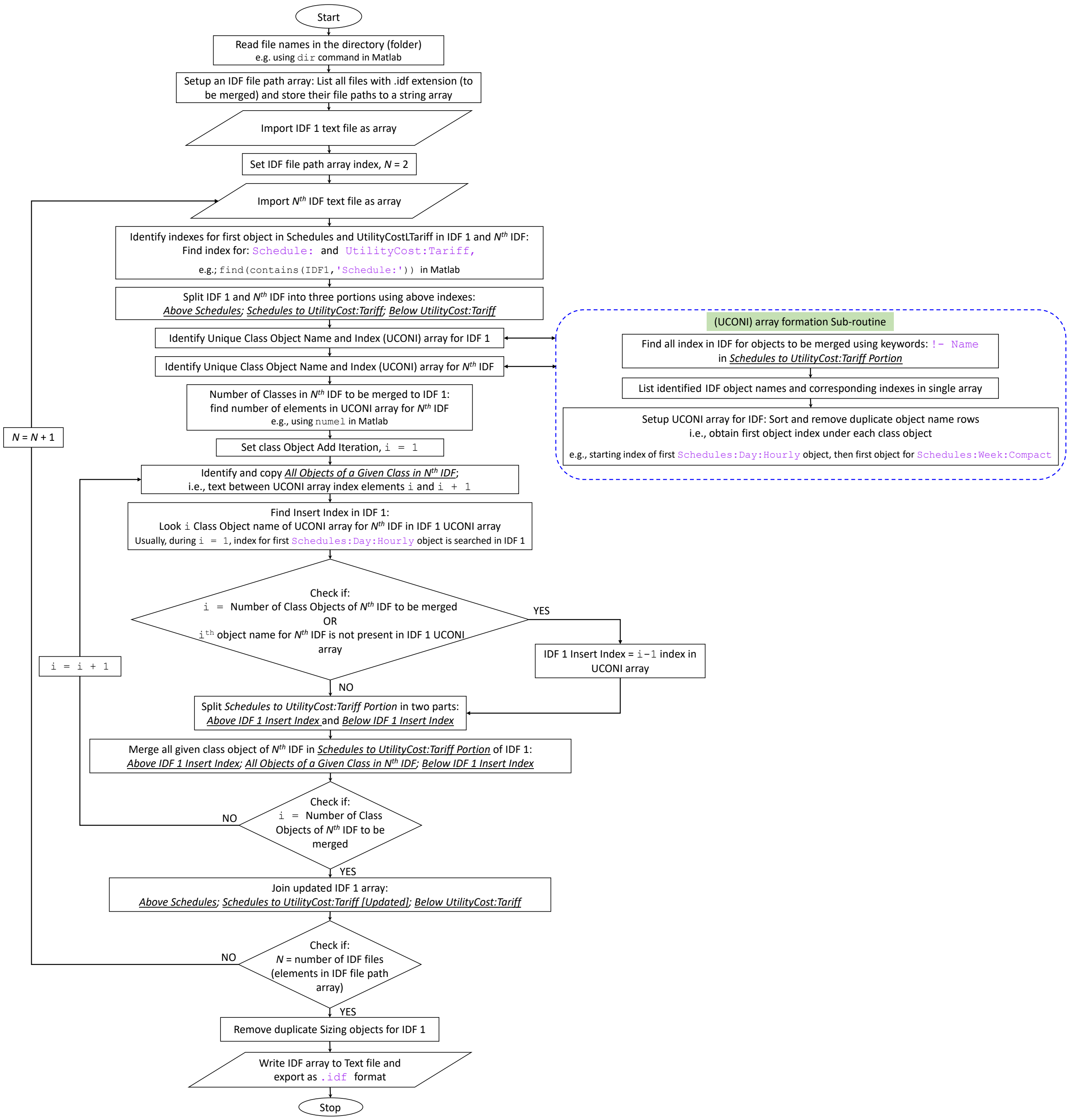


Figure 5: Archetype energy modeling algorithm (taken from (Singh and Hachem-Vermette, 2022)

5.2.4.1 Solar strategies implementation

Various solar strategies were implemented in the theoretical neighborhoods in conjunction with other renewable energy sources. An optimal mix of renewable and alternative energy resources is considered in each of these neighborhoods. Solar, wind and waste are considered as the main sources of renewable and alternative energy generation. Since wind and waste are beyond the scope of the work presented in this report, discussion around these topics will be restricted, focusing mostly on the role of solar energy in this mix. The optimal mix of various solar technologies, namely, PV systems and solar thermal collectors (STC) integrated with borehole thermal energy storage (BTES) is determined employing an optimization methodology (using genetic algorithm). This optimization process identifies the size of each of the considered renewable energy resources. Key assumptions of the energy sources employed in the optimization process consist of the following:

1. PV modules are assumed to be installed on specific façade and roof surfaces (with high solar exposure). The efficiency of PV modules is assumed to be 18.65%.
2. STC are only implemented in roof surfaces. STC water inlet temperature is considered as 30^{o}C. STC generation is calculated based on heat load, not accounting for any loss.

The optimization methodology prioritizes electrical energy generation in sizing energy resources. Consequently, the optimization first determines roof/facade areas required for PV modules. Based on the available surface areas for PV modules, the optimization methodology determines the area of solar thermal collectors to meet the thermal energy demand of the neighborhood units (NUs) which is defined as the central part of an archetype. The optimization process also considers the heat generated from the waste to energy combined heat and power (WtE-CHP) to make optimal sizing decisions for the STC system. The interaction of WtE-CHP and STC with borehole thermal energy storage (BTES) is taken into consideration by the optimization process, as well.

Energy credit (EC) approach is implemented to regulate surplus electricity produced by different energy sources. As such, excess electricity is fed into the local grid, resulting in the accumulation of ECs, which can be utilized during shortage of electricity generated on-site.

5.2.4.2 Energy performance

Using EnergyPlus, energy performance is examined in terms of energy consumption and potential energy production from PV and STC (National Renewable Energy Laboratory (NREL), 2016). The optimization process is developed using a Click or tap here to enter text.MATLAB [30] based optimization program. The building energy models of various building types are first created using SketchUp and EnergyPlus as part of the methodology used in the neighborhood simulation. As previously mentioned (Singh and Hachem-Vermette, 2022), a programming script in MATLAB is used to combine these models into different neighborhood arrangements. Next, the neighborhoodsClick or tap here to enter text. are replicated within the EnergyPlus platform.

Internal loads, energy systems, occupancy, materials, construction, and envelope designs are all taken into consideration by the building energy models. High efficiency building envelopes, such as electrochromic windows with a U value of 1.068 W/m^{2}K, and walls with insulation of 7 m^2/K/W and a roof with insulation of 14 m^2/K/W, are used in the design of buildings to achieve high energy efficiency in addition to LED lighting. The setpoints for heating and cooling are 20°C and 25°C, respectively, with the exception of a few areas in special buildings, like hospital operating rooms, where the setpoint is 22°C. Additional fundamental presumptions used in the neighborhood archetypes and energy simulations of the various buildings are as follows:

1. An occupancy of 2.5 person per unit is uniformly adopted for all residential building types.
2. Energy use intensity (EUI) of all buildings includes all electrical loads such as electricity used for equipment, appliances, and cooling.
3. Thermal loads for space heating and domestic hot water (DHW) are assumed to be served by non-electrical systems (i.e., natural gas or district heating) with the efficiency of 80%.

An optimal performance of each type of buildings is ensured through thorough parametric investigations, where various building components are varied until an optimal value is reached. All buildings constituting a neighborhood are then simulated together as a single model [28] to consider the mutual impact of various buildings.

5.2.4.3 Energy performance indicators

Several energy performance indicators are utilized to analyze the performance of various theoretical archetypes as mentioned below:

1. The annual electricity consumption per unit area for each theoretical archetype is calculated based on simulated results encompassing all electricity usage within the neighborhood. The annual thermal load is determined by aggregating the space heating and domestic hot water (DHW) loads of all buildings in the neighborhood.

2. The potential for achieving net-zero energy in a given neighborhood is assessed by calculating the ratio of onsite generation potential to electricity consumption. A ratio of 1 indicates a net-zero energy status, while a ratio exceeding 1 signifies an energy-positive status.

5.3 Selected results

Example of results of some of the analyses are presented in this section to demonstrate various output, and the impact of integration of solar strategies.

5.3.1 Existing neighborhoods

The simulation results displayed in Figure 55, presents the amount of energy consumed by different types of residential units: detached houses (DH), and attached houses, (AH) in their typical and retrofitted form and compare them to the baseline (see section 5.2.1.2.). This comparison allows to understand the performance of studied urban designs compared to the average energy performance of each province and highlights the impact of improved building envelope on the neighborhood performance.

Figure 55: Comparison of various typical and retrofitted detached house (DH) and attached house (AH) with baseline national data

As presented in Figure 55, the results show that the energy consumption of neighborhoods employing typical constructions conforms in general to the performance of the baseline (within a 10% difference). This is except for Mount Royal detached houses, which are 26% more efficient than the baseline model.

From the modeling and simulation, it is found that the overall energy demand reduction due to improved performance of the building envelope varies by up to 35% among the studied neighborhoods (Figure 56). The neighborhood that had the most energy reduction is a conventional grid with a tilted orientation (Parkdale), a 95% reduction in energy demand is achieved using retrofitting and solar installations. However, the one with the least reduction is the cul-de-sac (Glendale) resulting in energy consumption equivalent to 40% of original energy use after considering retrofitting and solar installations. The retrofit of the buildings' envelope is more effective for conventional grid with tilted orientation (Parkdale) and conventional grid (East York), achieving a 63% and 55 % reduction as compared to the original demand, respectively. The least energy reduction of 41% through retrofitting is associated with the curvilinear street layout (Brighouse).

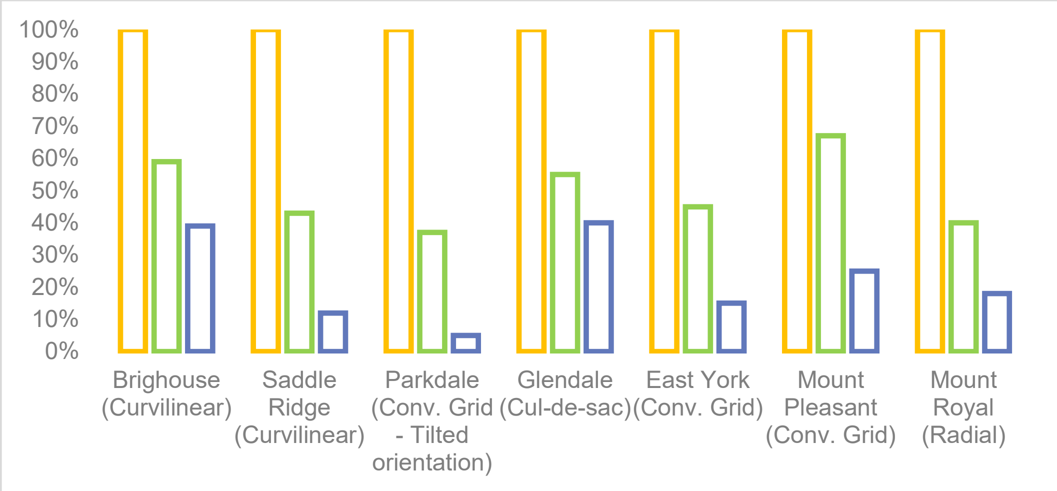


Figure 56: Comparison of energy reduction relative to the initial cases (100%) through retrofitting and solar strategies deployment in various neighborhoods

Considering the implementation of solar strategies into the model, the neighborhood with the best performance is the conventional grid with tilted orientation (Parkdale and East York) and the conventional grid, with a reduction of 32% and 30% (difference between retrofit and retrofit+solar bars in Figure 56) of the net energy consumption. The neighborhood with the worst solar performance is the cul-de-sac (Glendale), achieving 15% of the energy consumption. The urban layout with the most solar potential in this study is the conventional grid with tilted orientation (Parkdale) and the radial (Mount Royal), both with an installation capacity of 0.054 kWp/m². Conventional grid (East York) also presented a high capacity with 0.046 kWp/m², while curvilinear loop (Richmond) and cul-de-sac (Glendale) had the worst average solar potential, with 0.033 and 0.028 kWp/m², respectively. Figure 57 presents the comparison among the neighborhoods.

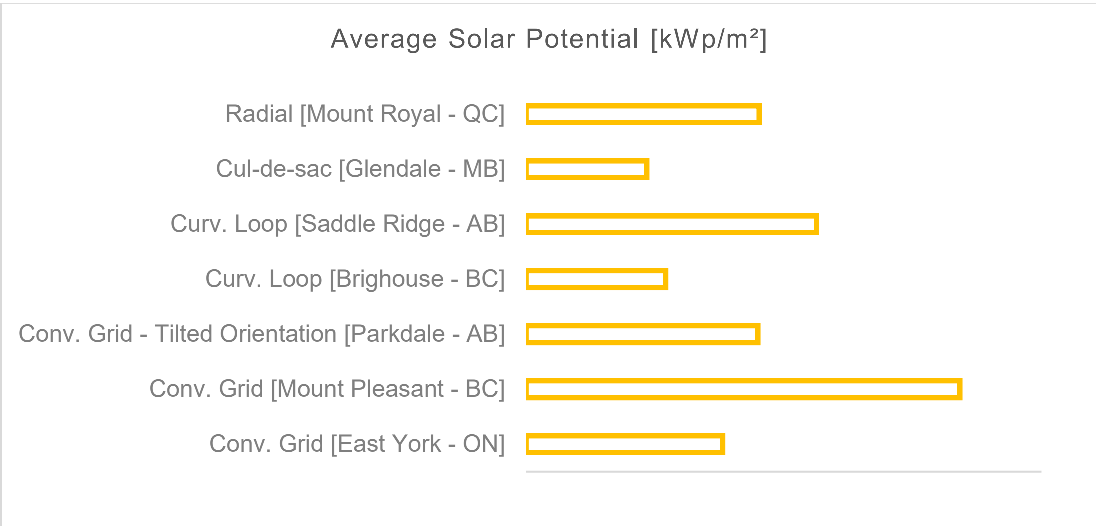


Figure 57 :Solar potential in various neighborhood configurations

Some of the observations that can be made regarding the design and modeling of existing neighborhoods, including application of solar strategies are summarized below,

- Urban layout – Energy performance comparison: Comparing the energy performance of all the urban layouts, some conclusions can be reached. Conventional grid with tilted orientation, conventional grid and curvilinear have a slightly better performance as compared to the baseline, while the radial layout presents the best performance among the neighborhoods. The cul-de-sac layout is the only urban form that has an initial energy performance worse than the baseline, and worst performance as compared to the other neighborhoods, both in solar potential and energy performance. For comparison terms, the unit used is kWh/m²/year, since the average floor area of each building is different than the provincial average floor area, used to model the baseline.

- Patterns of most commonly applied neighborhood patterns are identified and analysed. These, however, are restricted in this work to residential neighborhoods. Potentially the methodology can be extended to other types of neighborhoods such as mixed used, commercial neighborhoods, high density business districts and others.
- The study proposes some solar strategies and explores their applications in the presented archetypes. A simple decision-making tool is proposed to assist in identifying the most suitable and beneficial strategies for each of those archetypes, in order to achieve the objective of net-zero energy. This decision-making tool can be further developed to allow weighting various options and to determine the most optimal solutions according to various objectives, and according to different criteria such as ease of implementation, accessibility, cost and others. This is explored in Chapter 6. In addition, other solar strategies can be explored, including advanced passive strategies to understand their performance in various layouts, and their potential application and viability in existing neighborhoods.
- The main limitation of this work is related to reliable data on energy performance of the existing building stock. The existing information is mostly related to specific types of residential buildings, while information on commercial buildings is extremely limited. On the other hand, the information on residential buildings is general, as it does not link performance to specific design aspects of building envelope and energy systems. This made benchmarking a challenging task. As more detailed information on different types of buildings becomes available, design of other neighborhood archetypes and analysing them for improved performance becomes more feasible.

5.3.2 Results of unique archetypes: Cité Carl Vogt (Switzerland)

This section summarizes the main results of the unique heritage archetype considered. This example provides actual results, both in terms of energy saving and GHG emissions, as compared to other archetypes that employed simulations. Firstly, the renovation of the buildings has reduced the space heat index from 135 -150 kWh/m²/y (depending on the buildings) to 100 - 110 kWh/m²/y, based on the initial measurements taken after the renovation. The reduction in consumption is relatively modest because the renovation was partial, focusing on the roof and improving certain thermal bridges related to balconies and windows. It was not possible to insulate the entire facade due to the site's heritage protection.

Figure 58 :Measured heat index (in MJ/m²/year) before the renovation (left) and after the renovation (right) (source: SITG)

The maps in Figure 58 show the evolution of the heat index before and after the renovation based on the SITG database. The buildings are connected to a district heating network (DHN) whereas previously they were heated with oil. The network is currently provisionally supplied by a gas plant. However, in a few years (before 2030), it will be 80% powered by a central heat pump using water from the lake and 20% by gas.

The map in Figure 59 shows the master plan of the development of the energy district networks (for cooling and heating) with different levels of priority: existing (orange), by 2030 (yellow), by 2040 (light green), by 2050 (dark green). As indicated the studied neighborhood has been already connected to the network.

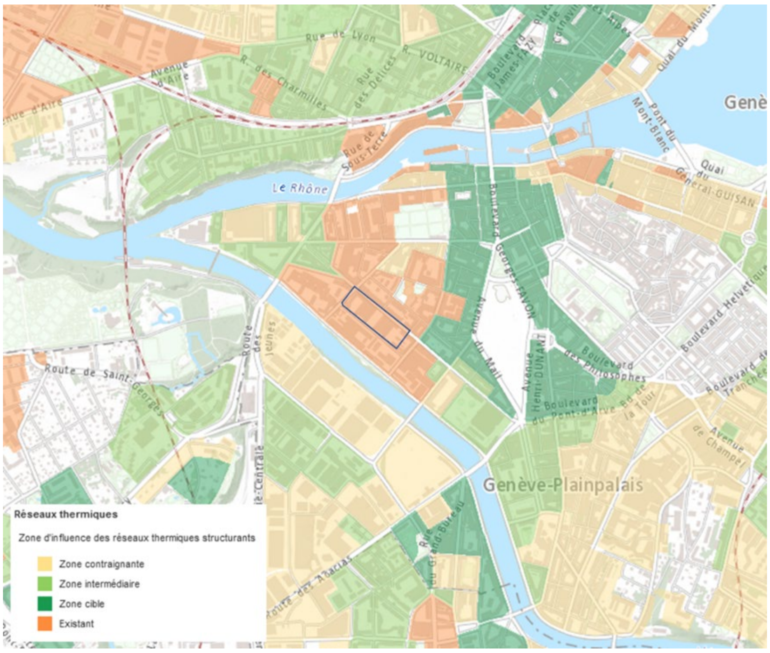


Figure 59 :Extract of the influence areas of the existing (orange) and planned (yellow and green) of the district energy networks (source: SITG).

Regarding the solar installation, the results are as follows:

Total production:	220 320 kWh/y
Energy demand (common areas only):	175 400 kWh/y
Annual demand coverage rate:	125%
Solar power self-consumption rate:	70%
Return on investment period:	<10 years

The annual demand coverage rate corresponds to the ratio between the total solar production and the total needs of the common areas of the building (solar power being used exclusively for the common areas, and possibly later for the shops). The self-consumption rate represents the portion of solar energy consumed within the buildings, with the remainder being sold back to the grid. This rate is 70%, indicating that a significant portion of solar energy is utilized within the buildings. It can be further maximized when the shops begin using solar power as well. The return-on-investment period is less than 10 years indicating that the solar installation will be profitable in a relatively short time. Below, the evolution of energy consumption and greenhouse gas emissions between 2018 (start of the renovation work), 2023 (completion of renovation work and connection to the district gas network), and 2030 (connection to the lake water network) is presented. These consumption and emission reductions are attributed to four interventions:

- Renovation and reduction of the space heat index.
- Solar installation (as the Swiss electrical grid is on average more carbon-intensive than solar panels).

- Transition from oil to gas (DHN plant) on a temporary basis.
- Transition from gas (100%) to the heat pump (80%) by 2030 in the DHN.

Figure 60 illustrates the changes in energy consumption according to various sources (oil, gas, grid electricity for heat pumps, grid electricity for non-thermal needs, electricity generated by solar panels for building common areas).

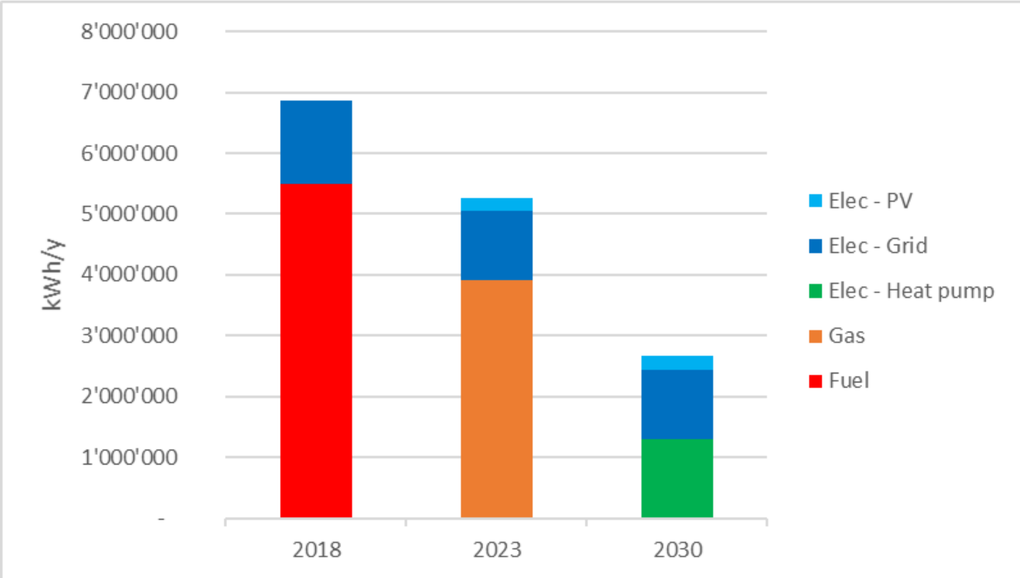


Figure 60: Evolution of energy consumption by the different sources

A significant decrease in thermal energy requirements can be observed, first due to the renovation (in 2023), and then by 2030 through the replacement of 80% of gas in the CAD network with the heat pump, assuming a COP of 3. The graph in Figure 61 represents, in absolute values, the evolution of greenhouse gas emissions for thermal and non-thermal electrical needs, and the reduction in emissions in relative terms, considering the renovation and the shift away from fossil fuels, as well as the substitution of a portion of the electrical grid with PV solar power.

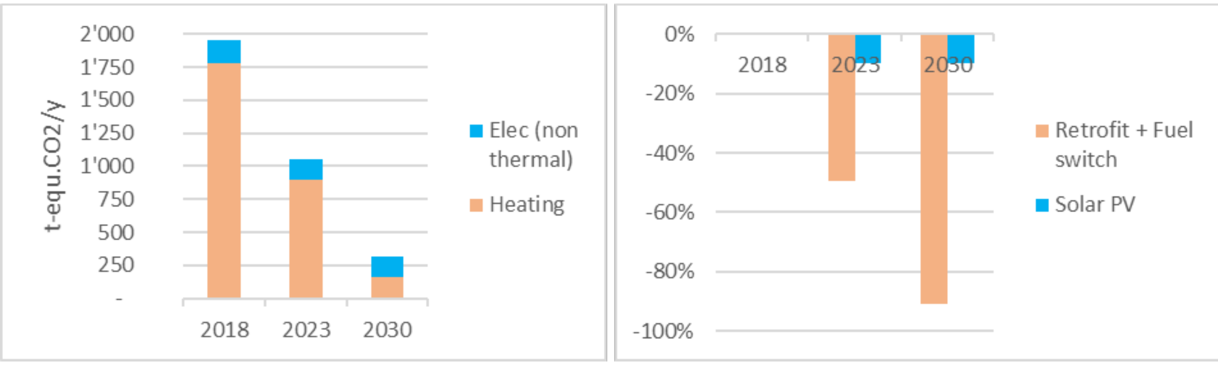


Figure 61: Evolution of greenhouse gas emissions in absolute (left) and relative (right) values

In total, greenhouse gas emissions decrease from 1 953 t-equCO2/yr to 316 t-equCO2/yr. This reduction is largely attributed to the renovation and the transition away from fossil fuels. Meanwhile, the substitution of a portion of the electrical grid with PV solar power results in a decrease of only 17 t-equCO2/yr. This is because the solar installation is limited to supplying a portion (70%) of the common areas of the buildings, which represent only about 13% of the total electrical needs (excluding heating) for the entire Carl Vogt complex. As discussed earlier, the roofs do not allow for additional solar panels due to partial obstruction. Therefore, reducing the greenhouse gas impact of electrical consumption will require a reduction in consumption itself through energy-saving and optimization measures.

5.3.3 Theoretical neighborhoods

This section presents and analyze some of the results of the simulation methodology applied to the hypothetical neighborhoods. Only results for sustainable future neighborhoods, introduced in Chapter 3 (in subsection 3.7.1), are presented below. The first step consists of analyzing the sensitivity of simulation methodology of a neighborhood as compared to building-by-building simulations. This is followed by the analysis of various energy performance criteria.

5.3.3.1 Sensitivity and significance analysis

The deviation in cluster simulation results in comparison to individual building energy model simulation results, is conducted to analyze the relative accuracy of the results. The relative arrangement of buildings with respect to each other can affect the significance of using cluster archetype simulations. For example, if the buildings in a cluster are arranged far from each other, then the mutual impact of buildings is reduced. Consequently, the deviation of cluster energy simulation results would be less in comparison with summation of individual simulation results. In addition, the type of building and whether the internal loads are dominant as compared to building envelope related loads, can also impact the significance of cluster energy simulations. Employing this method of validation, it is concluded that that the proposed archetype simulation methodology yields reasonable results as compared to the summation of individual building simulation results. A maximum error of ± 2.70% is observed for various annual performance parameters.

5.3.3.2 Definition of sustainable archetypes

Neighborhood units (NU) are intricately designed to integrate the concept of expansive green spaces while incorporating a diverse range of amenities necessary for comfortable living and local employment opportunities. Each neighborhood unit is meticulously planned to encompass various amenities like retail establishments, office spaces, eateries, as well as institutional structures such as schools and hospitals. The composition of land use follows the principles of the fused grid concept, which is a neighborhood framework that embraces sustainability principles. The fused grid builds upon an orthogonal foundation, although not rigidly uniform, allowing flexibility in lot dimensions according to building types and sizes (see Figure 62). Blocks intended for larger structures, such as apartments or commercial complexes, may necessitate different dimensions than those allocated for single-family houses. This fused grid concept adopts a modular design approach, resulting in neighborhoods with focal points and boundaries, where each module spans around 40 acres (161 874 m^2).

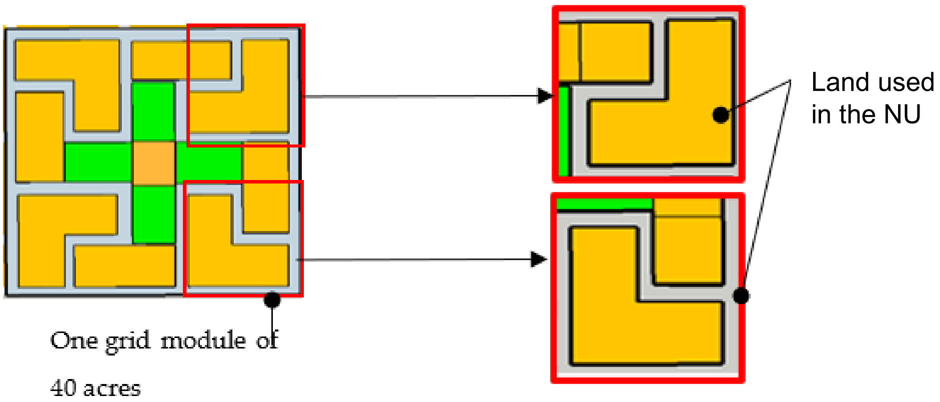


Figure 62: Illustration of one fused grid module (taken from (Hachem-Vermette and Singh, 2022b)**)**

The design of a neighborhood is rooted in one-eighth of a fused grid module (5 acres) as depicted in Figure 62. This specific neighborhood size is chosen to facilitate a comprehensive examination of energy systems at both the building and urban scales. It also enables the exploration of potential combinations of these studied neighborhood units (NUs) within the larger fused grid modules. Outlined in this study are the various neighborhood units (NUs), as summarized below and visually represented in Figure 63.

1. Core Cluster Archetype (CR): This primary archetype includes a fundamental mix of residential structures and essential amenities. It comprises a variety of detached and attached houses, a small retail outlet, a modest office space, a fast-food restaurant, and a full-fledged restaurant.
2. Residential/Institutional Archetype (CR/I): This archetype extends to incorporate institutional buildings (primary or secondary schools) alongside various other building types. Two variations are proposed within this category:
3. CR/I (V1): Encompassing attached houses and medium-rise apartment buildings, a primary school, a small office, a convenience store, a fast-food restaurant, and a full restaurant.
4. CR/I (V2): This variation leans toward higher density, featuring mid-rise apartment buildings with a secondary school, small and medium-sized offices, two restaurants, and a convenience store.
5. Residential/Commercial Archetype (MU-S): Comprising five mid-rise apartment buildings of four floors each, a medium-sized office, a large retail store, a supermarket, four restaurants, and a small-scale hotel.
6. Distinct Commercial/Institutional Archetype: This category entails a concentrated business district showcasing unique building types like large hotels or hospitals. Two variations are designed:
   - MU-P (V1): Featuring a medium-sized office, a small hotel, a hospital, four restaurants (including both full-service and fast-food options), a small retail store, and four 15-story apartment buildings.
   - MU-P (V2): Encompassing a large office, a substantial hotel, four restaurants (including both full-service and fast-food options), a large retail store, and four 20-story apartment buildings.

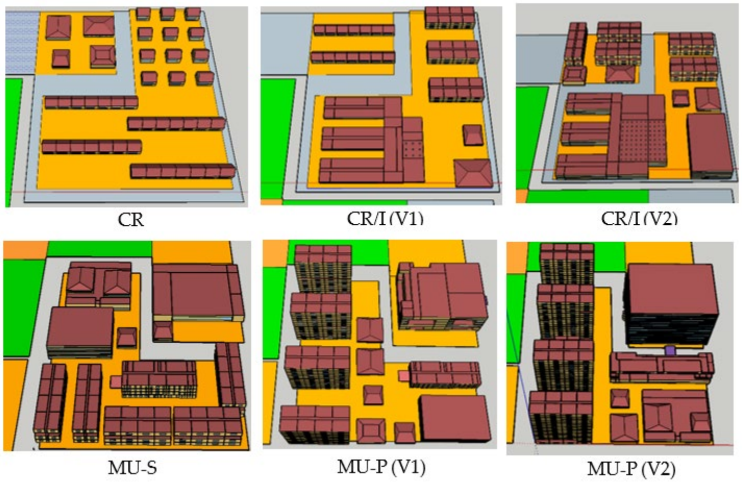


Figure 63: Representation of the studied neighborhood archetypes (taken from (Hachem-Vermette and Singh, 2022b)**)**

5.3.3.3 Energy performance

The energy performance of the NUs is presented separately for electrical and thermal performances.

5.3.3.3.1 Electrical energy

The results of electrical energy consumption and electricity generated by various sources (PV, wind, and waste-based CHP) are presented in Figure 64. The potential for generating electricity through photovoltaic (PV) systems in a neighborhood depends on the availability of suitable building surfaces for PV integration. For instance, neighborhoods predominantly composed of low-rise structures, like schools, with expansive roof areas, offer a greater capacity for PV integration due to the ample space available. In contrast, densely populated neighborhoods characterized by high-rise buildings lack substantial roof space in comparison to the energy demands of these structures.

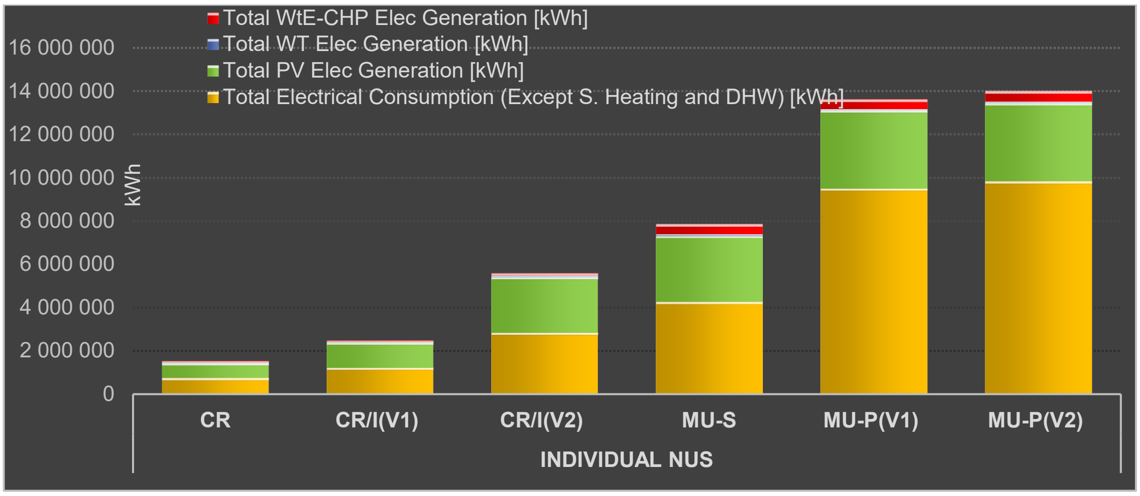


Figure 64: Energy consumption vs electricity generation by each energy source, for all NUs

The generation of photovoltaic (PV) electricity plays a crucial role in meeting a substantial portion of the overall electrical requirements across various studied archetypes, reaching as high as 95% of total energy consumption in certain neighborhood units. While roof-integrated PV systems are the primary source of PV electricity, the contribution from PV installations on south-facing facades is noteworthy in specific types of neighborhood units (Figure 65).The results analysis reveals that the core neighborhood (CR), characterized by predominantly low residential density and limited commercial buildings, along with the CR/I archetype featuring an institutional building, can generate electricity equivalent to their consumption. In contrast, all other neighborhoods necessitate additional space for the installation of both photovoltaic (PV) systems and thermal collectors to meet their energy needs.

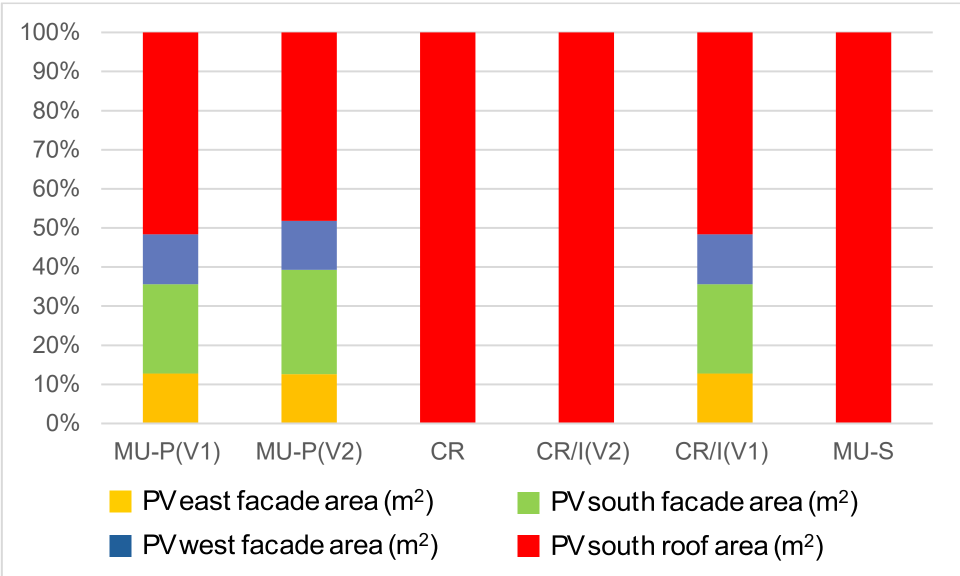


Figure 65: Contribution of various surfaces for PV electricity generation

5.3.3.3.2 Thermal energy

The examination of the thermal energy performance of neighborhood units indicate a substantial deficit in on-site thermal energy production, incorporating thermal collectors and other resources like waste-to-energy in conjunction with BTES. This deficit spanning from 63% to 91%, is partially due to prioritizing the integration of PV modules in available neighborhood surfaces (rather than STCs). The following discussion delves into the influence of the spatial design of these urban developments on the incorporation of supplementary Solar Thermal Collectors and storage solutions.

5.3.3.4 Land use for additional solar technologies

This section presents the analysis of the supplementary solar technologies, namely Photovoltaic (PV) and Solar Thermal Collectors (STC), needed to meet the total energy demands of individual Neighborhood Units (NUs) to achieve net zero energy (NZE) status. The assumption is that PV and STC panels are installed in open landscape areas, with a fixed south orientation and a 45º tilt angle. Minimum land area (MLA) refers to the smallest area necessary to accommodate solar technologies while ensuring a sufficient distance to prevent mutual shading between panels. Neighborhoods such as MU-P(V1) and MU-P(V2) demand a considerable additional land area to facilitate the installation of PV panels. The area required for PV installation in MU-P(V1) and MU-P(V2) neighborhoods accounts for approximately 80% and 85% of their respective neighborhood areas. In contrast, other neighborhoods demand relatively smaller areas for PV installation. For instance, MU-S requires approximately 10% of additional land, compared to the neighborhood area, to achieve net-zero electric energy status through PV installation. The three remaining neighborhoods are near net zero energy (generating 95% and up to 100% of their total energy consumption). **Figure 66** illustrates the energy needed for each neighborhood to attain net-zero electrical energy, along with the corresponding areas required for PV systems and the minimum land area necessary.

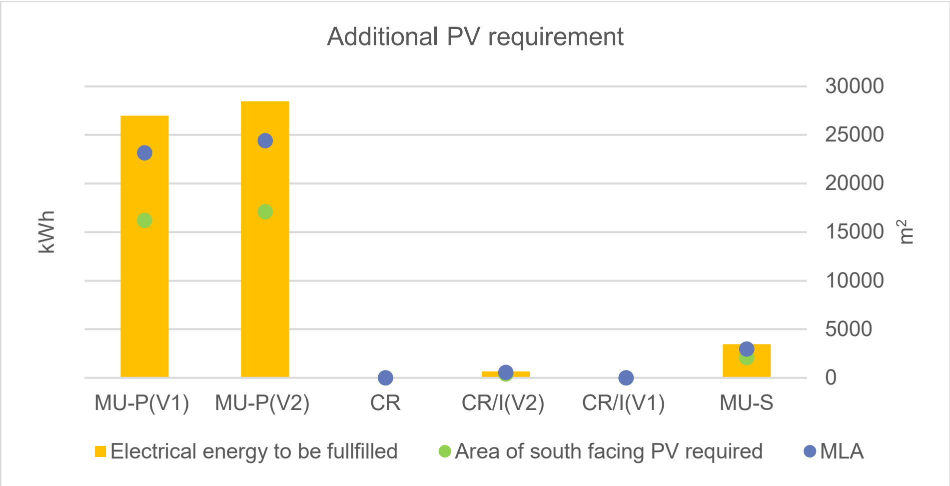


Figure 66: Electrical energy, PV size and minimum land area (MLA) required to achieve net zero electrical energy

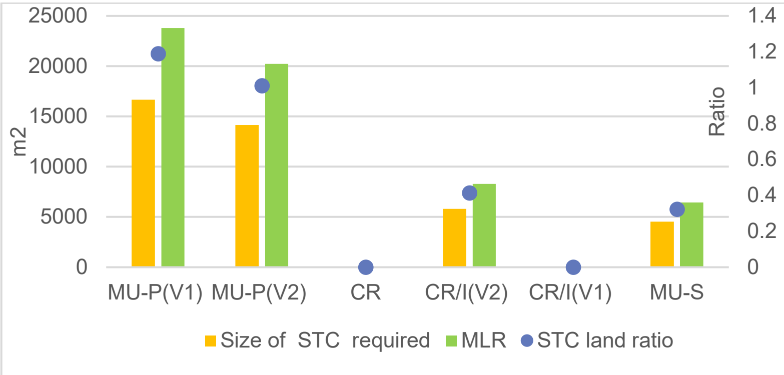


Figure 67: Size of STC and corresponding land area required to achieve net-zero thermal energy

Certain neighborhood units need a substantial amount of thermal energy to meet their entire thermal load. Consequently, the area required for additional Solar Thermal Collectors (STC) can be as high as 71% and 83% in comparison to the neighborhood area for MU-P(V2) and MU-P(V1) respectively. In contrast, the remaining neighborhoods require relatively smaller areas for STC installation. MU-S and CR/I(V2) require approximately 23% and 30% additional land area, respectively, compared to the neighborhood land, to accommodate the Solar Thermal Collector (STC) systems required to meet all thermal energy needs. In contrast, CR and CR/I (V1) do not require any additional STC, as they can fulfil their thermal loads using the existing original systems. Figure 67 illustrates the size of the required STC in each neighborhood, the land area required for these STC systems, and their minimum land ratio (MLR) compared to the existing neighborhood.

5.3.3.5 Observations on design and analysis of new neighborhoods

In the exploration of solar technology integration in neighborhoods, the potential of renewable energy generation by low-density mixed-use clusters is highlighted. Landscape solar designs, emphasizing multifunctionality, are discussed, and the role of optimization methodologies in facilitating energy resource sharing among diverse clusters is outlined.

5.3.3.5.1 Optimal combination of neighborhood types and planning of solar technologies

Low-density mixed-use clusters that include residential and school buildings have the capacity to generate their own electricity through renewable energy sources such as PV. However, to fulfil their thermal loads, these neighborhoods, with a density of 98 and 128 units per acre (u/a), would require substantial land allocations—up to 85% for PV and up to 83% for STC—relative to the total land area of the neighborhood unit. An intriguing and beneficial approach in planning new neighborhood units would involve considering a mix of buildings, especially in smaller neighborhood units, in a manner that balances the energy profile and enhances the management of the energy generation-consumption flow. For instance, a study conducted by (Hachem-Vermette and Singh, 2020) reveals that a combination of diverse neighborhood units, including low-density residential and higher-density commercial and residential neighborhoods, enables the attainment of a net-zero energy status, encompassing both thermal and electrical aspects. This achievement is primarily realized through the adoption of solar technologies, without significantly encroaching on the open green areas within the neighborhood. Optimal combinations of neighborhood units, facilitating the sharing of energy generation potential, contribute not only to achieve a net-zero electric energy status through PV integration in neighborhood surfaces but also to a substantial reduction in the proportional size of Solar Thermal Collectors (STC) and Borehole Thermal Energy Storage (BTES), along with the corresponding relative land area required for these technologies. Figure 68 provides an illustration of the potential grouping of small neighborhood units to form larger net-zero energy neighborhoods.

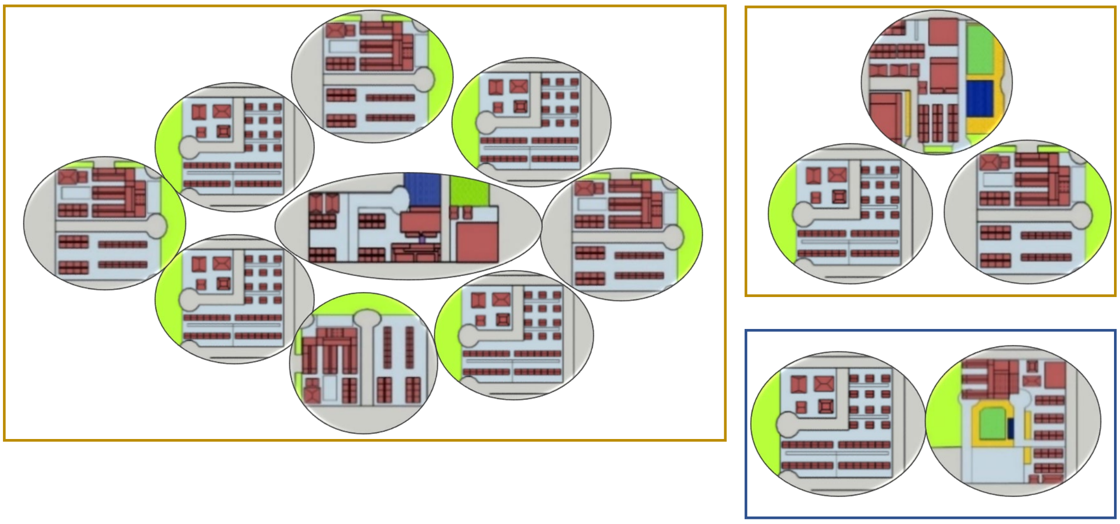


Figure 68: Spatial design of the neighborhoods

5.3.3.5.2 Design of landscape solar technologies

The public open spaces within the proposed neighborhoods can be strategically designed to facilitate an optimal integration of landscape standalone structures. This integrated design not only enhances the social desirability of these areas but also aids in managing shade and sunlit regions effectively. Furthermore, these designs can be harmoniously combined with other opportunities to enhance outdoor thermal comfort. Urban green infrastructure, such as public parks, stands as a crucial component of the urban fabric, providing a multitude of social, health, and well-being benefits. For instance, amid the ongoing COVID-19 pandemic, public open areas have played significant roles in mitigating the increasing stress and anxiety experienced by urban inhabitants who suddenly found themselves compelled to forego many customary social activities (Xie et al., 2020). These public green spaces can serve as fertile grounds for innovation and for advocating materials and practices that mitigate the adverse environmental impact while promoting a sustainable economy.

Conversely, the ratio of landscape to build area holds significance in determining the suitability of land development for the implementation of solar neighborhood units. These units rely on solar technologies to accomplish diverse energy and performance objectives. A centrally located green area, well-situated in relation to build spaces, can serve as an incentive for a multifunctional integration of solar collectors. This integration can address various criteria, including aesthetics, outdoor thermal comfort, shaded playground areas, and more.

The design of landscape elements can exhibit versatility and creativity to minimize the space needed for land utilization. For instance, the incorporation of meticulously designed double-height solar landscape structures, integrating PV panels (C Hachem-Vermette, 2020), indicates that land space can be decreased by up to 50%, while still presenting the potential to generate a comparable amount of energy. The concept of designing multiple levels of PV or STC plates mounted on top of each other not only offers an opportunity to expand available areas for integrating solar technologies but also holds significant potential for generating renewable energy in urban areas where land may be scarce and expensive. Furthermore, these standalone landscape structures present an intriguing design opportunity to mitigate the substantial visual impact that PV and STC structures might have, thereby reducing their intrusion on the landscape.

5.3.3.5.3 Role of optimization

The optimization methodology outlined in the design of hypothetical neighborhoods can be applied with various modifications to incorporate diverse energy resources and cluster types. While the examination of the specific archetypes developed in this study reveals that some of them have the potential to generate enough energy to meet all the cluster's energy needs without utilizing the entire neighborhood potential, other high-density mixed-use clusters may require a substantial amount of energy backup from alternative sources. The variation in energy profiles among clusters can offer benefits for potential energy sharing. While this aspect was briefly explored using the developed cluster archetypes, future work could delve into the possibility of adjusting the size and composition of each cluster to facilitate more effective sharing of energy resources.

6 Decision making tool for solar strategies

This section provides an overview of the decision-making tool framework. The framework encompasses a range of both passive and active solar strategies, aiming to address a comprehensive spectrum of options. The strategies, as discussed in detail below represent well-established approaches commonly employed in solar energy applications. It is important to note that this list can be expanded to incorporate cutting-edge technologies, aligning with the framework delineated in this work.

To evaluate and compare these strategies, a decision-making criterion has been devised, employing an adoption score methodology. This criterion or constraints assesses each strategy based on several key factors, including ease of implementation, feasibility (in terms of cost and accessibility), public acceptance, environmental impact, and overall effectiveness. The adoption scoring method has been refined through the collection of quantitative data obtained from a survey involving a diverse panel of international experts. Furthermore, this section presents specific neighborhood scenarios as practical illustrations of the effective application of the decision-making tool. These scenarios showcase how the tool aids users in selecting the most suitable solar strategies tailored to their unique requirements and circumstances. The subsequent sections delineate the various stages of our methodology in greater detail.

6.1 Data collection

In the initial phase of constructing the foundational framework for the proposed decision-making tool, a pilot study was carried out. This pilot study employed a survey meticulously designed to evaluate a spectrum of solar strategies and technologies based on predefined assessment criteria, as previously outlined. To gauge the efficacy of the survey instrument and to ascertain the range of responses, a limited population sample was targeted for this preliminary investigation. The sample group consisted of esteemed experts actively engaged in the IEA SHC Task 63 initiative. The survey solicited the insights and opinions of these experts regarding various facets of both active and passive solar strategies. The specific solar strategies under consideration encompassed a wide collection, including aspects such as window orientation (south, east, west, and north), skylights, operable windows, light tubes, solar chimneys, solar access, photovoltaics (PV) on rooftops, facades, and neighborhood surfaces, semi-transparent PV, PV/thermal technologies, PV combined with heat pumps, solar thermal collectors (STC) on facades, roofs, and neighborhood surfaces. Within the initial survey, experts are tasked with evaluating these solar strategies based on four principal criteria:

i. Ease of Implementation, accounting for various neighborhood contexts, such as existing and refurbished buildings.
ii. Feasibility in terms of cost and accessibility.
iii. Environmental Impact.
iv. Acceptance.

Experts were requested to provide qualitative ratings for each strategy on a graduated scale, ranging from ease to impossibility for the implementation criterion and from high to low for the other criteria. To transform these qualitative assessments into quantifiable data, a structured scoring system was devised. This scoring system assigned higher scores to strategies perceived as more straightforward to implement or exhibiting greater potential impact concerning cost, environmental considerations, and acceptability. The overall adoption score for each solar strategy was then calculated, taking into account the cumulative impact of evaluation scores across the various criteria. Subsequently, a second survey was conducted to elicit expert opinions on the potential of the aforementioned solar strategies in achieving specific objectives. These objectives encompassed a broad spectrum, including daylighting, passive heating, passive cooling, energy efficiency, electrical and thermal generation, as well as composite goals such as overall energy consumption reduction, the realization of net-zero energy neighborhoods, low operational costs, and the establishment of low or net-zero carbon neighborhoods.

6.2 Decision making framework

Figure 69 provides an overview of the decision-making methodology proposed in this research. The process commences with the development of surveys tailored for both new and existing neighborhoods. It is important to clarify that "new neighborhoods" refer to those in the planning stages for the future. The subsequent step involves the systematic collection of data, where the surveys are administered to domain experts participating in the IEA SHC Task 63.

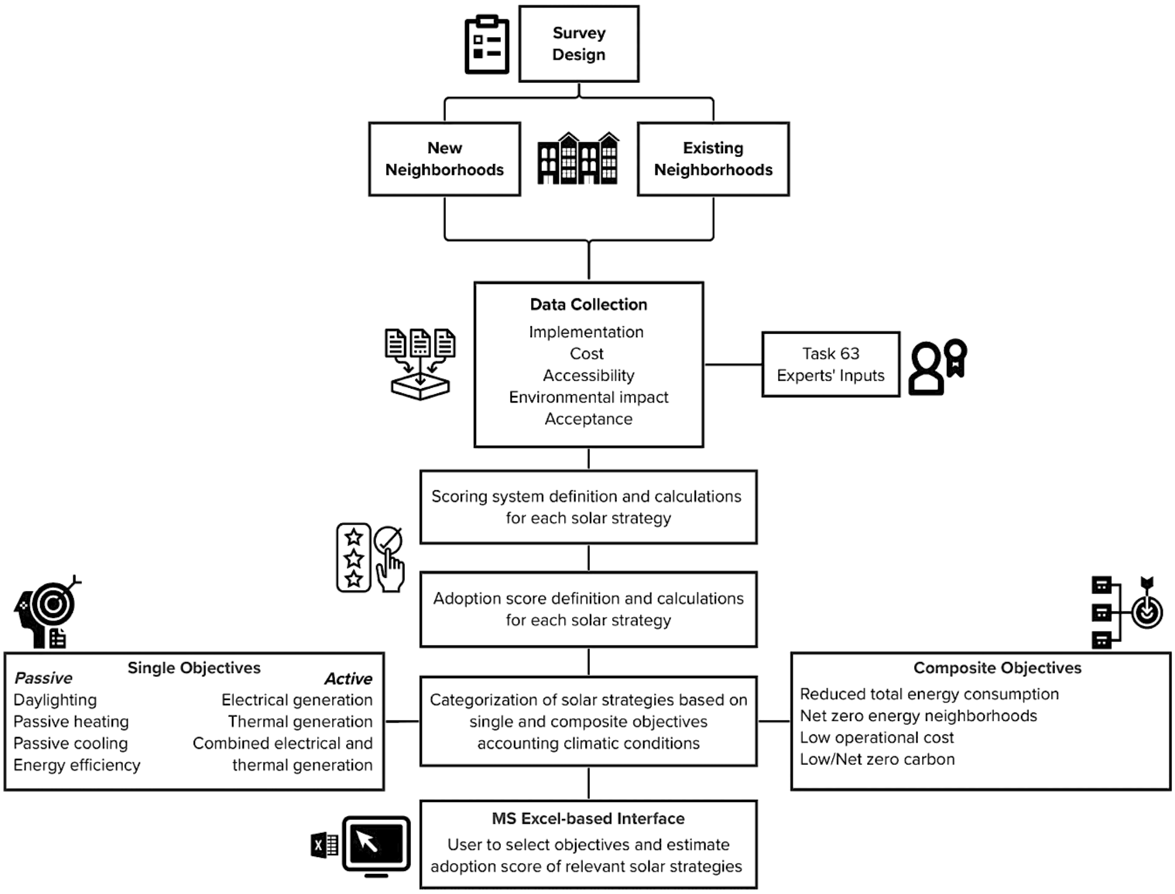


Figure 69: Workflow of decision-making method [taken from (Hachem-Vermette, Singh, Jolly and Yadav, 2023)**]**

The insights contributed by these experts resulted in the creation of a comprehensive database. This database encompasses evaluations of various solar strategies, meticulously assessed across different dimensions, as detailed in Chapter 3. These dimensions include implementation feasibility, taking into account various scenarios like new and existing neighborhoods, cost considerations, accessibility, environmental impacts, and societal acceptance. Following this, a structured scoring system was developed, closely aligned with the predefined evaluation criteria as outlined in Table 12. This scoring system plays a crucial role in converting the qualitative judgments provided by the experts into precise, quantifiable metrics. It operates on a weighted scale, strategically assigning scores to reflect the experts' assessments. For example, when evaluating the feasibility of implementing solar strategies in existing neighborhoods, strategies deemed highly feasible receive a maximum score of 10, while strategies considered unfeasible are assigned a score of 0. Likewise, for criteria such as cost, accessibility, environmental impact, and societal acceptance, a "high" rating corresponds to a score of 10, whereas a "low" rating corresponds to a score of 2. To accommodate intermediate evaluations, the scoring system introduces three intermediary levels: "high/medium," "medium," and "medium/low," which are numerically represented as 8, 6, and 4, respectively.

Table 12: Definition of weightage in scoring systems to evaluate solar strategies [taken from (Hachem-Vermette et al., 2023)**]**

Evaluation criteria	Score
For implementation in existing buildings and neighborhoods	
Easy (w_e)	10
Easy/need some renovation (w_{ensr})	9
Need some renovation (w_{nsr})	8
Need some renovation/deep renovation (w_{nsdr})	7
Need deep renovation (w_{ndr})	6
Need deep renovation/hard (w_{ndrh})	5
Hard (w_h)	4
Not possible (w_{np})	0
For implementation in new buildings and neighborhoods	
Easy (w_e)	10
Easy/easy depending upon other constraints (w_{eedc})	9
Easy depending upon other constraints (w_{edc})	8
Easy depending upon other constraints/moderate (w_{edcm})	7
Moderate (w_m)	6
Moderate/hard (w_{mh})	5
Hard (w_h)	4
Not possible (w_{np})	0
For cost, accessibility, environmental impact, and acceptance	
High (w_{hi})	10
High/Medium (w_{hm})	7-9
Medium (w_m)	6
Medium/Low (w_{ml})	3-5
Low (w_l)	2

In reference to Figure 69, following the establishment of the scoring system as described previously, the next step involved the computation of the comprehensive adoption score for each individual solar strategy. This score serves to quantitatively represent the cumulative influence of the strategy's evaluation ratings across various categories, including implementation feasibility, cost, accessibility, environmental impact, and societal acceptance. In this study, Eq. 1 has been formulated to calculate the adoption score, providing a structured methodology for this assessment.

$$S_{ad,overall} = [W_i S_i - W_c S_c + W_a S_a + W_{ei} S_{ei} + W_{ac} S_{ac}] \quad (1)$$

where $S_{ad,overall}$ signifies the comprehensive adoption score, various components contribute to its computation. Specifically, S_i represents the score for implementation, which is evaluated independently for new and existing neighborhoods. Additionally, S_c, S_a, S_{ei} and S_{ac} denote individual scores for cost, accessibility, environmental impact, and acceptance, respectively. Whereas W_i, W_c, W_a, W_{ei} and W_{ac} are weights associated with ease of implementation, cost, accessibility, environmental impact, and acceptance, respectively. To facilitate a more intuitive comprehension of this research, the overall adoption score, $S_{ad,overall}$, is transformed into a 10-point scale. Furthermore, Equation 2 outlines the procedure for calculating the cost score, incorporating weights (*w*) and the number of expert responses (*N*) for each weighting criterion.

$$S_c = \frac{(N_h w_h) + (N_{hm} w_{hm}) + (N_m w_m) + (N_{ml} w_{ml}) + (N_l w_l)}{N_h + N_{hm} + N_m + N_{ml} + N_l} \quad (2)$$

In Equation 2, besides the specified weights (as outlined in Table 12), N_h, N_{hm}, N_m, N_{ml}, and N_l, representing the number of expert responses categorized as high, high/medium, medium, medium/low, and low, respectively, are also considered. Once the adoption scores for each category have been calculated, a classification of solar strategies is performed based on both individual and combined objectives, taking into account prevailing weather conditions. Individual objectives encompass various passive aspects like daylighting, passive heating, passive cooling, and energy efficiency, as well as active components such as electrical, thermal, and combined energy generation. Composite objectives encompass broader objectives such as reducing energy consumption, achieving net-zero energy neighborhoods, minimizing operational costs, and establishing low, or net-zero carbon neighborhoods.

Subsequently, following the identification of appropriate strategies and the consideration of weather conditions for each individual and composite objective, an interface was developed using Microsoft Excel (MS Excel) for use by professionals. Figure 70 provides an overview of the decision-making tool's operation. Here, users can initially select their desired composite objective, specify the prevailing weather conditions, and indicate whether the neighborhood is new or existing. The tool then suggests a prioritized set of relevant individual objectives. Based on these objectives and considering implementation constraints and criteria, the tool recommends appropriate solar strategies for implementation within the neighborhood.

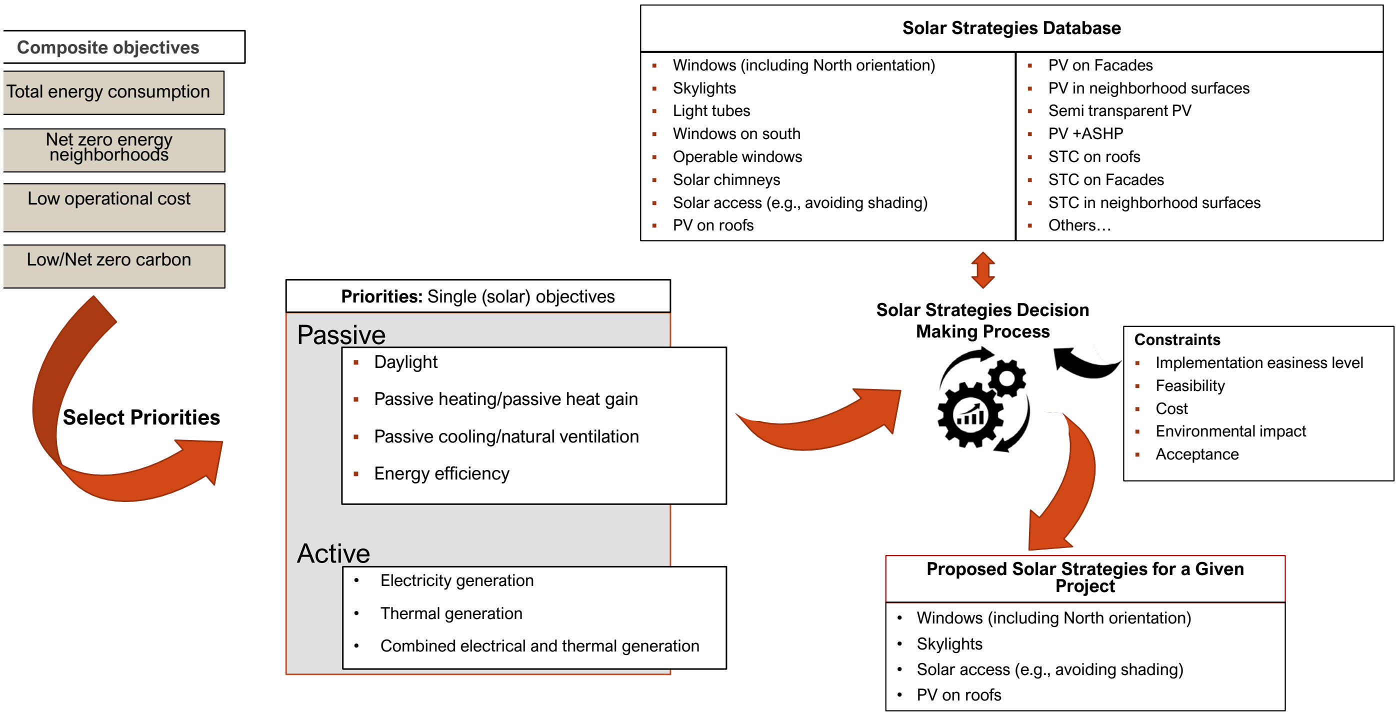


Figure 70: Overall working of the decision-making tool [taken from (Hachem-Vermette et al., 2023)**]**

Table 13 illustrates the connection between composite objectives and individual objectives in various climatic zones. These climate zones are categorized into five groups: very cold, cold, moderate, hot, and very hot. Consequently, the choice of pertinent solar strategies is contingent upon the specific climatic conditions encountered. It's important to note that a composite objective may encompass multiple individual objectives, working in concert to achieve broader objectives related to environmentally friendly neighborhoods.

Table 13: Relationship of composite objective with various single objectives [taken from (Hachem-Vermette et al., 2023)**]**

Composite objective	Climate type			
	Very cold/Cold	**Moderate**	**Hot**	**Very hot**
Total energy consumption	• Daylight • Passive heating • Energy efficiency	• Daylight • Passive heating • Passive cooling • Energy efficiency	• Daylight • Passive cooling • Energy efficiency	• Daylight • Passive cooling • Energy efficiency
Low operational cost	• Daylight • Passive heating • Energy efficiency	• Daylight • Passive heating • Passive cooling • Energy efficiency	• Daylight • Passive cooling • Energy efficiency	• Daylight • Passive cooling • Energy efficiency
Low/Net zero carbon	• Passive heating • Energy efficiency • Electrical generation • Thermal generation • Combined electrical + thermal	• Passive heating • Passive cooling • Energy efficiency • Electrical generation • Thermal generation • Combined electrical + thermal	• Passive cooling • Energy efficiency • Electrical generation • Thermal generation • Combined electrical + thermal	• Passive cooling • Energy efficiency • Electrical generation
Net zero energy neighborhoods	• Daylight • Passive heating • Energy efficiency • Electrical generation • Thermal generation • Combined electrical + thermal	• Daylight • Passive heating • Passive cooling • Energy efficiency • Electrical generation • Thermal generation • Combined electrical + thermal	• Daylight • Passive cooling • Energy efficiency • Electrical generation • Thermal generation • Combined electrical + thermal	• Daylight • Passive cooling • Energy efficiency • Electrical generation

The diverse individual objectives can be categorized into two main groups: passive and active objectives. Furthermore, as depicted in Table 14, each individual objective can encompass multiple solar strategies. In terms of practical application, the user initiates the process by specifying both the climate type and neighborhood type (i.e., whether it is an existing or new neighborhood). Subsequently, the user selects a composite objective, and based on this selection, relevant individual objectives are assessed, as illustrated in Table 14. Depending on the chosen individual objectives, the corresponding solar strategies are then selected. Finally, adhering to the previously established scoring system, the relevant solar strategies and their respective scores can be visualized and considered for implementation.

Table 14: Relationship between various single objectives and solar strategies [taken from (Hachem-Vermette et al., 2023)**]**

	Single objective type	**Passive**				**Active**		
	Single objective	**Daylight**	**Passive heating**	**Passive cooling**	**Energy efficiency**	**Electrical generation**	**Thermal generation**	**Combined electrical + thermal**
Solar strategy	1	South/equatorial Window	South/equatorial Window	Operable windows	South/equatorial Window	PV on roofs	STC on Facades	PV/thermal technologies
	2	North /non equatorial window	East/west window	Solar chimneys	North /non equatorial window	PV on facades	STC on roofs	PV + heat pump
	3	East/west window	Solar access		East/west window	PV in neighborhood surfaces	STC in neighborhoods	
	4	Skylight			Light tube	Semi-transparent PV		
	5	Solar access			Skylight			
	6				Operable windows			
	7				Solar chimneys			
	8				Solar access			

6.3 Application of the tool

This section begins by presenting the general ranking of passive and active solar strategies based on key evaluation criteria. It also includes a selection of results that can be achieved. Figure 71 provides a breakdown of the primary results of the ranking of passive and active solar strategies, as assessed by experts using a 10-point scale for existing neighborhoods. Figure 71a elaborates on passive solar strategies, and Figure 71b delves into active solar strategies.

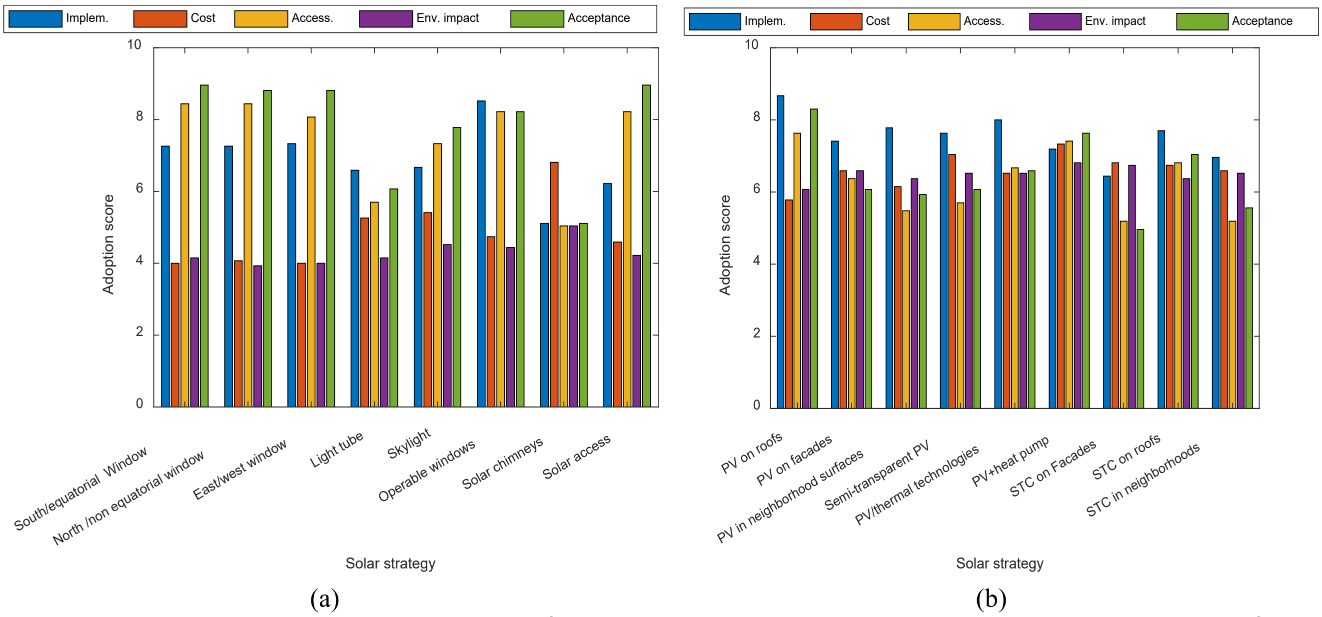


Figure 71: Evaluated adoption score in each criterion for (a) passive and (b) active solar strategies based on survey results for existing neighborhoods

Within the realm of passive solar strategies, operable windows received the highest score for implementation feasibility. From a cost perspective, all types of windows are the most cost-effective compared to other passive solar strategies. Conversely, solar chimneys and skylights come with the highest associated costs. Windows and solar access received the highest acceptance ratings. The environmental impact, indicating the potential negative effects of these technologies on the environment, was rated relatively low, with experts viewing passive technologies less favorably compared to passive solar strategies. As for active technologies, photovoltaics (PV) integrated into roofs garnered the highest scores for both implementation feasibility and acceptance. PV/thermal technologies came second in terms of implementation, while PV and heat pumps had the second-highest acceptance rate.

Figure 72 compares the overall adoption score calculated using Eq. 1 assigning equal weightage to each criterion, considering all criteria, including implementation, cost, accessibility, environmental impact, and acceptance for both existing and new neighborhoods. In passive strategies, windows received the highest ratings, followed by solar access and solar chimneys. For active technologies, PV was ranked first for both new and existing neighborhoods, with PV/T technology securing the second position. The overall adoption score is higher for new neighborhoods compared to existing ones, primarily due to the relative ease of implementation, leading to lower costs.

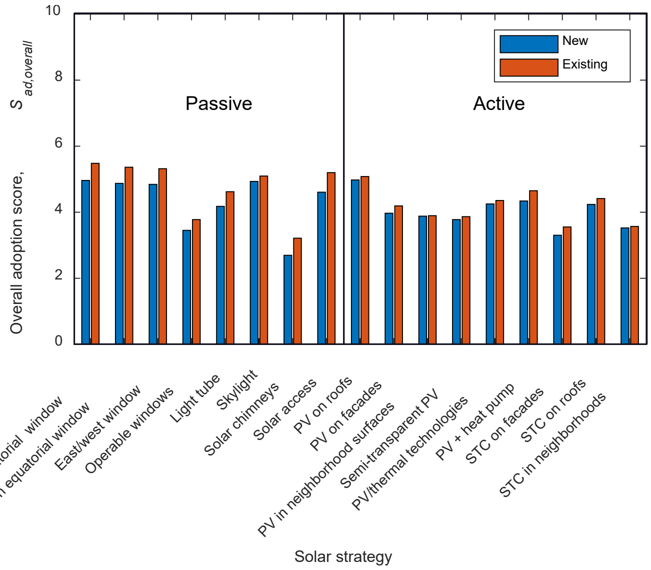


Figure 72: Overall adoption score of various solar strategies for existing and new neighborhoods

6.3.1 Sensitivity of weights for decision criteria

In the framework of the proposed decision-making tool, users can also set a weight to decision criteria or constraints such as ease of implementation, cost, accessibility, environmental impact, and acceptance. Based on the defined weight between 0 and 1, the overall adoption score is affected. Therefore, in this section the sensitivity of weightage to each criterion is assessed for existing and new neighborhoods.

6.3.1.1 Sensitivity analysis for existing neighborhoods

As shown in Figure 73 the sensitivity to each criterion can also be defined in this decision-making tool. For instance, in Figure 73a, it is shown that the variation in weightage for ease implementation can change the overall adoption score for active and passive solar strategies. While weightages are varied for a particular criterion the remaining amount of weightage is equally distributed among other criteria. For example, in Figure 73a if the implementation weight is set as 0.8 then the remaining weight of 0.2 is equally distributed in other criteria such as cost, accessibility, environmental impact, and acceptance.

When weightage for ease of implementation is reduced, the adoption score in turn reduces for all active and passive strategies, which means that implementation has a greater impact on an overall higher adoption score (Figure 73a). Assigning higher weightage to the implementation, results in a higher adoption score in the case of active solar strategies in comparison to passive solar strategies. This means that active solar strategies are easy to implement overall as compared to passive strategies. Referring to Figure 73b, the impact of assigning higher weightage to cost is presented. It is evident when the cost weightage is higher in decision-making (i.e., cost is critical to the user), the adoption score is negative which means that none of the active or passive solar strategies are favorable due to the higher cost of these strategies as per current market. When the weightage to cost decreases the overall adoption score improves. As shown in Figure 73c, when the accessibility weightage is higher the overall adoption score is also higher, and it eventually decreases when the weightage for accessibility decreases. However, it is interesting to note here that in general accessibility of passive solar strategies is more than active solar strategies as the weightage of 1 assigned to passive solar strategies results higher overall adoption score as compared to active solar strategies. This implies that most of the passive solar strategies are readily available in the market except light tubes and solar chimneys. Figure 73d presents how the weightage variation for environmental impact affects the overall adoption score. A higher weightage assigned to environmental impact in the case of active solar strategies results in a higher overall adoption score which means that the environmental impact of active solar strategies is greater than passive solar strategies in general. Also, overall, the acceptance of passive solar strategies is higher than active solar strategies as presented in Figure 72e. For both active and passive solar strategies, a higher weightage assigned to acceptance results in a high overall adoption score, and it decreases significantly when the weightage decreases.

		(a) Weightage variation for implementation					(b) Weightage variation for cost					(c) Weightage variation for accessibility				
		1	0.8	0.6	0.4	0.2	1	0.8	0.6	0.4	0.2	1	0.8	0.6	0.4	0.2
Passive	South/equatorial Window	7.3	6.7	6.1	5.5	5.0	-4.0	-1.8	0.5	2.7	5.0	8.4	7.6	6.7	5.8	5.0
	North /non equatorial window	7.3	6.7	6.1	5.5	4.9	-4.1	-1.8	0.4	2.6	4.9	8.4	7.6	6.7	5.8	4.9
	East/west window	7.3	6.7	6.1	5.5	4.8	-4.0	-1.8	0.4	2.6	4.8	8.1	7.3	6.5	5.7	4.8
	Light tube	6.6	5.8	5.0	4.2	3.5	-5.3	-3.1	-0.9	1.3	3.5	5.7	5.1	4.6	4.0	3.5
	Skylight	6.7	6.0	5.4	4.8	4.2	-5.4	-3.0	-0.6	1.8	4.2	7.3	6.5	5.8	5.0	4.2
	Operable windows	8.5	7.6	6.7	5.8	4.9	-4.7	-2.3	0.1	2.5	4.9	8.2	7.4	6.6	5.8	4.9
	Solar chimneys	5.1	4.5	3.9	3.3	2.7	-6.8	-4.4	-2.1	0.3	2.7	5.0	4.5	3.9	3.3	2.7
	Solar access	6.2	5.8	5.4	5.0	4.6	-4.6	-2.3	0.0	2.3	4.6	8.2	7.3	6.4	5.5	4.6
Active	PV on roofs	8.7	7.7	6.8	5.9	5.0	-5.8	-3.1	-0.4	2.3	5.0	7.6	7.0	6.3	5.6	5.0
	PV on facades	7.4	6.5	5.7	4.8	4.0	-6.6	-4.0	-1.3	1.3	4.0	6.4	5.8	5.2	4.6	4.0
	PV in neighborhood surfaces	7.8	6.8	5.8	4.9	3.9	-6.1	-3.6	-1.1	1.4	3.9	5.5	5.1	4.7	4.3	3.9
	Semi-transparent PV	7.6	6.7	5.7	4.7	3.8	-7.0	-4.3	-1.6	1.1	3.8	5.7	5.2	4.7	4.3	3.8
	PV/thermal technologies	8.0	7.1	6.1	5.2	4.3	-6.5	-3.8	-1.1	1.6	4.3	6.7	6.1	5.5	4.9	4.3
	PV+heat pump	7.2	6.5	5.8	5.1	4.3	-7.3	-4.4	-1.5	1.4	4.3	7.4	6.6	5.9	5.1	4.3
	STC on Facades	6.4	5.7	4.9	4.1	3.3	-6.8	-4.3	-1.8	0.8	3.3	5.2	4.7	4.2	3.8	3.3
	STC on roofs	7.7	6.8	6.0	5.1	4.2	-6.7	-4.0	-1.3	1.5	4.2	6.8	6.2	5.5	4.9	4.2
	STC in neighborhoods	7.0	6.1	5.2	4.4	3.5	-6.6	-4.1	-1.5	1.0	3.5	5.2	4.8	4.4	3.9	3.5

		(d) Weightage variation for environmental impact					(e) Weightage variation for acceptance				
		1	0.8	0.6	0.4	0.2	1	0.8	0.6	0.4	0.2
Passive	South/equatorial Window	4.1	4.4	4.6	4.8	5.0	9.0	8.0	7.0	6.0	5.0
	North /non equatorial window	3.9	4.2	4.4	4.6	4.9	8.8	7.8	6.8	5.9	4.9
	East/west window	4.0	4.2	4.4	4.6	4.8	8.8	7.8	6.8	5.8	4.8
	Light tube	4.1	4.0	3.8	3.6	3.5	6.1	5.4	4.8	4.1	3.5
	Skylight	4.5	4.4	4.3	4.3	4.2	7.8	6.9	6.0	5.1	4.2
	Operable windows	4.4	4.6	4.7	4.8	4.9	8.2	7.4	6.6	5.8	4.9
	Solar chimneys	5.0	4.5	3.9	3.3	2.7	5.1	4.5	3.9	3.3	2.7
	Solar access	4.2	4.3	4.4	4.5	4.6	9.0	7.9	6.8	5.7	4.6
Active	PV on roofs	6.1	5.8	5.5	5.3	5.0	8.3	7.5	6.6	5.8	5.0
	PV on facades	6.6	5.9	5.3	4.6	4.0	6.1	5.5	5.0	4.5	4.0
	PV in neighborhood surfaces	6.4	5.7	5.1	4.5	3.9	5.9	5.4	4.9	4.4	3.9
	Semi-transparent PV	6.5	5.8	5.1	4.5	3.8	6.1	5.5	4.9	4.4	3.8
	PV/thermal technologies	6.5	6.0	5.4	4.8	4.3	6.6	6.0	5.4	4.8	4.3
	PV+heat pump	6.8	6.2	5.6	5.0	4.3	7.6	6.8	6.0	5.2	4.3
	STC on Facades	6.7	5.9	5.0	4.2	3.3	5.0	4.5	4.1	3.7	3.3
	STC on roofs	6.4	5.8	5.3	4.8	4.2	7.0	6.3	5.6	4.9	4.2
	STC in neighborhoods	6.5	5.8	5.0	4.3	3.5	5.6	5.0	4.5	4.0	3.5

Figure 73: Sensitivity analysis of varying weightages for various criteria for existing neighborhoods such as (a) implementation, (b) cost, (c) accessibility (d) environmental impact, and (e) acceptance (while varying weight for one criterion remaining weightage is equally distributed)

Based on these results, it can be concluded that for passive solar strategies assigning higher weightage to acceptance has the most significant impact on the overall adoption score followed by accessibility and ease of implementation. However, for active solar strategies, ease of implementation impacts the overall adoption score the most, while accessibility and acceptance have similar implications. Furthermore, as per present market scenarios, the cost of both passive and active solar strategies is still high, therefore if cost is the priority for the user, then none of the solar strategies are recommended as per the presented decision-making tool.

6.3.1.2 Sensitivity analysis for new neighborhoods

In the similar manner as existing neighborhoods, weightages for the criteria are varied for new neighborhoods as shown in Figure 74. This sensitivity analysis related to new neighborhoods consists of similar results as existing neighborhoods, however, there are some interesting facts. For instance, as shown in Figure 74a, a higher weightage for ease of implementation results in higher adoption scores for new neighborhoods as solar strategies are easy to implement in new neighborhoods, especially passive solar strategies. For example, replacing windows in existing buildings will make it comparatively difficult to install windows in new buildings. Due to this fact increased weightage for implementation results in a higher overall adoption score.

At the same time in terms of cost (negatively impacting the adoption score due to high cost) and accessibility (Figure 74a and 6b), variation of weights results in very similar sensitivity results as existing neighborhoods since these criteria are market-driven and impact new and existing neighborhoods in the same manner. Referring to Figure 74d, the environmental impact is also very similar, which is also intuitive since the impact of these technologies will be almost identical independent of new and existing neighborhoods. As presented in Figure 74e, from the perspective of acceptance, it is slightly better in the new neighborhoods thus higher weightage to acceptance in turn marginally higher score than for existing neighborhoods.

		(a) Weightage variation for implementation					(b) Weightage variation for cost					(c) Weightage variation for accessibility				
		1	0.8	0.6	0.4	0.2	1	0.8	0.6	0.4	0.2	1	0.8	0.6	0.4	0.2
Passive	South/equatorial Window	9.9	8.8	7.7	6.6	5.5	-4.0	-1.6	0.7	3.1	5.5	8.4	7.7	7.0	6.2	5.5
	North /non equatorial window	9.7	8.6	7.5	6.4	5.4	-4.1	-1.7	0.6	3.0	5.4	8.4	7.7	6.9	6.1	5.4
	East/west window	9.7	8.6	7.5	6.4	5.3	-4.0	-1.7	0.7	3.0	5.3	8.1	7.4	6.7	6.0	5.3
	Light tube	8.2	7.1	6.0	4.9	3.8	-5.3	-3.0	-0.7	1.5	3.8	5.7	5.2	4.7	4.3	3.8
	Skylight	8.9	7.8	6.8	5.7	4.6	-5.4	-2.9	-0.4	2.1	4.6	7.3	6.7	6.0	5.3	4.6
	Operable windows	9.3	8.3	7.2	6.2	5.1	-4.7	-2.3	0.2	2.6	5.1	8.2	7.4	6.7	5.9	5.1
	Solar chimneys	7.7	6.6	5.5	4.3	3.2	-6.8	-4.3	-1.8	0.7	3.2	5.0	4.6	4.1	3.7	3.2
	Solar access	9.2	8.2	7.2	6.2	5.2	-4.6	-2.1	0.3	2.8	5.2	8.2	7.5	6.7	6.0	5.2
Active	PV on roofs	9.2	8.2	7.1	6.1	5.1	-5.8	-3.1	-0.3	2.4	5.1	7.6	7.0	6.4	5.7	5.1
	PV on facades	8.5	7.4	6.4	5.3	4.2	-6.6	-3.9	-1.2	1.5	4.2	6.4	5.8	5.3	4.7	4.2
	PV in neighborhood surfaces	7.9	6.9	5.9	4.9	3.9	-6.1	-3.6	-1.1	1.4	3.9	5.5	5.1	4.7	4.3	3.9
	Semi-transparent PV	8.1	7.0	6.0	4.9	3.9	-7.0	-4.3	-1.6	1.1	3.9	5.7	5.2	4.8	4.3	3.9
	PV/thermal technologies	8.5	7.5	6.4	5.4	4.4	-6.5	-3.8	-1.1	1.6	4.4	6.7	6.1	5.5	4.9	4.4
	PV+heat pump	8.7	7.7	6.7	5.7	4.7	-7.3	-4.3	-1.3	1.7	4.7	7.4	6.7	6.0	5.3	4.7
	STC on Facades	7.7	6.7	5.6	4.6	3.6	-6.8	-4.2	-1.6	1.0	3.6	5.2	4.8	4.4	4.0	3.6
	STC on roofs	8.6	7.5	6.5	5.5	4.4	-6.7	-4.0	-1.2	1.6	4.4	6.8	6.2	5.6	5.0	4.4
	STC in neighborhoods	7.2	6.3	5.4	4.5	3.6	-6.6	-4.1	-1.5	1.0	3.6	5.2	4.8	4.4	4.0	3.6

		(d) Weightage variation for environmental impact					(e) Weightage variation for acceptance				
		1	0.8	0.6	0.4	0.2	1	0.8	0.6	0.4	0.2
Passive	South/equatorial Window	4.1	4.5	4.8	5.1	5.5	9.0	8.1	7.2	6.4	5.5
	North /non equatorial window	3.9	4.3	4.6	5.0	5.4	8.8	8.0	7.1	6.2	5.4
	East/west window	4.0	4.3	4.7	5.0	5.3	8.8	7.9	7.1	6.2	5.3
	Light tube	4.1	4.1	4.0	3.9	3.8	6.1	5.5	4.9	4.4	3.8
	Skylight	4.5	4.5	4.6	4.6	4.6	7.8	7.0	6.2	5.4	4.6
	Operable windows	4.4	4.6	4.8	4.9	5.1	8.2	7.4	6.7	5.9	5.1
	Solar chimneys	5.0	4.6	4.1	3.7	3.2	5.1	4.6	4.2	3.7	3.2
	Solar access	4.2	4.5	4.7	5.0	5.2	9.0	8.0	7.1	6.1	5.2
Active	PV on roofs	6.1	5.8	5.6	5.3	5.1	8.3	7.5	6.7	5.9	5.1
	PV on facades	6.6	6.0	5.4	4.8	4.2	6.1	5.6	5.1	4.7	4.2
	PV in neighborhood surfaces	6.4	5.8	5.1	4.5	3.9	5.9	5.4	4.9	4.4	3.9
	Semi-transparent PV	6.5	5.9	5.2	4.5	3.9	6.1	5.5	5.0	4.4	3.9
	PV/thermal technologies	6.5	6.0	5.4	4.9	4.4	6.6	6.0	5.5	4.9	4.4
	PV+heat pump	6.8	6.3	5.7	5.2	4.7	7.6	6.9	6.1	5.4	4.7
	STC on Facades	6.7	5.9	5.1	4.4	3.6	5.0	4.6	4.3	3.9	3.6
	STC on roofs	6.4	5.9	5.4	4.9	4.4	7.0	6.4	5.7	5.1	4.4
	STC in neighborhoods	6.5	5.8	5.0	4.3	3.6	5.6	5.1	4.6	4.1	3.6

Figure 74: Sensitivity analysis of varying weightages for various criteria for new neighborhoods such as (a) implementation, (b) cost, (c) accessibility (d) environmental impact, and (e) acceptance (while varying weight for one criterion remaining weightage is equally distributed)

6.3.2 Application of single objective

Figure 75 presents this selection of solar strategies to serve various single objectives defining equal weightages to various criteria. For instance, in order to increase daylighting, all types of windows such as south or equatorial windows, north or non-equatorial windows, east-west windows, and solar access are almost equally preferred over other strategies such as skylights and light tubes. Nevertheless, the overall adoption score is moderate due to equal weightage to each criterion or constraint (i.e., ease of implementation, cost, accessibility, environmental impact, and acceptance). Changing the weightage will affect these results serving a given single objective and that can be correlated from sensitivity results presented prior in this chapter. For passive heating, south or equatorial windows and solar access are the favorable strategies, whereas for passive cooling operable windows are favorable with a moderate score but the solar chimney has low overall adoption score due to high cost and acceptance in cold climates. For energy efficiency, all eight considered solar strategies are evaluated and it can be seen that except skylights, light tubes, and solar chimneys all other strategies ranked comparably with similar overall adoption scores. To serve the single objectives of electrical and thermal generation active strategies are preferred, and among them, rooftop systems are ranked higher than façade and neighborhood surface installation options. Furthermore, due to the cost perspective, hybrid electric and thermal strategies got lower adoption scores.

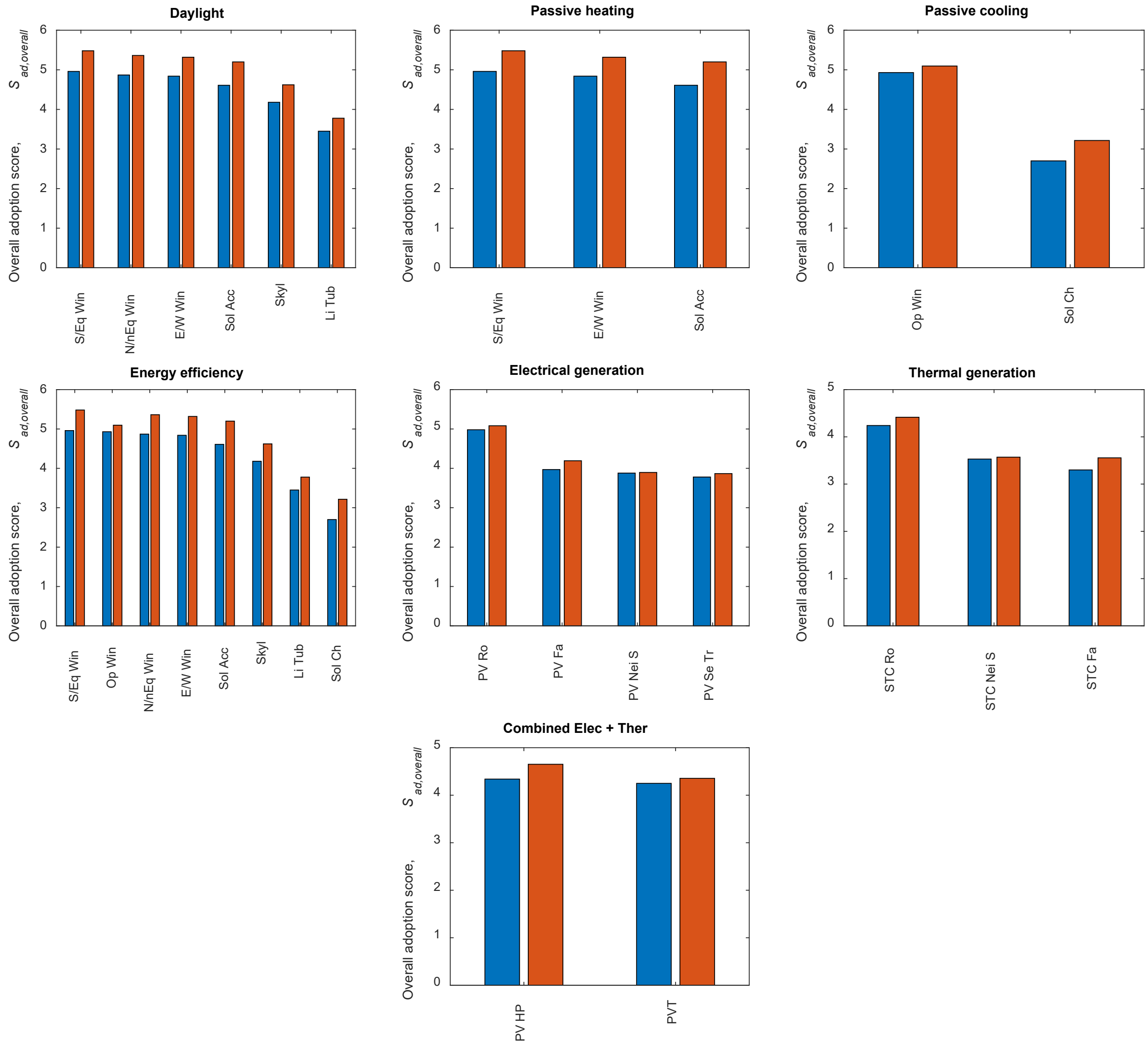
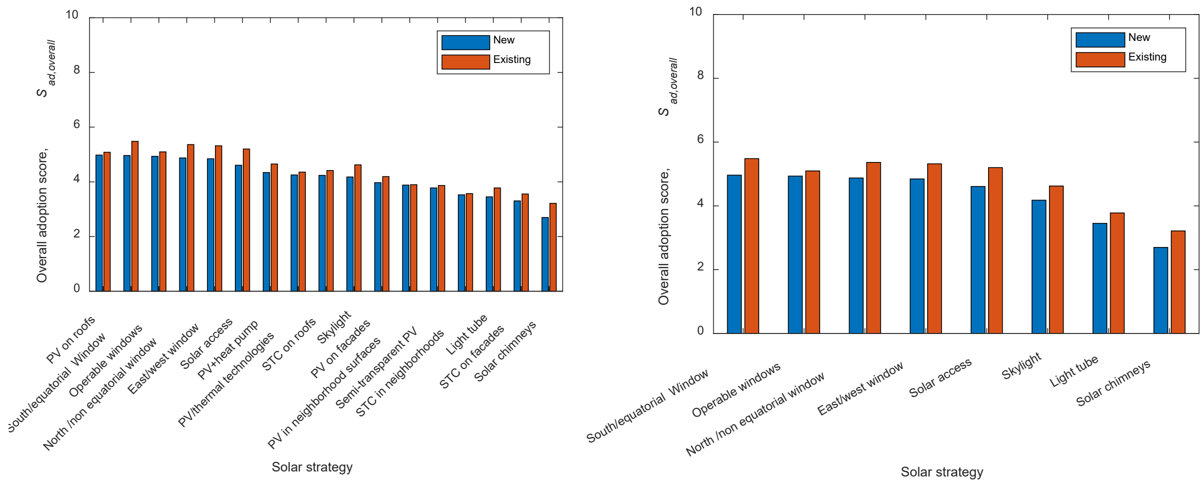


Figure 75: Selection of solar strategies for various single objective for cold and very cold climates

6.3.3 Application of composite objective

Currently, the tool is developed for the cold/very cold applications. However as the framework is already developed, in the future the application can be easily extended to other climates. This report focuses on the utilization of a decision-making approach in regions with extremely cold or cold climates. Figure 76 illustrates the assessment of solar strategies with the combined goals of achieving low/net zero neighborhoods and decreasing overall energy usage in both new and established communities. As depicted in Figure 76a, the most favorable strategy is PV panels on rooftops, followed by passive methods like integrating various window types. From active solar strategies perspective, PV integration into rooftops takes the lead, closely followed by the combination of a heat pump with PV. On the other hand, integrating STC into facades ranks as the least preferred choice among all options, while façade-integrated PV is favored. However, as presented in Figure 76b, when considering the goal of reducing total energy consumption, passive strategies take precedence. Among these, windows are the most optimal choice, followed by solar access, skylights, and light tubes. Solar chimneys, on the other hand, are the least preferred solar strategy when aiming for reduced total energy consumption in very cold/cold climates.



(a) (b)

Figure 76: Overall adoption score-based priority of solar strategies for very cold/cold climate to meet composite objectives of (a) low/net zero neighborhood and (b) reduced total energy consumption for new and existing neighborhoods

6.4 Future development avenues

This work introduces the initial phase of a decision-making tool's development aimed at ranking and prioritizing passive and active solar strategies and concepts to achieve specific goals. In this early stage, various passive and active solar strategies are considered. A decision-making criterion is established to evaluate these strategies based on factors like ease of implementation, cost, accessibility, acceptance, and environmental impact. The tool employs an adoption scoring method derived from a survey among international experts from the task, with diverse backgrounds in solar energy.

At this point, the tool provides a preliminary classification of strategies based on the defined criteria. This classification and ranking can be adaptable to different climates and neighborhood types. For instance, when applied to cold climate neighborhoods, it highlights the most desirable strategies, taking into account factors like access and ease of implementation. The tool's prioritization is dependent on the specific objective, with some objectives, such as achieving net zero energy and reducing energy consumption, leading to similar priorities, especially in passive strategies. Reducing costs may not necessarily align with these priorities as evident in sensitivity analysis. Additionally, achieving net zero carbon requires considering strategies that reduce carbon emissions throughout a neighborhood's lifecycle, not just during operation. The tool can also prioritize active and passive solar strategies based on climate conditions, showing which strategies are the most favorable for the specific objectives.

However, the tool is in its early stages and has limitations. Pilot testing and data collection involved a limited sample size of IEA SHC Task 63 experts, and future work will refine the survey design, determine an accurate sample size, and involve professionals from related fields. Regular updates are necessary to account for changes in solar energy technologies, regulations, and economic conditions. Future research will focus on improving the assessment's accuracy, elaborating more solar strategies, conducting scenario analyses to address uncertainties, and exploring nuances that quantitative data may not capture.

Acknowledgements

We thank our respective funding agencies for supporting this work:

- Natural Resources Canada (Caroline Hachem-Vermette).
- Natural Sciences and Engineering Research Council of Canada (Caroline Hachem-Vermette and Kuljeet Singh Grewal).
- The Swedish Energy Agency (Maria Wall).
- Swiss Federal Office of Energy (SFOE) for supporting the contribution of the Swiss expertise in the IEA SHC Task 63. The Hospice General for providing useful information on the Cite Carl Vogt neighborhood in Geneva. (Gilles Desthieux).
- SINTEF's strategic focus area "Sun and Wind" (Johannes Brozovsky).
- The Research Centre on Zero Emission Neighbourhoods in Smart Cities (FME ZEN), its partners and the Research Council of Norway under grant number 257660 (Johannes Brozovsky and Matteo Formolli).
- The Research Council of Norway under the grant number 324243 - FRIPRO FRINATEK HELIOS - enHancing optimal ExpLoitatIOn of Solar energy in Nordic cities through digitalization of built environment (Gabriele Lobaccaro and Mattia Manni).
- Danish Energy Agency: Energy Technology Development and Demonstration Programme (EUDP) & Danish Energy Management A/S (Danish experts).

References

A. K. Athienitis and M. Santamouri. (2002), *Thermal analysis and design of passive solar buildings.*, James & James, London.

M. S. Abd-Elhady, M. Nasreldin and M. N. Elsheikh. (2018), “Improving the performance of evacuated tube heat pipe collectors using oil and foamed metals,” *Ain Shams Engineering Journal*, Vol. 9/4, pp. 2683–2689, Elsevier.

Z. Abdmouleh, R. A. M. Alammari and A. Gastli. (2015), “Review of policies encouraging renewable energy integration & best practices,” *Renewable and Sustainable Energy Reviews*, Vol. 45, pp. 249–262, Elsevier.

A. A. Abdullah et al. (2022), “Effect of cooling method on the performance of PV/Trombe wall: Experimental assessment,” *Thermal Science and Engineering Progress*, Vol. 30, Elsevier Ltd, https://doi.org/10.1016/j.tsep.2022.101273.

A. G. Aberle. (2009), “Thin-film solar cells,” *Thin solid films*, Vol. 517/17, pp. 4706–4710, Elsevier.

B. Abu-Jdayil et al. (2019), “Traditional, state-of-the-art and renewable thermal building insulation materials: An overview,” *Construction and Building Materials*, Vol. 214, pp. 709–735, Elsevier.

Agenzia CasaClima. (2021), “CasaClima standard.”

H. Akbari, L. Gartland and S. Konopacki. (1998), “Measured energy savings of light colored roofs: Results from three California demonstration sites,” https://www.osti.gov/biblio/674928 (accessed July 4, 2023).

American Society of Heating Refrigerating and Air-conditioning Engineers Inc (ASHRAE). (2007), *Solar Energy Use . In: ASHRAE Handbook – HVAC Applications*, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta.

A. Armstrong et al. (2021), “Honeybee pollination benefits could inform solar park business cases, planning decisions and environmental sustainability targets,” *Biological Conservation*, Vol. 263, p. 109332, Elsevier.

F. Ascione et al. (2019), “Building envelope design: Multi-objective optimization to minimize energy consumption, global cost and thermal discomfort. Application to different Italian climatic zones,” *Energy*, Vol. 174, pp. 359–374, Elsevier.

ASHRAE. (2017), *Handbook of Fundamentals, SI Edition*, *Atlanta, GA*.

V. Badescu, D. I.-A. Energy and undefined 2011. (n.d.), “Pneumatic and thermal design procedure and analysis of earth-to-air heat exchangers of registry type,” *Elsevier*.

R. Baetens et al. (2012), “Assessing electrical bottlenecks at feeder level for residential net zero-energy buildings by integrated system simulation,” *Applied Energy*, Vol. 96, pp. 74–83, Elsevier.

N. Baker et al. (2022), *Identification of existing tools and workflows for solar neighborhood planning.*, (J. Kanters, Ed.), https://doi.org/10.18777/ieashc-task63-2022-0001.

R. K. Bansal, A. K. Goel and M. K. Sharma. (2009), *MATLAB and Its Applications in Engineering*, Pearson Education, New Delhi, https://books.google.ca/books?id=rweneNQZTyUC.

G. ’Barukh and M. E. ’ ’Hoffman. (1968), “Effect of building materials on internal temperatures.”

“BedZED - the UK’s first major zero-carbon community – Bioregional.” (n.d.), https://www.bioregional.com/projects-and-services/case-studies/bedzed-the-uks-first-large-scale-eco-village (accessed June 14, 2023).

A. B. Besir and E. Cuce. (2018), “Green roofs and facades: A comprehensive review,” *Renewable and Sustainable Energy Reviews*, Vol. 82, pp. 915–939, Pergamon, https://doi.org/10.1016/J.RSER.2017.09.106.

W. T. Van Bijsterveld and A. H. De Bondt. (2002), “Structural aspects of asphalt pavement heating and cooling systems,” *Proc., 3rd Int. Symp. on 3D Finite Element Modelling, Design and Research*.

M. Bojić, K. Johannes and F. Kuznik. (2014), “Optimizing energy and environmental performance of passive Trombe wall,” *Energy and Buildings*, Vol. 70, pp. 279–286, https://doi.org/10.1016/j.enbuild.2013.11.062.

K. Boriboonsomsin and F. Reza. (2007), “Mix design and benefit evaluation of high solar reflectance concrete for pavements,” *Transportation Research Record*, 2011, pp. 11–20, https://doi.org/10.3141/2011-02.

M. Boxwell. (2009), *Solar Electricity Handbook: A Simple, Practical Guide to Using Electric Solar Panels and Designing and Installing Photovoltaic Solar PV Systems*, Greenstream Publishing.

R. W. Bradley et al. (2012), “Biological photovoltaics: intra-and extra-cellular electron transport by cyanobacteria,” *Biochemical society transactions*, Vol. 40/6, pp. 1302–1307, Portland Press Ltd.

BREEAM. (n.d.), “Introduction to BREEAM,” https://www.breeam.com/BREEAMUK2014SchemeDocument/content/01_introduction_newcon/2introductiontobreeam_nc.htm (accessed February 16, 2021).

H. Breesch, A. Bossaer and A. Janssens. (2005), “Passive cooling in a low-energy office building,” *Solar Energy* (Volume 79, pp. 682–696), https://doi.org/10.1016/j.solener.2004.12.002.

S. C. Bronin. (n.d.), *Solar Rights*.

“Building: A better Trombe wall - Google Scholar.” (n.d.), https://scholar.google.com/scholar_lookup?title=A%20better%20Trombe%20wall&publication_year=2005&author=N.R.E.L.%20Building (accessed July 5, 2023).

M. S. Buker and S. B. Riffat. (2015), “Building integrated solar thermal collectors–A review,” *Renewable and Sustainable Energy Reviews*, Vol. 51, pp. 327–346, Elsevier.

Canton of Geneva. (2022), “Cadastre Solaire Du Grand Geneve,” https://apps.sitg-lab.ch/solaire/ (accessed October 25, 2023).

I. G. Capeluto and E. Shaviv. (2001), “On the use of ‘solar volume’for determining the urban fabric,” *Solar Energy*, Vol. 70/3, pp. 275–280, Elsevier.

C. Catita et al. (2014), “Extending solar potential analysis in buildings to vertical facades,” *Computers & Geosciences*, Vol. 66, pp. 1–12, Elsevier.

F. Causone et al. (2017), “A high performance home in the Mediterranean climate: From the design principle to actual measurements,” *Energy Procedia*, Vol. 140, pp. 67–79, Elsevier.

H. Y. Chan, S. B. Riffat and J. Zhu. (2010), “Review of passive solar heating and cooling technologies,” *Renewable and Sustainable Energy Reviews*, Vol. 14/2, pp. 781–789, https://doi.org/10.1016/j.rser.2009.10.030.

A. Charley. (1969), “The Economy of Cities [Mass Market Paperback],” p. 2003, http://www.amazon.com/Economy-Cities-Jane-Jacobs/dp/039470584X/ref=sr_1_1?s=books&ie=UTF8&qid=1322518413&sr=1-1 (accessed June 22, 2023).

Rémi Charron and A. K. Athienitis. (2006), “Design and optimization of net zero energy solar homes,” *Ashrae Transactions*, pp. 285–295, https://api.semanticscholar.org/CorpusID:54992578.

Remi Charron and A. K. Athienitis. (2006a), “Optimization of the performance of double-facades with integrated photovoltaic panels and motorized blinds,” *Solar Energy*, Vol. 80/5, pp. 482–491, Elsevier.

Remi Charron and A. K. Athienitis. (2006b), “Optimization of the performance of double-facades with integrated photovoltaic panels and motorized blinds,” *Solar Energy*, Vol. 80/5, pp. 482–491, Elsevier.

C. Chatzipoulka, R. Compagnon and M. Nikolopoulou. (2016), “Urban geometry and solar availability on façades and ground of real urban forms: using London as a case study,” *Solar Energy*, Vol. 138, pp. 53–66, Elsevier.

C. Chatzipoulka, M. Nikolopoulou and R. Watkins. (2015), “The impact of urban geometry on the radiant environment in outdoor spaces,” *9th international conference on urban climate*.

City of Boulder Solar Access Guide City of Boulder Planning and Development Services Center. (n.d.).

City of Toronto. (2017), “Toronto’s Zero Emissions Buildings Framework,” http://cleanairpartnership.org/cac/wp-content/uploads/2017/05/Toronto-ZEBFINALApril-2017.pdf (accessed February 16, 2021).

R. Compagnon. (2004), “Solar and daylight availability in the urban fabric,” *Energy and Buildings*, Vol. 36/4, pp. 321–328, Elsevier, https://doi.org/10.1016/J.ENBUILD.2004.01.009.

S. Croce et al. (2022), *Surface uses in solar neighborhoods*., https://doi.org/10.18777/ieashc-task63-2022-0002.

A. Czachura et al. (2022), “Identifying Potential Indicators of Neighbourhood Solar Access in Urban Planning,” *Buildings*, Vol. 12/10, MDPI, https://doi.org/10.3390/buildings12101575.

Danish Housing and Planning Authority. (2018), *BR18 Executive order on building regulations*. (Volume 2017).

P. Denholm and R. M. Margolis. (2007), “Evaluating the limits of solar photovoltaics (PV) in traditional electric power systems,” *Energy policy*, Vol. 35/5, pp. 2852–2861, Elsevier.

Dictionary.com. (2023), “archetype,” https://www.dictionary.com/browse/archetype (accessed July 6, 2023).

Direktoratet for byggkvalitet. (2017), “Building technical regulations (TEK17) with guidance,” https://dibk.no/regelverk/byggteknisk-forskrift-tek17/ (accessed September 16, 2021).

“DLSC homes have stringent requirements: DLSC.” (n.d.), http://www.dlsc.ca/homes.htm (accessed June 14, 2023).

V. Dobravec et al. (2021), “Multilevel governance energy planning and policy: A view on local energy initiatives,” *Energy, Sustainability and Society*, Vol. 11, pp. 1–17, Springer.

Duany Plater-Zyberk & Co. (2014), “The lexicon of new urbanism,” https://www.dpz.com/wp-content/uploads/2017/06/Lexicon-2014.pdf (accessed April 15, 2021).

G. Eder et al. (2019), “Coloured bipv: Market, research and development.”

Efficiency Canada. (2020), “What you need to know about the new building codes,” https://www.efficiencycanada.org/what-you-need-to-know-about-the-new-building-codes/ (accessed February 16, 2021).

M. P. Elements. (2009), *Expert Guide - Part 2 - Responsive Building Elements*, *iris.polito.it* (2009th edition, Volume 2), https://doi.org/https://hdl.handle.net/11583/2484617.

ENEA. (2020), *Report on Energy Certification of Buildings*.

J. A. Erdman, C. L. Douglas and J. W. Marr. (1969), *Environment of Mesa Verde, Colorado*, US National Park Service.

M. M. E. Van Esch, R. H. J. Looman and G. J. de Bruin-Hordijk. (2012), “The effects of urban and building design parameters on solar access to the urban canyon and the potential for direct passive solar heating strategies,” *Energy and Buildings*, Vol. 47, pp. 189–200, Elsevier.

R. Ewing and F. Rong. (2008), “The impact of urban form on US residential energy use,” *Housing policy debate*, Vol. 19/1, pp. 1–30, Taylor & Francis.

S. Ferrari et al. (2021), “A GIS-Based Procedure for Estimating the Energy Demand Profiles of Buildings towards Urban Energy Policies,” *Energies*, Vol. 14/17, p. 5445, MDPI.

FME ZEN. (2021), “The FME-ZEN Research Centre,” https://fmezen.no/ (accessed September 16, 2021).

J. A. Fonseca et al. (2016), “City Energy Analyst (CEA): Integrated framework for analysis and optimization of building energy systems in neighborhoods and city districts,” *Energy and Buildings*, Vol. 113, pp. 202–226, Elsevier.

M. Formolli, T. Kleiven and G. Lobaccaro. (2023), “Assessing solar energy accessibility at high latitudes: A systematic review of urban spatial domains, metrics, and parameters,” *Renewable and Sustainable Energy Reviews*, Elsevier Ltd, https://doi.org/10.1016/j.rser.2023.113231.

M. Foster and T. Oreszczyn. (n.d.), *Occupant control of passive systems: the use of Venetian blinds*., www.elsevier.com/locate/buildenv.

“Fujisawa Sustainable Smart Town: planning for the next 100 years.” (n.d.), https://tomorrow.city/a/fujisawa-sustainable-smart-town (accessed June 14, 2023).

G. Franta and K. Anstead. (1994), “Daylighting offers great opportunities,” *Wind. Door Specif. Lab*, pp. 40–43.

N. B. Geetha and R Velraj. (2012), “Passive cooling methods for energy efficient buildings with and without thermal energy storage–A review,” *Energy Education Science and Technology Part A: Energy Science and Research*, Vol. 29/2, pp. 913–946.

N. B. Geetha and Ramalingam Velraj. (2012), “Passive cooling methods for energy efficient buildings with and without thermal energy storage - A review,” https://api.semanticscholar.org/CorpusID:7306289.

D. Giannelli, C. León-Sánchez and G. Agugiaro. (2022), “Comparison and evaluation of different GIS software tools to estimate solar irradiation,” *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences* (Volume 5, pp. 275–282), Copernicus GmbH, https://doi.org/10.5194/isprs-Annals-V-4-2022-275-2022.

Government of Canada. (2018), “Pan-Canadian framework on clean growth and climate change first annual report: Complementary actions to reduce emissions,” https://www.canada.ca/en/environment-climate-change/services/climate-change/pan-canadian-framework-reports/first-annual-report/complementary-actions-reduce-emissions.html#32 (accessed February 4, 2020).

Green Building Council Italia. (2009), “LEED Italia.”

M. Grosso, L. R.-I. J. of Ventilation and undefined 2008. (2008), “Horizontal air-to-earth heat exchangers in northern Italy-testing, design and monitoring,” *Taylor & Francis*, Vol. 7/1, pp. 1–10, VEETECH Ltd., https://doi.org/10.1080/14733315.2008.11683794.

habitech. (2021), “ARCA - Certification of quality and sustainability.”

C. Hachem, A. Athienitis and P. Fazio. (2011), “Parametric investigation of geometric form effects on solar potential of housing units,” *Solar Energy*, Vol. 85/9, pp. 1864–1877, Pergamon, https://doi.org/10.1016/J.SOLENER.2011.04.027.

C. Hachem, A. Athienitis and P. Fazio. (2012), “Evaluation of energy supply and demand in solar neighborhood,” *Energy and Buildings*, Vol. 49, pp. 335–347, https://doi.org/10.1016/j.enbuild.2012.02.021.

C. Hachem, A. Athienitis and P. Fazio. (2014), “Energy performance enhancement in multistory residential buildings,” *Applied Energy*, Vol. 116, pp. 9–19, Elsevier.

C. Hachem, P. Fazio and A. Athienitis. (2013a), “Solar optimized residential neighborhoods: Evaluation and design methodology,” *Solar Energy*, Vol. 95, pp. 42–64, Pergamon, https://doi.org/10.1016/J.SOLENER.2013.06.002.

C. Hachem, P. Fazio and A. Athienitis. (2013b), “Solar optimized residential neighborhoods: Evaluation and design methodology,” *Solar Energy*, Vol. 95, pp. 42–64, Elsevier.

C. Hachem-Vermette. (2015), “Integrated design considerations for solar communities,” *Journal of Green Building*, Vol. 10/2, pp. 134–156, College Publishing.

Caroline Hachem-Vermette. (2020), “Introduction to Solar Neighborhoods,” in C. Hachem-Vermette (ed.), *Solar Buildings and Neighborhoods: Design Considerations for High Energy Performance* (pp. 167–192), Springer International Publishing, Cham, https://doi.org/10.1007/978-3-030-47016-6_6.

C Hachem-Vermette. (2020), *Solar Buildings and neighborhoods: Design considerations for high energy performance* (Green Energy and Technology), Springer International Publishing, https://books.google.ca/books?id=Kj_oDwAAQBAJ.

C. Hachem-Vermette. (2021), “Design and performance of landscape adaptable PV structures,” *EuroSun 2020 Proceedings* (pp. 1–12), International Solar Energy Society (ISES), https://doi.org/10.18086/eurosun.2020.13.01.

C. Hachem-Vermette et al. (2023), “Decision making method to prioritize and implement solar strategies on neighborhood level,” *18th Sustainable Development of Energy, Water and Environment Systems (SDEWES)*, Dubrovnik.

C. Hachem-Vermette and K. Singh. (2019), “Mixed-use neighborhoods layout patterns: Impact on solar access and resilience,” *Sustainable Cities and Society*, Vol. 51, p. 101771, Elsevier.

C. Hachem-Vermette and K. Singh. (2020), “Developing an optimization methodology for urban energy resources mix,” *Applied Energy*, Vol. 269/February, p. 115066, Elsevier, https://doi.org/10.1016/j.apenergy.2020.115066.

C. Hachem-Vermette and K. Singh. (2022a), “Energy systems and energy sharing in traditional and sustainable archetypes of urban developments,” *Sustainability*, Vol. 14/3, p. 1356, MDPI.

C. Hachem-Vermette and K. Singh. (2022b), “Energy Systems and Energy Sharing in Traditional and Sustainable Archetypes of Urban Developments,” *Sustainability*, Vol. 14/3, p. 1356, https://doi.org/10.3390/su14031356.

Z. Hao et al. (2023), “Simplified Model of Heat Load Prediction and Its Application in Estimation of Building Envelope Thermal Performance,” *Buildings*, Vol. 13/4, p. 1076, MDPI.

P. He et al. (2023), “The impact of neighborhood layout heterogeneity on carbon emissions in high-density urban areas: A case study of new development areas in Hong Kong,” *Energy and Buildings*, Vol. 287, Elsevier Ltd, https://doi.org/10.1016/j.enbuild.2023.113002.

P. Heinstein, C. Ballif and L.-E. Perret-Aebi. (2013), “Building integrated photovoltaics (BIPV): review, potentials, barriers and myths,” *Green*, Vol. 3/2, pp. 125–156, De Gruyter.

J. Hofierka and M. Zlocha. (2012), “A new 3-D solar radiation model for 3-D city models,” *Transactions in GIS*, Vol. 16/5, pp. 681–690, Wiley Online Library.

Z. Hu et al. (2017), “A review on the application of Trombe wall system in buildings,” *Renewable and Sustainable Energy Reviews*, Elsevier Ltd, https://doi.org/10.1016/j.rser.2016.12.003.

A. A. F. Husain et al. (2018), “A review of transparent solar photovoltaic technologies,” *Renewable and sustainable energy reviews*, Vol. 94, pp. 779–791, Elsevier.

Introducing Virtual Net Metering: A California First Solterra EcoLuxury Apartments. (2015), www.HESsolar.com.

Istituto per l´Innovazione e Trasparenza degli Appalti e la Compatibilitá Ambientale. (2011), “Protocollo ITACA.”

Y. R. Jabareen. (2006), “Sustainable urban forms: Their typologies, models, and concepts,” *Journal of planning education and research*, Vol. 26/1, pp. 38–52, Sage Publications Sage CA: Thousand Oaks, CA.

J. P.-L. Journal and undefined 1987. (n.d.), “The use of shrubs in energy conservation plantings,” *lj.uwpress.org*, https://lj.uwpress.org/content/6/2/132.short (accessed July 4, 2023).

S. A. Kalogirou. (2004), “Solar thermal collectors and applications,” *Progress in energy and combustion science*, Vol. 30/3, pp. 231–295, Elsevier.

T. Karlessi et al. (2009), “Development and testing of thermochromic coatings for buildings and urban structures,” *Solar Energy*, Vol. 83/4, pp. 538–551, https://doi.org/10.1016/j.solener.2008.10.005.

A. K. K. , Kawakami. (2008), “Development of a cool pavement for mitigating the urban heat island effect in Japan. ,” *1st International Symposium on Asphalt Pavements and Environments, Zurich, Switzerland.*

N. Kaza. (2010), “Understanding the spectrum of residential energy consumption: A quantile regression approach,” *Energy policy*, Vol. 38/11, pp. 6574–6585, Elsevier.

J. Keirstead, N. Samsatli and N. Shah. (2010), “SynCity: an integrated tool kit for urban energy systems modelling,” *Energy efficient cities: Assessment tools and benchmarking practices*, Vol. 21, The World Bank Washington DC, USA.

K. Kensek and A. Henkhaus. (n.d.), *Solar Access Zoning + Building Information Modeling*.

G. A. Keoleian and G. M. Lewis. (2003), “Modeling the life cycle energy and environmental performance of amorphous silicon BIPV roofing in the US,” *Renewable Energy*, Vol. 28/2, pp. 271–293, Elsevier.

R L Knowles. (1981), *Sun rhythm form*, United States.

Ralph L Knowles. (1981), “Sun rhythm form,” MIT Press, Cambridge, MA.

R. L. Knowles and R. D. Berry. (1980), *Solar envelope concepts: moderate density building applications* (Volume 98155), Solar Energy Information Data Bank.

Y. Ko and J. D. Radke. (2014), “The effect of urban form and residential cooling energy use in Sacramento, California,” *Environment and planning B: Planning and Design*, Vol. 41/4, pp. 573–593, SAGE Publications Sage UK: London, England.

Y. Kondo, T. Ogasawara and H. Kanamori. (2008), *Field Measurements and Heat Budget Analysis on Sensible Heat Flux from Pavement*., *J. Environ. Eng., AIJ* (Volume 73).

Korbinian Kramer et al. (2020), *Technology Position Paper PVT Collectors and Systems*., www.iea-shc.org.

Ž. Kristl and A. Krainer. (2001), “Energy evaluation of urban structure and dimensioning of building site using iso-shadow method,” *Solar energy*, Vol. 70/1, pp. 23–34, Elsevier.

D. Kumar et al. (n.d.), “Comparative analysis of building insulation material properties and performance,” *Elsevier*.

S. Kumar. (2002), “Canadian urban design practice: a review of urban design regulations,” *Canadian Journal of Urban Research*, Vol. 11/2, pp. 239–263.

B. Kundakci Koyunbaba and Z. Yilmaz. (2012), “The comparison of Trombe wall systems with single glass, double glass and PV panels,” *Renewable Energy*, Vol. 45, pp. 111–118, https://doi.org/10.1016/j.renene.2012.02.026.

L. Edwards and P. Torcellini. (2002), “Literature Review of the Effects of Natural Light on Building Occupants.”

W. Lang et al. (2022), “Measuring urban vibrancy of neighborhood performance using social media data in Oslo, Norway,” *Cities*, Vol. 131, Elsevier Ltd, https://doi.org/10.1016/j.cities.2022.103908.

A. Laouadi. (2009), “Thermal performance modelling of complex fenestration systems,” *Journal of Building Performance Simulation*, Vol. 2/3, pp. 189–207, https://doi.org/10.1080/19401490903046785.

N. Lechner. (2001), *Heating, cooling, lighting : design methods for architects* (2nd ed.), New York : John Wiley, New York.

K. S. Lee, J. W. Lee and J. S. Lee. (2016), “Feasibility study on the relation between housing density and solar accessibility and potential uses,” *Renewable energy*, Vol. 85, pp. 749–758, Elsevier.

Legambiente and CNAPPC. (2017), *“L’innovazione nell’edilizia italiana.”*

R. Levinson et al. (n.d.), *A novel technique for the production of cool colored concrete tile and asphalt shingle roofing products*.

C. Li, Y. Song and N. Kaza. (2018), “Urban form and household electricity consumption: A multilevel study,” *Energy and Buildings*, Vol. 158, pp. 181–193, Elsevier.

B. B. Lin, J. Meyers and G. B. Csiro. (n.d.), *THE ROLE OF URBAN VEGETATION FOR CLIMATE ADAPTATION IN CITIES*.

J. J. Lin and A. T. Yang. (2006), “Does the Compact-City Paradigm Foster Sustainability? An Empirical Study in Taiwan,” *https://doi.org/10.1068/b31174*, Vol. 33/3, pp. 365–380, SAGE PublicationsSage UK: London, England, https://doi.org/10.1068/B31174.

P. J. Littlefair. (2000), *Environmental site layout planning: solar access, microclimate and passive cooling in urban areas*, BRE publications.

K. Lloyd and C. Auld. (2003), “Leisure, public space and quality of life in the urban environment,” *Urban policy and research*, Vol. 21/4, pp. 339–356, Taylor & Francis.

F. De Luca and T. Dogan. (2019), “A novel solar envelope method based on solar ordinances for urban planning,” *Building Simulation*, Vol. 12/5, pp. 817–834, Tsinghua University Press, https://doi.org/10.1007/s12273-019-0561-1.

D. ; H. J. ; and R. M. Arasteh. (1986), “Experimental Verification of a Model of Heat Transfer Through Windows,” *ASHRAE Trans.*, Vol. 93/Part 1, pp. 1425–1431.

S. Marshall and Y. Gong. (2005), “Urban pattern specification,” *Institute of Community Studies, London*, Citeseer.

A. J. McCormick et al. (2011), “Photosynthetic biofilms in pure culture harness solar energy in a mediatorless bio-photovoltaic cell (BPV) system,” *Energy & Environmental Science*, Vol. 4/11, pp. 4699–4709, Royal Society of Chemistry.

X. Meng et al. (2018), “Optimization of the wall thermal insulation characteristics based on the intermittent heating operation,” *Case studies in construction materials*, Vol. 9, p. e00188, Elsevier.

Dr. A. Mermoud. (2022), “PVsyst (7.2.16).”

D. Mills. (2004), “Advances in solar thermal electricity technology,” *Solar energy*, Vol. 76/1–3, pp. 19–31, Elsevier.

Minergie. (n.d.), “What is Minergie?,” https://www.minergie.ch/fr/ (accessed December 25, 2023).

Ministry of Economic Development. (2020), *Integrated National Energy and Climate Plan 2030*.

Ministry of Economy and Finance. (2021), *Budget Law 2021*.

Ministry of Local Government and Modernization Norway. (2008), “Act on planning and building case processing (planning and building act),” https://lovdata.no/dokument/NL/lov/2008-06-27-71 (accessed September 16, 2021).

Ministry of Municipal Affairs and Housing. (2017), “Supplementary Standard SB-10 ‘Energy Efficiency Requirements’ Amended on December 22, 2016,” http://www.mah.gov.on.ca/Page15255.aspx accessed on January 31 (accessed February 16, 2021).

Ministry of the Environment and Protection of Natural Resources and the Sea. (2015), *National Strategy of Adaptation to Climate Change (SNACC)*.

Ministry of the Environment and Protection of Natural Resources and the Sea. (2018), *National Climate Change Adaptation Plan (PNACC)*.

T. Miyazaki, A. Akisawa and T. Kashiwagi. (2005), “Energy savings of office buildings by the use of semi-transparent solar cells for windows,” *Renewable energy*, Vol. 30/3, pp. 281–304, Elsevier.

A. Moreno-Rangel. (2020), “Passivhaus,” *Encyclopedia*, Vol. 1/1, pp. 20–29, MDPI.

National Renewable Energy Laboratory (NREL). (2016), “EnergyPlus,” https://energyplus.net/ (accessed November 27, 2018).

National Research Council Canada. (2022), *National Energy Code of Canada for Buildings: 2020.*, Ottawa, Canada.

Natural Resources Canada. (2019), “Comprehensive Energy Use Database,” *Government of Canada Website*.

A. A. Nazzal. (2005), “A new evaluation method for daylight discomfort glare,” *International Journal of Industrial Ergonomics*, Vol. 35/4, pp. 295–306, Elsevier.

“New Orleans Home To Largest Solar Neighborhood In SE | EarthTechling.” (n.d.), https://earthtechling.com/2012/11/new-orleans-home-to-largest-solar-neighborhood-in-se/ (accessed June 14, 2023).

D. of T. (DT) Office of Urban Planning. (2021), “Updated Cantonal master plan 2030,” https://www.ge.ch/document/plan-directeur-cantonal-2030-mis-jour (accessed September 16, 2021).

H. Omrany et al. (2016), “Application of passive wall systems for improving the energy effciency in buildings: A comprehensive review,” *Renewable and Sustainable Energy Reviews*, Elsevier Ltd, https://doi.org/10.1016/j.rser.2016.04.010.

“One Brighton – One Planet Living® Leader – Bioregional.” (n.d.), https://www.bioregional.com/one-planet-living/one-planet-living-leaders/one-brighton-one-planet-living-leader (accessed June 14, 2023).

Organisation for Economic Co-operation and Development. (2017), “The governance of land use: Country fact sheet Italy,” https://www.oecd.org/regional/regional-policy/land-use-Italy.pdf (accessed October 26, 2023).

C. R. Osterwald et al. (2023), “Improved Primary Reference Cell Calibrations for Higher Accuracy Photovoltaic Cell and Module Performance Measurements,” *Solar RRL*, Wiley Online Library.

J. R. Parkins et al. (2018), “Predicting intention to adopt solar technology in Canada: The role of knowledge, public engagement, and visibility,” *Energy Policy*, Vol. 114, pp. 114–122, Elsevier.

N. Pearsall. (2016), *The performance of photovoltaic (PV) systems: modelling, measurement and assessment*, Woodhead Publishing.

R. Perez et al. (1987), “A new simplified version of the Perez diffuse irradiance model for tilted surfaces,” *Solar energy*, Vol. 39/3, pp. 221–231, Elsevier.

"Perinjanam Model: How A Kerala Village Became Energy Self-Sufficient With Rooftop Solar." (n.d.), https://www.indiatimes.com/news/india/perinjanam-model-how-a-kerala-village-became-energy-self-sufficient-with-rooftop-solar-584782.html (accessed June 14, 2023).

B. Petter Jelle, C. Breivik and H. Drolsum Røkenes. (2012), "Building integrated photovoltaic products: A state-of-the-art review and future research opportunities," *Solar Energy Materials and Solar Cells*, Vol. 100, pp. 69–96, https://doi.org/https://doi.org/10.1016/j.solmat.2011.12.016.

K. Pickerel. (2018), "What are bifacial modules?," *Solar Power World*, https://www.solarpowerworldonline.com/2018/04/what-are-bifacial-solar-modules/ (accessed June 4, 2021).

Plan-og bygningsloven. (2008), "Lov om planlegging og byggesaksbehandling," Miljøverndepartementet Oslo.

B. Polly et al. (2016), "From zero energy buildings to zero energy districts," *Proceedings of the 2016 American council for an energy efficient economy summer study on energy efficiency in buildings, Pacific Grove, CA, USA*, pp. 21–26.

A. Poullikkas. (2010), "Technology and market future prospects of photovoltaic systems," *International Journal of Energy and Environment* , Vol. 1/4, pp. 2076–2909, Online.

M. C. M. Probst and C. Roecker. (2011a), *Architectural integration and design of solar thermal systems*, EPFL Press.

M. C. M. Probst and C. Roecker. (2011b), *Architectural integration and design of solar thermal systems*, EPFL Press.

M. M. Probst and C. Roecker. (2012), "Criteria for architectural integration of active solar systems IEA Task 41, Subtask A," *Energy Procedia*, Vol. 30, pp. 1195–1204, Elsevier.

Y. Qin. (2015), "A review on the development of cool pavements to mitigate urban heat island effect," *Renewable and Sustainable Energy Reviews*, Elsevier Ltd, https://doi.org/10.1016/j.rser.2015.07.177.

V. Rai, D. C. Reeves and R. Margolis. (2016), "Overcoming barriers and uncertainties in the adoption of residential solar PV," *Renewable Energy*, Vol. 89, pp. 498–505, Elsevier.

K. Ramalingam and C. Indulkar. (2017), "Chapter 3 - Solar Energy and Photovoltaic Technology," in G.B. Gharehpetian & S.M. Mousavi Agah (eds.), *Distributed Generation Systems* (pp. 69–147), Butterworth-Heinemann, https://doi.org/https://doi.org/10.1016/B978-0-12-804208-3.00003-0.

C. Ratti, N. Baker and K. Steemers. (2005a), "Energy consumption and urban texture," *Energy and buildings*, Vol. 37/7, pp. 762–776, Elsevier.

C. Ratti, N. Baker and K. Steemers. (2005b), "Energy consumption and urban texture," *Energy and buildings*, Vol. 37/7, pp. 762–776, Elsevier.

T. M. Razykov et al. (2011), "Solar photovoltaic electricity: Current status and future prospects," *Solar Energy*, Vol. 85/8, pp. 1580–1608, https://doi.org/10.1016/j.solener.2010.12.002.

Reijenga TH and Kaan HF. (2011), *PV in architecture: Handbook of photovoltaic science and engineering* (2nd edition, Volume pp 1043-1077), Wiley, Chichester, UK.

C. F. Reinhart et al. (2013), "Umi-an urban simulation environment for building energy use, daylighting and walkability."

L. Richardson. (2021), "Solar carports: how do they work and how much do they cost?," *Energy Sage*, https://news.energysage.com/what-is-a-solar-panel-carport/ (accessed June 7, 2021).

S. Roberts and N. Guariento. (n.d.), "Building integrated photovoltaics: a handbook. 2009," Walter de Gruyter.

D. Robinson et al. (2009), “CitySim: Comprehensive micro-simulation of resource flows for sustainable urban planning,” *Proceedings of the Eleventh International IBPSA Conference* (pp. 1083–1090).

P. Rode et al. (2014), “Cities and Energy: Urban Morphology and Residential Heat-Energy Demand,” *https://doi.org/10.1068/b39065*, Vol. 41/1, pp. 138–162, SAGE PublicationsSage UK: London, England, https://doi.org/10.1068/B39065.

J. Roth et al. (2020), “SynCity: Using open data to create a synthetic city of hourly building energy estimates by integrating data-driven and physics-based methods,” *Applied Energy*, Vol. 280, Elsevier Ltd, https://doi.org/10.1016/j.apenergy.2020.115981.

H. Sanaieian et al. (2014), “Review of the impact of urban block form on thermal performance, solar access and ventilation,” *Renewable and Sustainable Energy Reviews*, Vol. 38, pp. 551–560, Elsevier.

V. Sankaran and A. Chopra. (2020), “Creating Global Sustainable Smart Cities (A Case Study of Masdar City),” *Journal of Physics: Conference Series* (Volume 1706), IOP Publishing Ltd, https://doi.org/10.1088/1742-6596/1706/1/012141.

M. Santamouris. (2013), “Using cool pavements as a mitigation strategy to fight urban heat island - A review of the actual developments,” *Renewable and Sustainable Energy Reviews*, https://doi.org/10.1016/j.rser.2013.05.047.

M. Santamouris, D. K.-E. and Buildings and undefined 2013. (n.d.), “Passive cooling dissipation techniques for buildings and other structures: The state of the art,” *Elsevier*.

J. J. Sarralde et al. (2015), “Solar energy and urban morphology: Scenarios for increasing the renewable energy potential of neighbourhoods in London,” *Renewable energy*, Vol. 73, pp. 10–17, Elsevier.

P. A. Sattrup and J. Strømann-Andersen. (2013), *BUILDING TYPOLOGIES IN NORTHERN EUROPEAN CITIES: DAYLIGHT, SOLAR ACCESS, AND BUILDING ENERGY USE*., *Journal of Architectural and Planning Research* (Volume 30).

T. Schoen et al. (2001), “Task 7 of the IEA PV power systems program–achievements and outlook,” *Proceedings of the 17th European photovoltaic solar conference* (p. 2).

K. Sergei, C. Shen and Y. Jiang. (2020), “A review of the current work potential of a trombe wall,” *Renewable and Sustainable Energy Reviews*, Elsevier Ltd, https://doi.org/10.1016/j.rser.2020.109947.

L. J. Shah and S. Furbo. (2004), “Vertical evacuated tubular-collectors utilizing solar radiation from all directions,” *Applied energy*, Vol. 78/4, pp. 371–395, Elsevier.

A. Shukla et al. (2012), “A state of art review on the performance of transpired solar collector,” *Renewable and Sustainable Energy Reviews*, Vol. 16/6, pp. 3975–3985, Elsevier.

J. Simpson, E. M.-E. and buildings and undefined 1997. (1997), “The effects of roof albedo modification on cooling loads of scale model residences in Tucson, Arizona,” *Elsevier*, Vol. 25, pp. 127–137.

K. Singh and C. Hachem-Vermette. (2022), “Novel methodology of urban energy simulations integrating Open-source platforms,” *Energy and Buildings*, Vol. 263, Elsevier Ltd, https://doi.org/10.1016/j.enbuild.2022.112040.

SINTEF. (2011), “Vannbaserte solfangere. Funksjon og energiutbytte. Byggforskserien - Byggdetalje,” https://www.byggforsk.no/dokument/542/vannbaserte_solfangere_funksjon_og_energiutbytte#i12 (accessed August 8, 2021).

N. Skandalos and D. Karamanis. (2015), “PV glazing technologies,” *Renewable and Sustainable Energy Reviews*, Vol. 49, pp. 306–322, Elsevier.

J. Skea et al. (2019), “Building integrated photovoltaics,” *Energy Innovation for the Twenty-First Century* (pp. 282–321), Edward Elgar Publishing.

M. Slaman and R. Griessen. (2009), “Solar collector overheating protection,” *Solar energy*, Vol. 83/7, pp. 982–987, Elsevier.

Solenergiklyngen Norge. (2020), “SOLENERGI noe for din kommune? Råd og veiledning for økt kompetanse for bestillere og andre rettet mot offentlig sektor,” https://www.solenergiklyngen.no/wp-content/uploads/2021/06/veilleder_kompetanse_off_innkjopere_ny.pdf (accessed August 9, 2021).

W. B. Standard. (2018), “International WELL Building Institute.”

Statistics Canada. (2016), “Census profile, 2016 census,” https://www12.statcan.gc.ca/census-recensement/2016/dp-pd/prof/index.cfm?Lang=E (accessed May 20, 2022).

K. Steemers. (2003a), “Energy and the city: density, buildings and transport,” *Energy and buildings*, Vol. 35/1, pp. 3–14, Elsevier.

K. Steemers. (2003b), “Energy and the city: density, buildings and transport,” *Energy and buildings*, Vol. 35/1, pp. 3–14, Elsevier.

J. Strømann-Andersen and P. A. Sattrup. (2011), “The urban canyon and building energy use: Urban density versus daylight and passive solar gains,” *Energy and buildings*, Vol. 43/8, Elsevier.

Swiss Federal Office of Energy SFOE. (2021), “Federal act on a secure electricity supply from renewable energy sources,” https://www.bfe.admin.ch/bfe/en/home/supply/electricity-supply/federal-act-renewable-electricity-supply.html (accessed September 16, 2021).

A. Synnefa et al. (2011), “Experimental testing of cool colored thin layer asphalt and estimation of its potential to improve the urban microclimate,” *Building and Environment*, Vol. 46/1, pp. 38–44, https://doi.org/10.1016/j.buildenv.2010.06.014.

A. Synnefa, M. Santamouris and I. Livada. (2006a), “A study of the thermal performance of reflective coatings for the urban environment,” *Solar Energy*, Vol. 80/8, pp. 968–981, https://doi.org/10.1016/j.solener.2005.08.005.

A. Synnefa, M. Santamouris and I. Livada. (2006b), “A study of the thermal performance of reflective coatings for the urban environment,” *Solar Energy*, Vol. 80/8, pp. 968–981, https://doi.org/10.1016/j.solener.2005.08.005.

S. Tabet, K.A.; Sharples. (1990), “The Interaction of Preferred Window Size with Thermal and Visual Comfort.,” *Energy and the Environment Into the 1990s.*, Vol. 4, pp. 2648–2652.

M. Taleghani et al. (2013), “Energy use impact of and thermal comfort in different urban block types in the Netherlands,” *Energy and Buildings*, Vol. 67, pp. 166–175, Elsevier, https://doi.org/10.1016/J.ENBUILD.2013.08.024.

R. Tang et al. (2006), “Assessment of uncertainty in mean heat loss coefficient of all glass evacuated solar collector tube testing,” *Energy conversion and management*, Vol. 47/1, pp. 60–67, Elsevier.

A. K. Thakur et al. (2022), “Advancements in solar technologies for sustainable development of agricultural sector in India: a comprehensive review on challenges and opportunities,” *Environmental Science and Pollution Research*, Vol. 29/29, pp. 43607–43634, Springer.

The Swedish National Board of Housing; Building and Planning. (2016), *Mandatory provisions and general recommendations for temporary accommodation facilities*. (Volume 1), https://www.boverket.se/globalassets/publikationer/dokument/2016/ata-bfs-2016-5-english.pdf.

The Swiss Federal Office of Energy SFOE. (2019), “Federal act on energy,” https://www.fedlex.admin.ch/eli/cc/1979/1573_1573_1573/en (accessed August 18, 2021).

B. Tian et al. (2022), “Impacts of surface model generation approaches on raytracing-based solar potential estimation in urban areas,” *Renewable Energy*, Vol. 198, pp. 804–824, Elsevier.

Y. Tian and C.-Y. Zhao. (2013), "A review of solar collectors and thermal energy storage in solar thermal applications," *Applied energy*, Vol. 104, pp. 538–553, Elsevier.

Y. Tripanagnostopoulos et al. (2001), "Hybrid PV/T systems with dual heat extraction operation," *Proceedings of the 17th PV solar energy conference, Munich* (pp. 22–26), Citeseer.

J. Tschörtner, B. Lai and J. O. Krömer. (2019), "Biophotovoltaics: green power generation from sunlight and water," *Frontiers in microbiology*, Vol. 10, p. 866, Frontiers Media SA.

A. Tzempelikos and A. K. Athienitis. (2007), "The impact of shading design and control on building cooling and lighting demand," *Solar Energy*, Vol. 81/3, pp. 369–382, https://doi.org/10.1016/j.solener.2006.06.015.

A. Vartholomaios. (2017), "A parametric sensitivity analysis of the influence of urban form on domestic energy consumption for heating and cooling in a Mediterranean city," *Sustainable Cities and Society*, Vol. 28, pp. 135–145, Elsevier, https://doi.org/10.1016/J.SCS.2016.09.006.

M. Wall et al. (2012), "Achieving solar energy in architecture-IEA SHC Task 41," *Energy Procedia*, Vol. 30, pp. 1250–1260, Elsevier.

F. C. Winkelmann. (n.d.), *Modeling windows in EnergyPlus*.

J. Xie et al. (2020), "Urban parks as green buffers during the COVID-19 pandemic," *Sustainability*, Vol. 12/17, p. 6751, MDPI.

A. K. Yadav and S. S. Chandel. (2013), "Tilt angle optimization to maximize incident solar radiation: A review," *Renewable and Sustainable Energy Reviews*, Vol. 23, pp. 503–513, Elsevier.

S. Yadav et al. (2023), "Performance evaluation of building integrated semitransparent and opaque photovoltaic Trombe wall systems employing periodic thermal models," *Energy and Buildings*, Vol. 294, p. 113221, https://doi.org/10.1016/j.enbuild.2023.113221.

R. Zahedi et al. (2022), "Feasibility study for designing and building a zero-energy house in new cities," *Solar Energy*, Vol. 240, pp. 168–175, Elsevier.

L. Zalewski et al. (2002), *Study of solar walls-validating a simulation model.*, *Building and Environment* (Volume 37), www.elsevier.com/locate/buildenv.

ZEB. (2021), "The ZEB Research Centre," https://www.zeb.no/index.php/en/ (accessed August 8, 2021).

Z. Y. Zeng, B. C. Zhao and R. Z. Wang. (2021), "Passive day and night heating for zero energy buildings with solar-based adsorption thermal battery," *Cell Reports Physical Science*, Cell Press, https://doi.org/10.1016/j.xcrp.2021.100578.

J. Zhang et al. (2019), "Impact of urban block typology on building solar potential and energy use efficiency in tropical high-density city," *Applied Energy*, Vol. 240, pp. 513–533, Elsevier Ltd, https://doi.org/10.1016/j.apenergy.2019.02.033.

X. Zhang et al. (2018), "A review of urban energy systems at building cluster level incorporating renewable-energy-source (RES) envelope solutions," *Applied Energy*, Vol. 230, pp. 1034–1056, Elsevier.

Y. Zhao et al. (2014), "Near-infrared harvesting transparent luminescent solar concentrators," *Advanced Optical Materials*, Vol. 2/7, pp. 606–611, Wiley Online Library.