An Investigation of the Potential of Sustainability in Collective Housing Developments

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A thesis submitted to Welsh School of Architecture, Cardiff University

for the degree of Doctor of Philosophy

June 2023

Abstract

Collective housing suggests possible advantages in energy and sustainability performance over ordinary housing. Existing research shows that collective housing communities have the benefit of stronger social connection which contributes to building a sense of community. Research also suggests that many collective housings benefit from their sustainable design concepts and strategies, primarily because of their shared spaces, resources, and skills, and therefore have a low impact on the environment. However, whether these strategies last, and can be applied to future projects, and whether sharing would produce actual savings in energy are unclear and remain under-explored. The everyday life of collective housing residents is different from ordinary housing residents in many ways. However, energy-related occupant behaviour in collective housing has not been studied in detail.

This research aims to review the definitions, development, and sustainable features of various types of collective living housing; to explore the impact of building design configurations and occupant behaviours on energy consumption in collective housing developments; to find out the sustainable strategies and main challenges in existing collective housing developments at both design and in-use stages; to investigate the energy-related occupant behaviours in private and shared spaces in collective housing; and to discuss research findings from social and environmental aspects to provide suggestions for collective housing developments aiming to achieve better living environment.

The research uses mixed methods including a literature review, computer modelling studies, case studies, and empirical field work. Firstly, a literature review of collective housing concepts, history and development, benefits and challenges, review of

existing projects, and research topics and methods, as well as the impact of energy-related occupant behaviours in buildings, helps to identify what are the areas that need to be studied in collective housing. Then, a massing study of co-housing building typology aims to investigate which building design elements have the greatest influence on building energy consumption in co-housing buildings. After that, a desk-based case study reviews three collective housing projects in different locations. It provides an in-depth understanding of the project's design process, occupant participation, and sustainability. And lastly, two UK collective housing projects are studied through fieldwork including interviews and observations to provide an understanding of the design process, sustainability practices, and energy-related occupant behaviours of collective building in detail from collected primary data.

Acknowledgements

I would like to express my deepest gratitude to all those who have contributed to the PhD journey and the completion of this study.

First and foremost, I am immensely grateful to my supervisor, Prof. Chris Tweed, for his mentorship and invaluable insights throughout the study process. His expertise, guidance, and patience have been shaping the outcomes of this study. I also would like to express my gratitude to my second supervisor Dr Gabriela Zapata-Lancaster for her encouragement and advice on research methods.

I am grateful to the faculty and staff of Cardiff University, Welsh School of Architecture, who have provided a great academic environment and countless opportunities for professional and personal growth. I would also like to express my gratitude to my annual panel reviewers throughout my study. Their valuable support, encouragement, and suggestions have provided me with fresh viewpoints.

I am also grateful to all the participants in the two field study projects. Their selfless sharing of ideas allowed me to understand the research questions in various aspects. I am also grateful to the people who helped me make connections to professionals and residents and get access to the case materials.

My gratitude also goes to all my friends, and fellow research students at Cardiff University for shaping such an inspiring, and heart-warming community. Their support and friendship have made the research life much more fulfilling.

Finally, my deepest gratitude goes to my families, for their unconditional support, understanding, and love throughout this challenging journey.

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Chapter 1 Introduction

1.1 Introduction

This chapter introduces the basic concepts of energy consumption in private and common spaces in residential buildings, which forms the background to the research topic. This chapter identified the research aims, scopes and objects, presents the outline of the thesis structure and research frame.

1.2 Research Background

1.2.1 Research context

Energy consumption is shown split into four sectors in the UK, includes industry, transport, services, and domestic. According to latest Energy Consumption in the UK repost by Department for Business, Energy and Industrial Strategy (BEIS, 2021a), domestic energy consumption accounts for about 28% of the total energy consumption in 2015, and increased to almost 32% in 2021. Reducing energy consumption in domestic sector in the UK plays an essential role in lowering total energy use, which helping to mitigate the climate crisis. Therefore, there is a need to explore how to save energy in domestic properties.

Energy consumption per capita in housing is being affected by household size and house size. Average floor area per capita shows an overall upward trend based on government data from various countries (Ellsworth-Krebs, 2020). Household size declines and the proportion of one-person household increases in recent decades, from 1980 to 2015, one-person household in the UK increases from 22% to 28%;

Finland has the highest one-person household ratio of 42% in 2015 (27% in 1980) (UNECE, 2023). Smaller households can rise consumption per capita due to construction of more homes. And the increasing of floor area per person does not contribute to improve building energy efficiency (Lorek and Spangenberg, 2019). Additionally, a research about loneliness among adults by Victor and Yang (2012) found that household size is one of the factors linked with decreased levels of loneliness.

Residential buildings with private units, as well as shared facilities and spaces, as a building type is different from ordinary dwellings for its layout, functions, and occupant behaviours. This building type includes many collective housing schemes in various of time and regions, like central-kitchen houses in the 1930s, co-housing since the 1960s, cluster apartments in 1980s, co-living since 2010s. This study focuses on discussion the sustainability of collective housing, including co-housing, co-living and sustainable communities (concepts and definitions see Chapter 2). This study explores the energy saving potential and social benefits when people live in collective housing where there are some levels of sharing in space using and facilities.

In recent years, the environmental advantage of co-housing has been discussed by researchers. Building physics, low carbon technologies, household size, occupants' behaviours, openness to sustainable technologies, and adoption of pro-environmental behaviours are some of the aspects studied by researchers. Williams (2005) agrees with Marcus and Dovey's view (1991) that the co-housing model is a sustainable alternative to other housing models, and summarises the sustainability objectives of co-housing model in two dimensions – 'well-being and affordability' and 'networks, cohesion and inclusion'. However, the sustainable aspect of the co-housing model was not fully discussed.

There have been many attempts to explore where to draw the line between private and public in residential living under different economic and social contexts. Co-housing, as a popular form of community living, was first observed in the 1960s with the aim of supporting women returning to the workplace (Vestbro and Horelli, 2012) and taking care of children with help from the community. Since then, it has continued to evolve to respond to community needs - co-housing has created communities for particular resident groups, developed to deal with loneliness in cities, solve urban housing problems, built to practice sustainability, and helped to reduce energy usage (Williams, 2005b).

Communities with common spaces and facilities have developed rapidly, influenced by the sharing economy. Inspired by the co-housing concept, a co-living apartment is a modern form of shared living growing in many urban cities. Co-living apartments usually have a higher common space ratio than co-housing developments because they have smaller room sizes. This has the potential to reduce energy use from space heating; meanwhile, residents have more choices to spend time in the building. Collective co-living models are also emerging worldwide, including The Collective (London and New York), Roam (Miami, Bali, Tokyo, San Francisco and London), Zoku (Amsterdam) (Moore, 2016), and You + (multiple cities in China). However, the main marketing focus of these models is on its social benefit, using co-living as a way to provide an alternative to conventional modern living. As the common space layout and occupants' activities are different from standard residential buildings, there is a lack of research into the energy efficiency of this building typology.

1.2.2 Sharing in housing

Humans have a long history of living together and as a community. The co-housing concept (which began in Denmark in the 1960s and entered the public consciousness in the 1980s) is an intentional community where residents have their self-contained spaces as well as common spaces, and where they come together to manage their community, share activities, and regularly eat together (UKCo-housing, 2021).

The concept of sharing in housing itself differs by scope, purpose, and types of occupants, and correspondingly leads to different challenges. Vestbro and Horelli (2010) clarified several concepts used to study housing with common spaces and shared facilities - these concepts include co-housing which they defined as housing with common spaces and shared facilities, and where regular community events are organised; collective housing is used to refer to housing that is oriented towards collaboration among its residents, and is instead focused on the collective organisation of services. Other forms of sharing in housing may be designed to a specific type of people, such as shared accommodation aimed at providing living spaces for homeless young person. The challenges of sharing in housing include restricted choice, health and well-being problems due to the living environment, parenting and family relationship issues, vulnerability, on-site management difficulties, and insecurity (Green and McCarthy, 2015). In the meantime, sharing in housing has benefits for both residents and societies, especially in the current sharing economy.

There is a good deal of ambiguity in the terminology when defining collective housing, and several concepts have been used to identify similar phenomena in the study of housing with common spaces and facilities (Vestbro and Horelli, 2012). Elements like occupant participation in different stages of design and construction, living style, organization types, and residential management are all considered in the sharing practice.

1.2.3 Human-related energy use

In the EU, energy use in residential buildings includes space heating (68%), hot water (13%), electrical appliances (12%), cooking (5%), and lighting (2%) (European Commission, 2020). Each of the above elements can be primarily influenced by occupants behaviour, and researchers point out the importance of occupant behaviour studies (Stazi, Naspi and D'Orazio, 2017; Yan *et al.*, 2017).

Occupant behaviour research in buildings can be traced back to the 1950s and 1960s, which was focused on occupants' interaction with the ventilation system and window opening (Tam, Almeida and Le, 2018). The occupants' behaviour study started growing in interest in energy use after the 1980s. Main topics include adaptive occupant behaviour, thermal comfort and indoor environment quality. Social science researchers got involved in this field and contributed to the body of knowledge as well since the 1990s (Guy and Shove, 2000).

Primary factors of occupant behaviours, which influence building energy use in domestic building include climate, occupant control, dwelling characteristics, and occupant profile (Steemers and Yun, 2009). Shove (2011) explains in a presentation that attitudes of individuals drive their behaviour. Steemers and Yun (2009) also points out that energy use is directly impacted by climate, building physics and equipment, but these in turn affect behaviour. Moreover, they suggest that to better understand, evaluate and predict building energy use it is necessary to pay attention to the occupant and behavioural aspects in building performance.

Occupant related factors are different in the co-living building model than in a typical residential building. The co-living typologies minimise the influence of the individual by designing small private spaces and enlarging common spaces.

1.3 Research Aims, Questions, Objectives and Scopes

1.3.1 Research aim

The aim of this research is to investigate different types of collective housing, to explore the sustainable features of collective housing in both design process and in-use stage, to find out the challenges in collective housing communities in the UK and to explore what lessons could be learnt from existing experiences to guide future collective housing projects.

1.3.2 Research hypothesis and research questions

Research hypothesis and research questions are composed to explore the research aim.

Research hypothesis:

- Collective housing has potential for energy savings over equivalent individual dwellings.

Research questions:

- What, if any, are the features of collective housing that affect energy consumption and energy-related behaviour of collective housing in design and in-use stages?
- What lessons can be learned from existing collective housing projects' challenges and experiences to provide sustainable guidance for future projects?

1.3.3 Research objectives

- To review the definitions, development, and sustainable features of various types of collective living housing.

- To explore the impact of building design configurations and occupant behaviours on collective housing's energy consumption.
- To identify the sustainable strategies and main challenges in existing collective housing developments in both design stage and in-use stage.
- To investigate the energy-related occupant behaviours in private and common spaces in collective housing.
- To discuss research findings from social and environmental aspects to provide suggestions for collective housing developments aiming to achieve better living environment.

1.3.4 Research scope

This research is looking at the energy-saving measures in design and in-use stage of collective housing in urban areas. The configuration of co-housing typology is tested to identify design factors that impact building energy consumption. In-use stage field studies regarding energy usage measures and energy-related occupant behaviour observations are designed to carry out on residents in each case study. Due to the restrictions imposed by the pandemic, energy usage measures were unable to carry out. Therefore, three desk-based case studies were added in order to explore energy strategies, sustainable design, and social benefits in collective housing communities.

1.4 Thesis Structure

This thesis consists of 9 chapters:

Chapter 1 consists of the research background, research aim and scope, research hypothesis and research questions, and research objectives.

Chapter 2 is a literature review of energy efficiency studies related to collective living and occupant behaviour. It starts with an overview to clarify the definition of collective housing, and analyses the reasons and influences for the development of collective living. It then discusses the benefit of collective building from social, economic and environmental perspectives. Following a section presents collective housing in different categories, the limitations of co-housing are discussed as well as the modern alternative building model, co-living.

Chapter 3 discusses occupant behaviour (OB) in residential buildings and explores how OB have an impact on building energy. In addition, the methods using to study OB are discussed as well as their limitations.

Chapter 4 covers the design of the research method and methodology, and the analytical framework. Firstly, a number of typical architecture research methods are reviewed and discussed, then it introduced the specific research methods designed for this research. Next section introduced the field study method, which includes observation and interviews. Then present the building energy calculation model development. The following section includes the research framework and building energy calculation and simulation flowchart. At the last section, the limitations of the method are discussed.

Chapter 5 contains a mass modelling of collective residential building with common spaces, which tested different design factors on the building energy use. The result shows that floor to floor height, common to private spaces ratio and window-to-wall-ratio are the top three parameters effecting mid to high collective residential building. It leads to the in-depth exploration of the role of common space in collective building community in the following chapters.

Chapter 6 presents the desk-based case studies of collective building – three co-housing and co-living projects worldwide. For each project, it starts with the basic and background information introduction, then the design and sustainable features of the project, followed by the summary and the lessons learnt of the work. The key challenges, collective project processes, community management, sustainable technologies, and improvement potentials are discussed. At the end, three themes emerged from the case studies: design process and resident participation, use of space and community events, and sustainability potential.

Chapter 7 presents the interviews and observations on two projects in the UK from Dec 2019 to March 2020. Firstly, the introduction of the field study procedure and detail information of the interviewees are presented, as well as the list of open-ended questions for interviewees. Next, by analyzing the interviews, the results and themes are generated, interpreted and discussed. Lastly, presents the outcome of field study.

Chapter 8 contains the discussion of the above research interpretations.

Chapter 9 presents the conclusions of this research, as well as limitations. The recommendations for future studies are discussed.

The field work has been disrupted during the pandemic. Research plan have been revised to accommodate changes by restructuring the thesis, adding a new chapter of desk-based case studies (Chapter 6), reducing from three field projects (original plan) to two projects (Chapter 7).

1.5 Research Method and Framework

1.5.1 Research method

This study adopts a mixed method approach which includes qualitative research and computer simulation studies. Research methods include literature review, field study, observation, open-ended interviews, critical case studies, and building computer modelling and simulation.

1.5.2 Research framework

The research framework is presented as follow (see Figure 1.1). The literature review addresses two main topics: collective housing (see Chapter 2) and occupant-related energy consumption (see Chapter 3). This is followed by the research method and methodology section, which introduces the research design and identifies research methods (see Chapter 4). Following the building mass modelling in Chapter 5, desk-based case studies of three collective community projects are reviewed and discussed in Chapter 6. Chapter 7 present the field study data and analysis. The final two chapters (8 and 9) discuss and summarise the findings, limitations and suggest future studies.

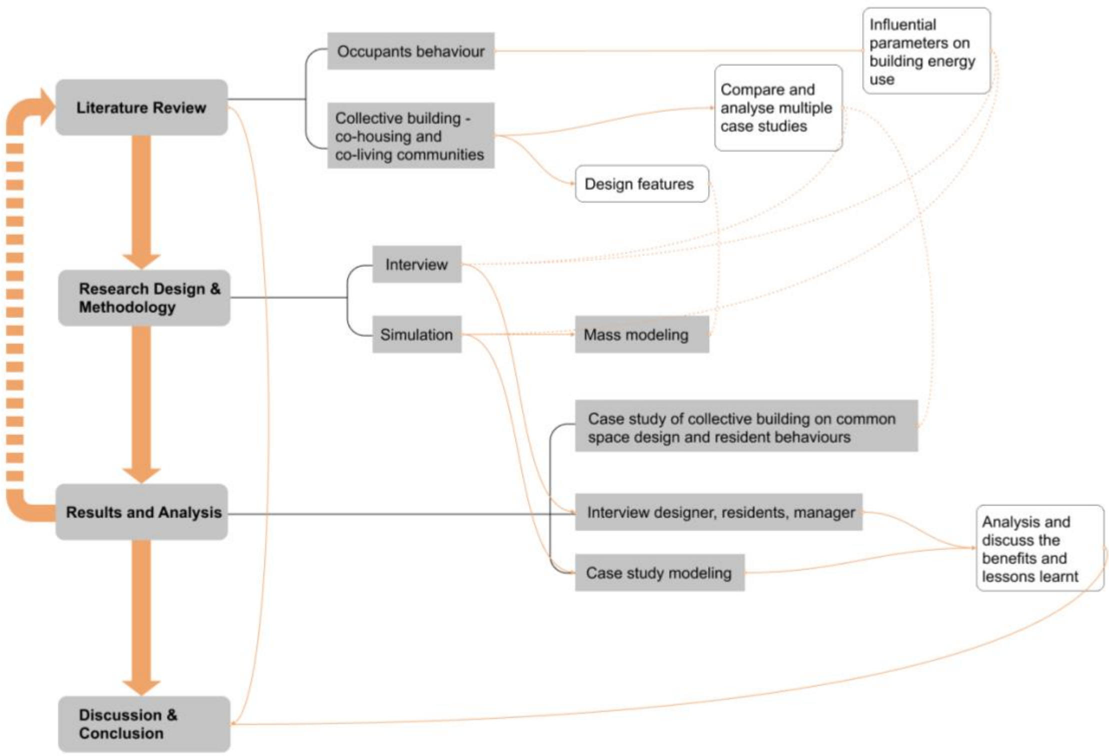


Figure 1. 1 Research Framework.

1.6 Summary

This chapter has established the background and introduced the underlying context knowledge of this research. Including research background, research aims and objects, followed by research methodology and framework.

Chapter 2 The development of different forms of collective communities

2.1 Chapter overview

This chapter reviews the literature on co-housing, co-living building development, and the existing research on community design of collective housing. Beginning with clarifying the definition and differentiation of similar terms, summarizing the typology of co-housing buildings, and exploring the private and common spaces in these building types. Followed by exploring the sharing practice in collaborative building communities and summarized the research themes and research gap in the existing co-housing studies.

2.2 Definition of key collective community concepts

2.2.1 Introduction

The concepts and definitions associated with shared facilities and alternative ways of living are varied. There is no particular standardization of the use of these related concepts among researchers. Drawing on the research of the concept and terminology by different scholars e.g. Dorit Fromm (1991), Dick Vestbro (2010), Williams (2005), Sargisson (2012), Jarvis (2015), Tummers (2016), Beck (2020), and more. The context of using related terms, co-housing, collaborative housing, collective housing, co-living, gated communities, eco-village, sustainable community are discussed in this section. Through understanding, analysing, and comparing related terms, this section aims to select appropriate conceptual definitions for this study.

The selected main collective housing definitions are presented as follow (summary of each concept see section 2.2.5):

- Co-housing defined as - ‘intentional communities, created and run by their residents. Each household has a self-contained, private home as well as shared community space. Residents come together to manage their community, share activities, and regularly eat together’.
- Co-living defined as – purpose-built and managed developments that comprising different types of private bedroom units and large amounts of communal amenity facilities and spaces.
- Collective community - the umbrella term of shared living housing types explored in this thesis. Including co-housing, co-living and sustainable community.

This section interprets co-housing from various aspects, which helps to gain insight into how co-housing is formed and defined, and better understand the strengths and weaknesses of co-housing. Firstly, co-housing concept and various definition are explored. Then, the development of co-housing and the three co-housing waves are discussed. Followed by understanding of co-housing in different countries and co-housing related organizations. Additionally, this section explores the definition of related collective living models.

2.2.2 Co-housing in context: community and sustainability

Before delving into co-housing, it is necessary to take a brief look at what is a community, how it has developed during urban development and urban design over time. As well as how sustainability in community design has evolved as people become more concerned with environmental issues.

Community is the basic unit of city life, which greatly influences on low carbon and sustainable development. Greek architect and town planner C. A. Doxiadia classified community as many levels (Constantinos A.Doxiadis, 1970) from individual to a larger scale. Community building means ‘a building which is managed by a voluntary management committee, run for public benefit, and plays host to a range of activities for a range of users’ and 4.4 million people (10% of the UK population) use community buildings every week (Marriott, 1997). The United Nations definition of community development is ‘a process where community members come together to take collective actions and generate solutions to common problems.’

People's needs for a living environment change over time. The understanding, definition and planning of community has changed accordingly as city planning concept updated. Concepts developed in the recent century. Industrial City (1917) was designed by Tony Garnier, with the background under the impact of industrial revolution increasing number of people move to cities from countryside looking for jobs. The messy and unlimited urban growth result in dirty streets, disease increase, numbers of slums and lack of green spaces in cities. Under such context, the notion of zoning was the most popular concept among early city planners at that time, including French architect and city planner Tony Garnier. He planned a town (Figure 2.1) in southeast France for about 35,000 residents. He designed the town of segregated function with a train station, a residential area and an industrial area. Garnier designed the town with energy efficiency in mind, that the town was powered by a hydroelectric station with a dam in the mountain. Meanwhile, built environment, building material and equality between people are considered in the design. One notable design concept in this design is that there is no law court or jails, no police station, and no church. Though Tony’s industrial city was never build and seems hard to put into practice, but it influenced later architects and planners, such as Le Corbusier, and was one of the most comprehensive plan ideas (Canniffe, 2010).

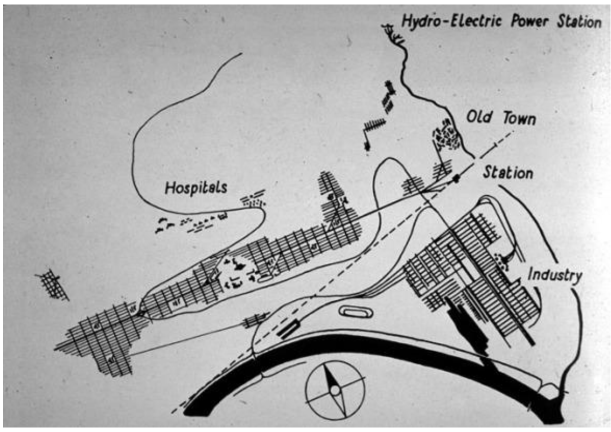


Figure 2. 1 Tony Garnier – Industrial City (1917).

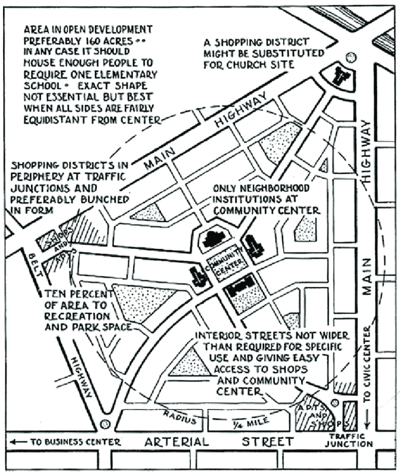


Figure 2. 2 Neighbourhood unit by Clarence Perry.

American planner Clarence Perry introduced the concept 'Neighbourhood Unit' (Figure 2.2) in 1929 as a part of the published Reginal Plan of New York. It is an early planning model for residential community in urban area, acting on the problematic overcrowded, polluted city. The physical and social dimensions of Neighbourhood Unit was shaped by several movements includes Settlement House Movement, Community Centre Movement, Garden City Movement, that bring the idea of internal streets, influence the location of school and garden in the planning, etc (Lawhon, 2009). However, Isaace and Bauer both claimed that Neighbourhood Unit was causing problems in social and public housing, and urban regeneration by executing racial and economic segregation (Brody, 2009).

New Urbanism arose in America in the early 1980s, and used the Neighbourhood Unit concept to create compact, walkable, mixed-use and diverse neighbourhoods solving post-war problems in the urban areas. It aims to promote an environmentally friendly habits by designing walkable neighbourhoods with a range of housing and functions. The environmentally sustainable metrics in New Urbanism include a walkable distance between most dwellings and the centre, encourage small scale streets for cycling and walking, assessable distance to parks and playgrounds etc. While, numbers of articles criticise New Urbanism as ‘a grand fraud’ (Marshall, 2006), and the effectiveness of New Urbanism method of mixed income developments don’t have any statistical support. Meanwhile, in the UK similar models like Sustainable Urban Neighbourhood (SUN) are emerged to embody sustainability in a more holistic way in neighbourhood design in the late 1990s (Rudlin and Falk, 1999). See more in Appendix a. Sustainable communities.

With the realization and growing needs to create better buildings for people, LEED was launched in 1993 (USGBC, 2023) by U.S. Green Building Council, and BREEAM was developed since 1990s by BRE in the UK. Later, LEED-ND (LEED Neighbourhood Design) rating system was formed to provide evidence for neighbourhood environmental design in the US in 2009 (USGBC, 2014). BREEAM Community was introduced in 2009 to assess new build and regeneration urban community development from environmental, social and economics perspectives, which covers a project’s design and planning stages (BREEAM, 2012) (Ameen, Mourshed and Li, 2015). The following categories are included in BREEAM Community: governance, social and economic wellbeing, resource and energy, land use and ecology, and transport and movement (Table 2.1).

Category	Aim	Weighting
Governance	Promotes community involvement in decisions affecting the design, construction, operation and long-term stewardship of the development.	9.3%
Social and economic wellbeing	Local economy: To create a healthy economy (employment opportunities and thriving business). Social wellbeing: To ensure a socially cohesive community. Environmental conditions: To minimise the impacts of environmental conditions on the health and wellbeing of occupants.	14.8% 17.1% 10.8%
Resource and energy	Addresses the sustainable use of natural resources and the reduction of carbon emissions.	21.6%
Land use and ecology	Encourages sustainable land use and ecological enhancement.	12.6%
Transport and movement	Addresses the design and provision of transport and movement infrastructure to encourage the use of sustainable modes of transport.	13.8%

Table 2. 1 BREEAM Communities category aims and weighting (BREEAM, 2012).

2.2.3 Interpretations of co-housing

There are numerous ways of defining co-housing, which have been interpreted and conceptualised differently at different times and in different regions (Beck, 2020). This section first explores the definitions and key features of co-housing at different times and countries. Followed with a discussion on the three waves of co-housing development. Although there are differences in the definitions and characteristics of these co-housing developments, they also share common features which is summarized in this section. What is the definition for co-housing using in this study and its reason are present at the end of this section.

2.2.3.1 Concept and various definitions of co-housing

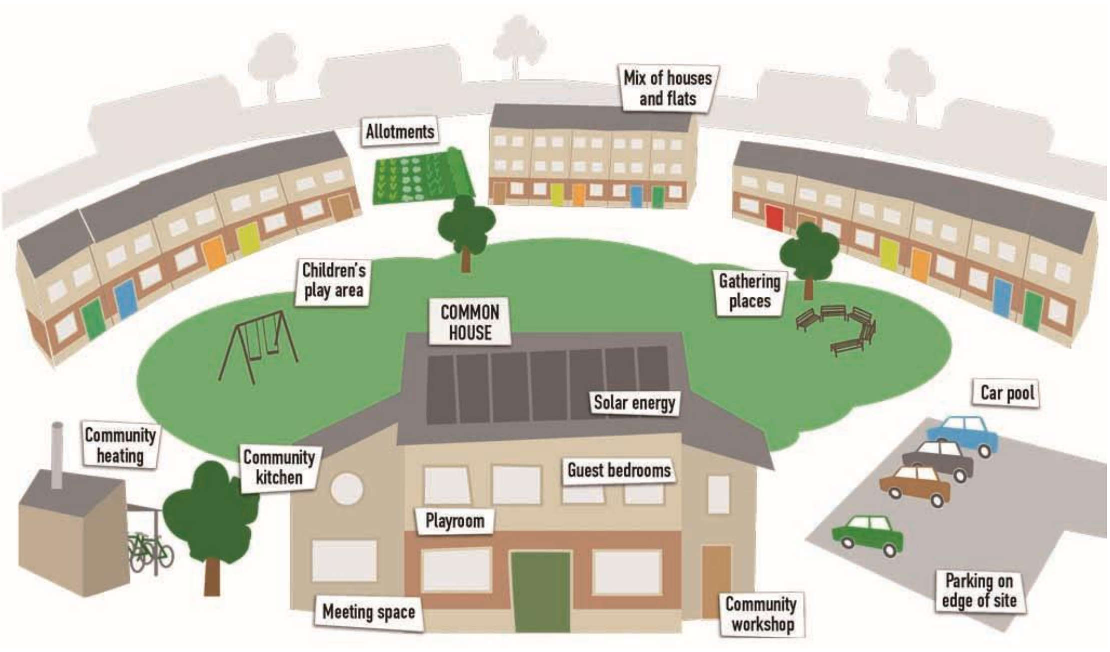


Figure 2. 3 Co-housing community (source: UK Co-housing Network 2018a)

Co-housing (Figure 2.3), is a co-design community where residents have the intention of communal living. Jarvis (2015) pointed out that the active ‘intention’ is the key to achieve the coordination and common purpose in co-housing communities. It is the fastest growing housing typology among different kinds of community types (Williams, 2008). Moreover, co-housing is considered as a housing typology to bring in vivid social network and positive environment (Krokfors, 2010; Vestbro, 2010), where tend to be more open for the neighbourhood to interact with each other (Fromm, 2000). For example, Bristol Village Co-housing describe their value as ‘We share resources, meals, community work and decision-making. We are grateful for the opportunity to be good stewards of our little corner of Vermont, and a positive model for sustainable living.’ (Bristol Village Co-housing, 2018) and LILAC Co-housing describes ‘LILAC isn’t just about building houses, it’s about building community. We want all residents to feel they are part of a strong, flourishing neighbourhood where they can directly participate and where their views matter.' (LILAC, 2018).

Concept

Co-housing concept could be tracked back to the utopian communal model for societies from Thomas More's *Utopia* (1516) or the building type *phalanstère* for a self-contained utopian community in early 19th century by Charles Fourier (Krokfors, 2010). Or inspired by even earlier works – *The Republic* by Plato in around 380 BC.

The concept of co-housing holds lots of meanings with interpretations from both people in academics and publics (Krokfors, 2010). Vestbo (2010) point out that co-housing could be explained from three aspects – collaborative, communal and collective. Collaborative mainly refers to the housing objectives that are collaboration among members; communal is explained as the houses were designed to form a community; collective emphasis on the collective organization of service in the community (Vestbro, 2010).

Definition

Co-housing was original from Denmark in 1960s, however, the concept of co-housing is an old idea as a contemporary approach to conventional living pattern (McCamant, Durett and Hertzman, 1994).

Co-housing is described differently and interpreted in many ways because of its vague boundaries (Chiodelli and Baglione, 2014). Co-housing is generally defined as housing with common spaces and shared facilities (Krokfors, 2010). Zhang (2011) described co-housing in more detailed as 'a private initiative to build neighbourhoods with strong resident participation in all stages, and with parallel goals of fostering environmental stewardship and social cohesion at the domestic level'. Priest (2015) identified co-housing community as an intentional grouping of typically between 8 and 40 households, created and run by its residents. UK Co-housing Network describes co-housing communities are created and operated by their residents, in which each household has a private home as well as common community spaces.

There is some scope for co-housing communities described by researchers: co-housing communities do not share income or working on a community owned business together, therefore co-housing is not a commune; also a commune is a communal living place without personal spaces, which co-housing has both common area and individual space; Generally, charismatic leaders and common ideologies are not part of co-housing (ScottHanson, 2005a; Krokfors, 2010). Cooperative housing is a term can be confusing with co-housing but cannot consider as co-housing, as cooperative housing refers to cooperative housing ownership which does not cover the idea of common space and shared facilities (Krokfors, 2010). American architect Grace Kim defined Co-housing as an ‘intentional neighbourhood’, which people are familiar with and take care of each other.

The definition of co-housing various due to the concept itself could refers to several layers of meaning, and different researchers emphasize co-housing features from various perspectives for different research focus. The multiple layers of definition and focus of co-housing characteristics exist among different countries as well (see – 2.2.3.3 co-housing in different countries). Furthermore, co-housing community may called differently from country to country, for instance, ‘collective housing’ was used as co-housing in Japan.

Characteristics

There are six fundamental characteristics in a co-housing model, which were summarised during the second wave (see co-housing developing waves in 2.2.3.2) co-housing development in the USA (Lietaert, 2010; The Co-housing Association of the United States, 2017). They are listed as follow with a detailed explanation illustrated (*Table 2.2*).

Characteristics	Explains
Participatory Process	Residents normally would take part from the design stage of the co-housing community. They are the drivers of the project (with help from professionals – lawyers, architects, planners, etc.), and this requires numbers of weekly meetings.
Neighbourhood Design	Apart from the individual house itself, the design of gardens, parking lot, green spaces, paths and common spaces etc, are the core aspect that connect residents together and encourage the sense of community.
Shared Facilities	Shared facilities and activities are considered as the most essential part of co-housing community.
Resident Management	Residents manage and complete most of the maintaining of the community themselves.
Non-Hierarchical Structure and Decision-Making	Consensus and voting are the primary means of decision-making. Residents also take responsibilities to the community according to their abilities, skills, desire and passion.
No Shared Community Economy	Co-housing is not a commune, where residents do not rely on the community to earn income.

Table 2. 2 Co-housing characteristics.

2.2.3.2 Three co-housing waves

Co-housing model arises in stages and did not been created overnight. Lietaert (2010) pointed out co-housing model can be viewed as a ‘grassroots and innovative answer to very specific problems that many citizens are increasingly facing’, especially in northern western society. With more people settling in urban areas, co-housing provides a solution for people to live in a ‘village-like community’ in urban context.

Co-housing development in different times and countries and their social background – see Krokfors (2010) and Williams (2008). Since 1990s, co-housing emerged in the US as an innovative housing form. These are the three waves in the history of co-housing development (Table 2.3).

	First Wave	**Second Wave**	**Third Wave**
Region	Scandinavian	North America	Pacific Rim
Typical countries	Denmark, Sweden, Netherlands	USA, Canada	Australia, New Zealand, Japan, China, Korea
Time span	1960s – 1970s	1980s – 1990s	1990s - now
Housing typology	Mainly new build and some retrofit	Both new build and retrofit	Both new build and retrofit
Cole value and	Social aspect, raise kids together, women release from work, Gender	Need of community	Environmental design, living as a community, affordable

motivations	equality		community;
Tenure ownership	Rented and private ownership	Owner occupation	Rented and private ownership
Government and other support	Mainly top-down; Social housing by non-profit organisations; political and financial support in Denmark;	Both top-down and bottom-up; Privately developed; support from professionals;	Mainly bottom-up; Privately developed; support from professionals;

Table 2. 3 Co-housing development stages.

2.2.3.3 Co-housing in different countries

In the UK, co-housing started to grown from the late 1990s. Over the past few decades, there are 19 completed co-housing communities (about 250 total units) and over 60 co-housing groups are development their communities. UK co-housing projects are middle sized that range from 10 – 40 households. There are various community type in terms of the residents, for instance, the major group type is intergeneration mixed communities where single people, couples, core families and seniors living in together; also there are other kinds of communities for certain groups of people e.g. for women only, LGBT groups, vegetarian etc (UK Co-housing Network, 2018b).

The co-housing community model is originally emerged in Denmark in the 1960s. Danish architect Jan Gudmand-Hoyer first proposed the co-housing concept, however he failed in managing a co-housing community to live with friends in 1964. With his continues writing about the concept to the public and an article by Bodil Graae – 'Children Should Have 100 Parents', in 1972, the first co-housing community in Denmark and in the world was completed. It is located near Copenhagen for 27 families (UK Co-housing Network, 2018c). From the first co-housing community till now, over 300 projects have been built in Denmark. Over 50,000 people are living in co-housing communities, which forms 1% of the Denmark population. Co-housing association in Denmark is called - Bofællesskab.dk (Denmark Co-housing Network, 2018). Danish-based charitable association Gaia Trust was founded in 1987, which provide support to sustainable future societies and work closely with ecovillage.

In Sweden, the idea of equally between genders and the feminist movement played an important role in the development of co-housing (UK Co-housing Network, 2017). The Swedish national association Co-housing Now – Kollektivhus NU – established in 1981, is working on collaborative housing. Currently there are 42 co-housing units and several projects ongoing (Co-housing Now, 2017). Unlike typical Danish co-housing style, co-housing in Sweden are dominantly medium and high rise apartment blocks. For example, the common spaces in Casa Malta (built in 2012 with 61 houshoulds) were located on the first and top floor; in Stacken (built in 1980 with 30 units), shared facilities were located in the ground and fifth floor.

In Netherlands, the idea of co-housing (centraal wonen) arose in the late 60s. Over half of the co-housing projects are formed as cluster, where the common house (equipped with shared facilities: living-room, kitchen, laundry, garden etc.) was surrounded by 4 to 8 houses. And a co-housing community was composed by several clusters (Figure 2.4 left) and have about 30 to 70 households. Additionally, each co-housing community had a common building. The idea of senior co-housing appeared in the 80s, in order to acquire the need of the growing population of people over 50. And senior co-housing received support from government, as an alternative way to reduce care cost.

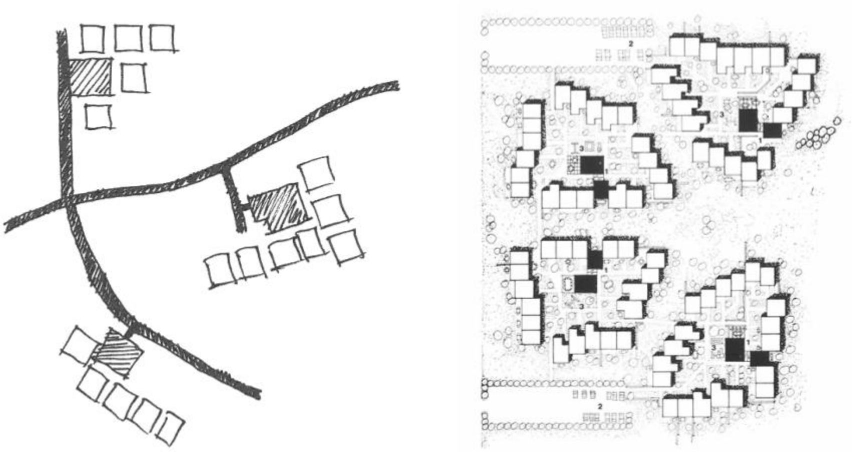


Figure 2. 4 Left: Cluster site plan of co-housing in Netherlands. Right: Bondebjerget Four in One in Norway (1982)

Co-housing model was brought to America by Katie McCamant and Chuck Durrett. They published their first book about co-housing in 1998 – Co-housing: A Contemporary Approach to Housing Ourselves. Unlike co-housing projects mostly developed as social housing by non-profit organisations in Scandinavia countries; in American, co-housing projects are predominantly privately organized and developed by residents themselves. As co-housing projects were appeared in many cities across the country, the architectural character of co-housing communities are diverse. Some projects adopted the local style – the South West (Figure 2.5 top right); the North West (Figure 2.5 top left); and recent years project are installing low carbon technologies (Figure 2.5 bottom). Different development patterns in America cause the diversity of architectural form, shape, community scale and building characters of co-housing communities, and America co-housing are normally smaller than the standards.

Figure 2. 5 top: Ashland Co-housing and Stone Curves Co-housing; bottom: Hundrefold Farm Cohouisng (source: (US Cohouisng, 2018)).

First co-housing project was built in Australia in 1991, Cascade Co-housing, however, the co-housing develop in Australia is slow. As communal living in the country has a long history and normally considered as a lifestyle choices that outside of mainstream. The first co-housing project in New Zealand, Earthsong Eco-Neighbourhood, developed its stage one between 1995 to 2002.

Co-housing is called Collective Housing in Japan, and the first collective housing complex is called Kankanmori located in Nippori, Tokyo. Main publication about Co-housing in Japan include -'Future Living: Collective Housing in Japan'. In Korea, the co-housing idea is mainly popular among academic. In Hong Kong and Taiwan, there are a form of co-living apartment community became attractive among young generation, that mainly operated by renting and living in a community in big cities.

For example, You+ in mainland China, 9 Floor Co-living Apartment in Taiwan and Tai Tung Co-housing in Hong Kong. This form of city apartment could be a future trend for young people as long as its affordable and sustainable.

In the third wave of co-housing development (see 2.2.3.2), there are some co-housing projects do not reflect all the fundamental characteristics. They do not design the neighbourhood from the beginning, but adopt the core value of co-housing community and build up the intentional living afterwards (e.g. 9 Floor Co-living Apartment in Taiwan, see more in Chapter 6). These type of ‘Co-housing’ community is hardly considered as co-housing, could be found in Hong Kong, Shanghai, Taiwan etc. It is mainly shaped in urban area especially metropolis where life pace is much faster. The major residents of this kind of co-living communities are young generations, who coming from other places and working in the city. As forming as an intentional community, apart from gaining family like living experience, their energy use pattern would be different from other groups of young people who rent apartments in the city. Therefore, how their behaviour influences the energy demand, what kind of apartment shape and size work best for this group of people in terms of minimum energy consumption, are the questions worth considering.

Co-housing is the word that widely using in English-speaking world describing housing with common spaces and shared facilities. Danish researchers use the word bofællesskab (meaning living community) and translated by McCamant and Durrett as co-housing using in the US. Vestbro summarized definition of co-housing from networks in US, UK and Canada in 2010: “the US Co-housing Network defines co-housing as ‘a type of collaborative housing in which residents actively participate in the design and operation of their own neighbourhoods’, Canadian co-housing network describes co-housing as ‘neighbourhoods that combine the autonomy of private dwellings with the advantages of shared resources and community living’”.

2.2.4 Other collective community concepts

2.2.4.1 Collaborative Housing

Collaborative housing is considered encompasses a wider range of building and community types than co-housing. In a book that introducing many new housing experiments to the US, Fromm (1991) views collaborative housing as different types of housing with shared facilities. These include co-housing in Denmark, collaborative housing in Netherland and Sweden. Collaborative housing has similar elements with co-housing, it emphasises on social contact as well as physical contact (design both private and shared facilities). Collaborative housing has various ways of resident management, some communities have a board of directors, some communities are non-hierarchical managed.

A definition was presented in a workshop from International Collaborative Housing Conference (2010) by 21 participants from 13 countries. They define collaborative housing from three aspects: physical setting, organization and community intention. Collaborative housing should have shared facilities and separate private households with private kitchen and bath, as well as design with focus on social contact. They have shared community vision, but live inclusively and emphasises less the individual consumption of resources. There are informal exchange of services among residents, regular gatherings and separate household economies, and no hierarchy on decision making. Additionally, they also point out that the term collaborative housing could be used more inclusively and ‘does not have to include complete resident management, strong participation in the development process, or dining together’.

In Lang, Carriou and Czischke's (2020) systematic review of collaborative housing research, authors pointed out that in recent years the conceptualization of collaborative housing was studied as an interdisciplinary research domain. From analysing 195 peer-reviewed paper, they expanded Fromm's collaborative housing definition and grouped five themes to be seen as cornerstones of collaborative housing research: socio- demographic, collaboration, motivations, effects and context.

2.2.4.2 Collective housing

When launched in 1930s in Sweden, the concept of collective housing (*kollektivhus* in Swedish) was to reduce women's housework load, therefore, they could still remain in the employment market when they get married and had children. Some early *kollektivhus* developments (e.g. YK-huest co-housing development in Stockholm) was designed with food lifts from the central kitchen. The focus of collective housing at the time was to provide a rational organisation rather than form community.

In 1980s, the term and concept of *kollektivhus* continues, however, collective housing focusing more on the sense of community and interaction of residents. In Swedish context, collective housing doesn't include residents from a special category, which distinguish collective housing from student halls, buildings for disable people, residential buildings for elderly and any groups of residents with special needs (Palm Lindén, 1992).

Now, collective housing is used to emphasise the collective organization of services in housing (Vestbro, 2010). This term is widely used in Japan for communities with shared facilities, private household.

2.2.4.3 Co-living

Co-living development

As the rapid technology development and changing in cities and urban infrastructure in recent years, people's living condition, habits and perspectives advanced correspondingly. Driven by the idea of living more sustainably and recognised the benefits of sharing, people are trying to create better forms of building designs both in working and living spaces. Therefore, co-working and co-living ideas are emerged and numbers of buildings and communities worldwide are planned and regenerated with this idea in mind.

Offices trying to create more diverse types of working environment to fit contemporary working need that didn't exist previously. Therefore, building and interior design emerges new functions and styles, e.g. sound proof room for skype meeting, transparent door and party walls, cells for private and focus, etc. Usually, big companies are capable to afford the build and maintain good working environment. Small companies and enterprise are usually sacrifice better work environment to increase profits, as well as freelance individuals which increased in number currently. To create better and cheaper working spaces for freelance, small companies, start-ups, co-working concept was emerged. It provide 'hot-desks' and working spaces for different groups to share, and social spaces and facilities to enhance group connection (Ziv Nalajima-Magen, 2018). Started in 2005 in San Francisco, becoming popular in metropolis in Europe and Asia countries and many examples could be found in China, Japan, France, UK, etc (Fost, 2005). Depends on cultural background, some are new build or retrofitted office building, some are designed to attached with residential building or within a community. From then on, discussions on the typology, working efficiency, collaborative capability in co-working spaces starts. Co-working spaces are categorized into two types, convenience sharing and community building (Capdevila, 2015). Castilho et al. (2017) conducted an exploratory research by interviewing 14 wo-working spaces in six Asia countries to investigate how a certain type of co-working space suits a company's comfortable level of collaboration capability, and to contribute to provide support to companies on choosing co-working spaces.

Concept

The concept of co-living has become increasingly popular in large cities over the past few years, especially for young professionals. A typical co-living project may include a small rental room, a wide range of common areas, an organised management team, modern décor, a vibrant community atmosphere and a diverse range of community activities. Some describe co-living buildings as making a neighbourhood in a building, where residents can eat at restaurants, go to events within a group, rest in a coffee shop or reading in a library (Semuels, 2018). Prescott (2020) described co-living as 'purpose-built and managed developments that include a combination of personal and shared amenity space'. Other researchers described co-living as 'for-profit, intentional, purpose-driven, privately managed and delivered shared housing, which emerged in large cities for young professional' (Bergan, Gorman-Murray and Power, 2020); and 'a form of housing generally comprising studio bedroom units and large amounts of high-quality communal amenity space such as gyms, co-working spaces, resident lounges and cinemas' (Savills, 2022). This study focuses on exploring co-living's architectural and build environment features. Therefore, based on the above researcher's definition, co-living in this study is defined as purpose-built and managed developments that comprising different types of private bedroom units and large amounts of communal amenity facilities and spaces.

It may seem that co-living fits in well with the current trend of the sharing economy. In fact, co-living is facing a number of criticisms, such as the cut down of private room spaces and the fact that it is not truly affordable housing. Bergan, Gorman-Murray and Power (2020) support the view that co-living is not truly affordable housing and pointed out that co-living may price over market rent.

The way people live also developed over times. 'Share house' is never a new term in the many areas of the world, however, the meaning and the level of ‘sharing’ is always changing along with time and depending on the location. Co-living is a concept emerging from the co-housing approach and absorbing the contemporary understanding of sharing. It sharing some common concept with co-housing, but at the same time, taking a step forward and becomes more adaptable in the changing world.

Different from co-housing development process, co-living community don’t require resident involve before they move in. It focuses on create a ‘family liked’ energetic community atmosphere by a management team. Examples can be found in many areas, like The Collective Old Oak in London, 9-floor in Taiwan, You+ and Port Apartment in many cities in China. Apart from private spaces (studios, 1-3 beds apartments), shared spaces and facilities includes – living essentials, entertainment facilities, guest hosting areas, fitness facilities, depending on each project, they might have additional facilities. Management team on site would organize and host different kinds and themes activities\events, like workshops, outdoor activities, tutorial, seminar, experience and goods share, crafts making, etc.

Here compares some features of co-housing and co-living community (Table 2.4):

	Co-housing	**Co-living**
Location	A mix of urban and rural areas;	Mainly urban areas;
Scale	10-40 people in the UK examples, bigger practices could be find in Europe;	Larger scale than co-housing, could have hundreds of residents;
Building type	Clusters of low-rise building, high-rise building, terraced, etc;	High-rise buildings and clusters;

Residents	Intergenerational, senior, certain group (LGBT, vegetarian, etc);	Mostly young people, or relatively energetic individuals;
Development	Intentional – residents are involved from forming the group, approach to architects, building contractors, etc;	Building are developed and managed;

Table 2. 4 Compare features of co-housing and co-living.

2.2.5 Term definition using in this study

Different definitions to the terms:

Term	Definition	Reference
Co-housing	'housing with common spaces and shared facilities' (widely using in English-speaking world, Austria, Belgium, Italy and Czech Republic)	Vestbro (2010)
	Is a type of collective housing community with no shared economy or income pooling, has individual homes, shared facilities and shaped through participatory processes.	Jarvis (2011)
	'independent from speculative developments and more based on the concept of sharing (material and immaterial) to create a community lifestyle inside and a network of relationships with the wider neighbourhood	Ruiu (2014)

	(outside)’.	
	‘intentional communities, created and run by their residents. Each household has a self-contained, private home as well as shared community space. Residents come together to manage their community, share activities, and regularly eat together’	UK Co-housing Network
Collaborative housing	Stands for various types of housing models with private and common house, and shared facilities, which includes co-housing.	Fromm (1991)
	‘housing that is oriented towards collaboration among residents’	Vestbro (2010)
	‘it at least partly integrates a range of smaller housing fields that were traditionally studied separately, such as co-operatives, light housing, eco-villages and intentional communities’.	Lang, Carriou and Czischke (2020)
Communal housing	‘is that people who are not necessarily related by family or marriage share residence in a more or less intimately organized way, with both communal spaces for social interaction as well as private areas’.	Törnqvist (2019)
Collective housing	‘housing for non-selected categories of people who eat or cook together in communal rooms connected to the private apartments through indoor communication’	Vestbro (1992)

Cooperative housing	cooperative ownership of housing and homeownership remains in the cooperative rather than the residents.	Baiges, Ferreri and Vidal (2019)
Co-living	'is for-profit, intentional, purpose-driven, privately managed and delivered shared housing', which emerged in large cities for young professional'	Bergan, Gorman-Murray and Power (2020)
	'purpose-built and managed developments that include a combination of personal and shared amenity space'	Prescott (2020)
	'is a form of housing generally comprising studio bedroom units and large amounts of high-quality communal amenity space such as gyms, co-working spaces, resident lounges and cinemas'.	Savills (2022)

Table 2. 5 Definitions of similar terms.

The relevant terms and concepts are analysed and a diagram of the interrelationship of the relevant concepts is drawn here (Figure 2.6). Intentional community is a broader and wider concept. It usually used to describe ways of living and working in a way of community. Collaborative housing and collective housing are similar concepts, with slightly different focus – the former emphasis on the collaboration between residents while the latter emphasis on the collective organization of service in the housing. They are both broader concepts than ecovillage, co-housing and co-living.

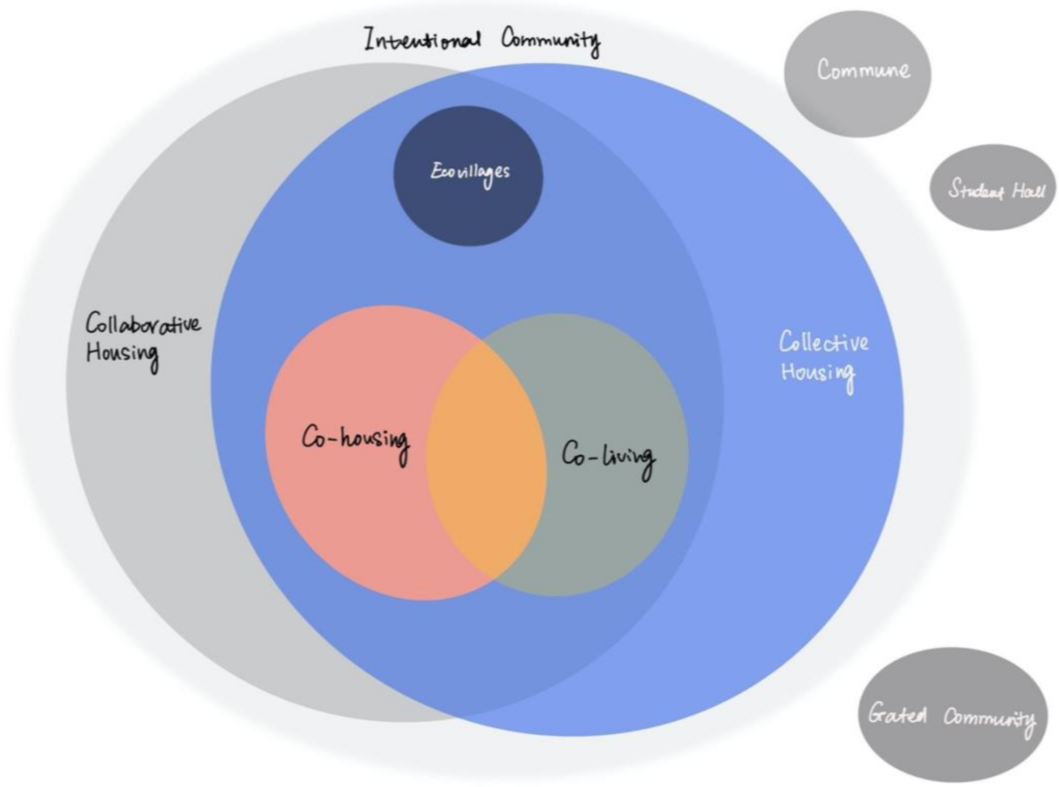


Figure 2. 6 Relationship of similar concepts.

Later years, the concept of co-housing has changed over time. Both US and UK co-housing networks set a broader boundary to the concept. The Co-housing Association of America defines co-housing as ‘a community designed to foster connection. Physical spaces allow neighbours to easily interact with others just outside private homes. Common areas including kitchen, dining space and gardens bring people together. Collaborative decision-making builds relationships’ (2021). The UK Co-housing Network defines co-housing as ‘intentional communities, created and run by their residents. Each household has a self-contained, private home as well as shared community space. Residents come together to manage their community, share activities, and regularly eat together’. It also lists five primary principals forms the basis of co-housing community, which are co-housing is co-designed with intentional community, includes both private and shared facilities, has appropriate size and scale for the support of community dynamics, residents managed in a non-hierarchical way, is part of the wider community.

There is no agreed definition of ‘co-housing’ and controversies exist among researchers about what should or should not be included in the co-housing definition. For example, Vestbro (2010) disagreed with Meltzer’s co-housing definition on includes non-hierarchical structure.

The UK Co-housing Network’s definition and principles will be used in this study, because it describes the relationship between resident and the community, and the inclusiveness of the community. However, one of the principles on the community size and scale will not necessarily always apply if more innovative co-housing model appears.

2.2.6 Scope and focuses

The main areas are going to be discussed in this study are co-housing, co-living and sustainable community building types. Because they are both spreading across the world and becoming welcomed by the public. Moreover, the common spaces and shared facilities are the main characters that distinguish them from other building types. Collective housing will be used as an umbrella term to represent three types of housing models: co-housing, co-living and sustainable community.

2.3 Broader discussion of collective living housing

2.3.1 Benefits and challenges

Co-housing as a housing typology are under discussion in recent decades. Its influences are noticed from individual, society and environmental level, and its benefits and challenges are listed as follow (ScottHanson, 2005b; Abraham and Grange, 2006; Lietaert, 2010; Marckmann, Gram-Hanssen and Christensen, 2012;

Wang, Hadjri and Huang, 2017):

	Benefits	**Challenges**
For Individuals	opportunities for more social interaction; feeling of fulfil by doing contribution to the community; providing a diverse and healthy environment for kids to grown up; lower living costs; saving time by shared dinner, travel time (more on site activities) etc.; benefit for seniors living in a intergeneration community;	stay motivated in the whole and long process; give space for public use; communication and living with a group of people; privacy; long time span to complete the project;
For Society	safe and supportive living environment; resident participation; diverse and intergenerational community provide a diversity experience for both young and old;	decision making sometime could be difficult; balance of private and public spaces; lack of support in current planning, financial and institutional infrastructures
For	saving energy by sharing	large variations among individual house in co-housing

Environment	sources; reuse, recycle, reduce in a community level is more efficient; preserve green space by build higher density housing; encourage residents to make contribution to the surroundings;	community; argument on co-housing community's sustainable potential; the ambiguous results of their measured environmental performance;

Table 2. 6 Benefits and challenges of co-housing house model.

Co-housing shows more social connection because it's formed as an intensive community. 'Intentional community is normally related to a situation where groups pf mostly unrelated people live together dedicated by intent to a specific common value or goal' (Chatterton, 2015a).

2.3.2 Space ownership and sharing

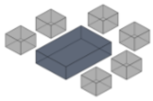
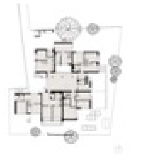
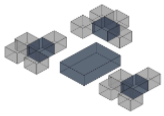
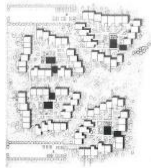
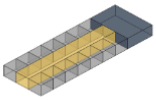
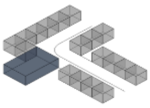
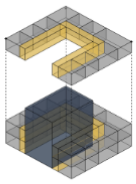
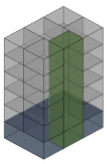
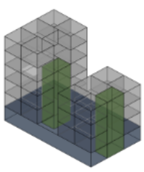
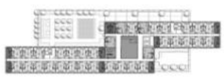
Informal sharing can be found in co-housing communities, where the community would have a list of items and lenders for members to reference when they need to borrow or consider buying additional items. Small items like gardening tools, building maintenance, cleaning tools, cooking items, outdoor items etc. Meltzer (2005) researched the change of residents' owning items before and after they move into co-housing community, which finds out freezers, dryers and washers reduce by around 25%, and lawn mowers reduced significantly by 75%.

'Sharing' is the core concept in these developments and can be seen in different practices. This concept can be applied in many aspects, sharing weekly meals, sharing tools and materials, sharing the common rooms, sharing opinions on community-related issues, and even sharing skills and network in some co-living communities. Sharing practice has the potential to reduce consumption and boost collective action among residents. Lietaert (2010) pointed out that occupants' daily consumption habits can be affected by living in co-housing community, which help residents save money, form individual contacts and reduce environmental footprint. To be more specific, Williams (2003) researched resource savings made living in co-housing in the US and UK shows that savings made in living in co-housing model by pooling of goods and equipment are 31% in spaces, 57% in electricity and 8% in goods savings on average. However, the saving potential of sharing practice may vary due to the average housing size differences in different countries. Co-living model echo to sustainable living through the communal sharing of assets, such as appliances, furnishings, transport and even food. Affordability is another attraction of co-living model, where residents can save around 40% on rent. However, there are limited in-depth researches on how co-living model performs on energy saving, community support and space can be found in the current literature.

Common spaces are designed in all collective communities. However, the type of function rooms and roles of using might be different from one to another.

2.3.3 Collective housing typology

Collective housing building types are listed as follow (Table 2.7). The UK co-housing communities are mostly low-rise and various in site layout, depending on the community size. Sustainable community and co-living developments are usually high-rise buildings, and the size of co-living development units has gradually increased in recent years (JLL, 2019).

Collective Housing Building Types		Layout	Design	Example		
				Project & Location	Site Plan (not to scale)	Community & Residents
Low-rise building	Central hall		In one building, common spaces surrounded by private homes.	Thundercliff Grange, Sheffield		Retrofit co-houing.
	Circel		Land with circler site plan, middle court, and common spaces in the middle.	Copper Lane Cohousing, London		Small to middle size cohousing community*. Common house on the ground floor.
	Cluster		Residents' houses are arranged in groups, forming clusters around the common house.	Bondebjerget, Odense, Denmark		The private houses form clusters around the common houses.
	Corridor system		In one building, common spaces located at one side or in the middle. Private homes accessed through corridor.	CoFlats Lansdown, Stroud		Small size church retrofit cohousing community. Common room at the end of corridor.
	Street system		Common house and private homes located on both side of a community road.	Springhill, Stroud		Combination of circle and street layout.
High-rise building	Yard		This building type is found in most of the coliving projects, as well as some Scandinavian cohousing communities. The specific type of yard, single staircase, or multiple staircase, depending on the location and functions of common facilities, as well as the scale of the scheme.	Treehouse, Seoul		76 studio and lofts with common area and internal garden in the middle.
	Single or multiple staircase system	 		The Collective Old Oak, London		550 units with common spaces on the ground floor and common kitchen on each floor.

* Typical co-housing neighbourhood, 10-40 homes (UKCohousing, 2021)

Table adapted from Field (2004) and Vestbro and Horelli (2012).

Table 2. 7 Collective housing building types.

Guinther (2008) categorized co-housing community into four typologies: traditional co-housing, retrofit co-housing, urban infill co-housing, and eco-villages. The traditional co-housing are referred to Danish co-housing form. Retrofit co-housing is a concern for urban settlement that start with a few existing homes in an block and then figure out an innovative idea to adapt the houses, gardens, yards, roads to make them pedestrian friendly and more community-liked. Urban infill co-housing projects are mostly in high density urban area and eco-villages are based in rural area. Moreover, co-housing community could be categorized by residents character, community site plan etc.

2.3.3.1 Residents group

Co-housing communities are usually formed by a group of people with intention to a common goal. The intergeneration is the most common type of residents of co-housing communities, where people of all age groups living together. Benefits like organizational support for relationship and partnership (Zeldin *et al.*, 2005), invoke powerful communication and social connect for people who participate and also generate community improvements to develop a community identity (Kaplan, 1997). Furthermore, there is an increasing interests of people share common interests, for instance, woman only, vegan, vegetarian and LGBT etc. Older Women's Co-housing Community (OWCH) is the first and only woman only co-housing community in the UK (see Figure 2.7.). However, these type of co-housing projects are mainly in developing stage at the moment.

Figure 2. 7 Older Women's Co-housing Community (OWCH) at High Barnet (source: (OWCH, 2018))

2.3.3.2 Site plan

There are four basic site plan of co-housing community model according to McCamant and Durrett during their practice in America from 80s (Figure 2.8).

a) There is a pedestrian street in between two lines of residents. For example, the Trudeslund Community (1981) (Figure 2.9 right). This more 'streets' liked community layout with the common house in the middle, provide a gathering spot and high level of privacy;

b) A courtyard is surrounded by separate houses. For example, Mejdal 2 project in Denmatk built in 1985 (Figure 2.9 left)

c) This is a combination of pedestrian street and a courtyard where provides an activity node.

d) Houses were connected with skylight atrium. For example, Jystrup Saccaerket (McCamant and Durrett, 1988) in Denmark built in 1984 (Figure 2.10). People are easier to connect and communicate with each other when living in these site plan, and the houses are built more compact than other site form. From an energy efficiency perspective, this layout has the potential to achieve low carbon living easier than other form, which built separately and demand more energy to heat/cool the building themselves.

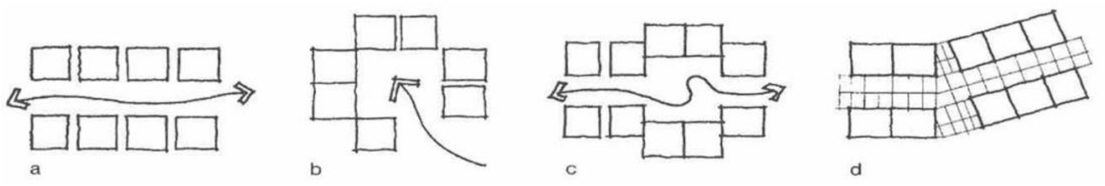


Figure 2. 8 Four generic co-housing site plan by McCamant & Durrett (source: (Garham Meltzer, 2005a)*)*

Figure 2. 9 Left: Mejdal 2; Right: the Trudeslund Community

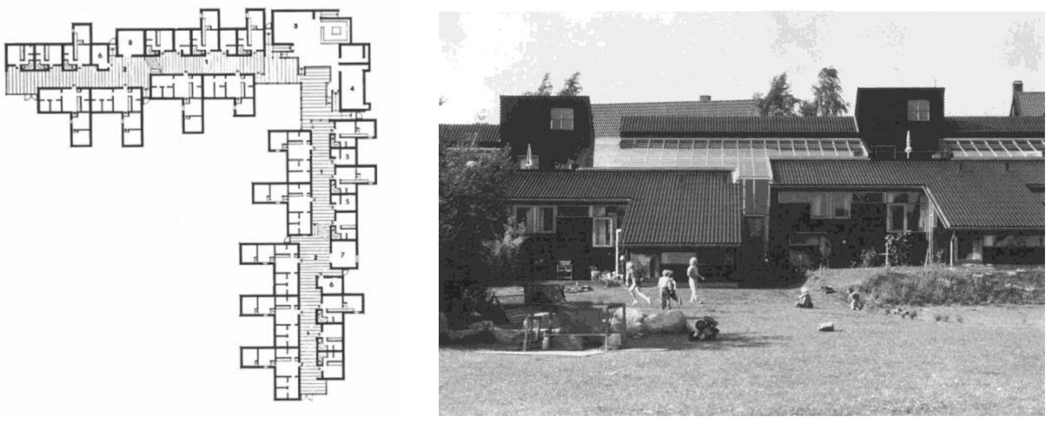


Figure 2. 10 Jystrup Savvaerket in Denmark.

Apart from the site plan, the location and the organization of the common house is another aspect to consider about co-housing typology. For low rise co-housing communities, common houses can be divided into two type – separate (Figure 2.11 left) and detached (Figure 2.11 right). While if the community size is large and the house is multiple storeys, then there could have more than one common house – there could be a main common house and several smaller ones in each level (Figure 2.12 right (Korpela, 2012)).

Figure 2. 11 Common house location in co-housing community. (Left: Marsh Commons Co-housing; Right: Swan's Market Co-housing)

Figure 2. 12 Common house location in co-housing community. (Left: Songaia Co-housing; Right: Casa Malta)

The energy demand of each type of co-housing community could be different, and due to the residents' group variety their building energy performance as a community vary as well. These questions related with community typology are worth research on - For a certain community size, would the centralized common house consume more than separated common house or vice versa? Will site plan influence occupants' activities in some extent and lead to higher/lower energy consumption in the community and how?

2.3.4 Collective housing size and space

Over time, an extensive literature has developed on what is the right resident size for a community. Anthropological evidence by Wallace (1952) shows that the maximum number of human group to reach basic decisions on public service and community land is 1500, and the more practical number of organizing community meetings is 500 (cited by Alexander *et al.*(1977)). Anthropologists and psychologists' studies on group size for modern human to maintain stability and the social brain hypothesis suggests that there is a cognitive limit of approximately 150 individuals as how many face-to-face social interactions a person can have, known as Dunbar Number (Dunbar, 1993). Within this 150, individual relationships are structured into layers of 5, 15, 50 and 150, which emotional closeness reduce with group size increase (Zhou *et al.*, 2005; Mac Carron, Kaski and Dunbar, 2016). Building social network and interaction in a community is an important aspect of community social sustainability (Dempsey *et al.*, 2011).

The importance of building space and layout can be found in the literature, which emphasis on its impact on social interaction within a dwelling. Most collective housing consists of common spaces (shared access to all residents) and private homes (private spaces for residents), while some maybe have public spaces (access by both residents and all other visitors). There has been numbers of studies exploring how the layout design of co-housing communities help boosting social interaction and sense of belonging by considering the size and location of their common house and private homes (Field, 2004b; Williams, 2005a; Stevenson, Baker and Fewson, 2013).

2.3.5 Sustainability of collective housing

The reason that co-housing is attracting people can be categorized into social aspect and its environmental sustainable potential (Tummers, 2015). Co-housing provide a living environment where people have more opportunity to communicate with each other as well as to interact with nature and land (Sanguinetti, 2014). In co-housing, residents are willing and committed to live together as a group and therefore gain the advantages from the supportive social environment (Garciano, 2011a).

People choose to live collaboratively from social aspect, as loneliness becomes a vital issue for people living in the city nowadays. And people living alone in the city could tend to feel loneliness, which experiencing a higher possibility to develops into numbers of mental health and psychiatric illnesses (Kato *et al.*, 2017). A quote from old Chinese proverb says, ‘Close neighbours are better than blood relatives in distance’. Though, internet had brought people closer, social environment in daily life is considered important for a long life and especially becoming more and more vital in recent times.

The sustainable potential of co-housing can refer to sustainable living and environmental sustainable. Shared meal, which always considered as the basic activity in co-housing housing model, is important for community every life because – socially, it bring people together, when people tend to eat together they start to plan activities together; practically, shared meal helps reduce cost and waste, and also could free people from making every day meal (Vestbro, 2012). In co-housing communities, people are doing shared meal in turn, which each people only need to in charge once every two weeks.

In terms of environmental sustainability, co-housing communities have more potential than individual houses. As the co-housing model could reuse , recycle and reduce energy in a community level, which could achieve higher efficiency in energy use

(ScottHanson, 2005c). Moreover, the larger housing scale give it opportunities to choose more ow carbon technologies with more flexibility. However, everyday behaviour of occupants are as much essential as building physics and efficient technologies (Gram-Hanssen, 2013).

In co-housing communities, people have their own spaces and they share significant area (both indoors and outdoors). People intended to choose living in co-housing communities, therefore they can improve their social connection; and benefit from living with a group of people. Though co-housing has its benefit both from social and environmental aspect, it is facing numbers of problems at the same time.

There are technology/physical related and social/routine related aspect of discussions on the sustainability of co-housing community. Co-housing is considered as an ideal eco-community type for its potential to implement solutions from both aspects comprehensively.

The arguments of sustainable potential of co-housing are categorized in the following themes (Table 2.8) (Williams, 2008):

	Sustainable strategies	Key criticism
Social sustainability	pro-environmental behaviour; a better sense of well-being; having strong social bonds and sense of togetherness, psychological advantages for coping with loneliness; residents felt they were valued in the community through the decision-making process; more open to new technologies;	the exclusion in some cases;
Environmental sustainability	communal gardens; more spaces for roads and green areas; less private spaces and more shared spaces; shared use facilities encourages residents to share resource;	increased peer pressure;

	less waste and lower level of resource consumption; implementing environmental schemes collectively; as a community, it's more capacity to install technologies;	
Economic sustainability	share living expense by sharing facilities, vehicles and daily goods; lower transport cost by car-sharing schemes; recycle and resale within the community;	New build communities are less affordable;

Table 2. 8 Sustainability potentials of co-housing

2.4 Summary

This section sets out the concepts and discourses related to collective housing. The opening chapter introduces concepts and terms related to collective housing, including definitions, identification and the controversies existing about what they should be defined among various researchers. The physical typology of the different communities is then listed and compared. This is followed by the analysis of sharing mechanisms in a community within various types of collective housing. The chapter concludes with a summary of what sustainable designs and practices are available for collective housing communities.

There are some discussions in the field about the sustainable aspects of the co-housing typology. Discussions mainly focus on its social and economic benefits, and fewer studies explored the sustainable capacity in the co-housing and co-living model. This research, therefore, hope to provide insights and discussions about the sustainable and energy-saving potentials of shared spaces in co-living development in urban cities. The data was collected during a field study to a co-living project through observation, conversations, and interviews.

Chapter 3 Energy Consumption in the Home

3.1 Chapter overview

This chapter reviews the literature on the topic of household energy consumption, everyday living behaviours in residential buildings, the existing research of energy-related occupant behaviour research methods, and available studies about energy related research on collective living. The chapter begins by seeking to understand energy consumption in buildings and how, when and where energy is used in households. This is followed by identifying energy-related occupant behaviours in residential context, exploring the socio-psychological factors in energy-related occupant behaviours, and understand occupant behaviour research methods. Finally, the chapter concludes by exploring the challenges and research gaps in the existing studies in the field.

3.2 Energy consumption in residential buildings

The building sector contributes about one third of global final energy consumption (IEA, 2022). In the UK, buildings are responsible for 59% of electricity consumption (CCC, 2020). According to Clark (2013), a pseudo equation for energy consumption is:

Energy consumption = $\frac{no.of\ people \times expectation}{efficiency}$

As the global population keeps growing and people's quality of life improves, especially in developing countries, there is a need to limit the growth of energy consumption by improving energy use efficiency. However, improvements in energy efficiency do not necessarily lead to lower energy consumption, as people's use of energy also depends on other factors like energy prices and standard of living. Historical evidence shows that the amount of energy consumption at the macroeconomic level has been increasing despite the improvement in energy efficiency, which support the Jevons Paradox effect (Brookes, 2000). The same applies at the building level. For example, when energy efficiency rises and energy becomes more affordable, people will continue to improve their quality of life and buy more electronics thus consuming even more energy.

3.2.1 Categories of energy consumption in residential buildings in the UK

The structure of energy use differs between office buildings and residential buildings. In the lowest energy office setting model, the energy consumption for heating, cooling, lighting and air account for 44% of total energy, with the remaining used for equipment (Clark, 2019). In the residential sector, according to eurostat (2021), space heating consumes 63.6% of final energy consumption in the EU households, followed by 14.1% for lighting and appliances,14.8% for water heating and 6.1% for cooking.

The domestic sector is the larger consumer of gas (accounting for 64%) but uses less electricity (accounting for 42%) in the UK (BEIS, 2021c). The UK household energy consumption meter point data in 2017 stated the annual median gas consumption was 12,300 kWh and the annual median electricity consumption was 3,100 kWh (BEIS, 2021b). Within 18 million total UK households, 85% use gas to heat their homes, provide hot water and cooking. The average electricity consumption breakdown reported in a Household Electricity Survey (HES) conducted in 2010 monitored 250 households in England is as follow (table 3.1). The 250 households are quiet representative in terms of social grade, number of occupants, life stage, and building age. Although it should be aware that this sample was not completely representative as all HES households are owner-occupied (not including rental homes and social housing) and only homeowners were included.

Item	% of total over year	Electricity Consumption (kWh/y)
Cold Appliances	13.8	566
Audio/Visual	13.1	537
Lighting	11.8	483
Cooking	10.9	488
Washing Appliances	10.7	437
Space Heating	5.5	227
ICT	5.1	207
Other	4.2	173
Showers	2.7	112
Water Heating	2.1	85
Unknown	20.0	819

Table 3. 1 Average electricity breakdown (resource: Palmer et al., 2014)

3.2.2 Energy requirements for residential buildings

3.2.2.1 The need for space conditioning

Space conditioning includes both heating and cooling. Over a quarter (434 TWh) of final energy consumption in the UK is to meet the space and water heating in homes (Ofgem, 2016). The peak time of energy demand in homes are from 6am to 8am in the morning and 5pm to 8pm at night. Most (over 70%) of the UK heat energy are from natural gas burning (DECC, 2015).

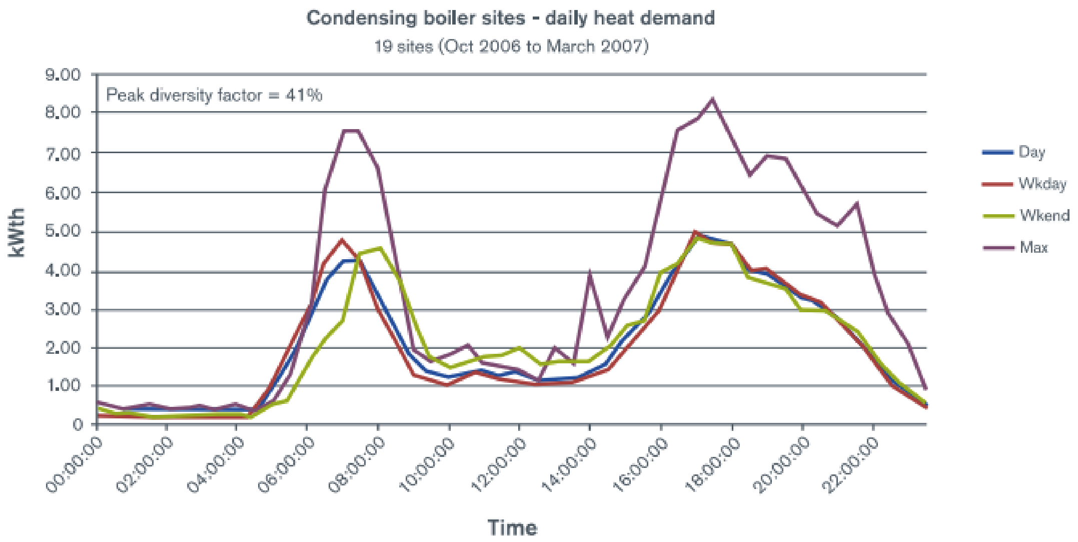


Figure 3. 1 Heat demand of gas throughout the day (Robert Sansom, 2014).

Cooling demand in the UK residential building is small currently with about 10% of total electricity usage (Khosravi, Lowes and Ugalde-Loo, 2023). However, there is the possibility of escalation as temperatures rise and the demand for comfort continues to rise.

The World Health Organization guide on thermal comfort pointed out the measure of both ambient temperature satisfaction and its link to health. In housing surveys, perception of thermal comfort is used to understand resident’s overall thermal comfort and opinion(Ormandy and Ezratty, 2012). The home scene is usually not steady state, the activity level and clothing value can change over short periods; internal gains can affect the indoor temperature; and the occupancy of rooms will influence the ventilation rate (Peeters *et al.*, 2009).

Domestic energy consumption has grown due to increasing demand for thermal comfort. However, current research lacks comprehensive understanding of how end users interact with modern technologies and respond to changes (Wei, Huang and Loschel, 2022). Farahani et al., (2021) pointed out most of the residential buildings are not designed or equipped with cooling system and are being designed for long winter and cold session. To tackle this, the UK government published updated Building Regulations in 2021 for passive cooling measures aiming to reduce overheating in new residential building (Khosravi, Lowes and Ugalde-Loo, 2023).

3.2.2.2 Hot water consumption and patterns in UK homes

Hot water refers to water that has been used to heat for cooking, personal washing and cleaning purposes (HCLG, 2010).

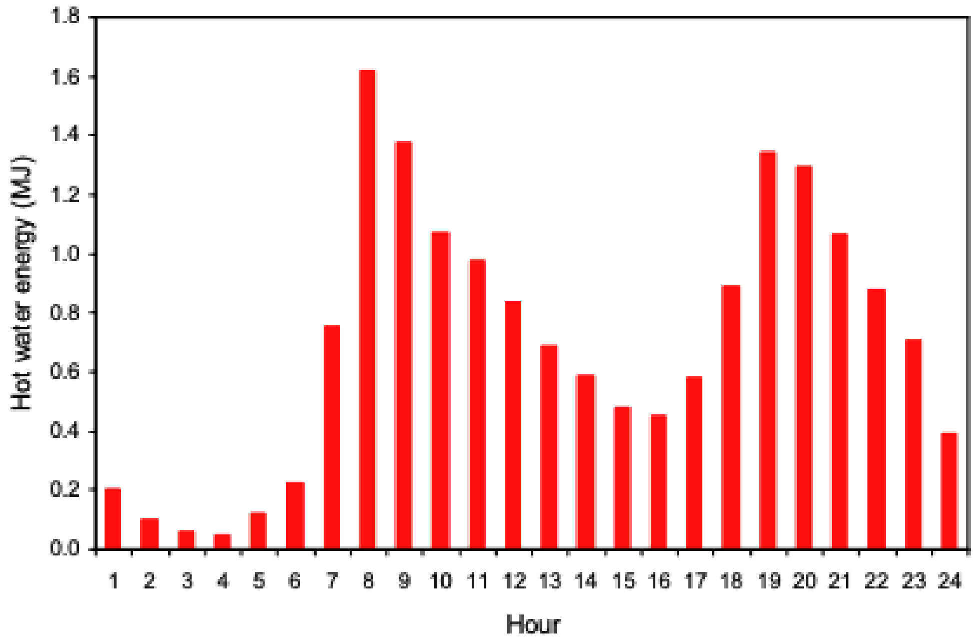


Figure 3. 2 Hot water energy consumption throughout a day (Energy Savingf Trust, 2008).

A domestic hot water survey carried out by Energy Saving Trust (2008) on 120 UK homes found that homes consume hot water at these locations: kitchen sink, bathroom basin, bath, washing machine, and shower. The peak hours for hot water usage are from 7am to 9am in morning and 18pm to 21pm at night. The mean duration of water heating hours daily is 2.6 hours/day and about 60% of homes fall into 2 – 4 hours/day range.

3.2.2.3 Energy used for domestic lighting

Lighting consists about 11% average electivity over year in UK homes. The report conducted by Palmer, Terry, Kane, *et al.* (2014) reveals substantial disparities in domestic lighting energy consumption, demonstrated that the number of occupants, house type and size play essential roles.

Lighting energy usage is related with many aspects in homes. Research found that the top 20% of households for lighting use is over 5 times than the bottom 20% households. People working part-time are more likely to use more energy in lighting. And there is some correlation between lighting use and other activities, for instance, households with less applications usually use less energy for lighting, and households have high energy use for lighting tend to be high users in total electricity usage (Terry *et al.*, 2013). Some lighting use patterns are lead to higher energy use. Palmer, Terry, Kane, *et al.* (2014) pointed out in a UK domestic electricity use survey that 80 out of 250 homes keep some lights on overnight, which used about 30 kWh per year each home.

3.2.2.4 Energy use in kitchen: cooking and food storage

Nearly every household owns refrigerator and about 93% household has freezer. Almost all households own ovens and hobs, while about 80% households own grill and microwave. Report also found that household with children or residents in during the day consume more energy by using hobs and microwaves (DECC, 2013). And single person households potentially could save about 80 kWh per year if they use half-size dishwasher. Cooking activities are highly related with TV use, which found by Palmer, Terry, Kane, et al. (2014) through survey UK household electricity use. The preference for household activities often influences energy consumption.

3.2.2.5 Washing and drying in homes

Overall, almost all UK households own washing machine, and over 60% of households own dryer. Owner occupiers are more likely to own both washing machine and dryers (DECC, 2013). Washing and drying account for 10.7% of household total electricity use. Single-person homes use washing machines almost half then other household groups. If households running dishwashers and washing machines at lower temperatures, at 55°C rather and 70°C, that would make a great change to save over 90 kWh per year for large households. Research found that the energy use of dishwashers and washing machines show little seasonal variation, while tumble dryer energy use in winter is over twice than in summer (Palmer, Terry, Kane, *et al.*, 2014). Household income shows corelation to washing patterns. Studies have found that high-income households tend to have higher total energy consumption, and high energy use for washing and drying. However, income doesn't corelated with washing temperature (Hess *et al.*, 2022).

3.3 Energy consumption in collective housing

Collective housing, as an alternative to traditional houses, differs from traditional housing in terms of layout design and occupant activity patterns which leads to energy consumption differences. Collective housing usually has less floor area per person, which consume less energy for space heating. However, some common spaces in collective housing projects may have higher floor-to-floor height which leads to higher heating energy use. Hot water usage pattern in collective housing is similar to ordinary house, where most hot water consumption are from heat for cooking, personal washing and cleaning purposes. Lighting use in collective housing can be divided into personal unit lighting use and common space lighting use. The common space lighting use is affected by the using time period of each common space. Cooking related energy consumption in collective housing could be significantly different from ordinary homes. Some collective housing communities have the culture of shared meal or cooking together regularly, which largely reduce the amount of time people spend in their private kitchen. Unlike ordinary households, where energy consumption pattern and usage are being studied and surveyed in current studies, collective housing energy usage patterns are not fully discovered.

3.4 Factors affecting residential building energy use

The energy consumption of a building is not influenced by a single cause, it is determined by the interaction between climate, use and design (Dekay and Brown, 2014).

3.4.1 Climate and Site

Climate and weather conditions affect building energy consumption for heating and cooling. Many studies have looked at the impact of climate change on building energy consumption and predicted energy use in future climate scenarios. Huang and Gurney (2016) summarized the methods to study impact of climate change on building energy consumption into three categories: observation-based prediction, regional energy modelling, and individual building energy simulation. With detailed building information and weather data, individual building energy simulation methods (via tools like EnergyPlus) can be used to simulate hourly temperatures and energy consumption for different building types. However, the housing stock is very diverse, as a result, this method has been used for certain building types in particular locations. For instance, Wilde, Rafiq and Beck (2008) explored the impact of climate change on UK residential buildings by testing three-bedroom terraced house using EnergyPlus. Though three-bedroom terraced house was picked because it is the most common type of housing in the UK, terraced housing accounts for no more than 30% of the UK housing stock (Piddington et al., 2017). Other researchers have studied the impact of the climate on the energy consumption of dwellings from a more unique perspective. For example, Kaufmann et al. (2013) pointed out that importance of tap water temperature on energy consumption was omitted, and they quantified the effect of domestic hot water on energy use. As the first study explores tap water temperature's changing on energy consumption, the study found that a 1 degree C rise in the temperature of tap water reduces residential natural gas consumption by 157 million kWh per month, which equivalent to 5.6% of average (from 1990 to 2011) annual residential sector natural gas use in the US.

Urban areas have different microclimates compared to the nearby countryside. The first study and measurements were taken by Luck Howard on the temperature difference between the countryside and city (London), which concludes that the *Urban Heat Island* was caused by heat added by humans, low evaporation due to lack of vegetation, reduced airflow, and the urban surfaces trapping radiation (Mills, Futcher and Stewart, 2021). The orientation, building height and distance from the surrounding buildings all influence the wind environment around the building, which in turn affects building energy consumption. Lack of building space reduces summer ventilation and winter solar gain. The recommended spacing between buildings is 1.5-2.5 times of building height, in order to get good natural ventilation, solar gain and natural lighting (Pelsmakers, 2015a). Streets with buildings (especially the skyscrapers in cities) on both sides of the road form urban canyons which affects temperature, wind pattern, solar radiation in the local area. Related urban design parameters include H/W ratio (height to the width of the street), street orientation, ground albedo and trees. Andreou and Axarli (2012) tested two sites with different street and urban characteristics and found that the increase of H/W ratio from 0.92 to 1.3 (equals to increase building height by one storey) leads to decrease on wall surface temperature by 6 degrees and decrease on maximum ground temperature by 3 degrees.

3.4.2 Residential building design

The design stage of a building project is the first and most straightforward stage to integrate sustainable design solutions. Buildings can be designed to be energy efficient by considering the optimum values of design parameters in the pre-design stage (Bektas Ekici and Aksoy, 2011). Sustainability objectives can be achieved by design strategies to reduce building energy consumption and potentially reduce the final cost of the building (Pacheco, Ordóñez and Martínez, 2012). However, poor building design strategies and improper implementation would be no help for buildings to meet sustainable objectives. For instance, high floor to ceiling height and the design of entrance door opening over the reception area can lead to greater heat loss (Evins, 2013). Many factors in building design stage affect the final energy use, which including building shape and orientation, building envelopes, design parameters and fabric.

Building shape and orientation

Building shape and orientation impact building energy performance and have been studied by many researchers around the world (Depecker et al., 2001; Catalima, Virgone and Iordache, 2011; Pacheco, Ordóñez and Martínez, 2012). Geometry and form of the building and compactness are usually tested at the early design stage. Theoretically, the most compact building shape is a cube. However, real projects are restricted by many reasons including site conditions, local character, planning permissions, daylighting and view access, client preferences, etc. A study of building shape and energy efficiency of office building by Alanzi, Seo and Krarti (2009) indicated three primary building shape factors that affect building energy use:

- relative compactness (RC);
- window-to-wall ratio (WWR) and
- solar heat gain coefficient (SHGC).

Building orientation also plays an important role in reducing building energy consumption. Abanda and Byers's (2016) study on a 3-storey family house in Hertfordshire, England about the impact of building orientation on energy use tested ten scenarios compared with the base sun (the front of the building facing North). They pointed out that South facing used lowest electricity (10475 kWh annually) which is 5% lower than the highest usage scenario and could save up to £878 worth of energy in its lifetime. Optimum building orientation is linked to many factors. Morrissey, Moore and Horne (2011) studied residential building orientation in passive design based on 81 different detached dwelling layout in Melbourne[1], which analysis suggested that floor area is the most significant factor to orientation change.

For the same living space, some types of collective buildings have smaller surface area to volume (S/V) ratio compared to detached, semi-detached and terraced dwellings in the UK. A lower S/V ratio helps collective buildings minimise heat gain/loss (Simone, 2017) and in turn increase a building's energy performance. Additionally, with smaller building surface area, cost for insulation material, construction, and labour would potentially be reduced accordingly.

Building envelopes and design parameters

The building envelope is a physical barrier between the unconditioned exterior environment and conditioned interior space. The barrier consists of the roof, walls, windows and doors, and foundations and the floor. Also known as opaque envelope system include walls, roofs, floors and insulation, and transparent envelope system include windows, skylights, and glass doors (Mirrahimi et al., 2016). It provides a comfortable living environment for occupants and plays a key role on building energy consumption. Energy-efficient building envelopes could reduce building energy consumption by using high thermal resistant materials, vapour control, window and door seals, and effective airflow control (Hailu, 2020). Different building envelope design strategies are used in different climate zones. For instance, UK is in Zone C (warm/mild temperate zone) in Köppen-Geiger climate classification system where insulation is used to minimize thermal losses and window area is increased to

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[1] UK and Melbourne both in Zone C in Köppen climate classification system which is warm/mild temperate zone. Köppen-Geiger climate classification map (1980-2016) see https://education.nationalgeographic.org/resource/koppen-climate-classification-system

receive natural light, on the other hand, external shading devices are rarely used. Uncontrolled airflow through gaps and cracks in the building envelopes is defined as air leakage and can be measured with standardised airtightness tests. The greater the airtightness of the building envelope, the lower the infiltration and resulting less heat loss. The current Building Regulation limits airtightness in new dwellings to lower than 8.0m3/(h.m2)@50Pa (HM Government, 2021). The natural ventilation through leaks and cracks in building envelopes are not able to provide good air quality. Instead, designed natural ventilation or mechanical ventilation system are need for promoting indoor air quality.

Design factors related to daylight, sunlight, wind and ventilation can affect the energy consumption of a building. The percentage of glazing, window-to-wall ratio and window location determine how much solar gain and daylight can enter the interior spaces, thereby influencing the amount of energy required to heat and light the spaces. Window location and the interior layout affect how well the design works with wind and whether or not it is able to create good ventilation and good indoor air quality. Both interior and exterior shading effectively resist direct sunlight and helps reduce heating in summer. A balcony in multistorey buildings can provide external shading, however the size of the balcony can affect the lower floors' access to sunlight. Specifically, the top-floor apartment residents wanted the balconies as deep as possible to maximize outside space, while middle-floor apartment residents wanted to reduce the size of balconies to reduce overshadowing. The final choice was 1.8m, which was reached after several evening meeting, a pros and cons analysis, cardboard models by the residents making it one of the most discussed design issues (Chatterton, 2015c).

Building materials

The Fabric First Approach is widely used in building design and seeks to optimise the material performance before building service systems. It is one of the most effective strategies in building design and retrofit (Designing Buildings, 2021) by aiming to minimise the building’s energy use through choice of building materials, using high levels of insulation, maximising air-tightness, and using thermal mass of building fabric to store heat and maintain stability.

Several sustainable design concepts related to building materials and construction processes are considered in the building design process, including embodied energy, embodied carbon, whole life carbon footprint, and cradle to gate/cradle/grave approach. Embodied energy is defined by Treloar et al. (2001) as ‘the energy required to provide a product through all processes upstream.” In buildings, embodied energy contains the energy used to construct a building, the production and transportion of the materials, and the demolition and disposal of the building. Embodied energy is difficult to quantify due to lack of standardized calculation methodology, while embodied carbon and carbon footprint are largely used on building material studies (Cabeza et al., 2013). Therefore, sourcing materials locally, reducing transport costs and recycle materials are all factors that need to be considered in sustainable design.

Insulation is one of the best strategies to reduce building energy use (Schiavoni et al., 2016). Well insulated buildings are determined by the choice of material and mass design that reduce the heat loss/gain through the building fabric (Pelsmakers, 2015b). U-value (W/m2K) indicates the thermal transmittance coefficient of the entire building element; the lower the U-value, the better it is at resisting heat transfer. Insulation materials can be categorized into mineral based, petrochemical derived and plant based insulations. Petrochemical derived insulations have higher embodied energy than plant based insulations. Asdrubali, D’Alessandro and Schiavoni (2015) compared the per functional unit energy consumption of extruded expanded polystyrene (petrochemical derived) and sheep wool, which are 127.31 MJeq and

17.12 MJeq respectively. Schiavoni et al. (2016) investigated several conventional and alternative insulation materials for building sector and indicated that sheep wool and recycled textiles have the lowest embodied energy. However, plant-based insulations are not suitable in area with flood risk or wet construction and are not rot resistant. Unconventional sustainable building insulation materials, mostly plant-based insulation, are worth considering especially if they are available locally. There are natural materials like straw bale, cotton, reeds, sunflower, etc.; and recycled materials like textile fibres, glass foam and plastics (Asdrubali, D'Alessandro and Schiavoni, 2015).

As some collective communities are involved in the design of a project early on, they are able to join the discussion of how they want to build their homes and have the choice of environmentally friendly building materials, especially if sustainability is one of their community priorities. For instance, the LILAC community in Leeds, UK is an ecological, affordable co-housing scheme, built with the ModCell system using straw and timber. From the beginning, 'LILAC's approach was driven by a passionate desire to use very low impact and high-performance natural building materials' (Chatterton, 2015h) the project leader group approached ModCell and eventually with a grant from the UK's Department of Energy and Climate Change and Home and Communities Agency, ModCell was chosen to build the project.

3.5 Occupancy effects on energy consumption in housing

Many studies have pointed out that occupant behaviours have an impact on both residential and commercial buildings across climate zones. However, the type and magnitude of the impact that occupants have on residential and commercial buildings are different. In commercial buildings, occupants' effect on building energy use is reflected in the comfort settings and occupancy schedules. Lin and Hong (2013) simulate two prototypical office buildings in three heating climates in the US, and find that work style influences energy consumption greatly. They compared a High Heating case and Low Heating case with the standard case (low, standard, and high heating cases have thermostat settings at 18, 21, and 23 degree respectively), and the results show the High Heating case consumes over twice as the standard case while the Low Heating case consumes less than half in all heating climates. In residential buildings, energy end-use varied largely because of several major impact factors, including construction faults, poor building envelope, engineering system misfunctioning and occupants behaviours (Hong *et al.*, 2016). Clevenger et al. (2014) found that the most significant factors, either directly or indirectly, affecting building energy performance are related to the amount of air introduced into the building. Moreover, the direct (infiltration from window and door opening) and indirect (ventilation rate) factors are all depending on the in-use operation. Hidalgo-Leon *et al.* (2019) pointed out that it is important to implement energy use good practice campaigns in buildings, as bad habits in energy usage of occupants highly affected building energy consumption.

3.6 Energy-related occupant behaviours

Energy-related occupant behaviours are categorized by the International Energy Agency (2013) to be the activities related to heating/cooling, ventilation and window operations, hot water, electric appliances and lighting, and cooking.

3.6.1 Energy and everyday living behaviour research process

Occupant behaviour research in buildings can be traced back to the 1950s and 1960s, which were focused on occupants interaction with the ventilation system and window opening activity (Tam, Almeida and Le, 2018). Interest in the influence of occupants' behaviour on energy use grew after the 1980s. The main topics included adaptive occupant behaviour, thermal comfort and applied models.

Social science researchers got involved in this field and have contributed to the body of knowledge since the 1990s. Many researchers pointed out that the research gap at that period included 'the building practice has not kept pace with building science' (Hutcheon and Handegor, 1983), and the lack of analyzing of consumer patterns (Cherfas, 1991; Lutzenhiser, 1993). Guy and Shove (2000) summarized the reason and background for social scientists to take part in energy efficiency research in their book *A Sociology of Energy, Buildings and the Environments*. They started research on understanding 'the mechanics of technology transfer and the relationship between research and practice', inspired by the work of Jaffe and Stavins (1994). Given the fact that building energy consumption accounts for around half of total UK energy consumption in 2000 (BEIS, 2020) and that a large amount of it is used to meet occupants’ escalating comfort needs, Shove's (2003) later research discussed the impact of social practice change on sustainability by looking at comfort, cleanliness and convenience in daily life. The research pointed out that most of the environmental consumption is not simply a result of personal choice but bound up with social practice norms and lifestyle. Therefore, for a better practice of sustainable living, social and cultural diversity should be encouraged first and followed with promoting energy efficient technologies (Shove, 2003b). Social and lifestyle changes could potentially reduce UK energy use by 35% (UKERC, 2009), however, lifestyle changes are difficult to achieve. The research project Energy Biographies, carried out by Henwood et al., (2015), found out that by looking at ‘how agency can emerge in different social and place-based context’ is more useful for changing energy using behaviours than just providing more information to occupants about how to reduce energy use.

3.6.2 Occupant behaviour in buildings

Better understanding of occupant behaviour provides essential support to build low energy buildings in both residential and commercial sector (Hong et al. 2016; D'Oca et al. 2018; Tam et al. 2018). Moreover, this can contribute to the planning of transport and services system by knowing people's preference and habit of using of and interaction with spaces.

Hong et al. (2016) categorized the occupant behaviours that impact on building energy performance into two groups: 'adaptive actions' and 'non-adaptive actions' (see Figure 3.1), referencing Nicol and Humphreys' work published in 2002 (Nicol and Humphreys, 2002). Occupants consume energy in buildings directly by using the HVAC system, artificial lighting, domestic hot water, appliances, etc. Moreover, occupants' activities like opening windows for a better view, allowing access for a cat, or greeting a neighbour could influence the indoor temperature and correspondingly causing more energy on the heating system. While the effect of these activities can add up to something significant, one single move like this would not have much influence on the indoor environment. The International Energy Agency (2013) categorized energy-related behaviours as a) heating/cooling, including deciding the temperature set point on controls, the number of heated rooms, heating duration and frequency of usage, user’s gender, age and expectations, knowledge of control function, and maintenance; b) ventilation and window operation, including mechanical and natural ventilation operation, and window opening or closing; c) hot water, including frequency and duration of shower or bath, frequency of sink use, frequency and setting of washing machines, dryers and dishwashers; d) electric appliances and lighting, including the number of appliances and energy efficiency, and usage frequency and duration; and e) cooking, including the type of equipment used for cooking, and their energy efficiency, usage frequency and duration.

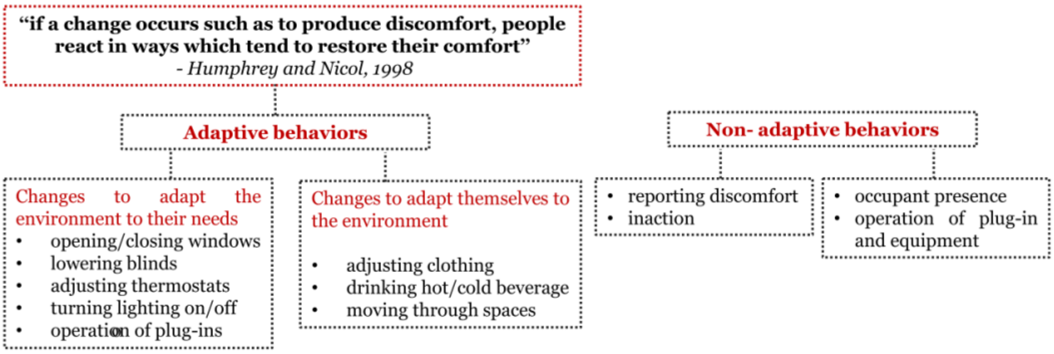


Figure 3. 3 Building energy consumption and comfort influence factors (Hong et al., 2016).

Occupant behaviours are related to multiple factors, like outdoor temperature, perception of indoor temperature, solar radiation, floor area. The results of a quantitative research on occupant behaviours and control of indoor environment indicated that both window open/close and heating on/off are strongly related to outdoor temperature (Andersen et al., 2009). Occupants' expectations for indoor environment and their perceptions for comfort and convenience differs due to location, culture and generations. Some people are used to wearing multiple layers in winter to keep warm indoor, while others are used to heating up their houses warm enough to wear t-shirts. Many everyday life practices change over time as a result of changes in the life style. For instance, Shove (2003) noted that daily showering replaced the standard British family life – 'Saturday night bath', due to its convenience. Moreover, occupants' everyday life is formed with many practices that bound up with energy consuming technology devices and systems. Many practices in everyday life are interdependent to each other, like oven and frozen food (Henwood *et al.*, 2015). By reducing the energy consumption of one of these practices, the energy consumption of the other will also be reduced.

Pro-environmental behaviour is a form of behaviour that consciously lower one's negative impact on the natural and built environment (Kollmuss and Agyeman, 2002).

Factors influencing environmental behaviours include motivational factors, contextual factors and habitual behaviour factors (Steg and Vlek, 2009). Both internal and external factors have influences on pro-environmental behaviours. In collective housing communities, with more residents working towards a more pro-environmental lifestyle, a great amount of energy could be potentially reduced.

3.6.3 Understanding occupant behaviour and reducing the energy performance gap

Occupants' behaviour was considered one of the main reasons for the mismatch between expected and actual energy performance in low energy buildings (Guerra-Santin et al. 2013). Buildings are not used in the way they were designed for, giving rise to the term 'performance gap'.

Apart from behaviour-related energy consumption, the reasons for energy performance gaps are attributed to: a) Building fabric: poor construction quality causes problems like poor building insulation, low airtightness and high heat loss. Differences between predicted and measured whole house heat loss in new build UK dwellings are high, with heat loss reduction being 25% higher than real measured reduction in over 75% of cases (Stafford et al. 2011). Retrofit projects also experience this issue, in which overestimation of the U-value of solid walls could result in a reduction on predicted carbon saving by up to 65% (Loucari et al. 2016); b) The inaccuracy of modelling: BIM and BEM tools are used in design and construction process to anticipate and monitor energy consumption. However, according to research by Reeves and Olbina (2012) who compared energy consumption in BEM tools and actual data, only 8.3% of cases were simulated accurately in the worst scenario; c) The quality of data collection, improper analysis and lack of coherent research methodology would result in poor understanding of actual building performance (Swan et al. 2015).

Several stages can create energy performance gaps during the whole procedure of a project, which includes design stage, construction stage and operational stage. An energy performance gap illustration was listed in the table below (see figure 3.2).

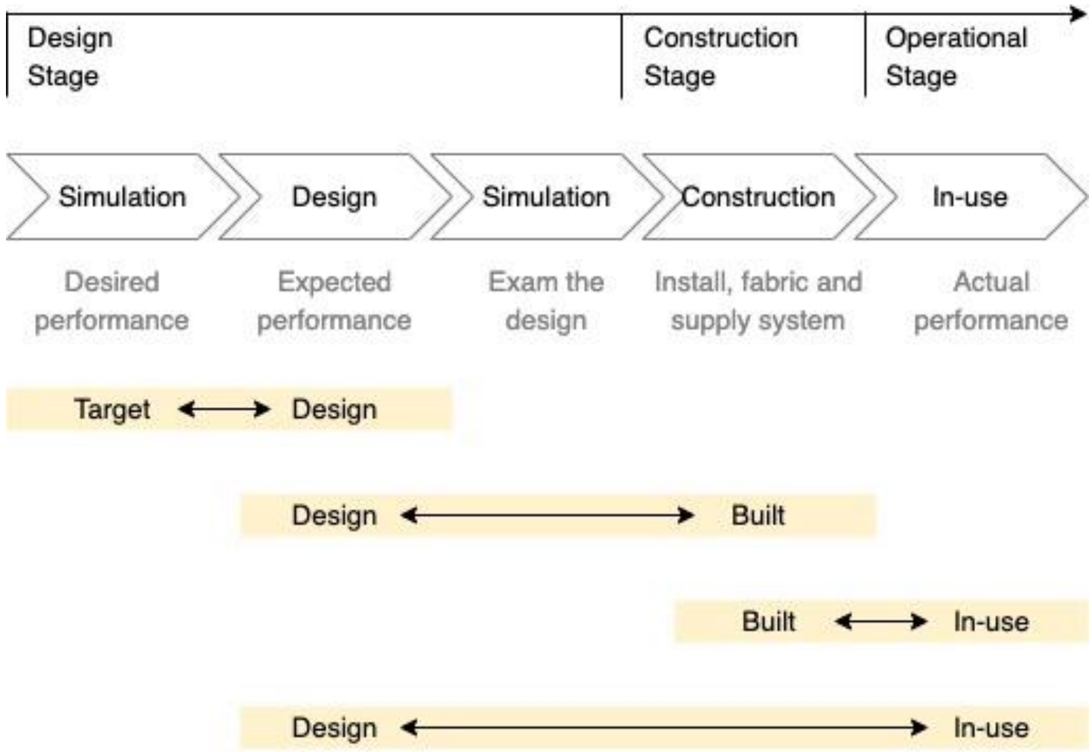


Figure 3. 4 Energy performance gap illustration.

3.6.4 Socio-psychological factors in occupant behaviour research

Energy consumption related behaviours in households are relevant to residents' everyday practices, like use of lighting, space heating and cooling, cooking, washing and cleaning, and appliances (Axon *et al.*, 2018). Practices are 'coordinated entities of sayings and doings that are held together by different elements' (Gram-Hanssen, 2011) . Four elements in holding together a practice: embodied know-how and habits, explicit rules and knowledge, engagement and technology. To be more specific, these four elements are the key factors that affect residents' day to day energy consumption. First one is residents' habit, which they gain as they brought up.

People’s habits are significantly different depending on their location and class. The next element is the rules and knowledge that residents have on household energy consumption. Many don’t know how much they pay for equipment on standby and some do not even know what standby consumption is, and so would not know how to reduce standby consumption. Then there is engagement, which refers to people’s willingness to make an effort to save energy. Lastly, the changes and development of technology have significantly impact on household energy consumption.

3.7 Occupant behaviour research methods

Energy efficiency is achieved by a comprehensive understanding of both technological and human dimensions of using buildings. Various methods have been considered using in energy-related occupant behaviour research, including both qualitative and quantitative methods. D’Oca et al. (2018) point out that in order to achieve high-performance building guidelines and compliance with low energy buildings, research need to study with state-of-the-art methods for valuing human impact on energy use. Moreover, this applies to both residential and commercial buildings at all scale and stage. Researchers often use building performance simulation software to investigate the influences of different impact factors by comparing the energy consumption of different scenarios calculated in the software. There are numbers of building performance simulation software tools, and they could be grouped into three categories, which are simulation engine, software docks to simulation engine, and software plugin tools, including EnergyPlus, ANN model, DOE-2. Apart from software-based simulation tools, web-based applications targeting to better model occupant behaviour has been developed. In 2016, the Occupancy Simulator, a web-based application using Markov Chain model was developed by Lawrence Berkeley National Laboratory. Qualitative research methods used in energy related occupant behaviour studies include questionnaire surveys, on-site observations, interviews and post occupancy study. Belafi, Hong and Reith (2018) reviewed 33 energy-related occupant behaviour studies which used survey and interview to draw out conclusions, and found out that these studies were designed and carried out by researchers with technical backgrounds and many key aspects of social science and human behaviour were disregarded.

3.8 Energy and everyday living in collective living developments

Energy consumption in collective living developments differ from ordinary housing due to their different building design, demand and community organization.

3.8.1 Energy consumption in collective living developments

Collective developments (especially co-housing) have smaller build spaces than ordinary households (Guinther, 2008) which consequently demand less space heating (a comparison see Section 8.2.2). A study of twelve co-housing projects shows that the average dwelling size built in the 1990s is 100 m^2, which is about half of the size compared to the average typical single-family house built in the same time in the US (Graham Meltzer, 2005a). Additionally, collective living developments are benefit from community scale energy efficiency designs. A resident of Nevada City Co-housing had an over 40% reduction in its electricity bill compared to its previous residence, which was attributed to the photovoltaic cells and other energy-saving measures (Mccamant and Durrett, 2011b).

Sharing spaces and resources could potentially reduce embodied energy in construction and save energy using by shared use of certain functions and activities such as cleaning, entertainment, dining and living spaces, etc. When looking at saving energy consumption in common spaces and resources, it is important to understand what are essential every-day practices and what are extra usage

(Version, 2016). However, people might have different perceptions on what are seen as ‘extra’. For example in *Lilac* project, some residents ‘stressed a strong preference for wood burners in their homes’ (Chatterton, 2015d), however, this would cause extra cost and logistical issue to store wood for all households which undermines the project’s commitment to sustainability. Eventually, instead having wood-burner in individual homes, they install a small wood-burning stove in the common house to act as a fire ‘heart’ for the community to gather round. Some might see having fireplace in common room rather than in every individual home as a ‘save’ in energy consumption, others might consider ‘having fireplace’ as an ‘extra’.

The energy use of collective housing is relatively low compared to the national average. Brown (2004) explored Cambridge Co-housing (located in the US) as a master thesis case study and summarized the community’s energy consumption from 1999 to 2003 with support from one of the residents. The average electricity use over the five years is 12,400 kWh per household, which is 20% less than the United States total average household energy use. The researcher pointed out the energy saving in co-housing could be a combined result of its environmental awareness and social consciousness. Another possible reason for consuming less energy in collective housings is space saving. Private homes in co-housing developments are usually smaller than ordinary properties which consume less energy for space heating and less resource in construction (Wilson and Boehland, 2005).

3.8.2 Student collective living

A similar housing type to collective living is student residences, which have smaller private spaces and share spaces with other residents for part of everyday practices, like laundry, kitchen and dining, and bathroom in some cases. An energy audit on Richard Feilden House (RFH) student accommodation was carried out from January 2008 to December 2009 by Vadodaria (2012). RFH (Figure 3.3) was designed by

Feilden Clegg Bradley Studios as the final phase of Westfield Student Village for Queen Mary University of London in 2007. One obvious difference between student residences and other residential building types is that the occupancy in student accommodations varies by term time and holidays, which significantly affect the building's energy consumption. Specifically, few residents stay during holidays, especially in wintertime during Christmas break. The energy data used in the audit was metered actual monthly fuel bills provided by the energy manager of the building. The total electricity and gas consumption of the building (200 student bedrooms and 20 common kitchens with total gross internal floor area of 3677 m^2) in 2008 is 356,000 kWh, and 279,000 kWh per year respectively. The actual electricity consumption was about 10,000 kWh lower than the predicted consumption in Decembers, because of the low occupancy during Christmas break (actual-predicted differences in other months are within 5,000 kWh).

Figure 3. 5 Left: RFH building, Right: RFH student's room (Vadodaria, 2012).

Its energy consumption is 53% less than good-practice benchmark building by CIBSE 2004, Guide F (Vadodaria, 2012).

Strategies for improving energy performance at RFH include higher levels of insulation, thermal mass, mechanical ventilation heat recovery (MVHR), off-peak heater, internal heat gains for space heating and proactive building management. Space heating accounts for 31% of total electricity consumption. Decentralized electric heating was equipped at RFH throughout the building. Electric wall mounted panel radiators are installed in bedrooms and kitchens with two-stage thermostat controls (Figure 3.4) which would raise temperature for 2 hours by pressing ‘touch’ button and would reduce setpoint to 5 degrees if boost operation has not been used for 48 hours. Such setting mechanism is suitable for student accommodations, as it prevents energy wastage due to students forgetting to turn off the heating before leaving for classes during daytime. Catering and services & pumps are the other two main end use in the building, accounting 25% of total electricity consumption respectively. By comparing the energy use for catering in student accommodation and UK household (Table 3.2), it can be found that student accommodation (445 kWh/y) consumes less electricity for catering than UK average (517 kWh/y), but more than the *Practical Considerations** cluster (261 kWh/y).

Type	**Floor area per occupant (m2)**	**Annual electricity consumption for catering per person (kWh/y)**
RHF student accommodation	18.4	445
Practical Considerations*	29.7	261

All household	/	517

***Practical Considerations is one of the seven household archetypes/clusters used in the 'Further Analysis of the Household Electricity Use Survey'. The survey investigated the electricity use in 250 household throughout the UK. Practical Considerations cluster has lowest floor area per occupant and has very green current belief (Palmer, Terry, Kane, et al., 2014).**

Table 3. 2 Comparison of electricity use in student accommodation and other household.

Palmer *et al.* (2012) found that smaller households use less electricity for cooking. However, with small floor area per person in RHF, electricity for cooking does not show a significant reduction compared to UK households. More in-use energy consumption of student accommodation needed for further investigation on how relevance it is between electricity for cooking and floor area per occupant.

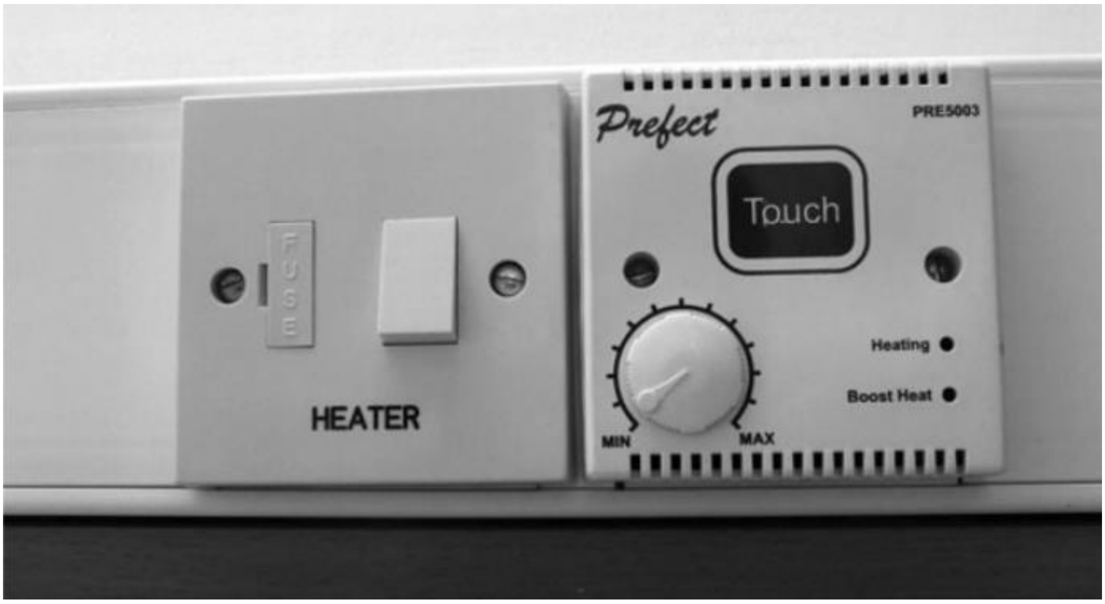


Figure 3. 6 The two-stage thermostat controls (Vadodaria, 2012).

Many studies of student accommodation are about energy consumption modelling.

There is little research or information about in-use energy performance of student accommodation buildings. More studies about this building type should be carried out in the future, in order to better understand how energy use in collective student accommodation differs from ordinary buildings and derive suggestions for sustainable design of collective student accommodation.

3.9 Challenges and research gaps

Researchers are paying attention to occupant behaviour when investigating building energy. In recent years, the occupant aspect has been the trend of gaining more attention. Gram-Hanssen (2013) points out that occupants’ household routines are as essential as the physical and technical aspect of buildings regarding environmental sustainability. Many studies are designed to test how much occupant behaviour have an impact on commercial buildings, and in turn, how building features are influencing occupants in what kind of ways. Fewer studies are researching the occupant behaviour and energy using pattern of residential buildings due to ethical limitations, as well as the studies exploring residential buildings with common spaces and shared facilities. Williams (2007) suggested it is more efficient for more people to live together regarding energy, resources and time. However, the sharing system relies heavily on every resident’s sense of responsibility and desire to form a community. Tam et al. (2018) developed a chronological review of energy-related occupant behaviour research, which summarized critical points in energy-related occupant behaviour research. The review highlights the main conclusions and gaps in the field. It suggests that energy-related occupant behaviour contributes largely to the gap ‘between real energy performance in a building and the one predicted at the design stage’. Furthermore, it pointed out that alternative methods are needed to address this issue, and occupants need to be given more information on the best practices when dealing with the building system.

3.10 Summary

The aim of this chapter is to explore the energy consumption in homes, energy-related occupant behaviour and research methods used in existing studies, and energy related research on housing with shared features. It has reviewed UK home energy use breakdown which found out that cold appliances, audio, lighting, cooking, and washing appliances account for about half of home electricity use.

Then, the main factors that affecting home energy use were discussed, as well as a review of energy-related occupant behaviour research process, understanding occupant behaviour in residential buildings, and research methods used in existing studies. It found that energy-related occupant behaviour in buildings can be categorized into heating/cooling, ventilation and window operation, hot water, electric appliances and lighting, and cooking. And occupant's behaviour toward change can be identified as adaptive behaviour and non-adaptive behaviours. This provided the framework for the field work research design.

Both qualitative and quantitative research methods are used for occupant behaviour studies. However, there is a lack of research on energy-related occupant behaviour from researchers with social science backgrounds compared to researchers with technical background. Therefore, some important issues in the social science area were less explored. After that, it explored the energy use and everyday living in some collective housing projects, which indicated that collective living developments are different from standard housing with regards to building design, demand and community organization. Therefore, this study chose qualitative research methods, including questionnaire, interview and observation to explore energy-related occupant behaviours in common and private spaces in collective housing.

Chapter 4 Research design and research methodology

This chapter starts with a summary of the research progress, research questions and research outline of this study. It then discusses the research methodology for this study, which explains the qualitative research approach and why the methods were chosen for this study. Next, the chapter provides detailed information about the research design, including (i) how and why the case studies were selected, (ii) how the field studies were carried out, (iii) what qualitative research methods are used in the field study, and (iv) why these methods were used. Finally, it discusses the analysis of results and limitations of the study.

4.1 Introduction

4.1.1 Summary of progress

This section summarizes the main points and conclusions of the previous literature review chapter, which includes the following topics:

- Collective housing community
- Assessing the impact of occupant behaviour on energy consumption
- Social practice theory and energy consumption

Based on the research gaps identified through understanding and summary of the literature, and the scope of this study, research questions can be formulated in the next section.

Collective housing community

Through the understanding of numerous related concepts in Chapter 2, key collective housing concepts, co-housing and co-living, in this study were defined and the term ‘collective housing community’ is used in this study to represent common spaces and shared facilities communities, including co-housing, co-living community and sustainable community designed with collective ideas.

Humans have a long history of living together and as a community. Various forms of collective living modals have been found in different periods and geographical areas. Co-housing as a concept emerged in the 1960s, and later became popular and known by the public through its three waves of development. The growing contemporary collective housing schemes are combining the co-housing building concept and the sharing economy. Mainstream discussions about the common spaces and shared facilities of these collective communities are through their social perspective. Their environmental sustainability discussions are limited and lack comprehensive study.

Assessing the impact of occupant behaviour on energy consumption

The IEA-EBC (International Energy Agency Energy in the Buildings and Communities Program) carried out research and identified that energy consumption in building is primarily influenced by: 1) climate, 2) building envelope, 3) building services and energy systems, 4) building operation and maintenance, 5) occupant activities and behaviour, and 6) indoor environmental quality (Yoshino, Hong and Nord, 2017).

Building fabrics and characteristics play important roles in effecting building energy consumption. The ‘fabric first’ approach is widely using in building design, which helps reduce cost, improve energy efficiency and reduce carbon emissions (Designing Buildings WiKi, 2019). Occupant behaviour also has a significant impact on how much energy a building consumes. The later three IEA building energy consumption factors, which all relate to occupant behaviour in buildings, are having greater influence than the other factors (Yan *et al.*, 2015). Existing research suggest that the energy performance gap between predicted and real building energy use is mainly caused by occupant behaviour (Balvedi, Ghisi and Lamberts, 2018). Zahiri et al. (2018) produced a questionnaire-based survey on the actual energy use pattern of occupants in a residential tower block, and compared it with standardised methodologies in DesignBuilder. The result shows that a large gap exists and energy use patterns need to be methodically considered in energy simulation modelling as a key parameter to reduce energy use in the operational stage.

Establishing knowledge of human-related impacts on building energy use is important in the building sector to achieve energy saving goals and act on climate change. Human-related impacts exist in many stages of a building’s life cycle. In the in-use stage, energy use effected by occupants’ behaviour is an important concern in recent years (evidenced by a significant increase in number of paper published in this topic – through key word literature search using Scopus).

There are several general direct and indirect factors that influence how energy is consumed by occupants. Direct factors include location and climate, building features, and indoor environmental quality; while indirect factors include the individual’s education, living standards, perception of comfort, and psychological factors, as well as broader aspects of socio-economic and cultural context in which the individual is placed (Tam, Almeida and Le, 2018). Moreover, within a building, an occupant’s presence has direct and indirect impacts on a building’s consumption of resources (Page, 2007). Specifically, the use of openings like windows and doors by residents directly affect the ventilation of the room, as well as having an impact on the temperature and humidity; occupants’ use of lighting is impacted by indoor illumination levels, which consume electricity while contributing to internal heat gains; the presence of occupant also contributes to the consumption of electricity and water through daily use of appliances.

Social practice theory and energy consumption

Social scientists have been engaged in energy consumption studies (micro and macrolevel) since 1970s. Lutzenhiser, 1990, reviewed the studies and summarized that it could be investigated through macro and micro levels; at the micro-level it is mostly using end-metering to analyse energy use and load shapes at the household level. Most studies on occupants' behaviour in buildings are focused on measuring physical parameters of the indoor and outdoor environments. Schweiker (2017) summarized literature in the field of occupants' behaviour studies in buildings and found that researchers are starting to look beyond physical impact factors and explore factors from other fields. There also exists a large body of methods, theories and knowledges in social sciences which could add value for occupant behavioural studies (Ajzen, 1991). The word 'behaviour' was used in this study when addressing these questions. As it is the word using in energy-related studies in psychological, economic and technically oriented methods, while in cultural oriented studies use the word 'practices' instead (Gram-Hanssen, 2013).

Many social scientists are investigating ways to reduce energy consumption to meet governments' goals. For example, Marckmann, Gram-Hanssen and Christensen (2012) studies energy consumption in households in Denmark, Shove (2003) and the research team investigates energy demand and change by focusing on social-technical processes, Pink (2012) focuses on the effects of everyday life practices.

Dynamics of Energy, Mobility and Demand point out, as a response to national and international policies and regulations requiring radical reductions in carbon emissions to limit future climate change, researchers have started to answer the question by asking – what is energy demand how and why it is changing. There is an increasing interest in studying energy consumption of households using practice theory (Aune, 2007; Shove, Watson and Spurling, 2015). Energy demand was understood as an integrated outcome of physical and cultural structures of everyday life practices and what people do at home, at workplace and in moving around (Gram-Hanssen, 2013). Pink (2012) indicated that social scientists play an essential role in the increasingly important issues related to sustainability, climate change and the reducing GHG emissions, especially, for activists, policy makers, and governments. And an effective way of understanding how everyday life practice and places are constituted and changed is essential.

Reducing energy consumption is not only about making individuals reduce their energy use, or making equipment and heating system more efficient. Instead, 'radical demand reduction is about shaping the ways in which energy-demanding practices develop over time' (Cass and Shove, 2017). The discrepancy between predicted and measured energy use in buildings exist in all building life cycles. The major driving factors include the uncertainty in design modelling, occupant behaviour, and poor operational practices, which exist in both domestic and non-domestic buildings (Dronkelaar *et al.*, 2016).

As the above researchers have suggested, occupants' behaviours or practices are related to the sensory places by activities and objects which create a certain 'atmosphere' (e.g. home, community, etc.). Most of these practices involve using sources like electricity and gas. Different occupants would create different 'atmospheres', and correspondingly consume energy differently. Heating in winter is a big part of annual energy consumption in the UK. Energy related to heating contributes a large proception in domestic buildings. End use space heating constitute 65% of annual energy consumption in domestic sectors (National Statistics, 2019), which excludes hot water and cooking. In this study, the focus is on common spaces and shared facilities residential buildings, how its occupants behave in common and private spaces, adaptions to the indoor environment in wintertime, and how that affects energy use in the building.

4.1.2 Research hypothesis and research questions

With the above research context and background, this chapter presents the research questions of this study and describes a research design to answer them. Based on the above sections and the conceptual framework obtained in the previous review (see chapter 2 and 3), these research hypothesis and research questions are formed and listed as follow, as presented in Section 1.3.2:

Research hypothesis:

- Collective housing has the potential for energy savings over equivalent individual dwellings.

Research questions:

- What, if any, are the features of collective housing that affect energy consumption and energy-related behaviour of collective housing in design and in-use stages?
- What lessons can be learned from existing collective housing projects' challenges and experiences to provide sustainable guidance for future projects?

4.2 Research methodology

In this section, the methodology is established to respond to the above research hypothesis and research questions. In order to research the energy saving potential of collective housing over individual dwellings, it is important to explore the unique features of collective housing in architectural layout, residents' activities, occupant behaviours and how these features affect social and environmental sustainability in this building type. To understand what energy-related activities in both private and common spaces a in collective housing buildings and why residents interact with spaces in certain ways requires the researcher to explore individual's experience and perspectives in detail. Therefore, the research method selection needs to consider how to get rich and nuanced experiences of individual residents in collective housing with less bias, and how to capture the usage of spaces by residents effectively.

This section explains the rationale for research methods used in the study and the reason they are picked to use among all the available methods in the field. Depending on the aims of the study (as follows), qualitative research can be used to explore concepts, and gather in-depth thoughts on the topics.

- to investigate different types of collective housing;
- to explore the sustainable features of collective housing in both design process and in-use stage;
- to find out the challenges in collective housing communities in the UK; and
- to explore what lessons could be learnt from existing experiences to guide future collective housing projects.

4.2.1 Literature review

In this study, the literature review was conducted at the start of this research, as presented in Chapter 2 and Chapter 3. It helps to explain Objectives 1 and 2 of this study: To review the definitions, development, and sustainable features of various types of collective living housing; and to explore the impact of building design configurations and occupant behaviours on collective housing's energy consumption.

The literature review started with a Google Scholar search on study and design about co-housing community. The content reviewed include co-housing concept, history and development, benefits and challenges, case studies, and existing research topics. As more literature were reviewed, I constantly return to the initial research questions, and reformulating and narrowing them as literature review progress. In the meantime, literature materials are categorized into several groups relevant to the research questions, which provides background and context for this study.

As the literature topic gradually took shape, keyword searches began to be used primarily. Keywords used in the Chapter 2 search include, ‘co-housing’, ‘intentional community’, ‘collective living’, ‘sustainable community’, ‘sustainable neighbourhood’, ‘co-living’. Keywords used in the Chapter 3 search include, ‘energy-related occupant behaviour’, ‘building simulation’, ‘energy consumption’, ‘residential building’, ‘home energy use’, ‘social practice’. Searches are mainly conducted using the university online library, Google Scholar, and Scopus.

The quality of literature materials is determined by the judgement of whether the article is well argued or using proper methods; the citation index of the article, and whether it is peer review or not. Apart from journal articles, books and reports are also reviewed. Source of these materials are from reference list of key journal articles, library search and recommended publications by related organizations.

4.2.2 Prototype building modelling

It was found through the study of different types of collective housing that the building size, layout, project location, range of function rooms, and occupant group vary. It is not feasible to copy all the collective housing building types in this study. Therefore, this study focuses on study collective living in single building. In order to identify the main impact factors of building energy consumption for this building type, a prototype of a single collective living building with private and common spaces was created as base model in Chapter 5 for testing. It specifies a few aspects that most affect the building’s energy consumption. Therefore, provides key aspects for the following fieldwork.

There are software tools (Figure 4.1) available to model and simulate the energy performance of buildings. Building performance simulation tools can be categorized into the following classifications: 1) simulation engine (EnergyPlus, DOE, etc), which have detailed settings and are complicated to operate; 2) software that docks to simulation engine (DesignBuilder, Sefaira, eQuest); 3) plugins for other software and tool, like Green Building Studio in Revit, OpenStudio and HTB2 in Sketchup, and Honeybee Ladybug in Rhino, etc (Han *et al.*, 2018).

Energy simulation software, such as IES-VE, DesignBuilder, EnergyPlus, DOE-2, DeST, are the commonly used tools for building energy simulation at early design stage. DesignBuilder uses the EnergyPlus simulation engine and provides a user-friendly interface for professionals, architects, and researchers in the field. This software package includes a three-dimensional interface, capable of producing dynamic and comprehensive building energy simulations (Taleb and Sharples, 2011). The accuracy of the simulation engine used in DesignBuilder - EnergyPlus was assessed and approved by National Renewable Energy Laboratory (NREL), using Building Energy Simulation Test (BESTEST) methodology (Polly, Kruis and Roberts, 2011). The energy consumption simulation is produced by DesignBuilder (Version 5.5) in this study, as it is based on the EnergyPlus dynamic simulation engine, has a user-friendly interface, and can easily make changes on simulation settings.

SAP2012 is the UK government’s national calculation methodology for assessing the energy performance of dwellings (DECC, 2014). Occupancy patterns and SAP 2012 heating patterns (PP219) were applied into the DesignBuilder simulation model.

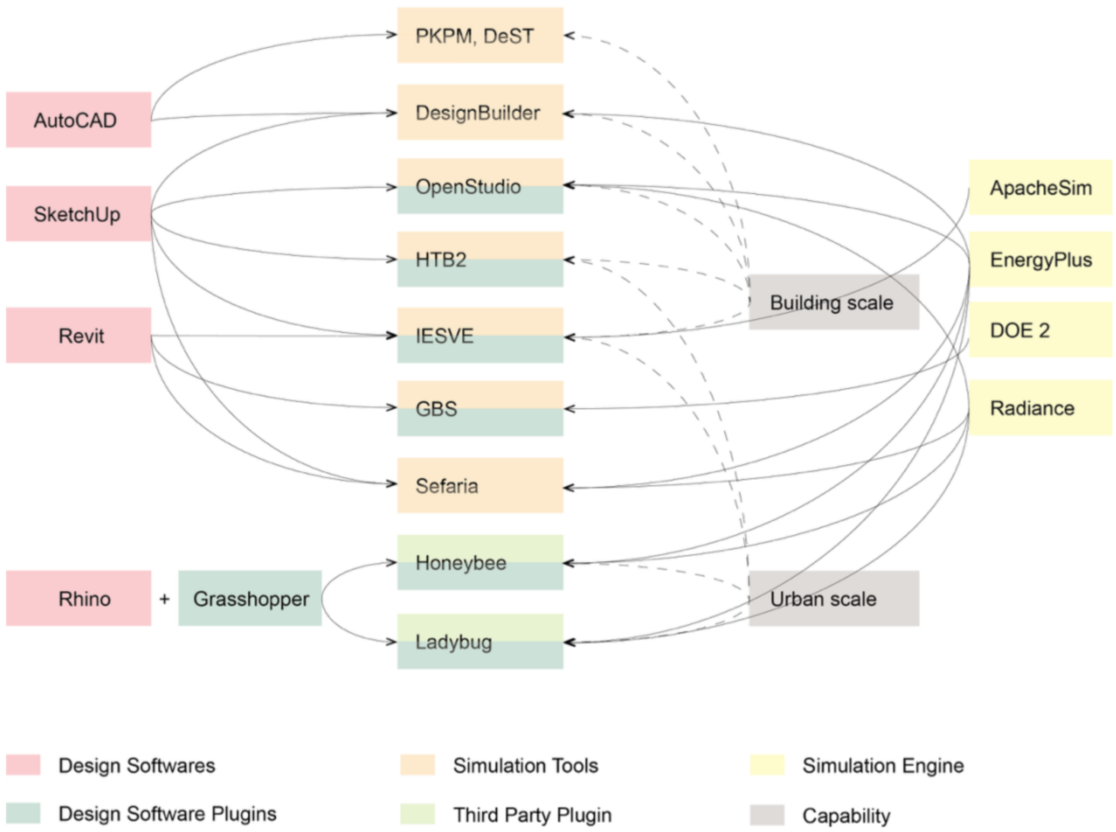


Figure 4. 1 BPS tools.

4.2.3 Qualitative research methods review and selection

Before proceeding with the understanding and selection of the research methods, criteria for suitable qualitative research methods are listed below according to the purpose of this study:

- Researcher should have as little influence as possible on the subject of the study.
- The discussion topics with participants should be directed by the researcher.
- Requires a detailed understanding of what the occupants' energy-related behaviours are and why they interact with collective housing in a certain way.

Given the aim of this study is explore the features of collective housing that affect energy consumption and energy-related behaviour, a non-experimental study is adopted. In a non-experimental study, the researcher does not influence the behaviour of the study phenomena, but observes and understand the subject being studied. Case study, multi-case studies and comparative research, cross-sectional studies, and longitudinal studies are some of the non-experiential study methods (Robinson and Seale, 2018).

Criteria / Method	Little influence	Direct topic	Detailed understanding
Case study	✓	✓	✓
Multi-case studies and comparative research	✓	✓	✓
Cross-sectional studies	✓	✓	✓
Longitudinal studies		✓	✓

Table 4. 1 Qualitative research methods and criteria.

Among these methods, longitudinal study has been used by researchers to explore occupant behaviour patterns (Langevin, Gurian and Wen, 2015; Sun *et al.*, 2018), as well as assess indoor environmental quality (Thatcher and Milner, 2016), mostly in office buildings. It was excluded from consideration because it requires more intensive, longer-term occupant participation.

The basic kind of case study design explores detailed analysis of a single case and the complexity and specificity of the case is the focus of case study research (Stake, 1995). When two or more cases are explored, a comparison study is usually involved. Multiple-case study helps to improve theory building, which by comparing two or more cases, the researcher is gaining more relevant concepts to an emerging theory (Clark *et al.*, 2021a). Additionally, comparison study draws out the unique and common features of cases. However, it needs to be noted that criticism of multiple-case study also exist. Dyer and Wilkins (1991) argue that there is a tendency for the researcher to focus less on the specific context and more on the differences between cases.

The case study research method is a better fit for research questions which explore the ‘how’ and ‘why’ (Yin, 2018). This study explores how residents use common spaces and how would these affect energy use in the building in different collective housing communities, and discusses the reason behind. Multiple cases are selected (Section 4.3.1) to explore collective housing communities, including co-housing, co-living and sustainable community.

This includes desk-top research of co-housing and co-living projects in Chapter 6, and two field studies of co-living and sustainable community projects in Chapter 7.

4.2.4 Qualitative research data-collection methods

Architecture research often uses a wide range of research methods to explore a topic. And context, methodology and theory are three parts that combine to shape an architecture study (Ray, 2016). Context-led research is used to identify a typical context which provides an case study for other projects; methodology-led research starts with an existing methodology and applies it to a new context, which test the applicability of a research methodology and possibility for further research; theory-led studies can use a number of different methodologies and often are cross-disciplinary (Ray, 2016). This study integrates a range of established methods used by previous researchers, which provides a comprehensive approach to explore different types of collective housing communities.

a. Qualitative research data-collection methods review

The following commonly used qualitative research data-collection methods in architectural study is discussed in this section:

- Interview, including structured, unstructured, and semi-structured interviews;
- Questionnaire, guided and self-completion questionnaire;
- Focus group;
- Observation;

Interviews are widely used in social science research, including structured interview, semi-structured interview, and unstructured interview. Structured interviews usually have a rigorous group of questions that do not let interviewer and interviewee to divert. It reduces mistakes which caused by interviewers' variability, improves accuracy in data collection, and lowers the difficultly of data processing (Fowler and Mangione, 1990). Although this research method is commonly used in social science research, it has the following challenges. Some respondents' answers have a social desirability bias, whereby individuals' responses to questions are influenced by their perception of what is socially desirable. The exploration of residents' everyday energy-related behaviour in this study may be a sensitive topic for some respondents, which makes it challenging to get their answers with as little social desirability bias as possible. Researchers have proposed several suggestions to reduce social desirability bias. Tourangeau and Yan (2007) suggested self-administered questionnaires or computer-assisted self-interviewing which could increase privacy and reduce social desirability bias. Other approaches to reduce social desirability bias include the use of ‘forgiving’ wording and a ‘loading’ strategy to encourage respondents to answer more truthfully (Groves *et al.*, 2009), and an ‘everybody-does-it’ approach (Bradburn, Sudman and Wansink, 1982). However, its validity was criticised by Presser (1990), and Näher and Krumpal (2012). Another challenge and critique of structured interview, survey interview, questionnaire and other similar less interactive techniques is the ‘problem of meaning’ which implies that interviewer and interviewee may referring different things in their use of words (Clark *et al.*, 2021e).

Semi-structured interview typically refers to an interview guide where researchers have a group of questions prepared but do not necessarily follow the sequence of the questions (Bryman, 2012). Semi-structured interview is suitable if researchers have a relatively clear focus, as it allows them to explore more specific issues. This requires interviewers to have a good knowledge of the field and be well informed about their topics. Additionally, semi-structured interview would benefit multi-case-study research because it ensures cross-case comparability (Clark *et al.*, 2021b). Bere, Godinho and Dina (2014) used semi-structured interview in a study to explore co-housing design intention and performance of development with design and delivery team. These interviews helped the researchers to explore how co-housing development differs from mainstream housing development from design and delivery professionals’ perspective. Langevin et al (2015) carried out 32 semi-structured interviews as part of a longitudinal study on occupant behaviour in air-conditioned offices in the US. The semi-structured interviews helped to shape and develop survey instruments and provide guidance and idea with interpretation in data analysis stage. Unstructured interviews also known as free-flowing conversations, which are often more informal in style. Such freedom also allows interviewees explore more paths and focus other than the questions asked by interviewers (Lucas, 2016a).

Apart from how interview is designed in terms of structure, there are also different ways to carry out interview that include face-to-face, telephone, video, and computer-assisted interviews. The ways to carry out interviews in research depend on the research aims and objectives, and their feasibility in a case.

In a face-to-face interview, the interviewer can explain questions or terms to interviewees when needed, which avoid ‘problem of meaning’. It also gives the interviewer more freedom to probe for more detailed information. However, it is more expensive for travel and stay on site, and it is one of the most time consuming methods for both interviewers and participants (Seale, 2018).

An alternative is a phone call interview. Several researchers have used phone calls to pick proper case studies for investigation, to find out the reason for certain unusual performance, to investigate how their participants interacted or behaved during the observation period. Love (2014) called two of her participants in her research on occupants’ interactions occupants, heating and building fabric, to find out why a monitoring point dropped. Topouzi (2015) used the phone call method to collect data effectively on 26 cases investigated in the research. One of the benefits of using the phone call method is that it is straightforward and quick when collecting answers to simple questions. It is also very cost effective when compared with some of the other observation methods, which usually involves traveling and a period of time spent on site. The limitation of the phone call method is that it requires more willingness of participants’ engagement, which should be discussed and agreed with participants in the consent form before the field study is carried out.

There are differences in the flexibility of qualitative research. Data collection methods like online survey, structured interview and close-end questions are suitable to the researchers who are clear about what they expect to find out. It is less flexible compared to semi-structed interview, focus group and observation, which give researchers some flexibility at the start of a research. Researchers can emerge themselves in a study and gradually formulate their specific research question as their research progress (Clark *et al.*, 2021a).

Observation requires research to immerse in the community that aiming to study (Nicholls, Mills and Kotecha, 2014). Researchers should see what happens, listen to what people say, make conversations, and focus on data collection related to research aims (Hammersley and Atkinson, 2019). It provides rich data and understanding that might be missed by other data collection methods. However, the researcher's varying degrees of subjectivity is the potential weakness of observation method (Mack *et al.*, 2005). Spradley (1980) identified three phases of observation: descriptive observation, focused observation, and selective observation. There are many options exist on what to be observed on the field. Janesick (2016) suggested careful decisions should be made about which aspects and what events and activities need to be observed, that would help to answer the research questions.

b. Selecting qualitative research data-collection methods for this study

Research methods are used as a tool to gather information to explore and answer the research questions. With the strengths and weakness of each of the qualitative research methods explained above, this section explores what methods are used in this research and the reasons of using them. Suitable data-collection methods must meet the following criteria:

- Be capable of gathering enough information to develop an understanding of how people experience and use collective housing features.
- Interviewees are free to express their views and comment either positively or negatively on the questions.
- Be able to understand the underlying reasons for respondents' energy-

related behaviour on collective housing.

When selecting the data collection methods for this research, in addition to considering the advantages and disadvantages of the methods themselves and their suitability for the research problem, the feasibility of the methods should also be considered. Taking these considerations into account, this study used face-to-face semi-structured interview, unstructured interview, questionnaire, and observation for qualitative research data collection. Next, each of them is discussed in detail on how they are appliable to this study.

Face-to-face semi-structured interview is selected as the main field qualitative data collection method to explore how people use collective housing features, what occupant behaviours are associated with energy consumption, and the reasons of these behaviours. It is mainly used in this research (how interview was conducted see section 4.3.2), as it is much more open with interview topics and directions, which allows the interviewer to ask further questions when needed. The advantage of this method ensures that first, interviews were conducted in the direction designed by the researcher; second, the interviewer can ask follow-up questions if needed; and lastly, the interviewer can update the interview questions in response to changes in the surrounding environment. Unstructured interview is also used in this research in the form of ‘conversational’ interviews with unplanned talk with residents during the field study.

Questionnaire is designed as a backup in this study when semi-structured interviews cannot be carried out. Based on observation and communication with the site managers during the first visit to the selected field study projects, one of the projects had a small number of users in its common spaces, which might have problem in finding participants to do interview. Therefore, a survey questionnaire with open-ended questions was designed (see detail in section 4.3.2) to explore how residents use energy in their home and the open-ended questions allow them to provide more ideas and opinions.

In order to explore the energy-related behaviour and sustainable features on the in-use stage of collective housing communities, observation on what sustainable measures there are in the community, how the residents use energy-related facilities in common spaces are carried out during field study.

The focus group method is not used in this study to collect on-site data. Because the information collected includes personal routine and preference, the participant might hesitate to give honest answers in a group discussion. The participants may subscribe to a kind of group thinking and be influenced by each other. This could be a problem or a benefit in different research situations (Lucas, 2016b). While in this stage of the research, as we are asking occupants' own behaviours in common spaces, therefore, we are expecting as fewer influences among occupants as possible in the data collection.

4.3 Qualitative research design

Through the discussion of research methods in the previous section, the appropriate method for this study was selected. This section aims to explain how these methods have been applied in this study. Starting with sampling fieldwork case study which states the criteria for selection of case study, source of potential case studies, and the reason for choosing the final case studies. Then each qualitative data collection methods used in the fieldwork were discussed. The last section explains how field data was documented and stored.

4.3.1 Sampling fieldwork case study

Purposive sampling involves strategically selecting information-rich cases. Research questions should be used as a guide to which people, location, and the focus of attention are taken into consideration in the case study sampling, in which researchers are able to generate meaningful data towards the aims and objectives central to the research (Clark *et al.*, 2021c). The study focuses on looking at the potentials in sustainability in the design and operation of common spaces and shared facilities in collective housing communities. Therefore, types of common spaces and shared facilities communities are considered. They have different levels of sharing among these communities, also in different aspects including share of using common spaces, share of facilities, share of time and effort, share of responsibility, and share of management. Co-housing, co-living and sustainable community stand at different points of these spectrum (Figure 4.2).

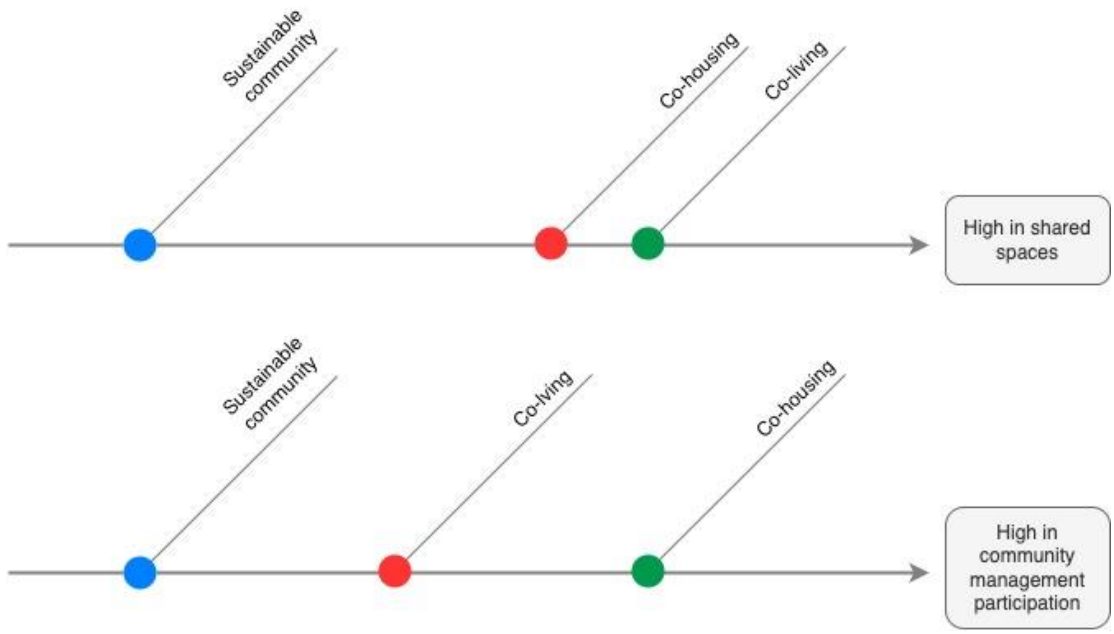


Figure 4. 2 Differences of collective housing communities.

As the scope of study is new build communities in urban area, all the selected case studies are located in cities. Most of the co-living and sustainable community projects are built in one building block, while most co-housing projects are laid out as terraces or clusters. Based on the focus of the study, first of all, the case studies should pick from residential projects designed with similar collective concepts – including co-housing communities, co-living apartments, sustainable communities. The case recruitment process was based on co-housing projects shown on UK Co-housing Network web, articles, papers about contemporary co-living schemes worldwide and web-based search of sustainable communities.

Three case studies (in Chapter 6) were selected for desk-top research, which aims to gain in-depth knowledge of the sustainable features, occupants' energy-related behaviour, and the challenges and benefits of different types of collective housing communities and select one case study from each co-housing wave. Therefore, the cases selected for this part of the study have different attributes, including different locations, time of build, and different purpose of building. The amount of useful information that can be collected and the sustainability of the case itself are also considered while selecting. The first desk-top case study is selected from Kathryn McCamant and Charles Durrett's book *Co-housing: A Contemporary Approach to Housing Ourselves*. The authors are the founders of the co-housing movement in the United States. They selected and presented eight co-housing community projects in Europe in the book, which represented the earliest co-housing communities. A list of features of these co-housing communities are as follow (see Table 4.2). After considering the project highlight and the amount of information presented in the book, *Sun and Wind* co-housing project was selected. *Sun and Wind* project was highlighted for its focus on reducing energy consumption in design and planning, and use of renewable energy. The second desk-top case study is aimed to study co-housing projects in the second co-housing wave. UK co-housing started to develop in 1990s and the planned field case studies were in the UK. Therefore, sources include UK Co-housing Network website, book *Co-housing In Britain*, book *Thinking about Co-housing*, and journal paper about UK co-housing, were considered when finding the case study suitable in this study. It was narrowed down to two projects, *Springhill* in Stroud and *LILAC* in Leeds. Both projects are designed with a low energy mindset. Eventually, *LILAC* was selected as there is more information available for reference. The third desk-top case study aims to explore recent and diverse housing projects that are inspired by the co-housing concept. This study mainly focuses on co-living communities. As co-living communities are relatively new, there is limited in-depth research on them. Co-living communities are widespread in major cities, e.g. London, New York, many cities in mainland China, Taiwan, Seoul. Before finalizing the case study on *9floor* co-living in Taiwan, some other projects are also considered - co-living communities in mainland China have been explored, but most of the information is about the design of the projects and there is a lack of research exploring occupant activities. *Treehouse* completed in 2019 in Seoul, was a well-designed 76-unit co-living complex. It was designed with consideration to create a good living experience for both private and common spaces. However, there is limited information about the project's energy use, occupant and living experience. *9floor* co-living is selected because it is the first co-living community in Taiwan, the founder of the project documented detailed information about the project in his master's thesis, and there are several video interviews about this project. But one of the disadvantages of this case is that there is very little information on the energy consumption of the building.

Project Name	Highlight	Location	Number of units	Completed Year	Ownership	Common house	Information
Sun & Wind	Saving energy together	Beder, Danmark	30	1980	private	550 m2	development goal; agreement; energy system; timeline; conversation transcript;
Jerngarden	Imporving on city life	Aarbus, Demark	8	1978	private	187 m2	site plan; ten years later describe; city;
Jystrup Savvaerket	design to improve winter time socializing	Jystryp, Denmark	21	1984	cooperative	404 m2	section; floor plan; private unit; development process; some resident interview;
Mejdal 1	One leads to another	Holstebro, Denmark	12	1979	private	200 m2	site plan; architect as resident; makeing workshop successful; surburban;
Mejdal 2			14	1985	private	150 m2	
Jernstoberiet	From iron foundry to cohouisng	Roskilde, Denmark	21	1981	private	300 m2	retrofit from an iron foundry; site plan; planning and design detail; section; community life today;
Tornevangsgarden	small-scale	Birkerod, Debmark	6	1978	private	190 m2	design detail; creation; floor plan; site plan;
Drejerbanken	Half owners, half renters	Skalberg, Demark	20	1978	private and rental	474 m2	organizaing agreement; site plan; house design; floor plan; management; one interview transcript with a resident
Bondejerget	Rental and support from housing association	Odense, Denmark	80	1983	rental	360 m2	rental cohousing community; site plan; floor plan; section; management, maintenance and common activities;

Table 4. 2 Eight co-housing communities in McCamant and Durrett (1988).

Two case studies were selected for field study[2] (in Chapter 7), which aims to explore first hand data on sustainable features and how residents on collective housing communities use common facilities and spaces. The field study case selected for this part of the study are two urban collective housing building blocks. The location, resident size, and accessibility are taken into account for case study selection. The Collective Old Oak co-living was selected for being the first and largest purpose built co-living building at the time (PLP Architecture, 2016). It has the key features of co-living building and relatively large numbers of literatures about it are available. One Brighton project was selected because it took lessons learnt from the UK's first sustainable community BedZED.

The following table summarized the profile of the two field study cases:

Name	**One Brighton**	**The Collective Old Oak**
Type	Sustainable community designed with sharing concept	Co-living apartment
Location	Brighton, UK	London, UK
Occupation date	2009	2016
Building info	172 apartments, offices, community space, and a café in two multi-storey blocks	546 rooms in total. 16000sqm.

[2] Three case studies were planned for field study. Due to restrictions of Covid, two case studies were carried out just before the lockdown.

Table 4. 3 Profile of fieldwork case studies.

Though these communities are inspired by co-housing concept, they are different in many ways - the size of common spaces, the level of intensive in the community. Below are listed some features of the communities:

	One Brighton	The Collective Old Oak
Common to private spaces ratio	Low	High
Intensive community	Low	High
Community management	Low	High

Table 4. 4 Features of fieldwork case studies.

4.3.2 Fieldwork

The design of the field study is developed from Stake's (1995) case study fieldwork guide.

Case Study Field Study Guide	
Anticipation	- what is expected in a case study? - what are the boundaries of the case? - what are the research questions? - what are the potential observe objects?

	- what should be included in the final report? - form a plan of action.
First Visit	- discuss potential costs; - discuss arrangements for maintaining confidentiality of data; - discuss need for persons to review drafts to validate observations; - discuss publicity to be given during and following the study;
Further Preparation For Field Study	- work out record-keeping system; - rework priorities for attributes;
Further Development of Conceptualization	- reconsider issues or other theoretical structure that may contribute to data gathering; - sketch final report plan; - pay attention to different viewpoint;
Gather Data, Validate Data	- take observations, interview, survey, etc,; - keep records of inquiry arrangements and activities;
Analysis of Data	- review field data; - explore patterns in data; - seek links between activities, and outcomes;

	- draw conclusion;
	- review data, see if new data are needed;

Table 4. 5 Adjusted from field data gathering guide by Stake (1995).

Visits were arranged to each of the field study project prior to carrying out the field study. The researcher conducted a one-hour community tour with *One Brighton*'s community managers in April 2019, which provided an initial understanding of the community on how common spaces were used and what facilities are available. It was found that the most frequent places encounters with residents are at the entrances and lift lobby, but not in the common spaces of the building. This helps in the design of the field study method in this project, which used poster and questionnaires to recruit interview participants. A poster about the study was posted on the entrance notice board of the building, and questionnaires and a questionnaire collection box were placed at the lift lobby. The researcher arranged a private community tour with a *The Collective Old Oak* resident before contacting The Collective for a field study, which learnt about that some of the amenity spaces in the building were heavily used by the residents and could be good spots to recruit research participants.

a. Interview

The case study projects all have common spaces where occupants spend time together. It is a good place to recruit participants and produce face-to-face interviews. The interviewees don't need to make extra effort to participate into the study; therefore, they might be more willing to take part in the study. As the study is focusing on looking at energy consumption and saving potential in wintertime, the field study contains site visits to the two case studies during Dec 2019 to Mar 2020, when heating is largely used in residential buildings. The duration of site visits to each case study is one to two weeks. All interviewees are voluntary and randomly selected. During the interview, a routine table was used to make it easier for the researcher to record the interviewees' routine. Interviews are carried out in common spaces in all case studies and recorded by a Sony recording pen with interviewees' consent.

A total of 14 semi-structured interviews were carried out at *The Collective Old Oak* project, including one with the architect, two with the community host and eleven with residents. The interviews were conducted by the researcher between Jan 2020 to Mar 2020. All interview with community host and residents were conducted and recorded at *The Collective Old Oak* common spaces.

b. Questionnaire

There are some principles to consider when designing a questionnaire, which include the layout and presentation, clear instructions of answering questions, and putting questions and answer together (Clark *et al.*, 2021d). Additionally, the choice of which mode of survey administration to use also needs to be based on the consideration of research questions together with their practicability in the case. Commonly used modes of survey administration include in-person, telephone, postal, email and online questionnaire. Email questionnaire was considered in both cases in the planning stage, because emailing the residents in the community would be the lowest cost and fast way to reach participants. However, both case's project managers refused to provide the email address as that it was private information. In-person questionnaire was selected to use for data gathering.

Researcher-administrated questionnaire is designed for the field study on *One Brighton* project. The questions on the questionnaire were designed with research questions in mind and with reference to Building Use Survey (BUS). There are four sections designed on the questionnaire A) general information, B) use of common spaces, C) energy using behaviours, and D) energy saving awareness.

During fieldwork on *One Brighton* project, two questionnaires were researcher-administered, and one followed with a one-hour interview. Five questionnaires were self-administered by participants and returned to the researcher.

c. Observation

Stake (1995) suggests that researchers should keep records of key events during observation for further analysis and reporting. It helps the researcher to document the situation and facilitates a more comprehensive analysis of the data after the fieldwork is completed. The observation data collection methods are developed from literature. Given and Leckie (2003) studied user's experience in two library public spaces with an observational approach – the 'seating sweeps' method. The benefits of this method are that researcher has the opportunity to find out what people really do in the observed space, and explore the data that is difficult to collect via other methods. Whyte (1980) studied sitting patterns in parks and plazas, which sighting map is used to quickly document the location of every sitter with information including gender, alone or with company. This method allows researcher to record relatively rich information within short period of time. It provides data to support following analysis, including density of use and common space activity.

Observation is another site task during the field study, which collects occupants' activities, numbers, location, etc., in different common spaces. The observation periods are divided into 6 time slots – 7-9 am, 9-12 am, 12-2 pm, 2-6 pm, 6-8 pm, 8-12 pm. During these time periods, the researcher will record the use of common spaces in the building in the following mapping method (Figure 4.3).

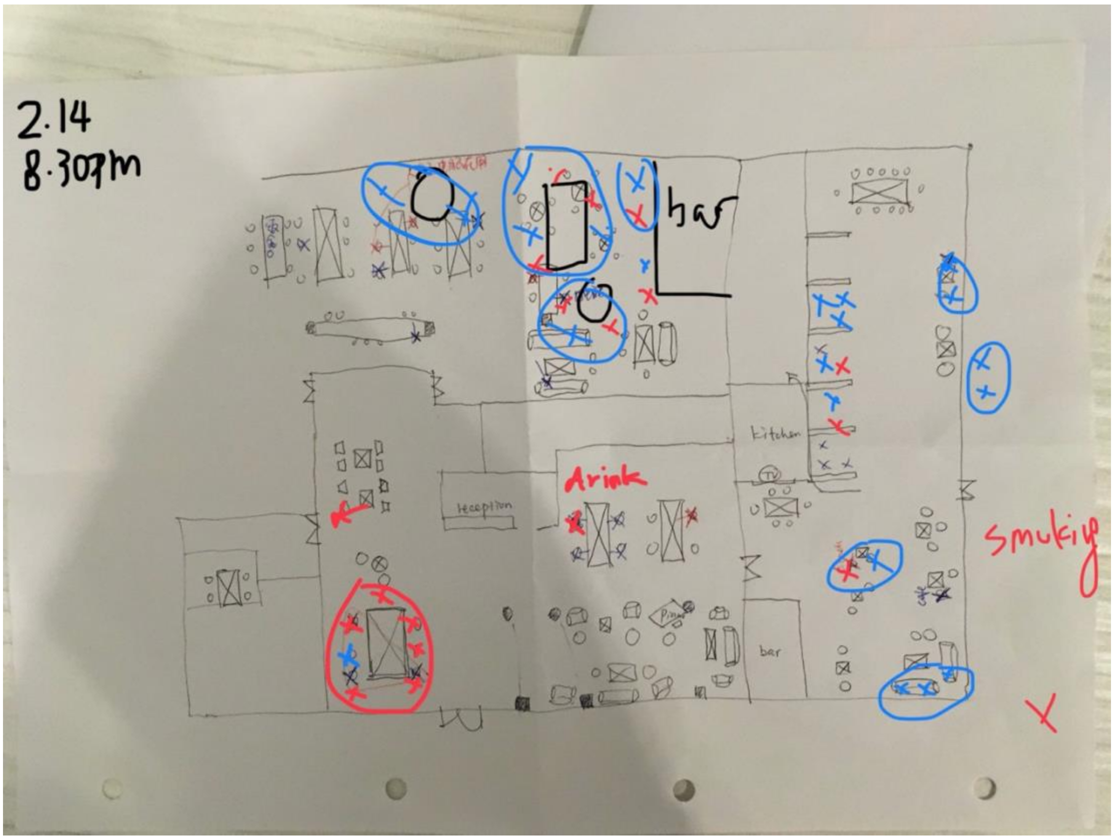


Figure 4. 3 Mapping the use of Ground floor common spaces. (Red indicates a woman and blue indicates a man. The circles are drawn to indicate that these people are interacting, like talking or playing games.)

4.3.3 Data documentation

A field journal was recorded digitally in an Excel document that reflected each day's site information. Photography on site is also used as supporting field data. Photographs only include photos of the common spaces in both field sites and for privacy concerns no photos of the residents were taken. Therefore, text and descriptions are needed to describe the use of space. Field photography was categorized into common spaces layout, space atmosphere, shared items, community notice, and surroundings.

4.4 Field data interpretation

This section explores various method for interpreting qualitative data. By understanding the advantages, disadvantages and boundaries of various analytical methods, thematic analysis is applied to this study in helping to generate findings. The rationale for the choice of this analytical approach is discussed in relation to the research questions of this study. In addition, the plan and process for the field analysis is described in detail at the end of this section.

4.4.1 Analysis method review

There is no set procedure or rules to follow in qualitative data analysis. With the large numbers of analysis methods in qualitative research, researchers have the opportunity to choose suitable ones depending on the nature and aim of a study. Some of the most commonly used qualitative data analysis methods include ethnographic accounts, life histories, content analysis, conversation analysis, discourse analysis, analytic induction, grounded theory, thematic analysis, interpretive phenomenological analysis, and narrative analysis (Spencer *et al.*, 2014: 270).

In occupant behaviour and sustainable community related topic studies, ethnographic accounts, grounded theory, and thematic analysis have been used in the past to explore the social perspectives of ‘how’ and ‘why’ research questions:

- *ethnographic accounts* are descriptive and use detailed information to illustrate the way of life of certain individuals, communities, and groups (Ritchie *et al.*, 2014; Hammersley and Atkinson, 2019).
- *grounded theory* ‘means that theory was derived from data, systematically gathered, and analysed through the research process’ (Strauss and Corbin, 1998). The relationship of data gathering, analysis and theory generation are

closely linked with one to another. And the theories built up through data are more likely to provide in-depth knowledge.

- *thematic analysis* is ‘a method for identifying, analysing and reporting patterns (themes) within data’ (Braun and Clarke, 2006b), and interprets different aspects of the research subject (Boyzatis, 1998).

One example is Jarvis' (2011) ethnographic accounts of the infrastructures of daily life on collective housing communities in the UK and US - the detailed picture of everyday life in these communities helps people to rethink the way of living and how to promote sustainability. Thematic analysis was used by Carr and Fang (2022) to explore findings that emerged from qualitative data collected about lived experiences around independence/ dependence of the retirement community in the UK and Australia. Zhao (2014) adopted grounded theory together with quantitative methods to research about occupant behaviour in Passivhaus, in which the qualitative data collected and analysed through grounded theory allowed themes to emerge from both the fields of build environment and holistic social domain.

This study employs thematic analysis as the method to analyse qualitative field data. The major advantages of thematic analysis are 1) flexibility - the method allows a wide range of description of the data set, and the themes within data can be elucidated either in an inductive approach (‘bottom-up’) or theoretical approach (‘top-down’); 2) can summarize key features of a large amount and various types of data (Braun and Clarke, 2006b). In this study, the qualitative data are collected through various methods and resources; thematic analysis allows the researcher to generate meaningful insights and provide an in-depth description of the data set.

The two main methods for thematic analysis are Braun and Clarke's (2006) six-stage process and a matrix-based framework developed by National Centre for Social Science (Ritchie *et al.*, 2014). This study follows Braun and Clarke’s thematic analysis method.

4.4.2 Field data analysis

Interview recordings are made into transcript and together with other qualitative data analysed using software MAXQUA. The field study data contains many types of data, including recorded voice file, text, transcription, website, PDF file, image, video, and photo. The software was chosen because it has high data capacity and can store more file types in one place.

Thematic analysis method was used to interpret the field study data for its flexibility and ability to analyse multiple data types including qualitative surveys, interviews, secondary sources materials, online materials, and observation materials. The six steps guide for thematic analysis proposed by Braun and Clarke (2006a) is summarized as follow:

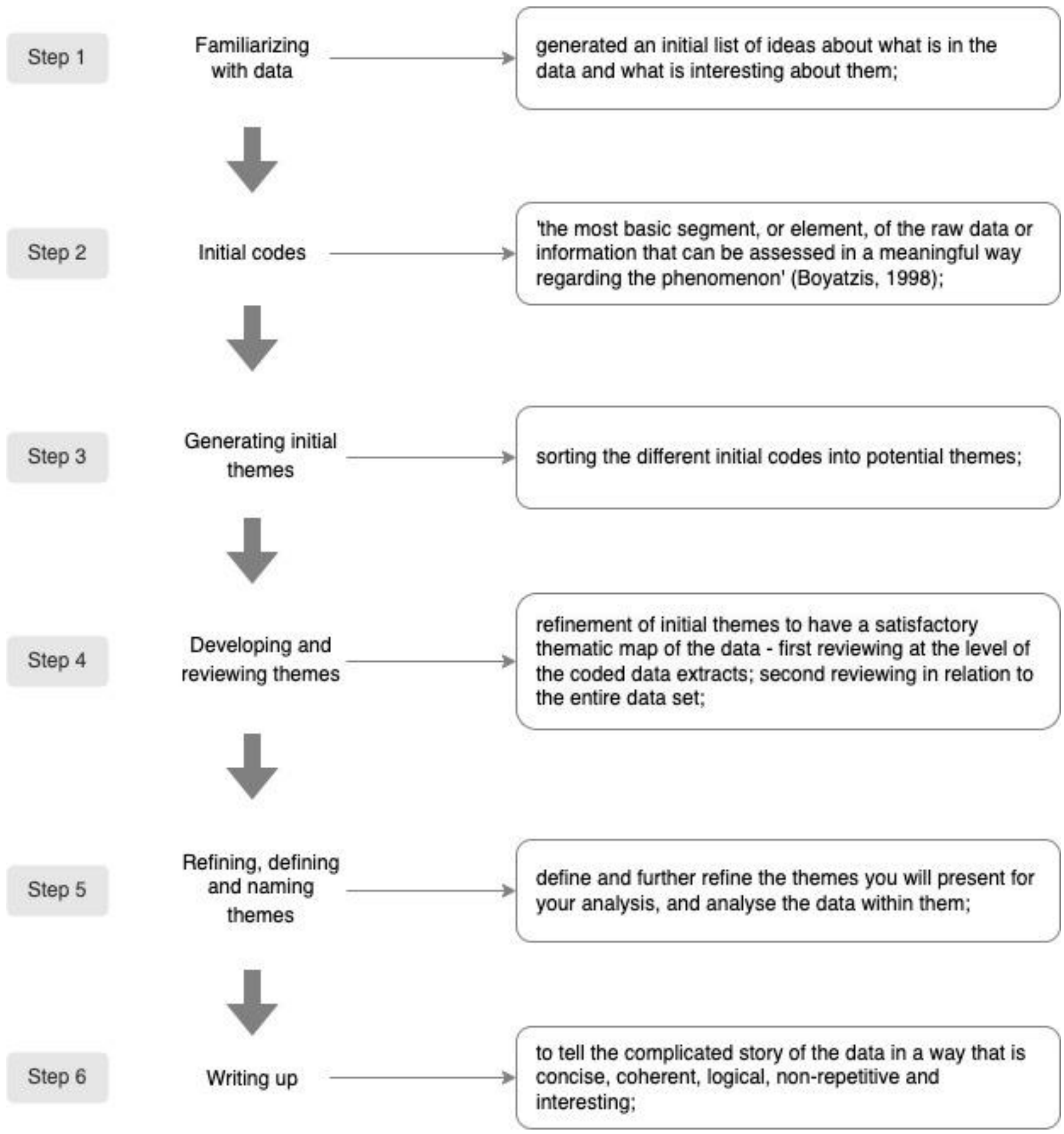


Figure 4. 4 Thematic analysis process adjusted from Braun and Clarke (2006a).

The field data analysis starts with *familiarizing with raw data* by transcribing the interview records, sorting out observation notes, tidying up field photos and maps, and collecting case related secondary material. Next, *initial codes* are produced to organize data into meaningful groups which provide a rich and broader set of data for next step's theme generation. See table 4.6 for an example.

Raw data extract	Initial coding

'I think the community aspect is quite like underappreciated here. I mean under appreciated by other people who live outside. So it's wrong. It's very good not under appreciated by us. Sometimes we take it for granted. I heard from people who moved out that it just felt very new – meaning It's like we're on our own. It's not like we can socialize whenever we feel like it, just walk down to the kitchen and just small talk to random people. And it's a little different. But when you're here, you feel like normal. That's the normal.' (Interviewee: R10)	1. resident talks about community aspect in co-living 2. meeting friends in co-living 3. 'normal' ins and outs of co-living community

Table 4. 6 Raw data extract with initial code applied.

After all data have been initially coded, in step 3: *generating initial themes*, a mind-mapping method was used to organize all the initial codes into candidate themes. In the next two steps, these candidate themes are reviewed and refined to the final themes which provide a comprehensive understanding toward the research aims, with concise names given to these themes.

4.5 Limitations of the method

The limitations of the study come from two aspects, the challenges of the chosen research methods themselves and the impact that COVID has had on the research.

The challenge of the chosen research method is that case study method is hard to generalize. The specific field study methods vary due to the individuality of each case. The qualitative research methods used for one case study might not always suitable for other cases.

In addition, due to the epidemic, only two of the three collective living community cases originally planned were completed. Fieldwork had been planned for three collective living communities with varying degrees of common facilities and sharing practices – co-housing community, co-living community (case study The Collective Old Oak in this study), and sustainable community with sharing facilities (case study One Brighton in this study). However, the first visit to a co-housing community (March 2020) was cancelled due to lockdown, and the case study of co-housing community was not able to be conducted. Considering the uncertainty of lockdown (as in duration and restriction) at the time, decision was made to give up on the fieldwork of the co-housing community. Instead, the focus was switched to co-housing literature and finding relevant insights from ethnographic studies. The disadvantages of this method are, firstly, existing ethnographic studies are conducted based on the authors' own research focus and does not necessarily fit in with the focus of this study. Therefore, finding suitable literature that fits this study is challenging; additionally, compared with conduct fieldwork, existing ethnographic studies found in literature are spread over different times and regions, which are not first-hand and most up to date.

4.6 Summary

This chapter summarises the literature review conducted in the previous chapters, which then leads to the research questions for the research in section 4.1. It then presents the combined methods which employed qualitative research to help answer the research questions. It explains the rationale for research methods used and the reason they are picked to use among all the available methods in the field. Literature review provides an overview of existing knowledge of collective housing and energy-related behaviour in home, relevant research topics, theories, and gaps in the existing studies are identified. Prototype building modelling was used to test different building factors' impact on building energy consumption. As the result suggests, common spaces in collective housing was identified as one of the most energy consuming feature, which provided a research topic for the following field study. Case study method and qualitative field study approach were used aiming for present rich, detailed, and descriptive data set of selected collective housing examples. Then in section 4.3, how the qualitative research was designed for this study was explained, including sampling fieldwork case study, methods of conducting fieldwork, and the data collection details. Following by the presenting of field data interpretation in section 4.4, which consists of a review of field data analysing methods and the field data analysis process of this study. Thematic analysis method is used to analysing collected qualitative data in this research. Lastly, limitation of this study's methodology was discussed.

Chapter 5 Massing Studies of Co-housing Building Typology

This chapter starts with stating the reasons for studying the impact of building massing on annual energy consumption, which is to investigate which building design elements have the greatest influence on building energy consumption in co-housing buildings. Then, it presents the building modelling details including model layout, simulation settings, and testing parameters. After that, it specifies the suitable software to use and explains the settings. Finally, the results and analysis are presented.

5.1 Introduction

The purpose of this chapter is to explore the geometric design parameters of building massing that have the most impact on co-housing energy consumption. Building massing is found to impact both energy consumption and energy production (Ndiaye, 2018). Additionally, geometric design parameters including window size and location, orientation, floor height, and surface-to-volume ratio affects daylighting, heat gain, and natural ventilation, which in turn affects the energy consumption of the building.

Five geometric design parameters of the co-housing typology model are tested in this part of the study which aim to explore their impact on building energy consumption. This helps the following research on identifying research topics and finding focus for the planned fieldwork.

5.2 Building modelling and alternatives studied

The building typology of co-housing was first analysed to construct a simple model for simulation. The base case model was then set up with basic building information. Finally, geometric design parameters related with building energy consumption are discussed and five geometric parameters are selected for testing with the parameters for each group listed.

5.2.1 Co-housing community typology

Pfeifer (2015) interpreted typology as ‘one among many’, with repeating and in principle similar elements. Existing research about co-housing typology is limited. Guinther summarized co-housing typology as: retrofit co-housing, urban infill communities, traditional co-housing, and eco-village (Guinther, 2008). However, it focused on the location of the site rather than community shape and form.

When co-housing concept was introduced to America in late 1980s. McCamant and Durrett generated four types of low and medium rise co-housing building forms (see Figure 5.1). They are a) a pedestrian street, b) a courtyard, c) a pedestrian street with activity nodes, and d) a glass-roofed atrium.

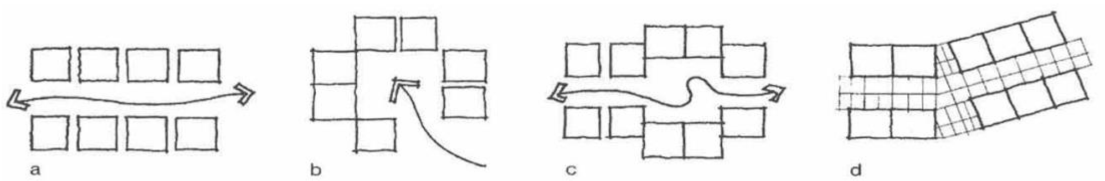


Figure 5. 1 Four generic co-housing building forms (drawing by McCamant and Durrett).

However, co-housing communities shows a high level of diversification, therefore, not all the projects fall within these four types. For example, to gain more solar gain and the restriction of site, Marsh Commons and Cascade Co-housing located their houses in the shape of a single row due to site restrictions and to maximise solar gain (Garham Meltzer, 2005b).

The physical location of a common house within the co-housing community highly influences its success as social centre. Grace Kim summarized co-housing common house location in her thesis and book *Design of the Co-housing Common House* in 2006 (Kim, 2006). These are the type of common house locations: centre of community, central of two wings, gateway to community, focal point, at end of covered street.

In recent years and especially in urban areas, the consideration of urban density and energy efficiency have led to many co-housing oriented communities built to medium and high rise. Examples include Malta Casa in Helsinki (high-rise co-housing), 9 floor in Taiwan (high-rise co-housing), and the collective (co-living apartment). These sustainable living communities all emphasize the value of their common area in the community.

Therefore, in this study, the simulation model includes private units and a common area – see Figure 5.2.

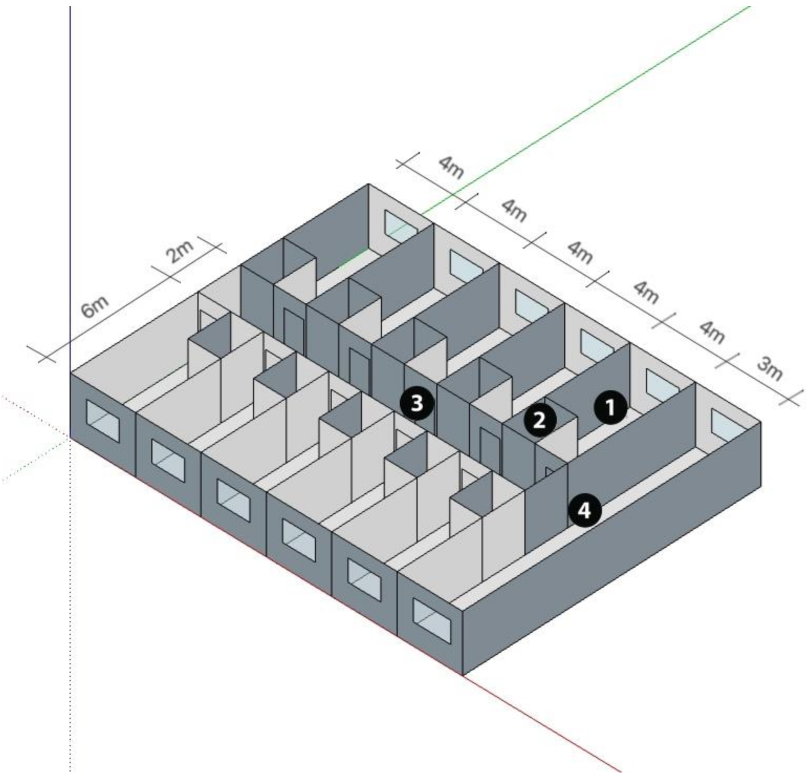


Figure 5. 2 Base case floor plan (1-private room, 2-bathroom in private room, 3-corridor, 4-common room).

5.2.2 Simulation model

The base model for these modelling studies was created as a prototype in DesignBuilder software. The design parameters and defining characteristics are generated from current co-housing projects. The range of design values of each parameter are listed in – Table 1. Building height is affected by number of floors and floor height. Most traditional co-housing communities are low-to-medium rise buildings, and some contemporary co-housing projects are developed as high-rise buildings. The floor height of co-housing buildings is mostly in the normal range, and in some cases, the unit is built as a loft style with a higher floor height. A medium-to-high rise building – 6 floors and 3.3m for floor height are considered in the prototype model in this study. Building orientation is affected by several factors, like layout of roads, existing water features on site, surrounding buildings, preferred view etc, and south is considered as prototype value in the model. Window-to-wall ratio in private and common area are different, common spaces generally have more window area than private units in most cases. The ratio of common to private spaces in co-housing projects are affected by each individual community group, and thus shows a great degree of difference from 0.02 to 0.24. The suggested ratio is 0.13 to 0.17 by the research of numbers of co-housing projects from social perspective (Garham Meltzer, 2005c). The prototype value in this model is 0.17.

Geometry design parameter	Range of design value	Base value
1 Building height	1 – 9 floors	6 floors
2 Orientation	Diverse	South

3 Window to wall ratio	30% - 70%	30%
4 Common to private space ratio	0.02 – 0.24	0.17
5 Floor height	2.7m – 4m	3.3m

Table 5. 1 Geometry design parameters and range of value.

5.2.3 Testing parameters

Several aspects should be considered for studying building energy consumption, which can be categorized into building envelope (building shape, orientation, u-value of floors, walls, and roofs, and shading), fixtures and fittings (u-value of windows and doors, solar heat gain of glass, blinds and curtains), HVAC and equipment (cooling and heating system, CHP, energy storage), and renewable energy (PV, wind turbines, wood boilers) (Longo, Montana and Riva Sanseverino, 2019). This study explores the impact of some building envelope aspects on energy consumption.

The building envelope testing parameters on building energy consumption in existing studies include building shape (Marks, 1997; Wang, Rivard and Zmeureanu, 2006), orientation, window size and area, internal heat gain, thermophysical properties of walls, floors and roofs. Ndiaye (2018) studied the impact of building massing on energy consumption of an office building and the results showed that the east-west orientation group (with various aspect ratios) is the best performer and saved 2.4% over the base-case (a square floorplan building), while the north-south orientation group is 8.5% worse than the base-case. Window size and area affects daylighting and the use of artificial light. The savings come from reducing lighting consumption (Bodart and De Herde, 2002). Surface area-to-volume ratio was considered when selecting the design factors for this study, as it is a representative design parameter related to building heat loss and gain and impacts on building energy performance (Oh, Jang and Kim, 2021). Taleghani et al. (2013) studied the surface area-to-volume ratio of different building shapes and their relationship with building energy consumption, which found out that single shape low floor model has the highest surface area-to-volume ratio and exposed most to outdoor environment whereas linear and courtyard models have lower surface are-to-volume ratios. Additionally, a compact building form can lead to energy consumption reduction. Research on building's surface area-to-volume ratios showed that for the same building floor area, the smaller the surface area-to-volume rate, the lower the heating loads of the building (Gratia and De Herde, 2003). In this study, given the housing function and everyday needs of collective living, many collective housing buildings are designed in the form of multi-storey linear or courtyard buildings. These building shapes and forms already have a relatively low surface area-to-volume ratio, thus surface area-to-volume ratio was not selected to test in this study.

The geometry design parameters considered in the design process include building height, orientation, window-to-wall ratio (WWR), common to private space ratio and floor-to-floor height. Figure 5.3 shows the design parameters that have been tested in this study. Building heights are tested as 3 floor, 6 floors (base) and 9 floors. Orientations are 0 degree (base), 30, 60 and 90 degrees. WWR is set as 30% (base), 50% and 70%. Common to private space ratio are 0.14, 0.17 (base), and 0.22. Floor height numbers are 2.7m, 3.3m (base), and 3.9m.

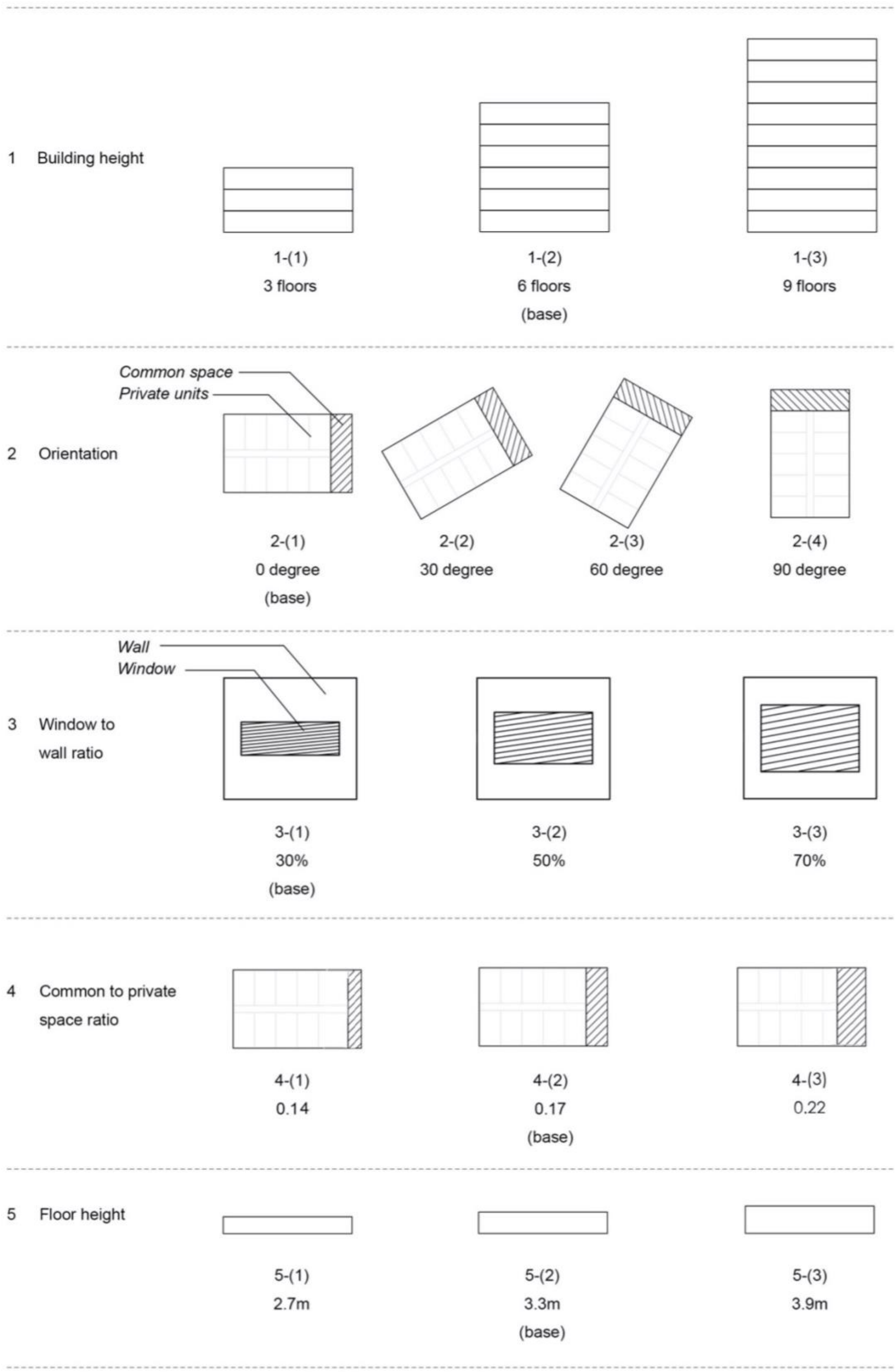

1 Building height
1-(1)
3 floors
1-(2)
6 floors
(base)
1-(3)
9 floors
Common space
Private units
2 Orientation
2-(1)
0 degree
(base)
2-(2)
30 degree
2-(3)
60 degree
2-(4)
90 degree
Wall
Window
3 Window to wall ratio
3-(1)
30%
(base)
3-(2)
50%
3-(3)
70%
4 Common to private space ratio
4-(1)
0.14
4-(2)
0.17
(base)
4-(3)
0.22
5 Floor height
5-(1)
2.7m
5-(2)
3.3m
(base)
5-(3)
3.9m

Figure 5. 3 Geometric design parameters and alternative patterns.

Test 1 examined the impact of building height on energy consumption by varying the number of building floors; the three tested scenarios are three-story, six-story, and nice-story. Other design parameters remain consistent with the base case setting. Test 2 examined the impact of orientation on energy consumption. The base model has a east-west orientation (0 degree), while the test cases respectively have 30 degree, 60 degree, 90 degree counter-clockwise rotation. Test 3 examined the impact of window-to-wall ratio, with all windows were all in the centre of walls with WWR of 30%, 50% and 70%. Test 4 examined the common to private area ratio, testing ratios of 0.14, 0.17 and 0.22. Test 5 examined the impact of floor height on energy consumption by testing floor height of 2.7m, 3.3m and 3.9m.

The basic settings for the five groups of tests are summarized as follow:

Parameters / Tests	Building height	Orientation	WWR	Common to private ratio	Floor height
Test 1: Building height	(1) 3 floors (2) 6 floors (3) 9 floors	0 degree (East-West)	30%	0.17	3.3m
Test 2: Orientation	6 floors	(1) 0 degree (2) 30 degrees (3) 60 degrees (4) 90 degrees	30%	0.17	3.3m

Test 3: WWR	6 floors	0 degree (East-West)	(1) 30% (2) 50% (3) 70%	0.17	3.3m
Test 4: Common to private ratio	6 floors	0 degree (East-West)	30%	(1) 0.14 (2) 0.17 (3) 0.22	3.3m
Test 5: Floor height	6 floors	0 degree (East-West)	30%	0.17	(1) 2.7m (2) 3.3m (3) 3.9m

Table 5. 2 Five groups of tests details.

5.3 Software use and settings

DesignBuilder (Version 5.5) was selected to use as the tool to simulate in this study (full rationale in Chapter 4) not only for its easy-to-use interface, but also for its build-in feature categories: activity, construction, openings, lighting and HVAC system. Each feature has a group of templates to choose from, and can be modified according to the information from the testing project. DesignBuilder models are organized in a hierarchy including site level, building level, block level, zone level, surface level, and opening level. As default data is inherited from the above level, it allows modifying the whole building setting by changing the setting at building level.

The tested building was set to locate in London, and the hourly weather data of London was selected at site level. There are four types of zones in this building model as presented in Figure 5.2: 1) private room, 2) bathroom in private room, 3) corridor, 4) common room. The activities were set using built-in templates and adjustments were made when the templates did not meet the needs. For example, as many London dwellings do not have air conditioning, the cooling section of the template has been changed. Additionally, there is no specific activity template for co-housing common room, therefore, a new activity template data was created for it. Table 5.3 shows the summary of key input for activity in this simulation.

	Occupancy	Heating and Cooling	Equipment
Private room	Density: 0.03 people/m2; Metabolic factor: 0.9	Heating setpoint temperature: 20 ◦C; Heating setback temperature: 12 ◦C;	Computer radiant fraction: 0.2
Bathroom	Density: 0.03 people/m2; Metabolic factor: 0.9	Heating setpoint temperature: 20 ◦C; Heating setback temperature: 12 ◦C;	/
Corridor	Density: 0.22 people/m2; Metabolic factor: 0.9	Heating setpoint temperature: 18 ◦C; Heating setback temperature: 12 ◦C;	/
Common room	Density: 0.24 people/m2;	Heating setpoint temperature: 20 ◦C;	Computer radiant fraction: 0.2

	Metabolic factor: 0.9	Heating setback temperature: 12 ◦C; Cooling setpoint temperature: 23◦C; Cooling setback temperature: 28◦C;	Catering radiant fraction: 0.2

Table 5. 3 Summary of the input data for activity in DesignBuilder simulation.

The construction setting for this simulation used the best practice Lightweight template with u-value of each component: wall (0.25 W/m^{2}K), roof (0.15 W/m^{2}K), ground floor (0.15 W/m^{2}K). Airtightness is set as 0.3 ac/h. Windows were set as double glazing with u-value of 1.98 W/m2K. The lighting schedule is synchronised with activity occupancy schedule and the recessed luminaire type simulate with following data: radiant fraction (0.37) and visible fraction (0.18). The HVAC system was set based in electricity from grid with heating in all zones and cooling only in common room.

The base model is set up according to the above settings. Test cases of building height, orientation, common to private ratio and floor height were modified through layout, and the window-to-wall ratio was modified through opening setting.

5.4 Results and limitations

5.4.1 Results and analysis

Each design parameter is tested separately meaning that in each examination, all the other design parameters are held at the base value. The base value in the study are 6 floors, south facing, 30% of window to wall ratio, 0.17 of common to private space ratio, and 3.3m for floor height. The prototype model is used as the base model here. Energy saving rate is purposed to show the annual energy use in the individual case when compared to the prototype model. The value used in energy saving rate calculation is annual energy consumption.

$$Energy\ saving\ rate = \frac{test\ case\ value - base\ case\ value}{base\ case\ value}\ x\ 100\%$$

The theoretical study of the effect of geometric design parameters of co-housing community in terms of energy performance is presented in the paper. And the primary results are listed as follow:

Among the many factors that influence building energy consumption, floor to floor height, common to private space ratio and WWR are the three top design factors to be consider in medium to high rise co-housing building – see figure 5.4. The impact of orientation and building height are less significant.

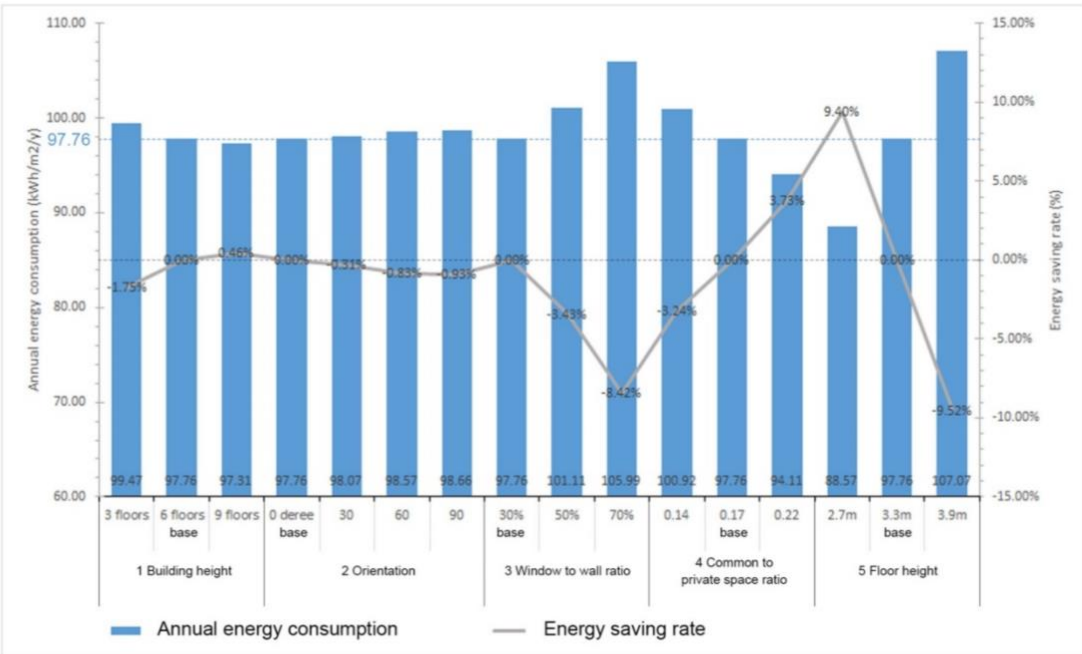


Figure 5. 4 Annual energy consumption and energy saving rate summary.

5.4.2 Limitations and future studies

One of the primary limitations of this massing study is that it was carried before the pandemic using DesignBuilder software on the university's computer. There are some additional simulation scenarios found later in this research that could be adding value to this study which are not tested, because there was no access to the university's computer during the lockdown. Another limitation is, this massing study is focusing on the geometric design parameters, rather than building system, occupancy parameters, fabric materials and climate zones. Real building cases are more complex than this simplified model.

Future massing studies could focus on the common area in co-housing community and alternative community type (use common area as social centre), like modern collective living apartment and student halls.

Occupancy evaluation and thermal comfort study could carry out together with massing study in future projects to form a detailed discussion of potential energy use in collective housing type.

5.5 Summary

The result of the mass modelling test of co-housing building type shows that floor height, common to private space ratio and WWR are the three top design factors to be considered in medium to high rise co-housing building; among which the common to private space ratio has the largest impact. This provides a good point for co-housing building study that the design of common space not only related with many social factors in a community, but also impacts energy consumption. However, this conclusion is based on this simplified model and hypothetical occupancy schedule data. The specific impact of the design of common space on building energy consumption in a co-housing project relies on more information and analysis of occupant activities and project goals. Therefore, how should one design a common space in communities to meet residents' need and aiming to reduce energy use to a minimum? What functions and rooms a common space must have? How people engage with each other in common space? Communities of different scale, size, resident groups and locations have various answers to these questions. In the following chapter, three communities with common spaces are selected to explore what role the common space plays in co-housing and collective communities and how much it contributes to the sustainable goal that communities set to achieve.

Chapter 6 Desk-based Case Studies of Collective Housing

6.1 Introduction

The chapter aims to explore the knowledge of current collective housing in-depth, particularly about their occupant participation and building energy use. Moreover, it seeks to answer the research questions - What are their common to private space ratio, occupant behaviour and energy use? Three residential projects have been selected based on the literature review. These have been included to supplement the later empirical studies because of the lack of in-person access to actual sites dictated by the Covid-19 restrictions in the UK.

Collective housing in different regions and formed in different years demonstrate a variety of design processes, management and operation system, and sustainability features. This chapter focuses on case studies that represent different types of collective housing provides this research with more comprehensive views. They are:

1) two co-housing projects (*Sun and Wind*, and *Overdervet*) in Denmark,

2) one co-housing project (*Lilac*) in the UK, and

3) co-living apartment projects (*WenZhou* and *TaiShun*) by *9floor* in China of different ages, location, development procedures.

Co-living is not a new concept, however there are fewer detailed research and case studies on the emerging type of co-living (available to rent but not buy). *Sun and Wind*, and *Overdrevet* are early established co-housing communities. They were originally the same group of people, but there was a disagreement over the choice of site location, and they split into two communities, *Sun and Wind* located in a suburban area, *Overdrevet* located in a rural area. The co-housing project, *Lilac*, is one of the selected case studies of co-housing by UK Co-housing Network. It was the first co-housing to use the Mutual Home Ownership (MHO) model, which provided affordability and reduced personal financial risk for their members. It also practised ‘fabric first’ using straw and wood to build private homes in *Lilac*, and installed several renewable technologies to reduce operational energy. *9floor* is an early practitioner of co-living in city and there are many reports, interviews and one research thesis about it. They provided good cases for comparing co-housing communities in different areas. The detailed information of these projects are listed as follow in Table 6.1.

	Location	Age	Units	Type	Tenure	Introduction
Co-housing projects in Denmark						
Sun and Wind	Denmark	1980	30	New-build	Private ownership	30 units co-housing community best known for use of renewable energy sources
Overdrevet	Denmark	1980	25	New-build	Private condo	25 units rural co-housing community with energy-conserving design

Co-housing project in the UK						
Lilac	Leeds, UK	2013	20	Eco-build	Mutual Home Ownership Scheme	20 eco-build households in West Leeds
Co-living apartments by *9floor* in China						
WenZhou	Taiwan	2015	1	Re-designed	Rental	Redesigned to co-living flat with four rooms.
TaiShun	Taiwan	2015	1	Re-designed	Rental	Redesigned to co-living flat with three rooms.

Table 6. 1 Information of case studies.

6.2 Case Study 1: *Sun and Wind*, and *Overdrevet*

6.2.1 Project background

Sun and Wind, and *Overdrevet* projects are co-housing community case studies in Kathryn McCamant and Charles Durrett 1988's book 'Co-housing: A Contemporary Approach to Housing Ourselves'. McCamant and Durrett introduced co-housing to North America for the first time and this led to the 'second wave' of co-housing development (Sargisson, 2012). They are discussed here together because they started out as a single project.

In 1976 Denmark, three medical students organized the initial meeting for the establishment of a living environment with several needs, women raising children alone, emotionally gratifying for parents, and safe for children to grown up. The meeting was attended by singles, single parents, couples and families, all with different aspirations. But they agreed on a tentative proposal of a community, which included shared facilities, common outdoor area, vegetable garden, focus on community and use renewable energy.

The initial group split due to different preference on community location. One year later (1977) one group established *Sun and Wind* in a suburban area south of the city (Aarhus) in Beder, the other group established *Overdrevet* in rural area north of the city (Aarhus) in Hinnerup. *Sun and Wind* project covers an area of 21,000 m^2, the size of two football pitches. There are 27 households are either terraced or detached houses, with floor areas ranging from 85 to 150 m^2. *Overdrevet* project comprises 25,000 m^2 and has 25 private homes for over 70 people with mixed age.

6.2.2 Architectural layout, design process and resident participation

Site

Both projects were completed in 1980. In *Sun and Wind* project, the architects' group Regnbuen, together with the residents, designed the scheme jointly. The residents participated in preparing plan proposals, interior design for both common and private houses. In the following years, many residents as well as children participated several joint activities, such as building the bicycle sheds, football pitch, and the construction of outdoor area.

Figure 6. 1 Sun and Wind project site plan (Bofællesskabet Sol & Vind, 2022e).

The L-shape building in the middle of the site contains the common house and bicycle and tool storage. The vegetable garden and soccer field are located on the north of the site. The triangular area on the south is the playground.

The planning processes

Comparing the process of *Sun and Wind* + *Overdrevet* project against the 7 stages of architecture design (RIBA, 2020), it is found that the initial group plays a very important role in the course of the project before architects joined. The initial group plays a key role in the early-stage decision-making by setting development goals and work out an initial organizing agreement. At the same time, it is also important to seek support from professionals at the right time.

The initial group started by defining goals, clarifying intentions, and bringing new participants up to speed on existing decisions. The development goals set by the initial group are 1) 25 households will participate in planning and design of the community and private houses; 2) affordable payments to accommodate people with diverse income level; 3) two-story houses to use as little land as possible and cars parked at the edge of the site; 4) minimum energy consumption through planning and design; 5) use of renewable energy; 6) small dwellings easy to be modified and added to when in need; 7) generous shared facilities and open space for group activities and boost social interaction. They also started a newsletter and formed work groups covering seven topics, which are site, fiscal, energy, ecology, common house, children's interests, and architecture (McCarmant and Durrett, 2011c).

Many decisions were made on site location, choice of architects to work with, recruiting professionals, codesign method, finance and growing the community. The initial group divided on the question, where to locate the community, and later split into two groups (*Sun and Wind*, and *Overdrevet*). *Sun and Wind* group set committee to research and visited the sites which proposed by the county. In the same year, each member paid 5000 DKK (the equivalent of £485 in the UK in 1977) for attorney to help with real-estate negotiation, agreements among residents, and legal questions (McCarmant and Durrett, 2011c). After interviews several architects, residents selected architecture practice Regnbuen. The codesign progress that the residents and the architects used is unique. They held design classes as part of the county school adult education program. The program lasted for months, they came out with the design of site plan, common house, and private houses at the end. The final site plan was published on local plan portal on 15th Jan 1980 (Aarhus Municipality, 1980).

Residents' participation in construction

Residents played a big role in the preparation and implementation of construction as well. The Construction Development Council sponsored the whole user-driven construction (Bofællesskabet Sol & Vind, 2022b). Once the contractors finished their parts as planned, the common house was the first scheduled to be completed by residents. Then 3-5 homeowners were grouped together as a team to finish their private houses one by one. The residents self-constructed parts include lay wood floors, ceiling finish, kitchen cupboard and appliances installation, and painting (McCarmant and Durrett, 2011c).

It is a good strategy to first build the common housing and to group homeowners together as teams so that they can gain experience in building the common housing before building their own homes (McCarmant and Durrett, 2011c). Furthermore, people have different skill sets and grouping homeowners in teams can bringing out the best in different people, which could make the self-build more efficient. Of course, good teamwork is based on mutual trust and a shared vision of the team as a group, which is usually easier to establish in co-housing communities.

6.2.3 Residents' use of space and community events

Common House

The common house (coloured in red in Figure 6.2) is about 600m2, which located in the middle of the site. It is the centre and first place for residents to meet each other, as well as organizing community events.

Figure 6. 2 Perspective drawing of the site by Arkitektgruppen Regnbuen (Bofællesskabet Sol & Vind, 2022e).

As the social hub of the community, the common house has functional rooms such as common kitchen, dining room, workshop, laundry room. There are flexible used rooms that can be booked for parties, meetings, and special occasions (birthday, wedding, etc). The common house contains the following function rooms (Table 6.2). And there are some picture of common house shown in Figure 6.3 (Bofællesskabet Sol & Vind, 2022a).

Room	Note
Communal kitchen	With industrial machines – oven, frying pans, potato peeler, mixer, dishwasher, etc.
Dining room	Seat for 90-100 people.
Communal laundry	Has washing machine, dryer and ironing roller.
Large freezer	For both shared food and sing-house food.
Cooled shed	For vegetable storage.
Workshop	Various machines.
Depot and technical room	With a descaling system to provide soft water for washing machine.
Newspaper room and TV lounge	With subscription to several newspaper and one major TV channel.
Activity room	Pool table, table tennis, table football, sofa, drawing table, small stage, etc.
The pillow room	Used by children for pillow fight and relax.

Teen room	Can be booked and used for all teenagers for game, TV and fun.
Guest room	Double-beds could be booked for guests.

Table 6. 2 Rooms and their functions in the Common House.

Figure 6. 3 Picture of common house. Left: pool table. Right: dining room (Bofællesskabet Sol & Vind, 2022a).

Meals

Like many co-housing communities, shared meals are one of the key activities here in *Sun and Wind* community as well. It is voluntary to participate in the 'meal plan', which one should commit to join the food team one week in every five weeks. Most people joined the meal plan in *Sun and Wind*. The food team would do the week's chores (four people cooking and three washing). During the week, each person should cook three times and wash twice (Bofællesskabet Sol & Vind, 2022d). In return, for the rest of time, members could relax and enjoy dinners without shopping, cooking, clean and wash up for a very low price (equivalent to less than £3).

Compulsory and voluntary activities

Most of the activities or tasks are voluntary in the community. However, cleaning the common house is a compulsory task for adults and older children. It is cleaned every weekend and each member usually attend the cleaning once in every eight or nine weeks. Other maintenance related tasks, such as painting, setting up racks, or weeding shrubs are voluntary. These tasks are arranged once per year, called ‘working days and weekends’, usually is two working days and two weekends activity. Joint meeting is a regular activity for residents to propose votes and make decisions. The topics cover big and small, from huge investment in the community to discuss daily rules on what should or should not do in the laundry room. The joint meeting holds on the first Sunday of each month on the evening for 1-2 hours, except for July and August (Bofællesskabet Sol & Vind, 2022c). There is still a lot of freedom in living here, with only one weekend of compulsory cleaning activity all year round. And plenty of community-building activities that residents can volunteer for.

6.2.4 Sustainability

Solar panels installed made *Sun and Wind* the largest and *Overdrevet* the second in Northern Europe on private owned solar collection system. *Sun and Wind* community has 600m^2 liquid-filled solar panels installed on the common house (as many as the common house roof area can take) and 15 private houses. The two heat accumulation tanks are located under the common house, which have total hot water storage capacity of 76 m^2. The solar panel system provides 30% of the community’s total energy requirements, through hot tap water and radiant space heating via underground pipes (Sheehan, 1997; McCarmant and Durrett, 2011b; Bofællesskabet Sol & Vind, 2022b).

The installation of the solar panel and collection system echoes well one of the development goals originally set by the community, to minimum energy consumption through planning and design. However, the solar panel installed on private houses were removed after 20 years of service (in about 2000). The southern part of the common house’s roof is used for solar heating and contributed to the later installed district heating (Bofællesskabet Sol & Vind, 2022b).

6.2.5 Lesson learned and critical review

Forming Process and Resident Participation

Sun and Wind, and *Overdrevet* project are set up in a different form to a conventional community. It is challenging for the participants in terms of the investment of time and effort. From the first meeting organized by three medical students in 1976 until residents moved in June 1981 (Bofællesskabet Sol & Vind, 2022b), it took about six years for *Sun and Wind* to complete. And the average completing time for co-housing communities ranging from three to ten years, depending on whether or not they are available to financial resources and professional services (The Cohousing Association of the United States, 2022a). With good management and organization, the completed community would be more in line with the vision of the residents. This is because from the early days of the community, members discussed and agreed on needs and visions, build up trust through participating numbers of meeting, and self-constructed their own homes. The connection continues after residents moved in through regular monthly 'joint meetings', shared meals, use of common house, and many activities. Holding activity and encourage residents to participate are good ways to foster community, however, this may leave the residents less free time for themselves or even get burned out. One resident of *Sun and Wind* community mentioned (2011b) feeling envious of their friends who could chill with a cup of coffee and Sunday paper on the weekends. This doesn't mean the co-housing residents don't have time to relax though.

The design processes and operation of *Sun and Wind* is different from a lot of other communities. The members of initial group, who started the project and participating from the early days, played a key role in the forming and designing process. Other residents who joint later also participated till the construction of the community. The initial group set *Sun and Wind*'s development goals, choose community location, purchasing land, interviewed architects to cooperate with, and hire professionals (attorney, lawyers, engineers, etc) as project progress. There were many design-decisions to be finalised during this period. For example, a final agreement was created at the end of 'design class' arranged by the architects and members of *Sun and Wind* (McCarmant and Durrett, 2011c). By agreeing on the designs in this way, the group prevented people raising objections to the design afterwards. After the residents have moved in, the community was operated by an executive committee (forretningsudvalg) of five people. Along with community activities, it also held monthly joint meetings where residents discuss and vote on all kinds of decisions they need to make. These decisions and operations require the community to have organisational capacity and an efficient management system. In the meantime, dealing with different views in the community and reaching consensus are important. At the very beginning of the *Sun and Wind* project, they recognized that there are different socioeconomic points of views among singles, couples, and families. They worked out that they have enough overlapping interests for them to form a co-housing community. These interests include use of renewable energy, emphasis on community, shared facilities, common outdoor areas and vegetable gardens (McCarmant and Durrett, 2011c). Identifying their shared interests helps community members to reach a consensus on the priorities of the project. Although this may need some people to compromise in some cases, residents do have the opportunity to personalise the design of their own houses with the architect as much as the budgets allow. *Sun and Wind* eventually developed five types of private house models for the residents with different needs (McCarmant and Durrett, 2011c).

Sustainability Potential

Reducing energy consumption and using renewable energy are the development goals of *Sun and Wind* community. The solar panels provide 30 percent of the community's total energy requirements and the windmill satisfies 10 percent (Sheehan, 1997). *Sun and Wind* perceived a grant of 500,000 DKK for their prototype energy system (including solar panel system for space heating and domestic hot water, windmill to generate electricity, and a solid-waste incinerator to provide supplemental heat) in May 1979 from the European Union and the Danish government, in return, they would open to visitors with interests in renewable energy (McCarmant and Durrett, 2011c). Some renewable features operated for several years, while others not. After 20 years of service, the solar panels were partly replaced by district heating, and the wind turbine was removed as the need of renovation or facing scrapping. The incinerator was replaced by a ventral gas furnace just after one year of use, as it 'took too much work to operate' (McCarmant and Durrett, 2011b).

The spotlight on the community gained publicity and helped them with growing membership and improve community rapport. However, not everyone enjoyed this especially in the years when the community was first built. McCarmant and Durrett (2011a) had a conversation with Thomas, a 38-year-old father to a five-years-old who residents at *Sun and Wind*, and he expressed the biggest drawback of living there is the outside attention - some weekends, 'there were more people wielding cameras than there were residents', especially, many of them are 'uninvited and unannounced'. This is less likely to be the case now, as many co-housing would organize open days and precent a lot online. Also because co-housing concept is not considered radical but become an alternative way of living for some people to consider.

A project SWOT analysis as follow:

Strengths	Weaknesses
Executive committee (forretningsudvalg) formed by residents managed the housing association on a daily basis (Bofællesskabet Sol & Vind, 2022c). Diverse and have people with different skill set in the community. Form connection and trust through numbers of meeting, discussions and activities.	Long project process (about six years in this case). Expensive if without grant or financial support.
Opportunities	**Threats**
More say on design for residents. Ideas and suggestions could be brought up and considered at joint meetings.	The unpredictable turnover of members. Disagreements may arise if a member feels taken advantage of.

Table 6. 3 Project SWOT.

6.3 Case Study 2: *Lilac*

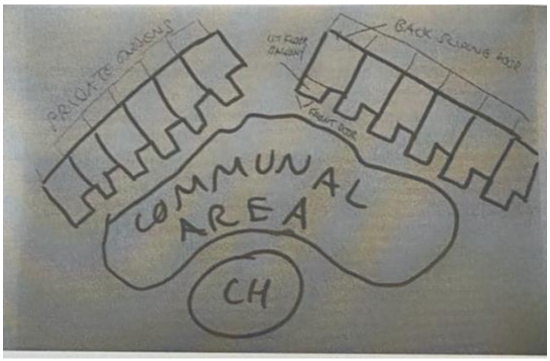
6.3.1 Project background

Lilac is one of the co-housing communities showcasing on the UK Co-housing Network website. It provides affordable homes for all residents with 'strong and flourishing neighbourhood where they can directly participate' through low impact living. *Lilac* explores sustainability in economic, social, and environmental aspects. Its Mutual Home Ownership (MHO) model provides an affordable approach to home owners, where MHO society members contribute financially on the basis of their income (UK Cohousing Network, 2022). Environmental sustainability is reflected in the use of natural materials, reduced energy consumption in all project phase, and the low energy bill. These features makes *Lilac* an outstanding example to study the sustainability benefits in co-housing community. Chatterson (2015) described the planning and design process of the community in detail in his book 'Low Impact Living: A Field Guide to Ecological, Affordable Community Building'. It is further discussed in several peer reviewed papers with good citations about *Lilac* project.

This pioneering, affordable, and low impact co-housing community project completed in 2013 located in the Bramley area of Leeds in the UK. It contains 20 homes (12 flats and 8 houses) and a common house for shared use, built with 'fabric first' design principle. The 3 million project received 410K grant from the Department of Energy and Climate Change (DECC) and the Homes and Communities Agency (HCA).

6.3.2 Architectural layout, design process and resident participation

The site was located at Wyther Park, Leeds. This 0.7-hectare (7000 m^2) L-shape plot was a former primary school demolished in 2006. With the initial key elements of the project agreed in an early meeting in 2009, the members held the first member-led design meeting in the end of May and did some general layouts of blocks through sketches (see Figure 6.4). The key elements include the number of units and blocks, the orientation of blocks, location of private gardens, communal area, car park, play area and food-growing area. Before meeting with architects, the member-led meeting covered a number of topics, including cars, orientation, boundaries, materials, gardens, block layout, gathering places, site levels.



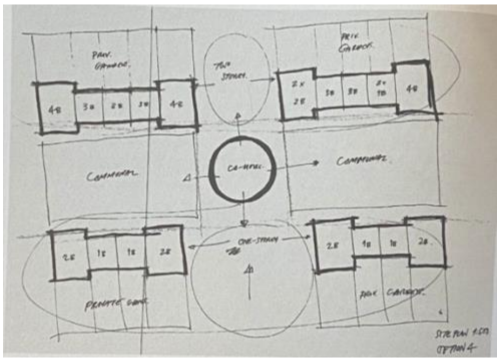


Figure 6. 4 Paul's initial sketch of the layout of the blocks (L), Roger's sketch (R).

The members of *Lilac* produced a framework for the collective design process together with the architect White Design. The framework consists of four parts: site, internal home layout, the Common House and energy strategy. The member-led design meetings are usually a few days before the design meetings with architect. *Lilac*'s design process consisted of three rounds of design (one member-led design meeting and one design meeting with architect) and a finishing design. The design programme started on 31st May in 2010 and closed with the finishing design meeting on the 21st of August 2010.

On the first meeting with White Design by Adriana and Craig White in June 2010, four site designs were provided for *Lilac* to choose from. Members eventually chose the site design (Figure 6.5) that contained 20 homes in five blocks with internal floor area of 1518m^2, and a Common House in the middle.

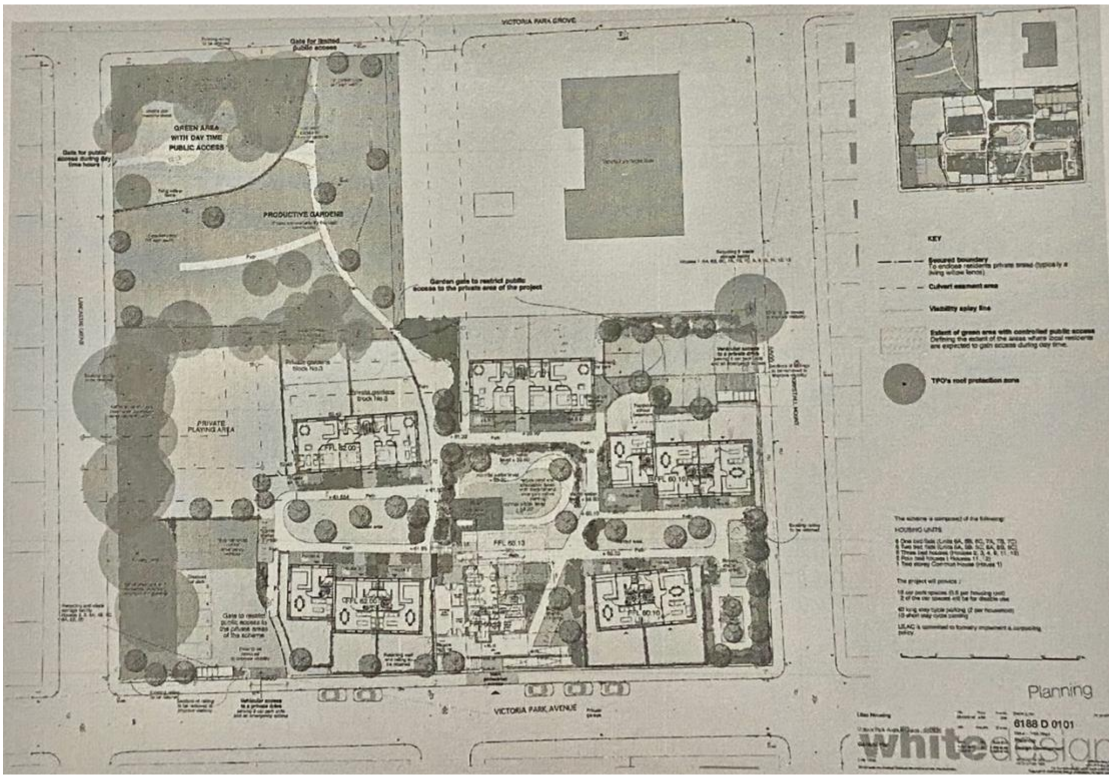


Figure 6. 5 Final site layout (Chatterton, 2015e).

Before *Lilac* formally hired an architect, six members held a design day facilitated by Roger (an architect friend of one of the initial members) in April 2009. They came up with a list of principles that they would like to follow for the internal layout of homes. The internal design is more constrained by budget and the choice of the modular Modcell build route. Other challenges included how to maintain window patterns of the street to satisfy the planners and how to make sure all houses also faced inward to create a sense of community. The architect presented initial internal layout designs to the residents and it went through several revisions (Chatterton, 2015f). There are 24 lists of principles presented to guide design of internals, in which four items are in relation to reduce building energy demand design (south-facing homes, houses long and thin to capture sun into houses, use of ceiling-to-floor glass, and smaller north-facing windows). Additionally, these initial principles also covered layout of site, use of spaces, equity in design (similar benefits for all household), and resilience in design (flexible internal stud walls).

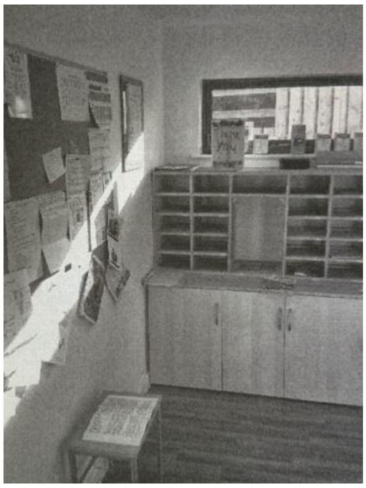
6.3.3 Residents' use of space and community events

Common House

The Common House (Figure 6.6) is a space that residents used every day to pick up post and mail, dine together, meet up, do laundry, and use workshop. The design of Common House started from late 2009, with over one year of discussion, compromise, and redesign, the tender documents were ready in mid 2011.

Figure 6. 6 Common House in Lilac. Source: Andy Lord

Due to the budget constraints for the Common House, the architect from White Design reduced the initial 300 m^2 design to 135 m^2 which meets the estimated budget of £150K. Hard choices were made about what essential features the residents want to retain. The final features of Common House are listed in Table 6.4.

Room	Note	
Office	/	/
Main dining room	Large enough for everyone to eat and hold other events, like general meetings, exercise, and films.	
Kitchen	Used for community meal preparation.	/
Lobby/post area	A small area for residents to collect mail and post. Notice-board is hanging on the wall.	
Flexible function room	With facilities include bookshelves, children play area, projector and media equipment.	
Sitting nooks	Window nook is designed to the south side.	/

Toilet	/	/
Laundry	Located in a shed attached to the Common House.	
Food store	Located in a shed attached to the Common House. For community owned stuff.	/
Workshop	Located in a shed attached to the Common House.	
Teen room	Received planning approval for future phases.	/
Guest bedrooms	Received planning approval for future phases.	/

Table 6. 4 Rooms and their functions in the Common House. Source: Lilac

The original plan was for community members to be involved in building the Common House. Self-build process required the contractor to provide training and supervision, which would be more expensive. Additionally, community members were also considered for doing the interior and decoration, but due to there are too many tasks (running society, finances, membership building) at the same time, members did not have the capacity to carry out the construction work. Therefore, at the end the Common House was built with a timber frame with locally sourced materials by contractor Lindum Group (Chatterton, 2015g).

Meals and community activities

Community shared meal works through a meal token system. Token money of those signed up for the meal would cover the meal spending (each token cost £3). In general, one needs to cook once every six weeks, and can receive about 12 meals. Community shared meals are hosted at least once a week (Chatterton, 2015g), and an interview of resident even mentioned they'll have shared meal three time a week (House Planning Help, 2015).

Since completion of the project, community members are expected to participant in some shared duties, including Common House cleaning rota and unlock and lock the gate to the public park at dawn and dusk. Community shared meals are not compulsory, members who signed up for meal are expected to take turns to cook and clean up.

6.3.4 Sustainability

Lilac project followed the 'fabric first' principle for the building construction, and achieved great insulation with low U-values (see table 6.1). The scheme as a whole meets Level 4 of the UK Code for Sustainable Homes (CSH4). The operational energy was benefit from using PV, MVHR units, gas boiler, and solar thermal panel. One mid-floor *Lilac* flat rated B in its SAP Energy Performance Certificate (Sharp, 2013), compared to 'D' for the UK average.

Using natural materials

Lilac agreed on the need to use low impact natural building materials at the beginning of the project. They chose straw and wood because these materials provide opportunity for them to self-build their own houses and because they could be processed locally. This not only reduces the carbon footprint of the materials during transport, the use of straw and wood in the construction itself is also considered low carbon and high performance in insulation. The carbon emissions of 1 cubic metre of straw are 14.12 kgCO2e/m3 (StrawWorks, 2022). And a standard plastered straw wall can achieve U-value of 0.11 which better than Building Regulation (ADL1A, 2022) requires. In order to build their home using straw and wood, members spent several months researching the advantages and disadvantages of building with straw and wood. Some members joined short course with Low Impact Living Initiative in London about timber frame buildings, and a course with Amazonails in North-England about their pioneered experience of strawbale construction. However, due to the lack of suitable people, skills and time, *Lilac* eventually selected Modcell to do the construction of the house. Modcell provide prefabricated strawbale and engineered timber system. The U-values of completed building are lower than the building regulation (Table 6.5)

Element	U-value W/(m^2/K)	
	Lilac project	2010 UK Building Regulations
External wall	0.19	0.3
Floor	0.23	0.25
Roof	0.16	0.20

Window	1.3	2.0

Table 6. 5 U-value of Lilac project and UK Building Regulations (Chatterton, 2015g).

Energy strategies at Lilac

Apart from choosing natural materials, *Lilac* benefits from triple glazed windows, mechanical ventilation and heat recovery systems, and solar panels. *Lilac* installed 1.25kW peak array solar photovoltaic cell for each home (20 homes in total) and a 4kW peak array on the Common House, make it 29 kW in total. Each household produces 1,170 kWh electricity from the solar panels on the roof. The final energy consumption is 104.95 kWh/m^2 per year, breakdown to 35.73 kW/m^2 for space heating, 39.22 kW/m2 for hot water and 30.00 kW/m2 for lighting and application estimated (Style, 2014). The energy bill of one family living in a four-beds *Lilac* flat is £190 per year (gas bill £30, electricity bill £160), which reduced 87% compare to the family's previous house energy bill of £1500 a year (BRE CICM, 2013).

MVHR units are installed above the cookers in every home. It intakes air from wet rooms (bathrooms and kitchens) and exhausted odours and moisture to the outside. While the heat is retained and mixed with incoming fresh air before been extracted back into the house. *Lilac* used Sentinel Kinetic units, which claims recover up to 94% of the heat energy depending on whether it is of cross-flow or counter flow type (Vent Axia, 2022). However, it is not stated which MVHR type or model *Lilac* installed. Renewable energy technologies like MVHR are easily installed but left unused after handover. With continues learning, theirs are operate well and provide good air quality and thermal comfort to residents' home.

Rainwater is reused in *Lilac* through collecting rainwater from the roofs by water butts and used for watering the garden (Lawton, 2019). Additionally, there is a 'sustainable urban drainage system' (SUDS) featured in the community, contains a pond at the centre of the community and permeable ground surface of the site, which contribute to flood protection (*Lilac* Learning Team and Bonner, 2021).

Saving through sharing and lifestyle

Sharing practices like tool share, sharing use of washing machine, are common in *Lilac*. According to a survey of 24 *Lilac* residents (about 50% of *Lilac* residents) in 2021 (*Lilac* Learning Team and Bonner, 2021), the lifestyle of *Lilac* residents have a positive impact on the sustainability of the community. 8% of *Lilac* residents drive to work and 58% walk or cycle to work. Compared with Leeds, where *Lilac* located, 42% drive to work and 16 walk or cycle to work. In food and waste area, residents reduce waste through food bulk buying, community compost, and food growing. Additionally, *Lilac* residents prefer to buy eco-friendly products and eat more plant-based diet. The increase in person-to-person social activity is consistent with the findings of many studies on the social sustainability of co-housing communities.

6.3.5 Lesson learned and critical review

Many lessons to learn from *Lilac* project from different perspectives like community member, development contractors, agencies, architects, and engineers (Chatterton, 2015).

For community groups, different skill sets are needed at different stage, bring in professionals in the right time. Need to have a realistic assessment of the group capacity, time, and the length of the project. Managing risk and get right advice in key decisions (cost, contractors, etc). *Lilac* project used a risk register to help classify risks and plan ahead. Variety of personality types are welcomed in the group to form a healthy and functioning group. Effective and clear internal communication in essential. The group also need to be disciplined when engaging with external professionals. *Lilac* used protocols, templates, single point of contact with external professionals, etc.

For industry, the development industry contains various types of contractors, like large-volume builders, self-builders, and bespoke builders. Larger-volume mainstream builders lack skills to develop long-term working relationship with cooperative community. *Lilac* used JCT (Joint Contracts Tribunal) Design and Build Contract which gives the contractor flexibility on both design and construction. This would reduce the role of architects in the project but benefit the client with cost certainty.

For external professionals, their training as architects and engineers has trained them to be accustomed to working with professional people. In the design of co-housing communities, there is a high level of participation from community members. Therefore, it is challenging and important for professionals to balance the involvement of community members with that of professionals, and to understand and practice the views of community members as accurately as possible. Especially if the parties have no previous experience of working together. Moreover, it provides the opportunity for professionals to cultivate long-term relationship with residents. As study suggested, fostering longer-term relationship with clients leads to higher quality design and more effective implementation of low energy strategies (Pitts, 2017). *Lilac*'s way of working with external participants is a tool called 'Ladder of Participant' introduced by Roger Hart, which demonstrate a way to work with mere information and consultation where grounded-work and trust among group members doesn't exist.

Challenge

However, no project is perfect, these critical views of *Lilac* project also provide valuable aspects for designers and participators to learn from. Challenges exist for *Lilac* model to replicate. The complexity of Mutual Home Ownership Societies (MHOS) could be a barrier for other communities to take-up. *Lilac* benefitted from grants. But grants are not always available when a community needs them. Moreover, *Lilac* relies on the time and effort of a small number of members. This mode of operation is not easy to implement for other communities, which requires a sustained commitment of time and enthusiasm from members.

Group members also need to be dealing with changes throughout the project. In the Common House design stage, group members compromised by the need to reduce ambition due to lack of funds; and in construct stage, group members end up not being able to self-build because it costs more money than hire a contractor.

When a group with many members needs to design and make decisions together, it becomes particularly important to respond effectively to different opinions and needs. For example, some members in *Lilac* group expressed a strong desire to have wood burners in their home. However, wood-burning stove has many drawbacks, like requires extra cost, cannot act as a replacement for gas heating, and difficult to deliver store wood for all the household. At the end, the group agreed on install a small wood-burning stove in the Common House to meet the desire of having a ‘fire heart’ to sit around. In order to reach a joint decision, it is inevitable that some of them will need to make compromise. And as a group, how to keep the majority satisfied, how to get everyone to agree quickly and how to maintain a long-lasting rapport are some of the aspects that need to be considered. After all, members of a co-housing community are not partners in a one-off project, but neighbours who will live in a community afterwards for years. A positive neighbourhood relationship is also a very important part of social sustainability.

6.4 Case Study 3: Co-living project *9floor*

6.4.1 Project background

The *9floor* case is presented in a TED talk by (Wei Kang Wang, 2017) about 'Living in a community'. He introduced their collective living projects and how it works as a community in Taipei. It is further described in a research thesis 'A case study of *9floor* – exploring the intent of co-housing from the perspective of shared economics' by Shu-Ling Chang from Tamkang University. This latter study adds a critical component to the consideration of this case.

9floor is a co-living community group located in Taipei city, founded in 2016. Facing the renting difficulties in the city, the founder started with renovating 10 old apartments to co-living apartments with common spaces suitable for living room, cafe and entertainment. Depending on the different layout and location of the flats, they have various of key features and functions. There are communities for intergeneration living, elderly, roof space with vegetable garden, shared kitchen, and shared working. *9floor* helps landlord with interior design and operation. Unlike many other projects, one needs to do application and interview before been accepted as a resident.

Co-living appeared in Taipei in recent years. Changes with housing, lifestyle and size of core family, and modern youth value are challenging topics for metropolis like Taipei.

Firstly, the urban population keeps growing worldwide, as well as in Taipei. 78.9% of the Taipei's population is urban (1). This number is higher than the Asia average in 2018, which is 50% (2). Housing supply experiences pressure when young people find it hard to find ideal housing. Instead of building large numbers of new buildings, co-living provides an alternative solution by redesign of the old flats that has not been fully used. For example, when children grown up and moved out, some middle-aged and elderly couples (or singles) are living in three-bed or four-bed flats. It brings senior and young people together, and provides a way to deal with urban problems such as loneliness, isolation and lack of interaction.

Secondly, the average age of getting married or buying first property are both shown delayed trend. Large numbers of young professionals are still renting at their thirties. Family models are no longer the same as early years. It transforms from 'big family' which generations living under one roof (before early 20 century); to 'core family' which typically formed with 2 adults and 2 children living in an apartment; to 'modern family' which ranging from single people, married couple, single parent with kids, divorced, etc., and the definition of family enlarged in the recent decades till today. Correspondingly, more diverse housing models are required to suit changing demands. Co-living model provides a housing and social solution to some of the demands.

Thirdly, influencing by the idea of sharing economy, people starting get used to sharing rather than owning in a lot of things. More people prefer investing on personal development and experiences rather than paying years of property debt. Young people also appreciating the benefit of sharing intangible values that the co-living model bring together, like professional network, time-lasting knowledge from elderly, skills and experiences, etc,.

The prototype of the *9floor* project started with a small group of likeminded young students living together in 2013. The first stage of the project started in 2015, when this group of young students began to act with their brand name of '*9floor*' to repair old apartments with no funding and rent out to other young students. With no experience and regulation at this early stage, the team rent out the rooms with relatively low rent. The main residents are students, which created very lively and active environment. The team founded the '*9floor*' company in 2016, and started to operate with company principals. They started to undertake renovating projects requested from homeowners and collaborated with professional interior and design teams. More young professionals joined the group of residents. Group activities and events were organised in certain apartments rather than all apartments. From 2017, the company became more institutionalize by set up resident, space and support services. With the improvement of quality of rooms, both rental price and resident group types became more diverse.

6.4.2 Architectural layout, design process and resident participation

The space design follows the rule to 'minimize private spaces and maximize common space'. The apartments are designed to fit 50% of total space with shared use indoor spaces, including kitchen, dining, living room, etc; and the 50% apartment spaces are designed to suit private rooms. Instead of the traditional renting system, where residents facing the challenges of living alone. *9floor* project aiming to provide the living experience with both the warm feeling and relaxing like home, and the convenience and social life of living at a well-managed apartment.

At the beginning projects, *9floor* started with redesign of several old apartments. The main design strategies include adding or reducing bedrooms to balance the private space to common space ratio. The design team would remove bedroom walls to enlarge living spaces, if the private space (bedroom) of the original apartments are large. For example, in *WenZhou* Apartment project (Figure 6.7), the original apartment contains five bedrooms, two bathrooms, a small kitchen and a small living room. The problem with the original floor plan are, firstly, the size of bedrooms are either too small (bedroom 1) or too large (bedroom 4), secondly, no space for dinning and limited living space. The redesign took some bold solutions including combining the living room and bedroom 2 to use as the new large living room and use bedroom 1 as dining area, which better suit the idea of living together and provide enough spaces for residents to spend outside of their room. While the large bedroom 4 were divided into two small bedrooms, all four bedrooms in the new plan are as similar size.

Figure 6. 7 Original (left) and redesigned (right) floor plans of WenZhou Apartment project. (Orientation and scale not available)

For other apartments with less private spaces, the design team would increase the number of bedrooms to keep a balance of private and common space area. In *TaiShun* Apartment project (Figure 6.8), the original apartment has a large balcony and indoor living room. The design team converted the kitchen to a bedroom, switched the living room to an open-plan kitchen and dining area, and enlarge the living space to the balcony.

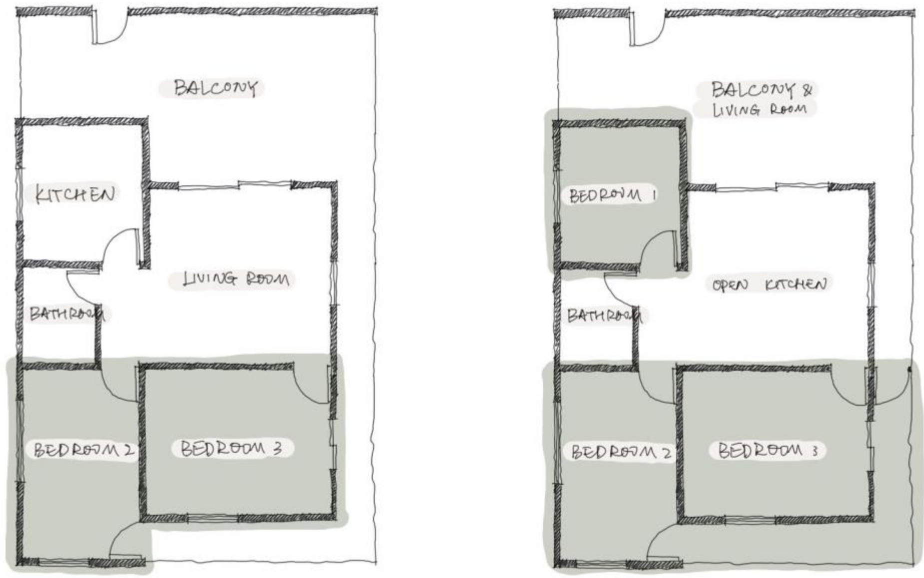


Figure 6. 8 Original (left) and redesigned (right) floor plans of TaiShun Apartment project

Recent projects include larger flat redesign and whole building retrofit. For example, the latest PuYuan Apartment project could home 80 residents and was retrofitted from one of the post-war ZhongQin Apartments (ZQ) built in 1960s. ZQ Apartments was built for single veterans, which contains three apartment buildings with large event centre and common kitchen facilities. With the young people from various of places brought together by PuYuan Project, ZQ Apartments would welcome both young and retired residents in the community.

6.4.3 Residents' use of space and community events

Residents

The most popular reason for choosing co-living apartment with *9floor* is the residents prefer of co-living lifestyle. Residents picture the co-living lifestyle as a place that they could meet like-minded people and enjoy premier living condition. Other reasons for choosing co-living apartment include the fixable rental options that suit the people who visiting the city for a short period of time, people who spend lots of time at home like freelancers, and people who want to expand their social network.

The residents are quite diverse in profession and nationality. Apart from over 30% students, artists (15%), business management (8%), tech and engineers (8%), self-employers (6%), other professions include doctors, civil servants, catering, journalists, retired people, etc (4). The majority of the residents are from Taiwan, which take part of about 70%. The rest of the residents are from all around the world.

Events and activities

9floor co-living was inspired by the post-war Scandinavian co-housing concept, where people live together and share part of their life within the community (5). Lv and Wang (2017) stated three core concepts of *9floor* projects, which are bring the coffee shop vibe into living room, embrace the concept of sharing and shared ownership, and enlarge weak ties and network among residents.

Pan (2017) summarized event type in *9floor* apartments into the following five groups: entertainment, residents-oriented events, work and networking, food sharing and gathering, young and elderly interaction.

9floor usually holds regular community events. The participants are not limited to the members living in the flat. All *9floor* residents from other flats, even the neighbours, can also come and participate.

6.4.4 Sustainability

Co-living apartment creates a new service and business model that is different from the traditional renting market for people in big cities. Shu-Ling Chang (2018) selected *9floor* as the case study in researching shared economy, which found out the business model of co-living can be accepted by the audiences and most of the people involved in the research are positive about its shared economy value.

6.4.5 Lesson learned and critical review

The core principles of *9floor* co-living projects aim to enhance living experiences by minimizing personal space and maximizing common areas. To foster a sense of community, a reward system is implemented to incentivize social activities. However, it is important to note that living experiences may vary based on the management of each project and the interactions between flatmates, which can introduce an element of uncertainty. Unlike other co-living cultures in Taiwan, *9floor* places less emphasis on energy saving and environmental protection. Instead, their focus lies in cultivating a community-oriented atmosphere, promoting activity, convenience, and a homelike experience. By prioritizing the social sustainability aspect and facilitating shared experiences, *9floor* strives to build and maintain a vibrant co-living community, offering unique benefits to its residents.

In the co-living context, if issues arise with the contract between *9floor* and the landlord, there is a potential for negative consequences affecting the current residents. It's important to note that *9floor* does not have complete control over their projects. To mitigate such risks, it is advisable for *9floor* to establish contracts or collaborate with local government authorities, as demonstrated by the successful implementation of the 'young and old living together' project, which serves as a positive example.

The participation preference of local and international residents shown great difference. This is helpful for advance community to be more active, however, at the same time it made the prediction of the residents using behaviour more difficult. This is one of the future challenges for co-living projects if they expand their building scale.

6.5 Summary

Based on the insights from literature review and massing study in the earlier chapters, this chapter selected three collective housing projects to explore how residents use spaces and consume energy in collective housing and what lessons can we learn from them regarding energy saving and sustainability in community. All three cases were studied around three themes design process and resident participation, use of space and community events, and sustainability potential. Although they can all be summarised as residential communities with common spaces and shared facilities, and with strong community social connections, they also differ from each other in many aspects.

The three cases have a similar starting point, with the core members being motivated to bring the project into shape. The differences are that the case study 1 - *Sun and Wind*, and *Overdrevet*, and case study 2 – *Lilac*, are co-housing communities that started with choosing site, then project planning, building design, and construction, while case study 3 – *9floor*, is a co-living community redesigned from existing residential homes. The benefits of the first two cases are that residents own their homes and are able to participate from the beginning of the project, therefore, have more say and involved in decision making on project's design principles. And in terms of building sustainability, they can propose and discuss on various of energy-saving technologies and design strategies to suit their needs and preferences. However, the decision making and the long project forming time can be challenging. In the last case, core members formed *9floor* who operates the co-living scheme, from redesign the homes, recruit residents, and organize community events. Relatively few decisions needed to be made by residents. Comparing three case studies, the difference in location, architectural layout, the common space and shared facilities, lead to the different types of events and residents' activities in the communities. It provides some lessons for developing collective housing community, especially, when considering occupant behaviour and everyday energy usage. However, what occupant behaviour affects energy consumption in collective housing, and how residents' use of private and common spaces are not discovered yet. The following chapter that presents field study data and results could provide a more comprehensive understanding to the above questions.

Chapter 7 Field Research in Two Developments

7.1 Introduction

This chapter presents the field studies of two collective housing projects in the UK. Case Study 1 is project *The Collective Old Oak* in London and Case Study 2 is project *One Brighton* in Brighton. Each case study begins by introducing the project background and the reason for it being selected as a case study. Then, the field study procedure and details of interviewing questions are provided. This is followed by the analysis of transcript content and a summary of results.

The aim of the field research is to understand the design process and explore the sustainability practices of collective building in detail from collected primary data. It addresses Research Objective 3: to explore the present sustainable strategies in design and community operation in existing collective living buildings.

7.2 Case Study 1: The Collective Old Oak

Completed in 2016, *The Collective Old Oak* was at that time the largest co-living development in the UK. It emphasises community creation, sharing and convenience in a big city. After several years of operation, it has achieved almost -full occupancy (Corfe, 2019). It is a good example to look at as it's a co-living model in a contemporary context. And it was the very first model of its kind to be built (PLP Architecture, 2016).

The Collective Old Oak is a commercial co-living development which accommodates 550 people located in Willesden Green, west London (see Figure 7.1 and 7.2). It provides single ensuites to rent, as well as plenty of amenity spaces in the building for sharing across the community. It is very diverse in its resident background. 70%

of the residents are under 30 with the age range from 18 to 61. Residents are mixed of different nationalities, though mostly from the UK and EU. The most popular occupations of those living there are consultant, operation, and finance.

Figure 7. 1 Photo of The Collective Old Oak. (resource: photo taken by researcher).

Figure 7. 2 West façade rendering (resource: PLP London website).

The building is composed of two slim volumes sliding across one another, one has ten floors, the other one has seven floors. The building information is listed in the following chart (see Table 7.1).

Term		Area	%	m^2/pers.
Outdoor spaces (m^2)		830	/	1.5
Total floor area (m^2)	Total	11880	100	21.6
	Public access	1915	16	3.5
	Common use	4720	40	8.6
	Private use	5245	44	9.5
Minimum suggested space area for 1P in London.				39

Table 7. 1 Project building information.

Public spaces, common spaces and private spaces are designed and interspersed in the building. Public spaces, where anyone can use are located on the ground floor.

7.2.1 The field study research process

The qualitative research methods used in this study are interviews (semi-structured and unstructured) and observations. As discussed in Chapter 4, these were chosen because semi-structured interviews provide more freedom for interviewers to explore paths and focus while interviewing. Observation allows the researcher to look at the activities taking place in the present from the perspective of a bystander. The fieldwork consisted of interviews with the architect, the community hosts and eleven residents (details see Table 7.2), and observation with a week living in the The Collective Old Oak community (details see Table 7.3). Secondary data are organized for the case study, which includes journal articles and interview transcript material collected from web search. The analyses and conclusions are drawn from the primary data and secondary data.

Interviews

A semi-structured interview was carried out with the architect (interviewee code: A1) of the project on 14th January 2020 from 2 pm at PLP London office. Semi-structured interviews provide key interview topics and directions, and allow the interviewer to ask further questions when needed. In this case, before the interview, the main topics of the interview were sent to the architect, including: What is the project background and brief? Are there any design theories for this project? What are the design processes and main considerations? How do you design common spaces and private spaces? What did you consider in the kitchen design and amenity spaces design? What sustainability design from social and environmental aspects are considered? What is the potential of co-living model? (full interview outline see appendix b).

Two community hosts were interviewed. The community hosts are staff employed by the co-living building developer ‘The Collective’, who take care of the residents and the running of the building. One interview (interviewee code: H1) was a semi-structured interview with a community host. The interview is focused on the day-to-day operation of the building, while we are walking through the while building. Therefore, the conversational styled semi-structured interview is more suitable in this case. Because different topics can be inspired while entering various spaces in the building. Moreover, while walking through the building, we cannot avoid interacting with residents, which might break off a topic or bring in other topics to discuss. This interview was not recorded and took place on 13th Feb 2020. The other one (interviewee code: H2), a scheduled semi-structured interview, took place in the ground floor meeting room on the 25th of February 2020 from 11 am to 12 pm, and due to the timetable of the interviewee, it was arranged for one hour.

The interviewed residents differed in age, length of stay, occupation, and gender. They were not approached in particular order or preferences. Eleven residents (interviewee code: R1 – R11) participated in the research through face-to-face structured interviews. The interviews took place between 17th February and 11th March 2020.

Role	No.	Interviewee code	Occupation	Date	Location
Architect	1	A1	/	14/01/2020	PLP London Office
Community host	2	H1	/	13/02/2020	The Collective Old Oak building

	3	H2	/	25/02/2020	Gallery* (GF)
Resident	4	R1	Worker	17/02/2020	Restaurant* (GF)
	5	R2	Graduate	19/02/2020	Lobby* (GF)
	6	R3	Baker	19/02/2020	Common Kitchen* (6F)
	7	R4	Student	25/02/2020	Restaurant* (GF)
	8	R5	Student	20/02/2020	Restaurant* (GF)
	9	R6	Student	20/02/2020	Restaurant* (GF)
	10	R7	Young professional	26/02/2020	Restaurant* (GF)
	11	R8	Student	26/02/2020	Restaurant* (GF)
	12	R9	Nurse	27/02/2020	Restaurant* (GF)

	13	R10	Graduate	11/03/2020	Restaurant* (GF)
	14	R11	Retired	11/03/2020	Lobby* (GF)

Table 7. 2 List of interviews (these are different rooms in The Collective Old Oak building).*

Observation

The observation was taken during a week-long stay at *The Collective Old Oak* from 13th Feb to 20th Feb 2020. It consisted of observations of resident behaviour in the common spaces and investigates their day-to-day activities through participating in community events and conversations with residents.

Observation of community events by joining and experiencing include: one *The Collective* organized community event, Sunday Brunch, on 16th Feb; and one resident organized event, Cookie Making, on 15th Feb. Sunday Brunch event was chosen because it is the largest weekly event in the community where residents could come together and help on a late morning buffet. The relaxed and welcoming ambience makes it easier for residents to interact and communicate. The Cookie Making event was introduced by a neighbour, it was chosen to observe because it is the smallest and resident-oriented form of event in the community. By comparing these two different events in both scale and organization, it is helpful to get a good idea of residents' preferences for attending events and the behaviour of participants in using the spaces during the different events.

Observation of resident behaviour in common and public spaces in the building took place in two forms: sweeping and timed observation. The ‘sweeping’ included seven-times-daily observational walks through the building for four day from 14th Feb to 17th

Feb 2020, making detailed observations of 22 functional spaces/rooms from ground floor to top floor (10th floor) concerning how many people present and what activities they are conducting at specific spaces and times of the day, as well as documented the use of energy-consuming equipment in the rooms using a 'sweeping chart' (see Table 7.3) together with sighting map. The 'timed observation' consists of one-hour long observations at specific locations in the building. Several locations and activities are worth looking into, therefore 'timed observation' is used to get more detailed information on what people do and how they use these spaces over a longer period of time. Four locations were picked: the lobby on the ground floor, the laundrette on the second floor, the secret garden and kitchen on the fourth floor, and the library on the seventh floor.

DATE	day/month/year											
	Ground Floor					F2			F3		F4	
	Lobby	Bar&K	The Ex	Event	Gym	Kitchen	Laundry	Terrace	Kitchen	Spa	Kitchen	Secret Garden
7:30												
10:00												
12:30												
15:00												
17:30												
20:00												
22:30												

	F5			F6		F7		F8	F9	F10
	Kitchen	Dinning	Cinema	Kitchen	Game room	Kitchen	Library	Kitchen	Kitchen	Kitchen
7:30										
10:00										
12:30										
15:00										
17:30										
20:00										
22:30										

note 1	note 2	note 3	note 4	note 5	note 6

CODES		ACTIVITY	
CODES	template: number of people_location codes on map/gender/activity_(*note number) example1: 2_a/W/PC_b/M/R_*2 edample2: 1_a/M/CO colour codes in red for notes	ACTIVITY	R = reading PC = using computer C = chating RE = resting E = eating CO = cooking other activities can be added

Table 7. 3 sweeping chart used during observation.

7.2.2 Analysis process

Based on the analysis of collective housing case studies in Chapter 6, the research questions focus on these three themes:

- Design process and resident participation;
- Use of space and community events;
- Sustainability potential.

Field study data was analysed using thematic analysis (Braun and Clarke, 2006a) method, which following the six phase of familiarizing with data, initial codes, generate initial themes, developing and reviewing themes, refining, defining and renaming themes, writing up. The 'category' are generated by reviewing and developing the three above themes. And the 'topic' are refined topics for writing up.

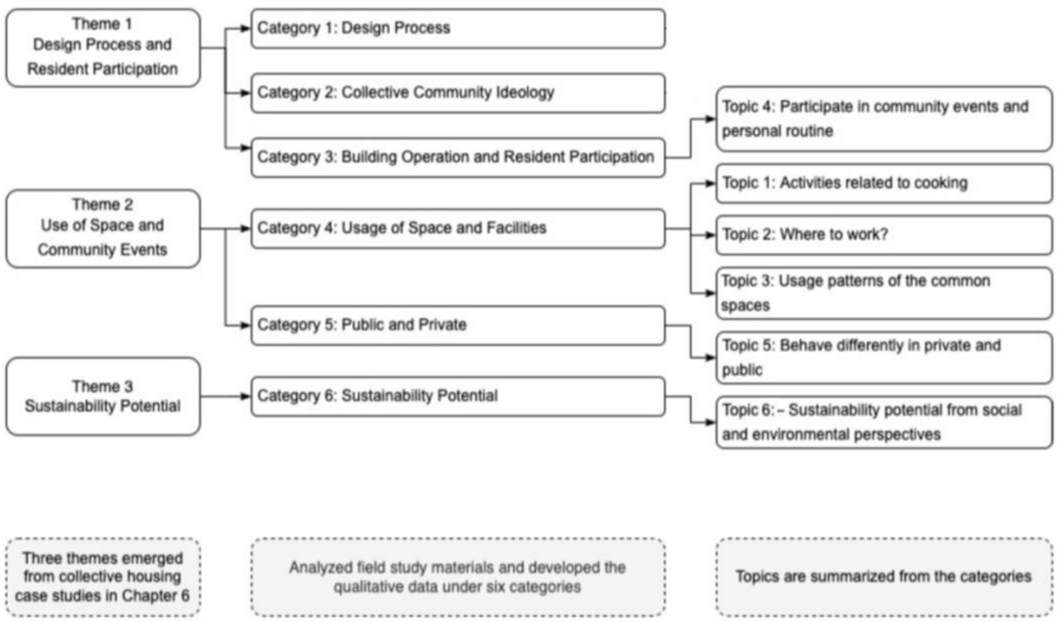


Figure 7. 3 Relationship of themes, categories and topics.

7.2.2.1 Developing the categories

Three themes emerged from collective housing case studies in Chapter 6 (design process and resident participation, use of space and community events, and sustainability potential). The analysis of the field research case study integrated the three themes and developed the qualitative data under six categories.

Category 1, Design Process, explores the design concept and process in order to understand what differences in the design phase collective building face.

Category 2, Collective Community Ideology, explains understanding and vision of the collective community concept by the residents.

Category 3, Building Operation and Resident Participation, explores the decision-making process and event organization system in the community in both design and in-use of the project, and how residents participate in the community events.

Category 4, Usage of Space and Facilities, discusses how different functional spaces are used in terms of frequency, preference and experience.

Category 5, Public and Private, looks into the boundary between private and public spaces together with the ‘three-scale of privacy’ design concept.

Category 6, Sustainability Potential, discusses the sustainability practices in the collective building from both social and environmental perspectives.

7.2.2.2 Generating topics through coding

The topics were summarized through analysing field study materials under the six categories. Field study materials include interview transcripts and observation notes. Field study analyzing tool MAXQDA is used to help with organizing interview materials and sorting topics. To form a storyline for readers to follow, the topics are not ordered the same way as the categories. Instead, residents' behaviour and experiences are discussed first, followed by the design concept and community sustainability topics.

7.2.3 Analysis result

7.2.3.1 Six categories

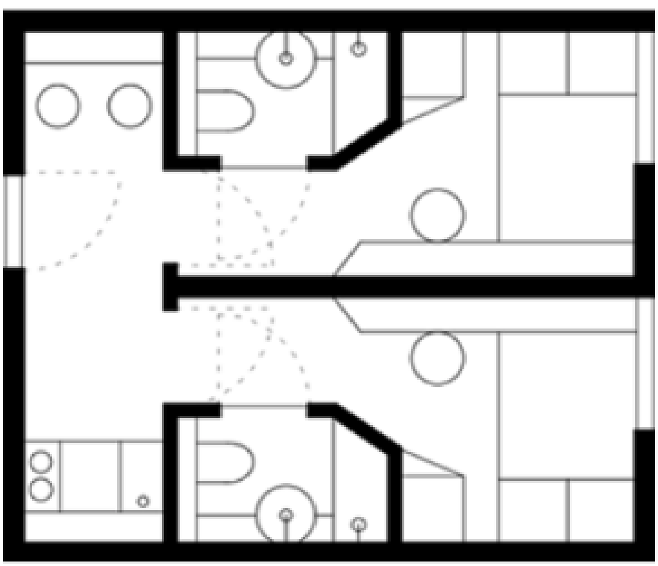
Category 1: Design process

Preliminary planning

The Collective Old Oak project started initially with the developer buying the site and outline planning consent, which was given for a student housing development and later switched to residential buildings. Purpose build student housing and co-living building are similar in many ways, they both contain numbers of private units, various types of amenity spaces, and building management. Their differences are they are designed to accommodate different groups of residents, therefore, the building function, layout and building operation would be different. At the time the project was designed, there was no planning designation for co-living. It depends on the architects and the developers to choose which planning designation. And this affects how long residents could stay. For instance, *The Collective Old Oak* project the planning designation is for residential building, the minimum stay for residents is 90 days. While another co-living project developed and designed by the same team, The Collective Stratford, the planning designation is for hotel, the length of stay is limited to 90 days (Martin, 2020). However, *The Collective Old Oak* is different from normal residential projects in many ways. For example, the common amenity function rooms and common spaces are generous, but the room size is relatively small (12m2) because they are intended for single individuals to occupy. The main room types in the project are studio, '*twodio*', standard unit and large unit (see Figure 7.4 and

Figure 7.5). '*Twodio*' is a unique room type in this project, which contains two single rooms (with individual bathroom) and shared small kitchen. There are 20% studios, 10% large units for disable use, and 70% of *twodios*.

Figure 7. 4 Room types.



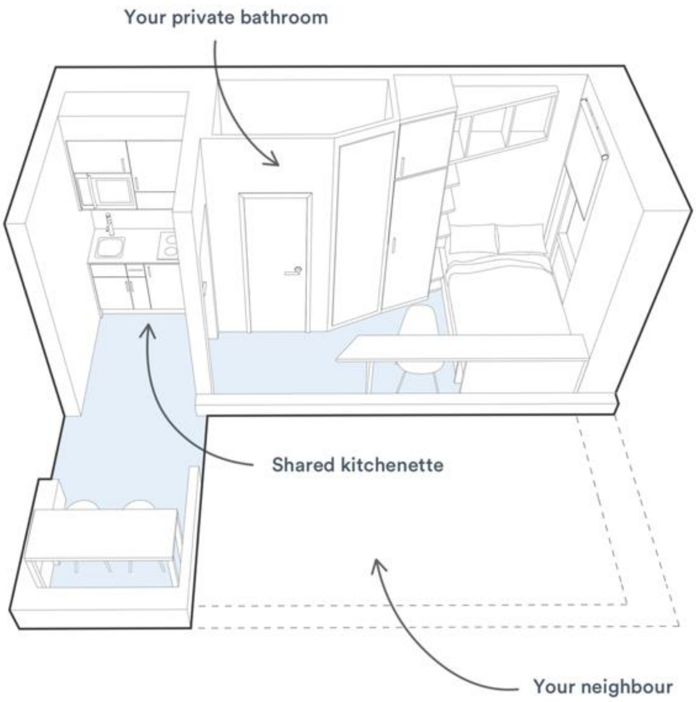


Figure 7. 5 Private unite Twodio at The Collective Old Oak co-living scheme (two residents share one kitchen), top: plan, down: illustration (source: The Collective Old Oak website).

Creating the design concept

Starting with the client's brief, the design team researched the history and development of co-living thoroughly. The design team found out from research that people behave differently in different scales of development, and this determined the layout. The developer's interests also shaped the design concept, the architect (2020) said "he (the developer) was interested primarily to develop something that wasn't so much about a real estate product for accommodation, but more like a lifestyle brand." Therefore, the first brief was to 'get people to come out of their rooms' (Martin, 2020), forming public life by creating a sense of community. This idea might be inspired by the experience - the architect's visits to the developer's other residential project in which residents rarely interact with neighbours and the buildings lack public spaces. Especially, in this case, the sense of community is one of the key merits to attract residents.

Three scales of privacy in the building

The architect applied these ideas by designing three levels (see summary in Table 7.4) for people to gather in different scales in the building (Martin, 2020). The smallest scale called ‘pajama factor’, as described by the architect (Martin, 2020). The ‘pajama factor can be seen as something like camping, where a small group of people are very accustomed to each other and feel at ease, have a nice sense of familiarity...where one can come out in their pajamas. The middle scale was developed in reference to Dunbar’s Number by British anthropologist Robin Dunbar. Dunbar Number refers to the size of the human’s social network is limited to between 100 – 200 individuals due to the human brain’s biological constraint on social interaction. It is the largest scale for people to self-organize and make group decisions. The largest scale called ‘metropolitan factor’, it represented the whole community with over 500 people. At this scale, one can expect the experience similar to public spaces in cities where they can meet unexpected people, have different kinds of amenity spaces, coffee shops, etc.

Three Scale	Name	Size	Key words
Smallest scale	‘Pajama factor’	10 – 15 people	Small groups of people, feel at ease, with a sense of familiarity.
Middle scale	/	120 – 150 people	Dunbar number
Largest scale	‘Metropolitan factor’	550 people	

Table 7. 4 Three scales of privacy summary.

Category 2: Collective Community Ideology

The Collective Old Oak project is different from co-housing projects. Though co-housing is defined differently depending on locations and times, here it refers to the basic principles of the UK Co-housing Network (UK Co-housing, 2022). In the Collective Old Oak, firstly, there is no resident participation in the design phase. Secondly, it is a rental apartment that is not available to buy. Thirdly, it relies on high city density as well as urban infrastructure to support this resident density. More specifically, the PTAL (public transportation accessibility level) in this area is 4 (PTAL ranking from 0 – 6, 6 as the highest).

Unlike co-housing communities usually formed by likeminded people who desire to live together before the building was designed, the residents of The Collective Old Oak are not necessarily familiar with co-living concept. However, they are attracted by the co-living model by having ‘simple living in big cities’ (Resident 8), ‘social and networking opportunities’ (Resident 2), etc.

Category 3: Building Operation and Resident Participation

The building is operated by the staff of ‘The Collective’ which also in charge of residents’ whole co-living process and experience. There are two types of residences in terms of the length of stay: short or long stay. Among the three commercial The Collective co-living projects, *Old Oak* in west London provides long stay, *Canary Wharf* in east London provides both short and long stay, and the *Paper Factory* in New York provides short stay. In addition to considering the targeting residents at the project location, the restrictions of planning designation which states the minimum and maximum length of stay also affects whether the project is short or long stay. For example, Martin (2020) mentioned the minimum stay for *The Collective Old Oak* is 90 days. This does not mean that the *Old Oak* residents cannot invite their friends and families to stay overnight. There are *twodios* on the top two floors available for occasional pre-booked visits at day rates. Compared to co-housing projects, most co-housing communities do not charge for the use of guest rooms for family and friends, and suggest a donation for guests who are not related directly to the community members (The Co-housing Association of the United States, 2022b). Co-living is more expensive for guests than co-housing, but at the same time, it brings a lot of conveniences. For example, guest rooms at co-housing community usually require the resident to make the reservation, clean and tidy up, but co-living residents only need to make the reservation for their visitors, and the community management team is responsible for the rest, like arranging rooms, check-in and check-out, clean and tidy up.

The community management team by *The Collective* contributes in many other ways to the community, for example by organising events and activities. Weekly updated community events are presented on the event board (Figure 7.6) near the lift on the ground floor where everyone should pass by. There is a timetable attached to the cinema room door on the 5th floor, in which residents are welcomed to plan their own movie nights and write them down on the timetable for others to join (Figure 7.6). The community management team encourages the residents to take the initiative and organize their own events. Martin (2020) mentioned that when a resident moves in and is being shown around the building, the community host would take this as an opportunity to know the resident and provide support if they express their interest in engaging community event planning. There are many resident-organized events, for example, Resident 12 (2020) said they have an event called ‘Supper Club’ organized by around 15 people which they gather regularly at the Themed Kitchen on 8th, 9th or 10th floor, one or two people in charge of cooking for the group and participants cooking in turns. This form of gathering is relatively less organized and promising than shared meals in many co-housing communities. In terms of frequency, shared meal in co-housing is almost one meal a day, while 'Supper Club' is once a week (sometimes can be irregular). Essentially, the purposes of these two shared meals are different. Share meal in co-housing communities is about meeting people's day-to-day needs of saving time for cooking and reducing the cost of living, while 'Supper Club' is more about meeting people's need to communicate and spend time together.

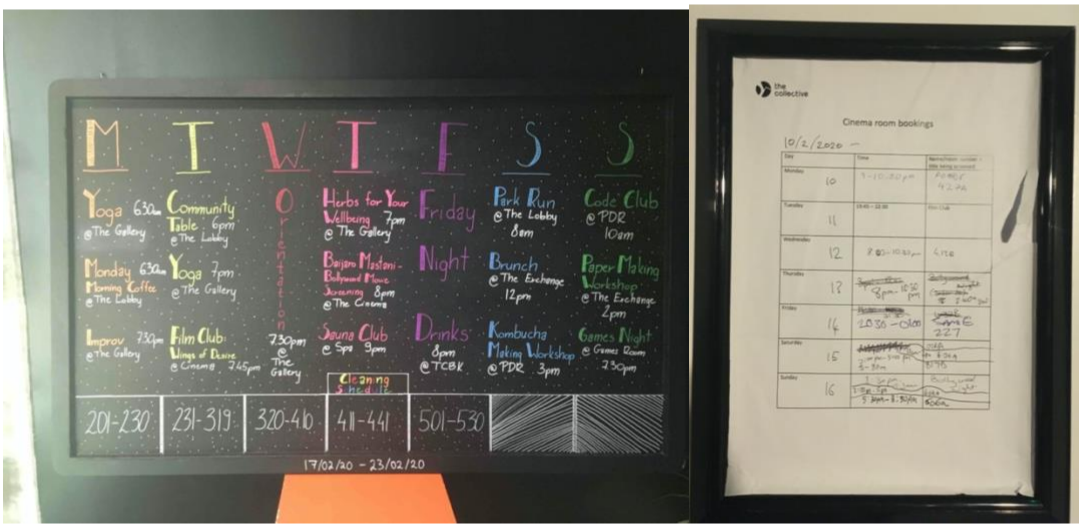


Figure 7. 6 Left: Community events board on the ground floor. Right: Movie table pasted on the door on the 5th floor.

Category 4: Use of Space and Facilities

Amenity facilities are spread throughout the building (Table 7.5). There is a common kitchen on each floor and a function space on each floor except the top three floors, while most of the large common spaces are located on the ground floor.

Floor No.	Common spaces	Number of Private rooms
10th	Themed kitchen – Tea Room	33

9th	Themed kitchen – French Bistro	34
8th	Themed kitchen – English Pub	34
7th	Library, Common kitchen	75
6th	Game room, Common kitchen	77
5th	Cinema room, Common kitchen	75
4th	Secret garden, Common kitchen	73
3rd	Spa, Common kitchen	75
2nd	Laundry room, Terrace, Common kitchen	73
1st	Offices	/
GF	Gym, Lobby, Co-working space, Bar & Kitchen	/

Table 7. 5 Common spaces in each floor and private room numbers.

The whole building is well signed with the location of different functional spaces. There is a notice board on each floor near the lift, which provides the location information of common spaces and a sketch map of the floor (Figure 7. 7 Left). Notice boards that show common spaces locations and current locations are placed in the staircase as well (Figure 7. 7 Right).

Figure 7. 7 Left: notice board with sketch map on 7th floor. Right: notice board in the staircase.

Category 5: Public and Private

The common spaces in collective community were categorized as public and collective (Schmid, Eberle and Hugentobler, 2019a). Public spaces refer to the areas that can be accessed by anyone, while collective spaces (equal to common spaces in this thesis) can only be accessed by community members. The public, common and private spaces are illustrated as follow (Figure 7. 8 and Figure 7. 9) and their floor area ratio are 16% (public), 40% (common), and 44% (private).

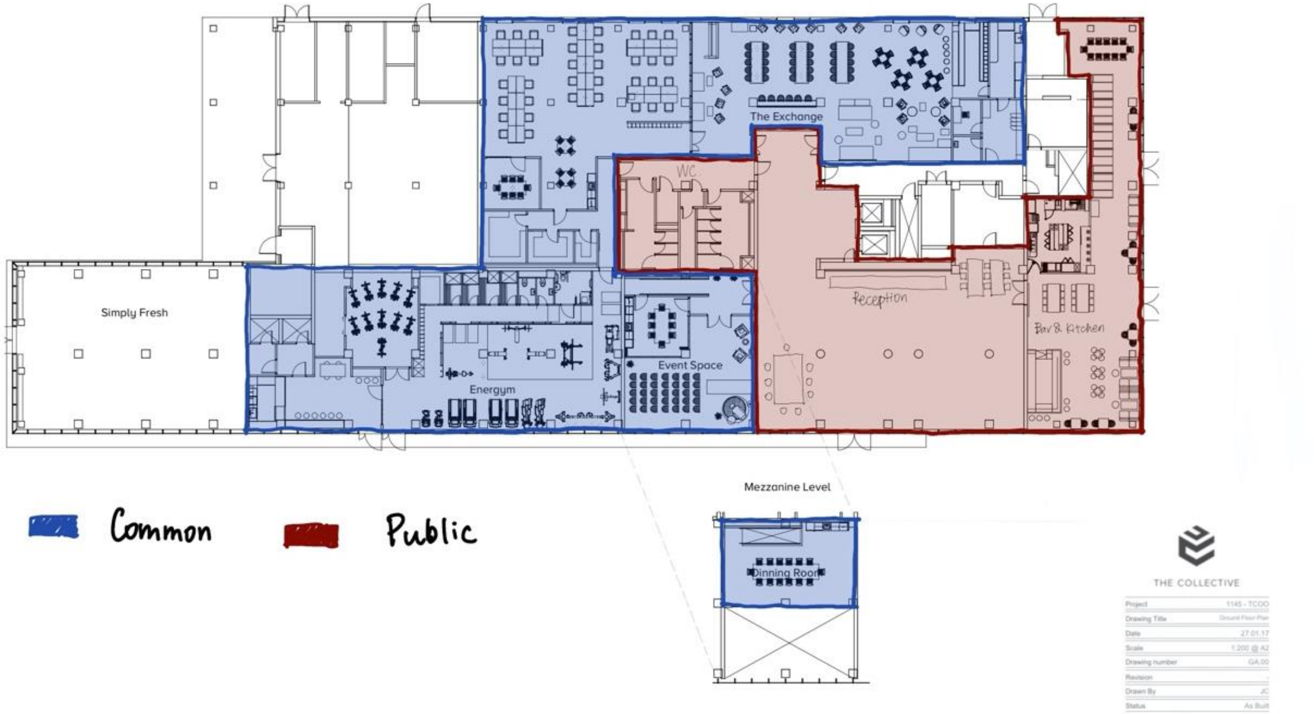


Figure 7. 8 Public, common and private spaces in the building on Ground Floor (resource: floor plan provided by The Collective, scale: 1 to 200 in A2 paper).

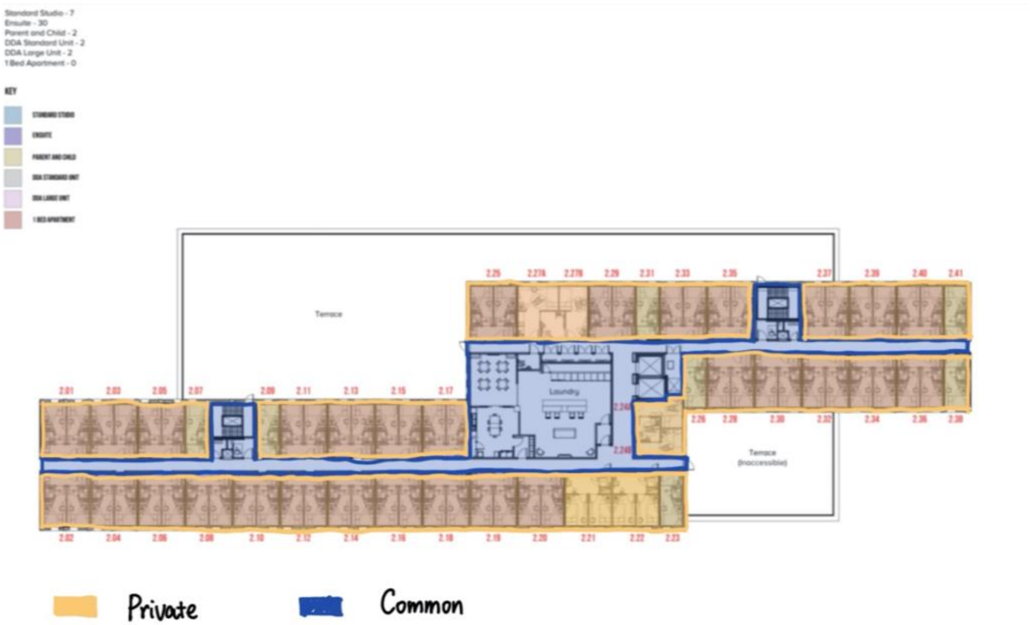


Figure 7. 9 Public, common and private spaces in the building on 2 Floor (resource: floor plan provided by The Collective, scale: 1 to 200 in A2 paper).

Category 6: Sustainability Potential

Sustainable considerations can be found in this building from design to in-use stage. The architect considered how much light could come into the room by adjusting the size of private room windows. As the private rooms was the shape of shipping container and the rooms are deep, room windows are maximized to let more light into the room. The common spaces are programmed to have variety with light touch of fit out, which are easy to be changed and reorganize. The design strategy behind this is to enhance the flexibility of the interior space to suit the changing requirements of the occupants (Martin, 2020). There are three sustainable promotions found in the community building. First, community featured recycle and reuse systems, like the waste recycle (Figure 7. 10 Left) and clothes recycle (Figure 7. 10 Right). Then one of the community host promoted using eco-friendly bottle to reduce disposable cups in the community (Host 2, 2020). Moreover, residents have developed their own system for reduce waste (Figure 7. 11) by having a ‘box with free item’ corner in the common kitchen. Resident 1(2020) mentioned that he would regularly put things in here that he doesn’t use and check out these boxes to see if there is anything he can make use of as well.

Figure 7. 10 Left two: waste recycle system notice. Right two: clothes recycle collection in the laundry room at 2nd floor.

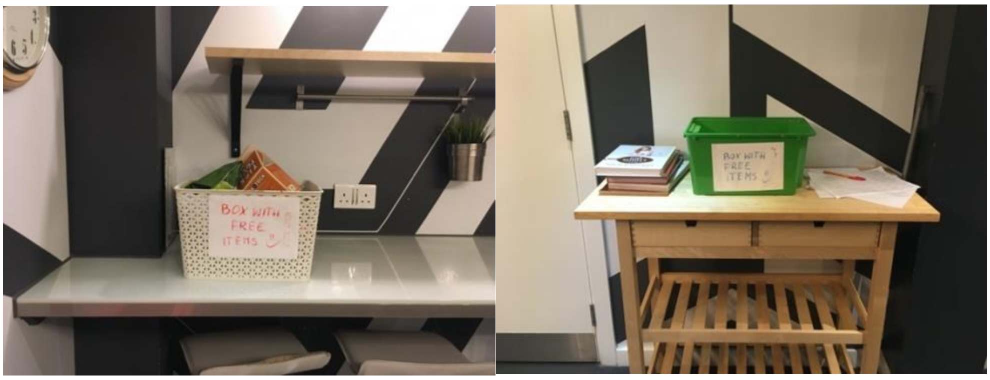


Figure 7. 4 Box with free items placed in the common kitchen in each floor.

7.2.3.2 Topics

Topic 1: Activities related to cooking

The cooking-related energy consumption in domestic accounts for 5% of total end-use energy in the EU (3% in the UK). While parts of the electricity consumption are related to cooking activities, like lighting in the kitchen and dining, entertainment during cooking and dining. The location and accessibility of cooking spaces are varied depending on the purpose of designed target users.

At The Collective Old Oak, there are three types of kitchens: 1) the private kitchen either shared by two residents or within the studio unit; 2) common kitchen in each floor, themed kitchen on the top floors; and 3) the event kitchens in the event rooms on the ground floor. The event kitchens are accessible to a wider range of users, for instance these kitchens are used during community events which might include people who don’t live in the building. The common kitchens and the themed kitchens can be used by the residents for sharing. The private kitchens are only accessible by the resident if one lives in a studio, or accessible by the two roommates if they live in a *twodio*. The location of these kitchens are illustrated in the following image (Figure 7.12).

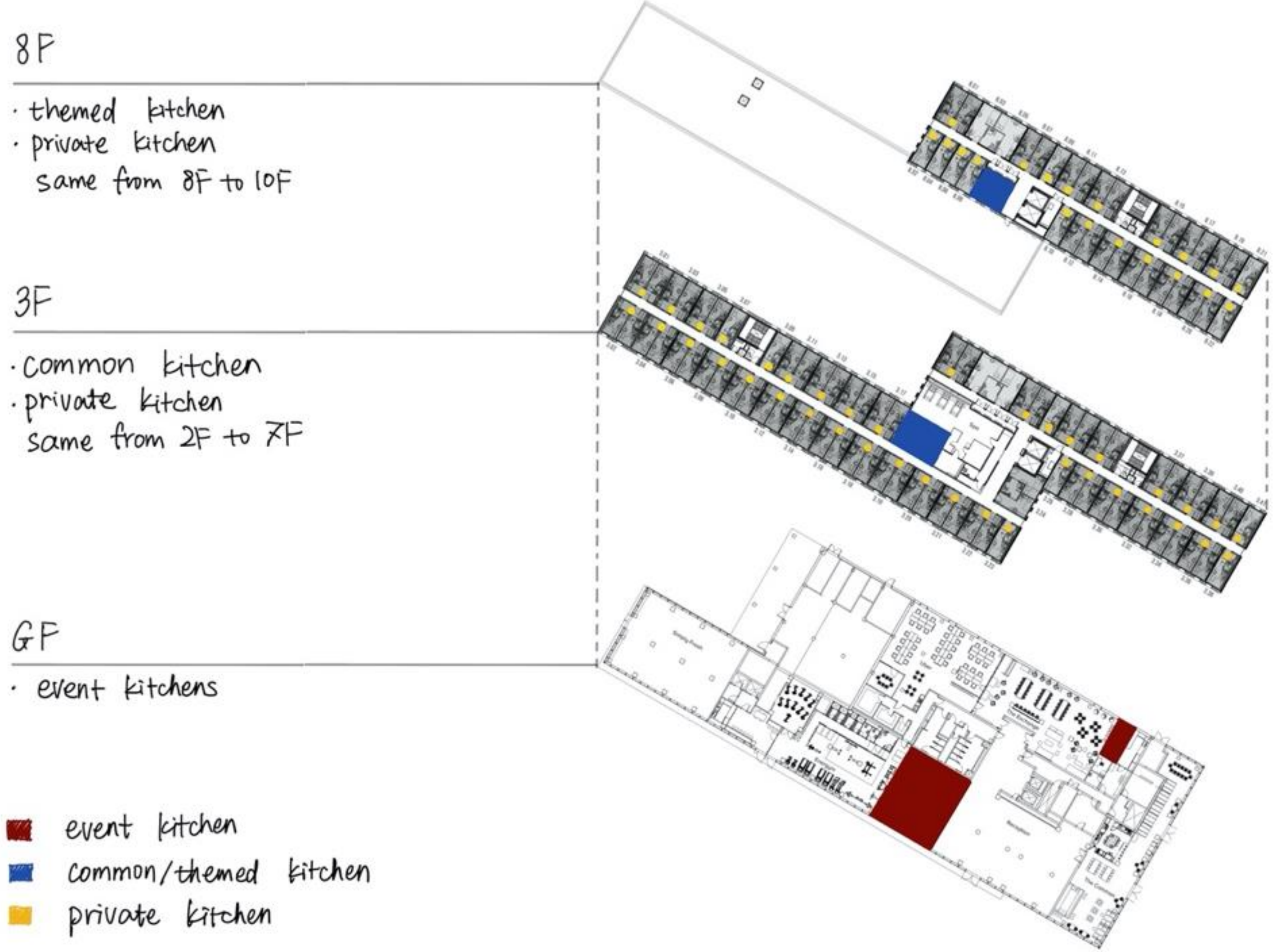


Figure 7. Location of three types of kitchens in the building.

Furthermore, the freedom of using the communal kitchen spaces offers more flexibility for residents to meet their cooking and gathering purpose, depending on doing individual meal or shared meals.

The equipment in private and common kitchens are slightly different. The private kitchens are equipped with a microwave, a two-zone electric hob, a mini-fridge. There is an oven, a dishwasher additional in common kitchens as well as two refrigerators and a four-zone electric hob. So as residents have the choice of using different kitchens, how would they decide where to cook? Moreover, what influences their decisions and preference? These questions were asked when interviewed the residents about their using preference for cooking activities. People's choice varies, as some residents cook most of their meal in the common kitchen and rarely use their private kitchens, because of the kitchen layout - 'my kitchen is so small, and the smell after cooking is hard to go away' (Resident 1, 2020) or enjoy the social environment of the common kitchen as 'I like to come to the common kitchen where I normally could meet people and talk during dinner' and 'sometimes when I run out of something I could check all the free stuff in the common kitchen' (Resident 2, 2020). While others rarely use the common kitchens because 'it is far from my room and I have to bring all my cooking stuff with me and pass two doors, while my kitchen has all I need for cooking' (Resident 3, 2020). Though all the common kitchens and themed kitchens are open to all residents, residents might feel the boundary between private and public (or semi-public). As the themed kitchens are on the 8 – 10th floor where also have residents living, some residents said that they rarely or never go there even though it has a better view and beautiful decoration, because they feel 'step into other people's space' as they do not live in that floor (Resident 1, 2020).

Therefore, residents' usage pattern of cooking is not only related to the designed cooking spaces but also closely associated with an individual's preference. There is a bottom-up solution to reduce individual cooking by organizing group meal among residents. They have a group that people meet up once a week for a group meal, which generally cooked by one or two people in the group. However, this form of shared meal is not stable as the residents may come and go year by year.

Topic 2: Where to work?

When talking about the location of people work, they have several options in the building. The building was designed to let everyone have their spots, even though there are lots of spaces for events and gathering, people who prefer quiet could still find places to go (PLP Architect, 2020). Furthermore, due to the modern working flow, a great number of people can work anywhere as long as they could access to power and internet. This also means that people have different preferences for how they work.

The main concerns for people in choosing a place to work include noise level, privacy, and conditions of workspace, though people do not necessarily prefer to work in designed workspaces. Their reasons for liking and disliking a working place are summarised based on responses from interviews with residents (Table 7.6), which shows great conflict for same feature. For example, ‘quiet’ could be the advantage and disadvantage at the same time for different people. This could also be found on the ‘privacy in common spaces’, the ‘background noise’, and ‘access to people’.

Function rooms	Reasons given for liking this working space	Reasons given for disliking this working space
Library	‘It is quiet, I would go to the library when I really need to get	‘It is just too quiet. I worried about bothering other people if I make

	something done.’	any noise.’
The Exchange (co-working space)	The atmosphere of working - surrounded by people busy at work.	‘There always have someone talking on their phones.’ Uncomfortable table and seats. No view to the outside.
The Galley	Big window. Fewer people	Unable to fit many people.
Lobby	Big window beautiful view. Good background noise. Able to make social contact with people.	Privacy (apply to all common spaces) Too loud.
Common kitchen	Quiet when not during mealtime. Convenient to get some food. ‘I could socialise when I want to.’	The smell of food. Interrupt by people.
Private room	‘It is a habit to study on my bed.’ ‘I have all my settings in my room, and these are comfortable for me.’	Small space, especially for couples. ‘There are too many disruptions – my bed, snacks, TV.’

Table 7. 6 Reasons collected from residents about like and dislike of working spaces in the co-living building

People’s preferences for the working environment are different, as some choose to use a quiet space while others may prefer to have some degree of noise and random conversations. Though there are 4 out of 11 interviewees said that they preferred to work in their own rooms either because of the level of privacy or because they were considered more convenient. They did mention that they spent more time working outside of their room than in their previous accommodation. Some residents commented that they might spend less time in their room and on their computer because they found themselves more involved in community activities and meet more neighbours in a day. One interviewee talked about preferring to study in the room out of the habit of studying in bed as a child.

Topic 3: Usage patterns of the common spaces

The common spaces are located on the ground floor and the middle part of each floor close to the lifts. The designed space functions and activities in each space are listed as follow (Table 7. 7).

Floor	Space	Activities in the spaces	
		Energy-related activities	Non-energy-related activities
10th, 9th and 8th	Themed kitchen	Cooking meals Working	Relaxing Gathering
2nd to 7th	Common kitchen in each floor	Cooking meals	Working Communicating
7th	Library	PC	Reading/Studying

6th	Game room	Watching TV Video games/Music	Board game Ping-Pong, Pool
5th	Cinema	Watch film Watching TV	Relaxing Chat Eating
4th	Secret Garden	PC	Reading Relaxing Eating Gathering
3rd	Spa	/	Relaxing
2nd	Laundry room	Washing/Drying Watching TV Ironing	Chatting
1st	Office	/	/
GF	Gym, Lobby, Co-working space, Bar & Kitchen	PC	Chatting Gathering

Table 7. 7 Activities in different common spaces in the co-living building.

The usage pattern in each of the common spaces is different as well as at different times of the week. For instance, in general, people spend more time at the bar, cinema, launderette and library at weekends, whilst the co-working space is more prevalent during the weekdays. It is because co-working space is also opened to the public with a sign-up fee, that people who do not live in the building could also use this space to work. The following chart is generated from data collected on-site. The data are collected during the field study period by visiting each space to record every three hours (Figure 7. 14).

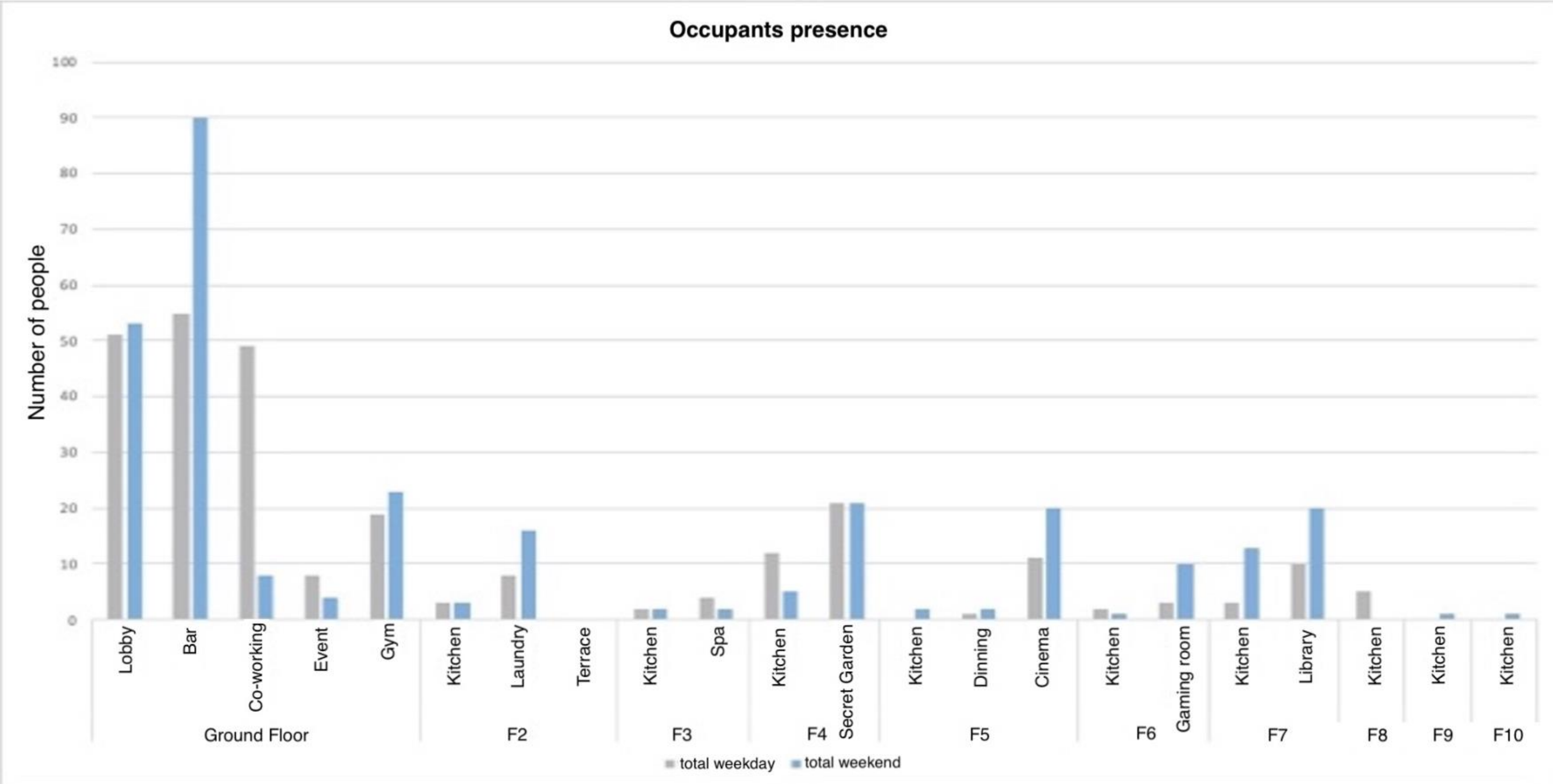


Figure 7. 5 Occupants' presence.

Topic 4: Participate in community events and personal routine

The co-living community has a wide range of activities and events. And these events are mostly popular in a city context, which means it can be attractive to its residents. Over half of the interviewees said that community activities were one of the factors that attracted them to co-living. Apart from the fact that the variety of co-living community activities differs from that of co-housing community, the nature of involvement of residents in community activities also varies. Specifically, participation in certain community activities in co-housing is part of residents' responsibility, like common meal preparation and common garden maintenance. While co-living residents have no obligation to attend community events.

Topic 5: Behave differently between private and public

The boundaries between private and public influence the coexistence of the residents living in buildings with common spaces and shared facilities on a day to day basis (Schmid and CU-Lucerne, 2019). Architects could create a different level of accessibility and publicness by spatial design.

Not only the energy-related behaviours are found different in private spaces and common spaces, but the energy adaptive behaviours are also varied in these areas. The observational studies and the interviews to residents highlighted numbers of factors that might result in different occupants behaviours in private and common spaces in co-living buildings. Interviewees were asked to number their reaction to discomfort in both their private rooms and in common spaces And the result is summarized in the following Table 7. 8 (numbered by the frequency of mention).

Energy adaptive Behaviours in different areas	Private Spaces	Common Spaces
Open/close the window	1	3
Open/close the door	4	/
Adjust clothes	3	1
Go to another place	5	2
Do some exercise to warm-up	/	/
Adjust the radiator	2	4
Use an extra electric heater	/	/
Tell the manager to adjust room temperature	/	5

Table 7. 8 Energy adaptive behaviours in different areas.

Residents tend to adapt with the room environment in their private spaces by open/close the window, adjust the radiator and changing their own clothes. While in common spaces most frequent behaviours are adjusting clothes, change place and open/close the window. As the private rooms are small, close/open window and adjust radiator could quickly change the room temperature, whereas in common spaces the room temperature is pre-set at 21 °C and unable to control by occupants.

Topic 6: Sustainable potential from social and environmental perspectives

This section looks at the energy saved in co-living apartment by shared use of house equipment. Firstly, room types and the number of residents were calculated. Then, the total co-living apartment electricity consumption of each house equipment was calculated. Lastly, co-living apartment consumption was compared with one-bed and two-bed apartment consumptions.

The most common room types in this apartment are Standard Studios and Twodios. Standard Studio can accommodate one person, which has a private bathroom and a small kitchen area. Twodio can accommodate two person and they share one kitchen area, but have their own bathroom. Large Studios are designed for residents who bring child, but they were not actually build as such and used as Twodios. Large and Standard Shared Bathroom Units have similar layout, which both of them are two units sharing one bathroom. While Large Shared Bathroom Units have kitchen area and Standard Units don't. The room types and their layout (take the second floor as an example) are illustrated as follow (Figure 7.14):

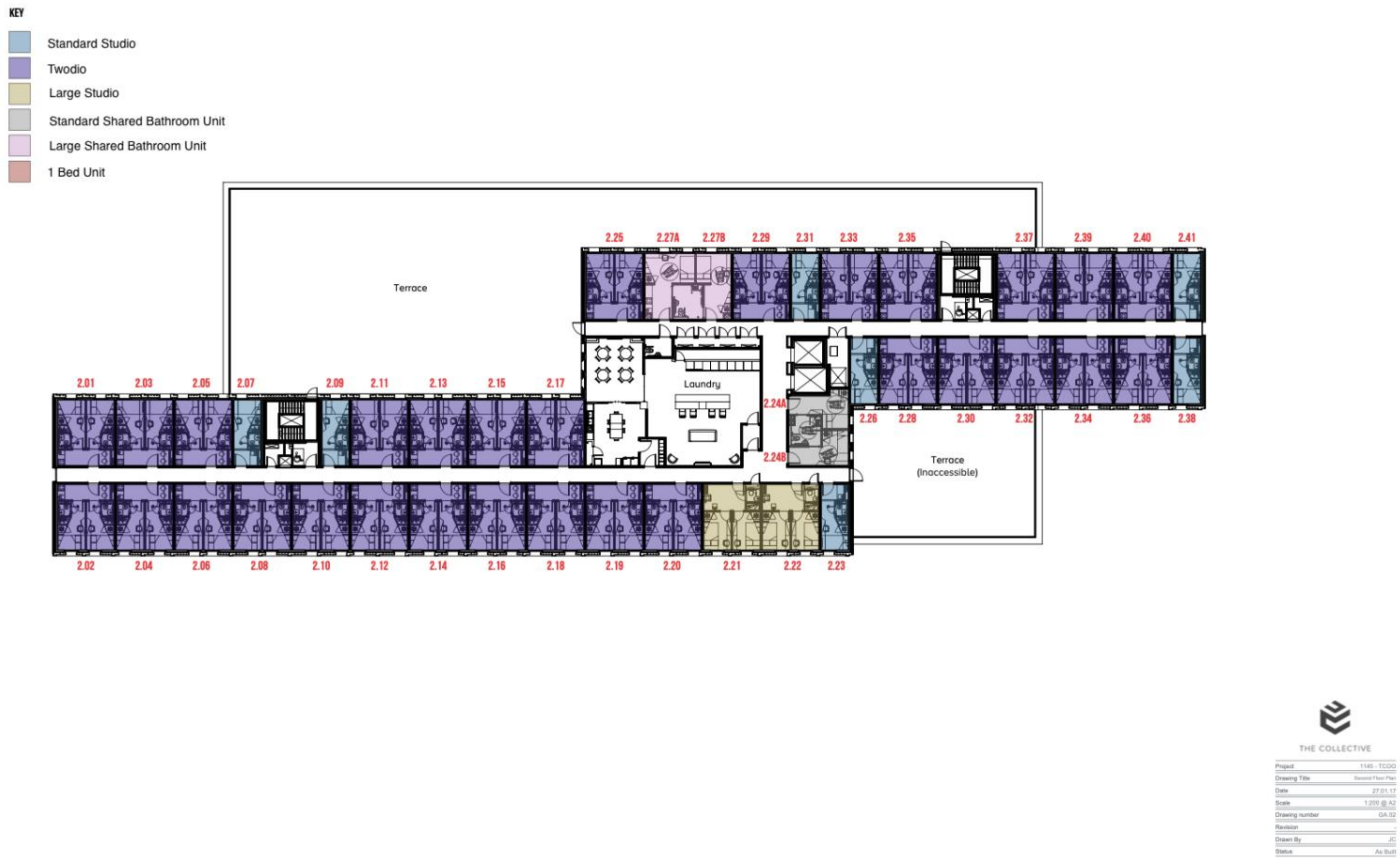


Figure 7. 6 Second floor plan and room types (source: The collective).

Apart from Twodios accommodate two people, all other room types accommodate one people. The total number of residents per floor is calculated as:

$$No._{\text{(resident per floor)}} = No._{\text{(standard studio)}} + No._{\text{(twodio)}} \times 2 + No._{\text{(large shared bathroom unit)}}$$

$$+ No._{\text{(standard shared bathroom unit)}}$$

The number of each room type and total number of residents in each floor are summarized in Table 7. 9.

Floor	Number of Room Type					Total number of residents
	Standard Studio	Twodio (resident two people)	Large Shared Bathroom Unit	Standard Shared Bathroom Unit	1 Bed	
10F	5	12	4	0	0	33
9F	8	12	2	0	0	34
8F	8	12	2	0	0	34
7F	7	32	2	1	1	75
6F	19	26	2	1	1	75
5F	7	32	2	1	1	75
4F	57	7	2	1	1	75
3F	7	32	2	1	1	75
2F	7	32	2	2	0	75
1F	/	/	/	/	/	/
GF	/	/	/	/	/	/
						551

Table 7. 9 Number of room type and residents in each floor (summarized from floor plans provided by The Collective).

There are three types of kitchens in the co-living building, as discussed in Topic 1, where residents cook is one of the key features that set the occupant pattern in collective living buildings apart from ordinary homes. Energy consumptions in kitchen include heating and hot water, cooling and freezing, cooking, and washing machine and dishwashers. The use of kitchen appliances is hard to investigate due to the great variety of appliances that residents use, and most residents keep their appliances in their own or Twodio kitchen. The number of refrigerators in the co-living building can be estimated based on number of rooms, room type and number of common kitchens. Therefore, taken refrigerators as an example to compare the energy use between co-living and ordinary apartments.

Each Standard Studio, Large Shared Bathroom Unit and 1-Bed Unit has their own kitchen area. One Twodio (shared by two people) has one kitchen area and Standard Shared Bathroom Unit has no kitchen area. Their kitchen area all equipped with mini fridges. While the common room in each floor has one or two full size refrigerators, floor 2 – 7 have two refrigerators as they accommodate more residents than the rest floors. The summary of number of mini fridges and refrigerators in each floor and in total are shown in Table 7. 10.

Floor	Number of Room Type					Total number of residents	Total number of mini-fridge	Total number of refrigerator
	Standard Studio	Twodio (resident two people)	Large Shared Bathroom Unit	Standard Shared Bathroom Unit	1 Bed			
10F	5	12	4	0	0	33	21	1
9F	8	12	2	0	0	34	22	1
8F	8	12	2	0	0	34	22	1
7F	7	32	2	1	1	75	42	2
6F	19	26	2	1	1	75	48	2
5F	7	32	2	1	1	75	42	2
4F	57	7	2	1	1	75	67	2
3F	7	32	2	1	1	75	42	2
2F	7	32	2	2	0	75	41	2
1F	/	/	/	/	/	/	/	/
GF	/	/	/	/	/	/	/	1
Total number in the whole buidling						551	347	16

Table 7. 10 Number of mini-fridge and refrigerator.

Basic refrigerator power annual consumption calculates the total energy consumption using for one equipment:

$$E_{(kWh/year)} = (P_{(W)} \times t_{(h/day)} / 1000_{(W/kW)}) \times 365$$

Over 70% of the UK homes own at least one fridge freezer (Gemmel *et al.*, 2017). Therefore, in this estimation, ordinary 1-bed apartment is equipped with one fridge freezer. And common kitchens in co-living are equipped with fridge freezers. The ***P*** (power consumption) of each refrigerator is different. Depending on the size of refrigerators, their power consumptions are between 100 watts to 400 watts. And mini fridges power consumption is half to one third of refrigerators. Here take 100 watts for mini fridge and 300 watts for refrigerator. Refrigerators are plugged whole day, but they are not running all the time. Here take 8 hours to calculate as the time for running.

The total fridge energy consumption for a co-living apartment that accommodate 551 residents is the sum energy use of 347 mini fridges and 16 refrigerators:

One mini fridge annual energy use = (100W x 8h / 1000) x 365 = 292kWh/year

One refrigerator annual energy use = (300W x 8h / 1000) x 365 = 476kWh/year

Total fridge energy consumption in co-living =292kWh/year x 347 + 476kWh/year x 16 = 115340 kWh/year

If the same amount of people is resident in one-bed flats. Then the total fridge energy consumption would be 476kWh/year x 551 = 482676 kWh/year. And if the same amount of people us resident in two-bed flats. Then the total fridge energy consumption would be 476kWh/year x276 = 241776 kWh/year. The fridge energy consumption in co-living is 76% less than in one-bed flat and 52% less than two-bed flat.

The formed social network benefit from the rich kinds of community events and activities organized by the on-site management team, as well as the willingness of residents' get together and make connections. Common kitchens and various type of amenity facilities play an essential role, as they are the places that residents meet, talk, and connect. Community events and activities are also important, as they bring together residents with common interests. It also provides an opportunity for residents to broaden their interests.

7.3 Case study 2: One Brighton

Completed in 2010, *One Brighton* is a high-density multi used community development as part of the New England Quarter Masterplan (Block E and F) near the Brighton train station (Figure 7. 15 and Figure 7. 16). It contains 172 apartment units on top of offices and community spaces.

It is a good example to look at as *One Brighton* is the first One Planet Living community to be completed in the UK. Moreover, it provides people to live in quality and sustainable lifestyles, as well as low carbon footprints (FCB Studios, 2009; Bioregional, 2010)

Figure 7. 7 West façade with elevation rendering, from left to right are Block F and Block E (resource: FCB Studio).

Figure 7. 8 North-West community view (resource: photo from FCB Studio website).

This community consists of two block buildings, Block F to the north of the site has 8 storeys and Block E to the south has 11 storeys. Block F contains mainly affordable housing apartment units, while Block E contains mainly private apartment units. There are 4 three-bed apartment units, 81 two-bed apartment units, 68 one-bed apartment units and 19 eco-studios spread across the two blocks (Table 7.11). 54 of the apartment units are for affordable housing, accounting for over 30% of the total number of apartments.

Apartment Unit Type	Private (mainly in Block E)	Affordable Housing (mainly in Block F)	Total
3 Bed	/	4	4
2 Bed	60	21	81
1 Bed	39	29	68
Eco Studio	19	/	19

Total	118	54	172

Table 7. 11 Residential apartment type detail.

Residential flats were designed to sit on top of commercial and community spaces (Figure 7.17). The flat ranging from Eco-studio of 30.5 m^2 to 3-bedroom flat of 77 m^2. Affordable housing includes 25 shared equity flat (mix of 1-bed and 2-bed) and 29 social rent flat (mix of 1-bed, 2-bed and 3-bed). The development has total residential floor area of 4541 m^2, 925 m^2 community space and 1134 m^2 commercial space (BioRegional, 2014; Kivimaa and Martiskainen, 2017a).

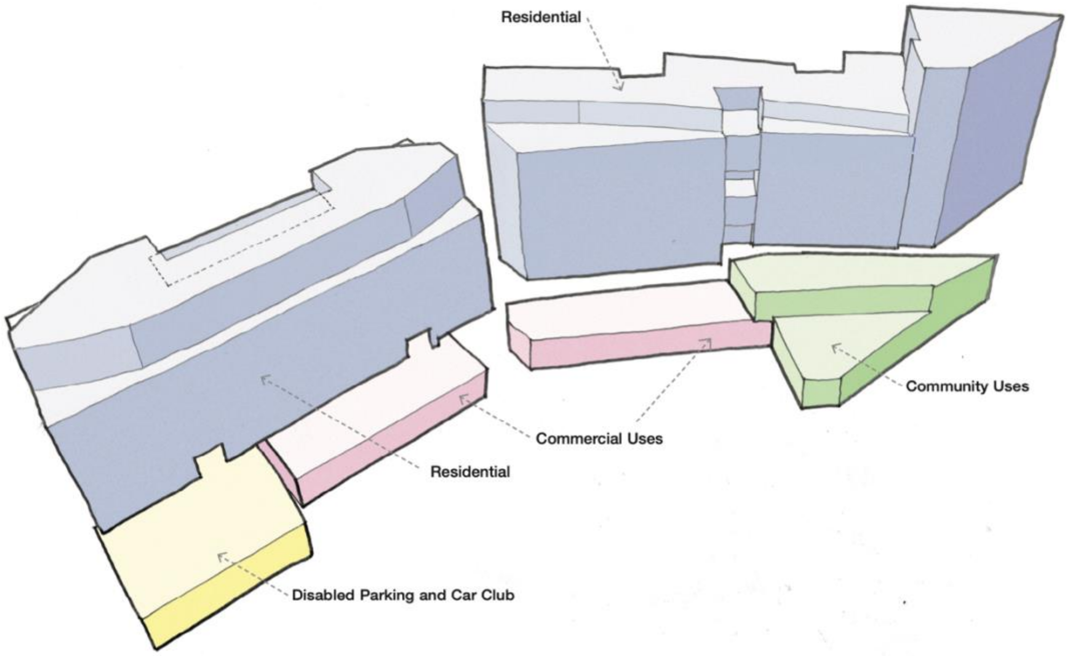


Figure 7. 9 Design concept (resource: FCB studio).

7.3.1 The field study research process

The research methods used were case study research with qualitative first and followed by data collected by questionnaires from seven residents and one detailed semi-structured interview with one resident, an on-site learning tour to One Brighton with building manager and energy manager, a two-day observation at the *One Brighton* community, and existing literature on One Brighton project. Secondary data are discussed in the case study, which includes reports, papers, and web information. The analyses and conclusions are drawn from the primary data and secondary data.

As discussed in Chapter 4, these were chosen because researcher-administered questionnaires provide deeper qualitative information, and the follow-up interviews allow both the interviewer and the interviewee to elaborate more on the topic. Observation allows the researcher to see and record the activities taking place in the present from the perspective of a bystander. Two questionnaires were researcher-administered and one followed with a one-hour interview. Five questionnaires were self-administered by participants and returned to the researcher. Interview was digitally recorded and transcribed. The field study took place in December 2019.

7.3.2 Analysis process

The relationship of themes, categories and topics are illustrated as follow:

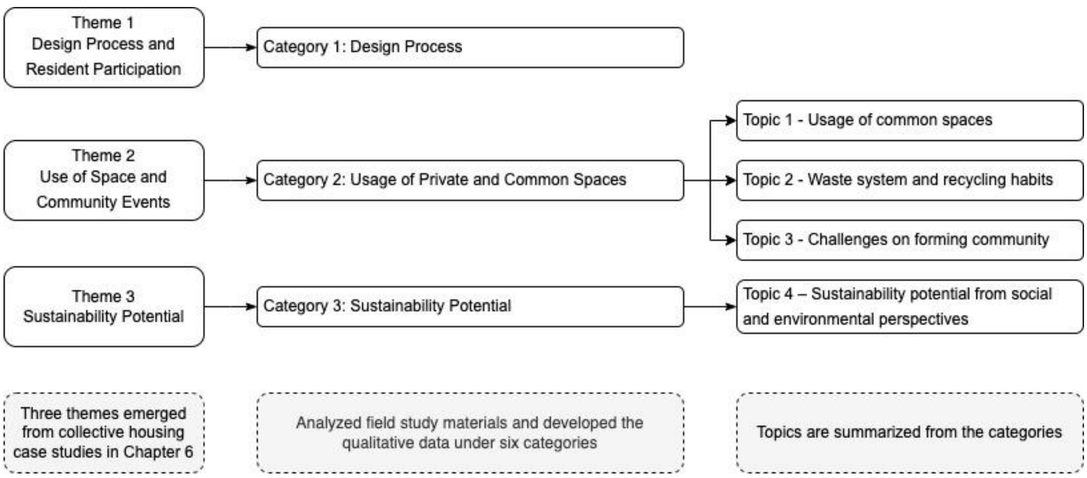


Figure 7. 10 Relationship of themes, categories and topics.

7.3.2.1 Developing the categories

Three themes emerged from collective housing case studies in Chapter 6 (design process and resident participation, use of space and community events, and sustainability potential). The analysis of the field research case study integrated the three themes and developed the qualitative data under the following three categories.

- Category 1, Design Process, explores the design concept, process and principles.
- Category 2, Usage of Private and Common Spaces, discusses how different functional spaces are used in terms of frequency, preference and experience.
- Category 3, Sustainability Potential, discusses the sustainability practices in the community and how they aligned with the One Planet Living principle.

7.3.2.2 Generating topics through coding

The topics were summarized through analysing field study materials under the four categories. Field study materials include questionnaires, interview transcripts and observation notes. Field study analysing tool MAXQDA is used to help with organizing interview materials and sorting topics.

- Topic 1, Usage of common spaces.
- Topic 2, Waste system and recycling habits.
- Topic 3, Challenges on forming community.
- Topic 4, Sustainability potential from social and environmental perspectives.

7.3.3 Analysis result

7.3.3.1 Three categories

Category 1: Design Process

The development of New England Quarter (NEQ) masterplan area started with a plan to redevelop an old railway site back in the mid-1990s. Before Bioregional contacted by the local community group Brighton Urban Development and Design (Budd) in 1999, the masterplan was opposed by the local community concerning might be not affordable. Later the planning authority Brighton and Hove City Council and the developer QED Property together with Budd and Bioregional's updated the NEQ masterplan to base on a mixed-use development and creating sustainable neighbourhood. Eventually in 2003, the new masterplan was approved, which aiming for an exemplar sustainable development where offer good public transport, free car parking, reduced energy consumption within high density development (Kivimaa and Martiskainen, 2017a).

In 2005, three organisations Crest Nicholson, Bioregional and Quintain Estates and Development formed a joint venture for the One Brighton project. They chose Feilden Clegg Bradley Studios as the architect for this project for its strength in sustainable design (Kivimaa and Martiskainen, 2017a). Developers bring a variety of experiences and skills to the project, but also with different objectives. The One Brighton final report carried by Technology Strategy Board (2014) pointed out that through interviews with architects, there is a lack of freedom in design because the space planning of the buildings was mostly controlled by the estate agents for the development.

Input from the local community is incorporated into the project in the pre-planning stage with support from sustainability consultant. From 2005 to 2007, the sustainability consultant organized several activities in order to obtain views and improve engagement among the local community. Activities include meetings with local community groups, public meetings, conduct surveys and display boards in the city. Key outcomes from these activities results on suggesting to have rooftop allotments, café area, a community kitchen and usable community spaces in the final development (Kivimaa and Martiskainen, 2017a). The One Brighton project was designed with reference to the BioRegional's One Planet Living (OPL) principles. OPL principles are as follows (Bioregional, 2022):

1. Zero Carbon Energy: Making buildings and manufacturing energy-efficient and supplying all energy with renewables
2. Zero Waste: Reducing consumption, reusing and recycling to achieve zero waste and zero pollution
3. Materials and Products: Using materials from sustainable sources and promoting products that help people reduce consumption
4. Travel and Transport: Reducing the need to travel, encouraging walking, cycling and low carbon transport
5. Local and Sustainable Food: Promoting sustainable, humane farming and healthy diets high in local, seasonal organic food and vegetable protein
6. Sustainable Water: Using water efficiently, protecting local water resources and reducing flooding and drought
7. Land and Nature: Protecting and restoring land for the benefit of people and wildlife
8. Culture and Community: Nurturing local identity and heritage, empowering communities and promoting a culture of sustainable living
9. Equity and Local Economy: Creating safe, equitable places to live and work which support local prosperity and international fair trade

10. Health and Happiness: Encouraging active, social, meaningful lives to promote good health and wellbeing

Project completed in 2010 with a 128 m^2 allotment roof garden located on the 8th floor of Block F, three interlined courtyards connected with sloping ramps across the site, and 925 m^2 community spaces located on the ground floor of Block E named Brighton Junction.

Category 2: Usage of Private and Common Spaces

The community space was filled with community organizations until six years after project completion in 2016. When the project was completed in 2010, due to the effect of the financial crash, many community organizations did not move into the building as planned because of funding cuts (Kivimaa and Martiskainen, 2017a). Friends Centre is one organisation that moved into Brighton Junction in the early days. This charity had provided adult education service for 75 years, however, announced its closing on 31st July 2020 (Winter, 2020). During its time at Brighton Junction, Friends Centre was one of the largest tenants in One Brighton. It provided courses covering art and craft, IT, counselling skills and English language to about 1200 learners annually (Kivimaa and Martiskainen, 2017a).

The community space on the ground floor (Brighton Junction) is open to the public, while the common space upstairs are accessed by the residents only. The function, location and images of common spaces in the buildings are listed as follow (Table 7.12and Figure 7.19). The use of common spaces and the perception of residents will be discussed in Topic 1.

Space type	Floor	Block	Function and activities
Roof garden	11F	E	Located on the top floor, designed with sitting

			spaces and good view.
Allotment roof garden	8F	F	Residents can sign up for a slot to grow own plants.
Sky garden	8F, 6F, 5F, 4F, 3F, 2F	E	Designed with vertical growth structures to bring greening to the building and provide outdoor communal space for residents on each floor.

Table 7. 12 Outdoor common spaces in the buildings.

Figure 7. 11 From left to right are roof garden, allotment roof garden and sky garden.

Category 3: Sustainability Potential

With One Planet Living design principle, the One Brighton project aimed to meet its design targets by building an efficient thermal building envelope, using sustainable construction materials and energy saving appliances. The heat was provided by biomass and gas boilers and benefit from the MVHR system. The design targets for carbon emissions for the One Brighton project were under 25 $kgCO_2/m^2$ per annum, electrical consumption less than 45 kWh/m^2 per annum. The photovoltaic panels installed on the roof was aimed to generate 5% of electrical energy for the community (Good Homes Alliance, 2014). The measured mean electrical consumption in One Brighton dwelling (common area not included) was 45.8 kWh/m^2 per annum, which approximately the same as the expected 45 kWh/m^2 per annum. However, the measured carbon emission for delivered heat and electricity were 41 $kgCO_2/m^2$ per annum, which were much higher than the design maximum of 25 $kgCO_2/m^2$ per annum. This maybe because the extra emissions from plug-in applications. The measured data was for the year October 2012 to September 2013. The suggested investigation on reduce carbon emission include looking at the factors relating to communal heating performance and efficiency of biomass boiler (Good Homes Alliance, 2014).

Due to the high quality of building fabric, the residents benefit financially from lower energy bills than initially predicted. In 2010, the energy bill for existing 2-bedroom home is £1560 per annum, while the predicted One Brighton 2-bedroom annual energy bill is £1111. The in-use energy bill in 2013 for 2-bedroom One Brighton apartment is averaged £892, which is about 20% lower than the predicted energy bills (BioRegional, 2014) (Hermon, Haynes and Desai, 2014). Moreover, the annual energy bill at One Brighton was about half of a typical gas-heated property in the UK, including the cost of boiler maintenance (Good Homes Alliance, 2014).

7.3.3.2 Four topics

Topic 1: Usage of common spaces

The community space in One Brighton is used by both residents and people from surrounding area. A learner from the local area came to Friends Centre for an English course and enjoyed a coffee and a quick meal with her child at the Brighton Junction common room (Figure 7.20). She commented that Brighton Junction is close to where she lives and provides affordable and good quality meals (interview comment, Brighton Junction user). As a result of the community meetings through the pre-planning stage, the final project included roof allotment and a café. In addition, many other community spaces that contribute to improve residents' community living experience include ground floor outdoor community space, a community centre, roof garden and sky gardens. Apart from the community centre and café, other spaces are outdoor spaces or void, which make these spaces less frequent use in winter times for the reason that 'I wouldn't go to there as it's cold and windy' (interview comment, One Brighton resident), In summertime, these outdoor spaces become popular and the good place to be close to nature, 'I like going to the to the one at the ceiling (roof garden). Usually when it's summer with a bottle of iced tea, and look at the view and have some iced tea, you can chill out just for half an hour and then go back in' (interview comment, One Brighton resident).

Figure 7. 12 One Brighton community common room (photo taken on Dec 2019).

The common area electricity consumption accounts for over 20% of the total dwelling measured carbon emission in One Brighton (Good Homes Alliance, 2014). The electricity consumption in common area and non-domestic use include lighting in the corridors and common area, lifts and security systems, which each dwelling would be equivalent to 1,106 kWh per annum. The residents pay it through a service charge to the management company. The TSB report on One Brighton (2014) pointed out that the electricity use in common areas in apartment buildings is not included in the SAP assessment and Energy Performance Certificate. Suggestions were made in the report, that EPC should include carbon emission assessment associated with common areas. However, the latest SAP 10 (will be adopted from June 2022 in England) excludes common areas in the assessment for apartment buildings.

Topic 2: Waste system and recycling habits

One of the design initiatives aligned with One Brighton's sustainable lifestyle is providing a recycle and waste disposal system (Hermon, Haynes and Desai, 2014), which also respond to one of the One Planet Living (OPL) principle – Zero Waste. The OPL Zero Waste was addressed through action plan in design, construction and operational stages. Recycling system was designed to make recycling easy in One Brighton, including a food waste composter 'Big Hanna' system. In OPL operational stage, the 'Big Hanna' system works in order but the planned community recycling (put up notes to promote sale and exchange unwanted goods) was not conducted. The 'Big Hanna' could generate 480L of compost per year, which was used on the allotment and the planter in the community and the surplus goes to Brighton's Whitehawk Community Food Project (BioRegional, 2014). However, the food waste compost was not in operation and waiting for repair (green chute in Figure 7.21). 'There was a composting system in operation when I visited. At least one of the bins is for compost, but it has become faulty, and it has not been fixed for months' (interview comment, One Brighton resident).

Figure 7. 13 Food waste and other recycle system at One Brighton (photo taken on 19th Dec 2019).

The change in lifestyle behaviour can be seen from one resident’s comment - ‘We carefully separate and dispose of our waste, which we have never done before and we really appreciate how easy it is to manage the waste here’ (resident interview comment from One Brighton Impact Report 2007-2014). However, at the community level, maintaining a sustainable lifestyle can be challenging and needs constant effort to get residents onboard with the One Planet Living sustainable ethos. The facilities manager at One Brighton pointed out in One Brighton Impact Report (2014) that a large ratio of apartments are ‘buy to let’ and there is a regular turnover of tenants who need to be informed of One Brighton’s OPL living principles. And this is not an easy or quick process. The tenants are connected to landlords through letting agencies which means the facilities manager cannot contact tenants directly. Peter, the facilities manager, said ‘I have done a lot of work with letting agents to try and address this’ (interview comment from One Brighton Impact Report 2007-2014). It could be argued that tools can be used to simplify the cost of communication between multiple parties, as well as get new tenants onboard with OPL lifestyle easily.

Topic 3: Challenges on forming community

The local community was involved in the pre-planning stage through engagement activities facilitated by the sustainability consultant (Kivimaa and Martiskainen, 2017b). These were conducted over two years and included public meetings, surveys and display boards. They not only reached a key outcome for the One Brighton to have usable community space for social benefits, but also persuaded some residents to come on board with the ethos of the development. However, the demographics at One Brighton, where large numbers of apartments (up to two thirds) are rented out, means the current group of residents living in the community were not involved in the pre-planning stage and it’s possible that they don’t fully understand the sustainability ethos of the development. The good location and modern building facilities attract tenants, “especially language students most of whom don’t care (about the sustainable principles of the development)” (facilities manager interview comment from One Brighton Impact Report 2007-2014). Compared to typical co-housing developments where residents have participated in forming and designing the community, projects like One Brighton face more challenges in forming a community and require more effort to shape new lifestyle behaviours. One of the similar apartment types like co-living community can be seen as an example to learn from, especially on building operational stage and community management. Co-living community activities like regular organized events by both management team and individuals, weekly eat together, plenty of indoor amenity spaces are some of the key elements for community bonding. However, it requires management team members to keep the system going.

Topic 4: Sustainable potential from social and environmental perspectives

Environmental sustainability of One Brighton project reflects in many ways. Under the BioRegional’s One Planet Living (OPL) principles, the project performs well in terms of building energy consumption which results in lower energy bills for residents. Additionally, residents' feedbacks are positive on comfort of living and the design of the community. There are numbers of design strategies that aim to provide multi-functional social space and enhance social connections, including both indoor and outdoor spaces and facilities. However, it doesn't show much stronger social networks than ordinary block building communities. The reasons are that social networks require long-term and active involvement, as well as sufficient group of people to organize. The increasing mobility of residents make it hard to build or maintain community social network.

7.4 Summary

This chapter presents the field work on two collective housing projects. Each project starts with descripting the field study research process, followed with field data interpretation and discussion of result. Based on the three themes summarised in the Chapter 6, the analysis of the field study developed the qualitative data under various of categories in the two projects which lead to further discussion in different topics. From social aspect, there are three types of sharing in co-housing communities that contribute to form the sense of community, firstly, sharing use of physical space and materials; secondly, residents could save time on cooking by the community shared meals; and share in responsibility, collective management, and decision-making in the community. Moreover, there are support and positive social networks in the community which create a sense of togetherness for coping with loneliness. Additionally, collective housing communities are more open to new low energy technologies and open to pro-environmental behaviours. Lastly, community events and social spaces play important role in community forming.

From environmental aspect, the scale of community makes it able to use renewable energy, like solar panels on private homes and common houses, windmill and MVHR in the community. In some cases, solar panel and windmill could cover over 40% of community total energy use. Collective housing projects are more likely to choose to use natural materials and low impact materials, as well as willing to source locally. Moreover, they open to the concept of sustainable lifestyle, including less driving, use eco-friendly product, and reduce food waste.

Chapter 8 Discussion

This chapter lists and discusses the findings of this study and contextualizes these findings within the existing research through interpreting the field data. It starts summarising the definitions of different types of collective housing and their sustainable features, and follows by exploring main building design configurations and occupant behaviours on collective housing's energy consumption. Then, it presents the sustainable strategies and challenges in existing collective housing developments through data collected via case study and field work. These topics have been discussed in Chapters 2, 3, 5, 6, and 7. This chapter brings together and discusses the factors that have been taken into account and aims to explore the benefits of collective housing and provide a comprehensive discussion on suggestions for better living environments and with sustainable outcomes. This section aims to provide answers to the hypothesis and the two main research questions of this study, as presented in Section 1.3.2:

Research hypothesis:

- Collective housing has potential for energy savings over equivalent individual dwellings.

Research questions:

- What, if any, are the features of collective housing that affect energy consumption and energy-related behaviour of collective housing in design and in-use stages?
- What lessons can be learned from existing collective housing projects' challenges and experiences to provide sustainable guidance for future projects?

8.1 Collective housing concepts

The study reviewed concepts relating to buildings with common spaces and shared facilities and finds that there is a large variety of definitions and terminologies associated with this concept (‘collective housing’ in this study). Some of the community features of these concepts overlap, which makes it important to be clear about the definition and scope when studying a particular concept, as well as to distinguish it from the rest of concepts.

Concepts relating to buildings with common spaces and shared facilities were discussed in the literature review. Co-housing can be defined as housing with common spaces and shared facilities with residents involved in all stages of decision making, and fostering a community through sharing practices and activities (Krokfors, 2010; Vestbro, 2010; Zhang Rui, 2011; Priest, 2015). Collaborative housing is considered to have a wider boundary than co-housing, and, for example, can refer to housing that does not have strong participation from eventual occupants in the development process or in gathering for meals together once completed. Co-living is used to describe purpose-built and managed developments with private spaces as well as public amenity spaces (Prescott, 2020). It has become increasingly popular in large cities among young professionals. Collective housing here is used to describe housing with shared facilities including the collective organization of services (Vestbro, 2010). Other similar concepts include ecovillages, student halls, communal housing, communes, intentional community, and house-share. Detailed definitions of these concepts and the relationship of similar terms are discussed in Section 2.3. Researchers in different regions sometimes use the same concept for different building types. For example, the term collective housing is widely used in Japan to describe communities with individual households and shared facilities. Collective housing is used in this study to refer to communities with common spaces and shared facilities, including co-housing, co-living, and collaborative housing developments. As the living and housing types vary and change over time, it is reasonable to keep the diversity of these concepts.

There are overlapping features in these similar concepts even if they identify separate phenomena. Both ecovillages and co-housing communities focus on community sustainability, including environmental sustainability, such as use raw materials, integration with nature, and promote energy saving lifestyle; and social sustainability, such as caring for children, social support, and support in forming community culture. However, some key features in co-housing community – shared meals, collaboration, and common spaces – are not considered essential to ecovillages (Meltzer, 2010). Therefore, it is important to distinguish between different concepts and set the appropriate research scope for related topics.

8.2 Building geometry and organisational form

8.2.1 Building geometry

Chapter 5 examined how design features, sustainable practice, and sharing practices influence energy consumption in collective housing projects. The results of the massing tests on multi storey co-housing building types indicates that floor to floor height, common-to-private space ratio and window-to-wall ratio are the three top design factors affecting building energy consumption. Surface area-to-volume ratio was considered when selecting the design factors for this study, as it is a representative design parameter related to building heat loss and gain and impacts on building energy performance (Oh, Jang and Kim, 2021). Taleghani et al. (2013) studied the surface area-to-volume ratio of different building shapes and their relationship with building energy consumption, which found out that single shape low floor model has the highest surface area-to-volume ratio and exposed most to outdoor environment whereas linear and courtyard model have lower surface are-to-volume ratio. However, given the housing function and everyday needs of collective living, many collective housing buildings are designed in the form of multi-storey linear or courtyard buildings. These building shapes and forms already have relatively low surface area-to-volume ratio, thus surface area-to-volume ratio was not selected to test in this study. Analysis of a co-housing prototype shows that higher common to private space ratio results of lower energy consumption, specifically, when common to private space ratio goes from 0.14 to 0.22, the energy consumption per square metre would reduce by 7 percent

8.2.2 Organisational form

Analysis of the sustainability of collective housing shows that communities and individuals could both benefit from this community and organisational form. For residents, their access to common areas and shared facilities allows them to do more activities locally, as well as make connections with other people in the community. By participating together in the design, construction and eventual move into the community, residents spend time and do more activities together, which provides a good foundation for later community building. Co-housing residents are welcomed and encouraged to participate in community planning and design, shared meals and activities, and joint management of the community which reward with the benefit from a positive social environment (Garciano, 2011b). For example, as described in a study by McCamant and Durrett, Tom, lives at Sun and Wind co-housing community with his wife and son, enjoys the sense of community and the ‘renewed freedom’ provided living here (Mccamant and Durrett, 2011a). It was easy for him and his wife to decide to go out one evening because they can easily find neighbours to take care of their son, and they do the same for others. Co-housing model has a lot to offer to older people as well. By living in community, older people benefit from reduction of loneliness, being active and engagement, and stay independent and the possibility of staying healthier for longer times (Brenton, 2011). In the case of New Ground Co-housing (OWCH, Older Women's Co-housing Group), first senior co-housing scheme completed in 2016, one of the residents who also researched senior co-housing in many countries spoke at a conference (Co-housing Here about New Ground Co-housing): 'the primary benefit from that participation of workshops with the architects was that we began to feel this is what (a senior women's co-housing community) we have worked forced for so long, is ours, a sense of ownership, the sense of commitment' and 'we play games and did exercises that brought the group together and help people to know each other to a certain extent. The life in New Ground is much the same as when they are living in their private houses before, the difference is they all know their neighbours and they know they can rely on their neighbours' (Brenton, 2019). This trust and support among residents make co-housing groups different to ordinary communities. Their residents can live in a more comfortable environment not only getting access to additional facilities and community activities, but also gaining a supportive and positive social network. Drawbacks discussed in the next paragraph. From communities' perspectives, the collective housing model may facilitate co-housing communities to experiment with emerging low carbon building designs. In the case of co-living communities the managers can make timely adjustments to the building layout and function based on user and market feedback. In the work done at *The Collective Old Oak*, the community host (H2) reflected on the adjustment of the building that the co-living developer are upgrading two floors of *Twodios* (two units share one kitchen, with private bathroom) to studio units in 2019 based on the high demand of studio rooms. Developers and operators heavily involved in co-living and sustainable communities' establishing, which allowing them to gain experience that can be applied to similar later projects. The community host (H2) stated that the second The Collective co-living project in East London, learning from the experience from Old Oak project, was designed to bring all amenity spaces to the ground floor and increased the proportion of studios to suit demand. Sustainable community, *One Brighton*, benefit a lot from the experiences gained through other Bioregional sustainable community projects.

However, there are drawbacks to this model and the residents would have to take on responsibilities and risks. The analysis of sharing features in collective housing case studies and field work suggests that sharing features and practices are widely present in different types of collective housing communities. It comes in the form of sharing use of spaces, function rooms and facilities, sharing skills, ideas and knowledge, responsibilities, time, and value. How common space is used and managed is an important part of collective living, and it is also related to and building a sense of community and belonging. Ataman and Dino (2019) explored spatial use of a co-living unit by interviewing residents who pointed out that co-living residents made minimal physical adjustments to common areas for three reasons: lack of use of these spaces, low interest in making changes and lack of financial resources. The findings of this study, through the analysis of the fieldwork and observations, partially support the above view. Some interviewees (R2, R8, *The Collective Old Oak* (TCOO)) stated that for the common space in the building, the functions well-suited their needs and they do not think they are allowed to make changes to the common spaces, because those are to share among all the co-living residents; the common kitchen and common room at the floor they live is more exclusively used by this floor's residents.

There is a great diversity of housing types in collective housing (Table 8.1), including community size ranging from large communities of hundreds of units to small communities of under ten households; community located in metropolitan cities as well as in rural countryside; building type of mid to high-rise buildings, housing clusters, terraced housing, as well as new build and retrofit.

The common feature is that many collective housing developments tend to build smaller units (floor area per household) than the national average. The reasons for that are 1) the main collective housing type is multi-storey building which has a compact layout (high-rise building); 2) part of the living practices can be accommodated in the common spaces, therefore, individual dwellings can be reduced in size. To be more specific, in most co-housing and co-living developments, instead of having a washing machine in each household, there is a laundry room with numbers of washing machines, dryers and ironing tools in the community common space for everyone to share. This may not save much on total energy consumption of laundry, as the frequency of people doing laundry is not related to where they do the laundry, but related to how many people living in a house. A survey about household electricity use conducted by Palmer *et al.* (2012) found that the frequency of washing machine use increases with the number of people living in a household, and half of single person houses use their washing machine less than twice a week. This is not very different from the frequency of washing machine use derived from field study in *The Collective Old Oak* where most of the interviewees do laundry once a week. Some entertainment activity spaces available for shared use like home cinema, game room, study, living room can be found in co-housing and co-living developments, where energy use can be reduced by residents' joint use of spaces. The expansion in floor area of both residential and commercial dwellings and population globally drives the growth in building sector energy use (IEA, 2019). The average residential floor area per capita of different types of collective housing are compared in Figure 8.1, as well as compared with country average. The UK and US data are from a report (Floor Space in English Homes) commissioned by Ministry of Housing Communities & Local Government (2017), where UK data is from 2008 and US data is from 2009; the EU countries data (Denmark, Romania, being the highest and lowest respectively) are from ENRANZE project which has been supported by Intelligent Energy Europe Programme (2014), where there latest data area from

2008. The first bar in this chart represents the co-housing average floor area per capita in the US, which calculated using data from Meltzer's (2005b) field study on seven US co-housing projects (see Table 8.1). The remaining bars represent the different collective living models in Europe summarized by Schmid, Eberle and Hugentobler (2019). What can be clearly seen in this chart is that the average floor area per capita of US co-housing projects is about 25 precent lower than US average floor area per person of 61 m^2 in 2009. Comparing collective living models' floor area per capita with EU highest, lowest and UK averages, it can be seen that collective living models might not help with reducing average floor area per resident. The relative high floor area per capita in Housing and Culture Projects, and Community Household and Cluster Apartments are due to the additional collective facilities. As the floor area per capita in collective living models counts both common and private areas as total floor area, therefore, the actual private floor area per capita would be lower than the data shown in the chart. The latest collective living model, co-living, has the lowest floor area per capita of 22 square metres, which is two-thirds of the UK average for dwellings of 37 square metres. It is achieved through a very compact layout and the design concept of minimize personal spaces.

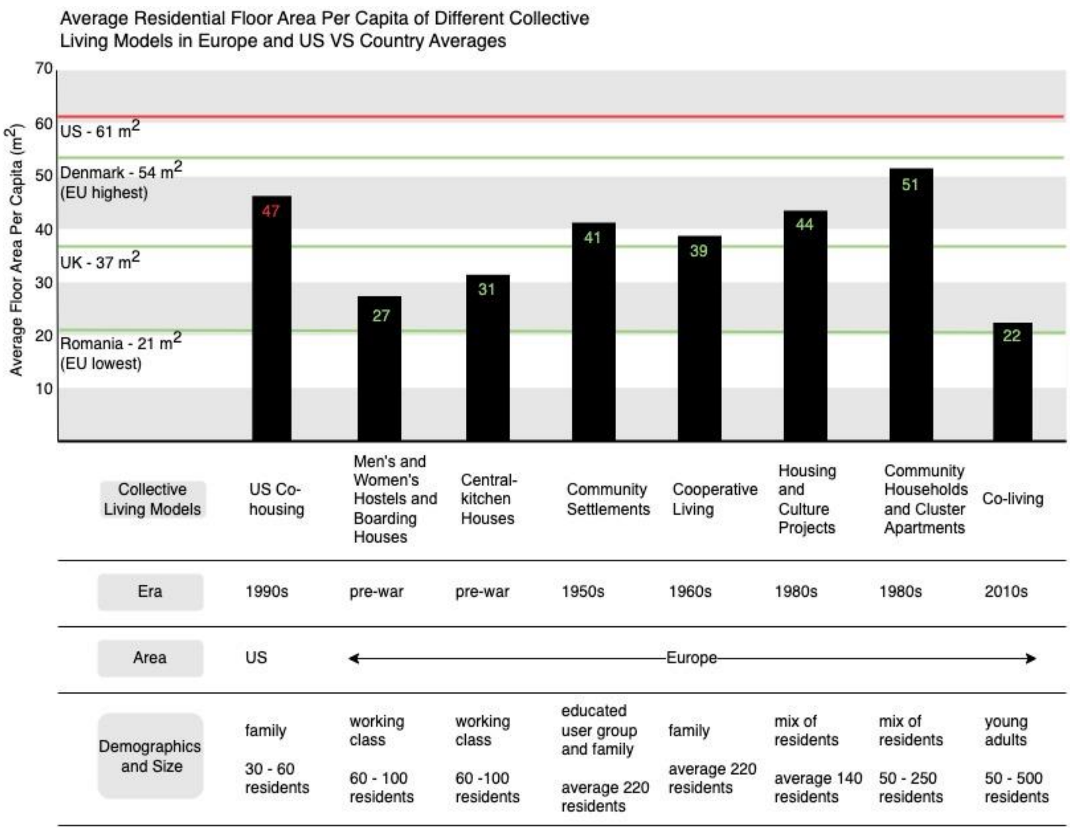


Figure 8. 1 Residential floor area per capita of different types of collective housing and country averages.

Recourse from Mnistry of Housing Communities & Local Government (2017), Meltzer (2005b), and Schmid, Eberle and Hugentobler (2019).

Cohousing Project	**Studios**		**1 bed**		**2 bed**		**3 bed**		**4 bed**		**Total Dwelling Area**	**Number of Household**	**Number of Residents**	**Resident Floor Area Per Capita**
	No.	**Size**	**No.**	**Size**	**No.**	**Size**	**No.**	**Size**	**No.**	**Size**				
Berkely Cohousing			5	70	8	95	2	111			1332	15	26	51
Swan's Market Cohouisng	3	70	5	70	12	111					1892	20	35	54
Puget Ridge Cohouisng			3	63	11	88	7	109	2	130	2180	23	53	41
Cascade Cohousing			3	80	8	100	4	120			1520	15	28	54
Marsh Commons	3	37	1	42	7	93	3	158	3	167	1779	17	35	51
N Street Cohousing					1	84	9	102	7	125	1877	17	58	32
Songaia Cohousing			2	79	3	93	8	152			1653	13	36	46
Average Resident Floor Area Per Capita of US projects														**47**

This table was generated from two tables (Density analysis, Dwelling size by numbers of bedrooms) in Meltzer's (2005b) study.

Table 8. 1 Calculation of US Co-housing average resident floor area per capita.

8.3 Multiple scales of sustainable practice

Collective housing models can help to build communities which are sustainable both environmentally and socially. This section provides a detailed discussion of the sustainability of collective housing from both environmental and social perspectives.

There are many claims in the existing literature which suggest co-housing is a more environmentally friendly alternative to conventional housing and could reduce environmental impact (Krokfors, 2010; McCamant and Durrett, 2011; Middlemiss, 2011). Discussions of the environmental sustainability of collective housing have focused on their encouragement of sustainable design measures and pro-environmental behaviours, such as the potential for using energy-saving technologies, and reduce resource consumption by pooling (Williams, 2008; Jarvis, 2011; Tummers, 2016). Given the nature of collective housing, varied in forms and location, quantitative studies of actual in-use measures are scarce. Daly (2017) conducted a systematic review of quantitative research (from 16 separate studies covering 23 communities) of environmental impacts by comparing ecological footprint (EF) and carbon footprint (CF) across ecovillages and co-housing communities with relatively mainstream communities, which found that the intentional communities achieved lower footprints than similar ordinary communities. The finding supported the claim that intentional communities have significant improvements on environmental impact. However, a plausible criticism of this study lies in the great variety of methodological in the footprint calculations in different countries, as well as big differences on what is considered as 'mainstream communities' in various countries.

Co-housing buildings are found to be more energy efficient. Architect Bruce Coldham (2011, as cited in Zhang, 2011) pointed out that a co-housing model enables more appropriate and effective sustainable measures to be achieved on a community basis than in conventional housing. These measures include central district heating, carpooling, wind turbines (and other renewables), bio-intensive gardening. Additionally, household consumption in co-housing model can also benefit from the economy of scale from various sources. Household public goods which 'consumption by one household member may not rule out, or rule out completely, the consumption of the same good by another member' (Julie A . Nelson, 1988), like television, refrigerator, sofa, and light in a room, warm and inviting living room with fireplace, could reduce the cost for each person to enjoy the same level of living standard. Moreover, living in a community could take advantage of bulk discount in shopping 'family size' or 'three for two' sale. Many co-housing communities use the above measures, for instance, the windmill of Sun and Wind co-housing community provides 10% community's total energy requirement (Mccamant and Durrett, 2011a). Saving through sharing is considered by Swedish co-housing residents, with 70% of residents willing to reduce apartment size and 53% of residents willing to reduce kitchen equipment (Vestbro, 2012).

Reduced resource consumption can be seen in the co-housing model, which includes reducing average floor area of personal occupied spaces and the number of items of household equipment. A comparative analysis of one-person households living in co-housing with self-contained accommodation in the US has shown that one-person households living in co-housing consume less space, about 200 sqft (18.5 m^2) than self-contained accommodation; additionally, Williams's (2003) researched living space in one-person co-housing and self-contained accommodations by different annual income level, the result shown that the low-income (under $20,000pa) one-person household consume more space living in co-housing than in self-contained accommodations, other income level are all consume less space living in co-housing than in self-contained accommodations (with those earning $20-50,000pa have 23% space saving and over $50,000pa have 39% space saving). This might because low-income person can only rent smaller accommodations one the market, while living in co-housing their living spaces are their private unit plus their share of common space. Meltzer (2005c) explored the quantities of household appliances before and after moving into co-housing communities, the results showed there is a negligible increase in refrigerator, television, and dishwasher (2%, 1%, 3% respectively) and significant reduction in freezer (22%), dryer (29%), washer (26%), and mower (75%).

Household appliances savings in a co-living model are explored by calculating the household appliance number using one co-living project data (*The Collective Old Oak, details of this project see section 7.2*), and compare with the household appliance number if the same number of residents (550 residents) live in one-person household model. Household appliance needed for 550 residents living in one-person accommodation and co-living are calculated in Table 8.2, which shows by living in co-living building model large number of cleaning equipment (washing machine, dishwasher) and cooking equipment can be reduced. Cold appliances didn’t reduce much in number because each private unit in co-living is equipped with small fridge-freezer. Though cooking appliances are equipped in private units in co-living, they are reduced in size. People tend to own less personal equipment after moving to co-living apartment, interviewees (R3 and R10, TCOO) from the field study said they own fewer personal belongings compared with when they lived at home with other family members.

	One-person household	Co-living	Amount lower in co-living than one-person household
Cold appliances			
Small fridge-freezer	0	500	500
Fridge-freezer	550	30	-520
Launday, dishwashing and cleaning			
Washing machine	550	10	-540
Dryer	0	10	10
Dishwasher	550	10	-540
Cooking			
Oven	550	20	-530
Hob	550	270	-280
Microwave	550	520	-30
Kettle	550	520	-30

Table 8. 2 Household appliance needed for 550 residents live in one-person household building model VS co-living model.

The number of appliances does not directly affect the overall energy consumption of a building. However, it appears to influence the occupants' usage behaviour of the appliances to some extent, as observed in the fieldwork for this thesis. Specifically, with the small private kitchen size and limited capacity of kitchen appliances, residents might find private kitchen ‘slightly cramped’ (interviewee R6, TCOO) and only use them for light meal or breakfast. Other everyday activities related to energy consumption, such as washing clothes, do not change much due to the reduction in the number of appliances, as most of the interviewees said their frequency of washing clothes does not change. The centralized and shared-use laundry room in co-living developments offers several benefits, including integrating private laundry spaces to a larger laundrette where not only more laundry space made available for personal use but also forms a social hub while people wait for their clothes to be collected. Interviewee (R2, TCOO) said many of his friends in the building were met in the laundry room.

8.4 Social sustainability

Social sustainability is another aspect that is discussed in collective communities. The density and layout of units and common spaces, quality of spaces, private and common spaces ratio, type of amenity spaces are the key design factors relating to social interaction in co-housing communities (Williams, 2005a). Positive aspect of social sustainability of co-housing communities include sense of belonging, improve self-esteem, reduce emotional loneliness, supportive living environment, sharing skills and expertise, and sharing values and interests. living with people with similar interests, and sharing expertise (Brenton, 1998; Marcus & Dovey, 1991; Williams, 2005a). However, Rusinovic, Bochove and Sande (2019) conducted qualitative fieldwork in eight co-housing communities and found that older people could reduce emotional loneliness by living in co-housing to some extent, but co-housing is not the solution to the issue for which professional support is needed. Collective housing is also a good model for addressing the disadvantages of modern life when people who live alone don't have close relationships with their communities or next-door neighbours. Often they express concerns about their living area with neglected open spaces, antisocial behaviours, or lack of facilities for young people. Social, practical and moral support can be found in co-housing communities. Examples include support groups or committee in a community, care for other residents' garden or pet when they are away, and community support for minorities and attention to equity (Meltzer, 2011). Co-living is designed with various amenity spaces for people to meet and connect, and 'It has been perfect about making friends and things' (interviewee R11, TCOO).

People understand and practice 'sharing' differently - 'people are complex and active and have their own diverse meanings and motives for acting' (Gray, 2016). In co-living communities, where over half of the floor spaces are shared-use among all residents, understanding what, how and why people share in the building is fundamental. In this study we consider the following aspects of sharing:

- Shared use of physical space and materials;
- Cooking and meals; and
- Responsibility, time and duty and collective decision-making.

Shared use of physical spaces and materials. Shared space, especially common house consists of amenity facilities (kitchen, dining, game room, living room, library, workshop, cinema, spa, etc) provides a physical space for residents to use and generate community activities. Shared space in co-housing is a necessary element for development of collective activities and maintaining community culture, which plays the role as 'an arena of action' and 'a producer of meanings' (Horelli, 2013). In co-living development, people enjoy having a common kitchen, as 'you can sit there, and people will come in and you can start chatting' (interviewee R1, TCOO). Resident owned personal items are considered in both co-housing and co-living communities in existing research studies and in this study's fieldwork. Meltze (2005a), for example, explored the community's guide of *Commons on the Alameda* co-housing community and found that residents share household items by creating a lending list so before they purchase an item, they would first check the list and find out if they already have one in the community. This suggests that co-housing residents are willing and even prefer to share and are more concerned about consumer goods' functionality rather than keeping up with the trend. Item sharing in co-living project *The Collective Old Oak* is more informal by asking if any resident willing to share via their social media groups. Reasons for this might be co-living buildings like *The Collective Old Oak* was well equipped with basic household items, like an iron and ironing board in the laundry room, additionally, with relatively small private units without much storage space residents 'don't have too much of my own stuff' (interviewee R12, TCOO).

Cooking and meals. Personal preferences for cooking, food, using kitchen tools, tolerance to kitchen smoke, etc., influence the use of space for cooking, as well as participation in shared meals. In co-housing communities, shared meal has been seen as critical to community social cohesion and community building (Guinther, 2008). However, the shared meal is not the most attended event in some co-housing communities. The reasons for this include food preferences and allergies with some people on special diets, and difficulty in meeting children's demand (Graham Meltzer, 2005b). Meltzer (2005a) quoted one child's comment as 'I don't really like the Common House dinners because a lot to them have soup and I don't like soup…I'd be eating at the Common House a lot more if they had stuff I like'. In response, co-housing communities had proposed some solutions. For instance, Berkeley Co-housing developed a food chart that documents residents' allergies and preferences. Such solutions are suitable for communities with a small number of residents, as it takes care of each residents' dietary needs without making meal preparation too complicated (Graham Meltzer, 2005b). For larger communities like co-living developments, a more systematic and concise approach is needed. In *The Collective Old Oak (co-living in London)*, cooking spaces can be grouped into three categories, an event kitchen, a common kitchen and private kitchens (see Section 7.2.3.2), depending on the level of sharing. Resident (R2, *The Collective Old Oak*) complains about how inconvenient it is for her to carry all her cookware to the common kitchen and private kitchen is too small for her weekly big meal preparation), because she prefers using her own tools for cooking, claiming they are more hygienic. The activity type also affects whether people use semi-shared private kitchen or common kitchen. Resident (R3, *The Collective Old Oak*) is a baker and occasionally makes cookies for community events, apart from this type of cooking she prefers using private kitchen because it's enough for her daily meals. For residents who do not regularly cook for themselves, resident (R10, *The Collective Old Oak*) together with some other residents have a group that they often sharing meals, which reduce the hassle of cooking, save money, and fostering friendship. Gray (2016) mentioned similar grocery sharing and meal sharing in the co-living community which save on food costs.

Responsibility, collective management and decision-making. Collective decision-making has been seen as an important element in modern co-housing communities, even before the buildings have been built (Fromm, 1991). The organizational structure in *LILAC* is evolving through time and the progress of the project from the beginning of the idea in 2008 to building complete in 2013 (Figure 8.2). At the very beginning of the project in 2008 a fairly centralized ‘development group’ (five to eight people) was set up by the co-founder for making foundational decisions like finance, land, legal and membership. Later as new members joined and workload increased, from 2011 this small group was no longer able to manage the workload. They divided the work into eight task teams (membership, landscape, finance, maintenance, publicity, process, community outreach, learning/research/replicability) which meet once a month to maintain effective decision makings. These task teams still operate after residents moved in and hold general meetings every three months using templates for proposals and keeping meeting minutes for consistency (Chatterton, 2015b).

Figure 8. 2 The evolving organisation structure at LILAC (summarized from (Chatterton, 2015b)).

Denmark has developed an organized process for senior co-housing, in which specialized agencies (government agencies at beginning, now both non-profits and for-profits groups) would get involved once more than 25 people sign up for a co-housing project. The people signed up would go through four phases together with help from the agency to create their co-housing (Cohen, 2005). Even different professionals get involved in the building of co-housing communities, co-housing residents are the core members who share responsibility to shape community stability and neighbourhood relationship, not authority on the outside to decide how changes emerge (Field, 2004a). In summary, while enjoying the advantages of making decisions together, residents of co-housing communities also need to take on a certain amount of responsibility, time, and effort. Co-living and sustainable communities are not the same regarding to decision-making and responsibility as co-housing communities. Many decisions will have been made beforehand, like the location and scale of the project, layout and design of private rooms, and amenity functions. Therefore, their residents are also not as involved as co-housing residents (residents' involvement of various community development phases shown in Figure 8.3).

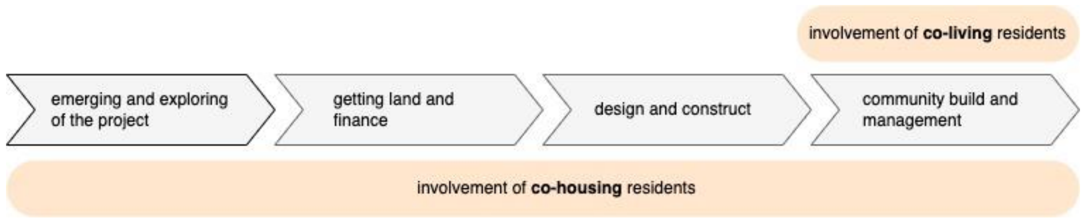


Figure 8. 3 Resident involvement of collective living developments.

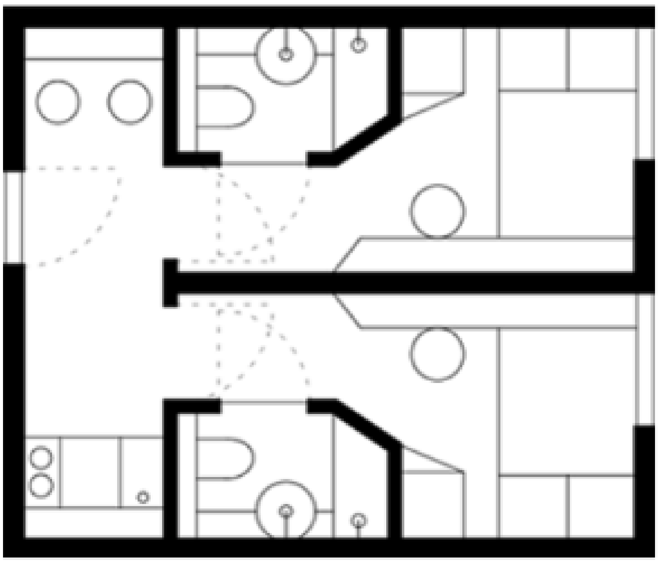
Additionally, sharing of transport, skills and knowledges are common in collective housing models. Shared use of transportation in co-housing and use of public transport are common in co-livings. 10 households (one third of the residents) at Marmalade Lane co-housing community in Cambridge are sharing an electric car. They use Google Diaries to book the car and people share journeys to go to supermarket (Peel, 2019). A car club in Lancaster Co-housing is run by a not-for-profit cooperative and in 2020 a car-sharing software was developed by a community member who is an software engineer (Villins, 2020). Residents contribute to the community by bringing different skill set which enables development happening on-site and learn from each other. If the community plan to develop a car-sharing software, as the resident living in the community and already has some understanding of what they want at the end, it eliminated the effort to search for software engineer and get professional on board and understand how the project works.

Skills and knowledge sharing are also present in co-living communities. Residents are encouraged by the community manager to organize workshops using their speciality and their interests (interview with community host H2). This not only creates a sense of ownership for *The Collective*'s residents of this place by half of the events hosted by its residents, but also reduced management workload for community managers (Studio Weave, 2018).

8.5 Challenges

Issues related with living experience, design, community development have been discussed by residents, community managers and designer during field study. The themes in the section are common topics generated by thematic analysis on the field study data and literature review.

Rules and norms. Living in a collective community may come with social control which may be considered a downside and can be challenging to some residents. Sense of community, shared facilities and generous outdoor spaces are considered as positive elements in co-housing communities, however, sometimes they start with disagreements and lead to conflict among residents. ‘There is always gossip and rumour’ Rusinovic et.al (2019) cited interviewees in their study. Similar complaints can arise in co-living communities. In *The Collective Old Oak*, the semi-shared small kitchen area acts as a transitional space between a frequently used corridor and private units, which are shared by the two residents in the *Twodio* (Figure 8.4). A living guide is provided by the community management team on residents’ arrival, but there is not much about specific rules on using *Twodio* shared kitchen. Therefore, informal rules of using shared spaces usually agreed between the two *Twodio* residents, otherwise, people’s different perspective on ‘sharing use of space’ might cause conflict. *Twodio* residents’ preferences influence what these rules are and how these rules are set. Examples include, some residents view the two people shared-kitchen area as an extension of private unit. Some residents may store personal stuffs, like luggage, storage box in there, which would cause conflict with the other *Twodio* resident if they didn’t previous agree on what should be kept in this shared-kitchen area and what should not. Some other residents, on the contrary, rarely use the *Twodio* shared kitchen because they worry the cooking smells or smoke will annoy their roommate.



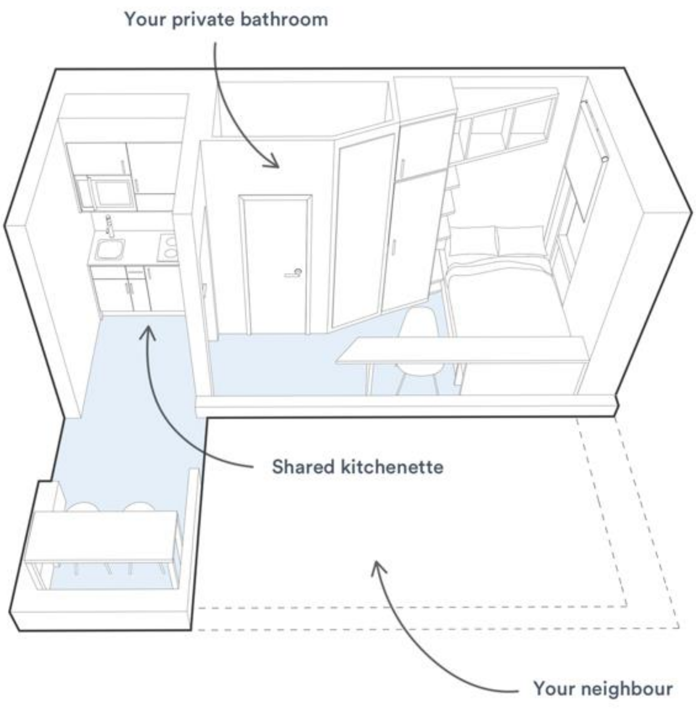


Figure 8. 4 Private unite Twodio at The Collective Old Oak co-living scheme (two residents share one kitchen), top: plan, down: illustration (source: The Collective Old Oak website).

Workspaces. Collective housing model especially co-living developments are equipped with co-working spaces, which provides a comfortable and convenient working environment for the residents at their doorstep. How to achieve work-life balance became a new issue derived from it. Gray's (2016) interview with *The Collective Old Oak* staff Stephanie addressed this issue, ‘it is important to create a variety of inspiring spaces that make room for creativity and productivity, so that when they do choose to work from home, they have enough options so that it doesn’t feel like they are just working from bed’. Especially since lockdown people have developed new habits including more used to work from home. Co-living developments also needs to evolve with the times and respond to the changing needs of people.

Resilient design. The Exchange on the ground floor in *The Collective Old Oak* is used as working space in daytime and hold events and weekly gathering meal on Saturdays. The idea was to maximise the use of the space and make it suit residents’ need for a working space and large gathering space. However, it can be challenging when designing multifunctional spaces. In this case, interviewee (R10, TCOO) described The Exchange as working space ‘quite industrial, not very inviting, and there is always at least one person shouting on their phone’, another interviewee (R7, TCOO) said: ‘I used to work there a little bit, but I found the environment of the room uncomfortable, and I get a sore back after a while’.

Collective housing model to apply widely. Co-housing development is time consuming, difficult to scale up. If the principle co-housing model is to be applied more widely, the size of the community and the extent to which residents are involved in the design and community management process needs to be discussed (Williams, 2005a). Co-housing communities also face challenges in planning and financial, which need support from central and local government, and lenders. From the cases in Denmark and the cases in the United Kingdom, it can be seen that different regions have various types of support for collective housing projects. Finding the right professionals is critical to co-housing groups, for example, architects who had experience working with community projects, and can make positive suggestions are needed (Field, 2004c). Co-living model become popular recent years because it fills the gap in the current housing market, which provides convenient, good quality and vibrant living environment for young professionals who are not yet ready to enter housing market. The number of co-living units submitted for planning increased from under 500 in 2015 to about 4500 in 2021 (Savills, 2022). Benefit of co-living model also includes reduce loneliness, inspiring personal growth and social support. Criticism toward co-living model mostly on room size which most local authorities have no policies for co-living room space standard (Trowers & Hamlins, 2019). Another challenge for co-living model found through field study to TCOO is the high rate of resident turnover in co-living scheme made it challenging for community building which is act as core to TCOO (Studio Weave, 2018).

8.6 Limitations and ideas for future studies

The main limitations of this study are: Firstly, this study is impacted by the Covid-19 pandemic in the UK. The field study was disrupted by lockdown. The original planned three field study had to be dropped to two. The research plan was revised to accommodate this change, by adding a new chapter on desk-top case studies in Chapter 6 aiming to explore existing co-housing communities.

The second limitation is the limitation of the method. The case study method is hard to generalise, as qualitative research method used for one case study might not be suitable for other cases. And there may be bias exist in interview and observation.

More limitations include lack of detailed energy consumption data of case study projects; location of fieldwork in multiple locations, as the current field studies are all in the UK; and the prototype did not reflect energy use of actual projects.

Therefore, there are some ideas for future studies to address the above limitations. It is worth conducting a long-term study on energy-related occupants behaviour study in collective housing which use questionnaire to collect occupants' patterns, use of appliances, preference of energy using behaviours. Additionally, conduct quantitative analysis of monitored data on energy consumption breakdowns in collective housing and compare it with ordinary dwellings. As collective housing is a building type that appearing in various areas worldwide, to understand more collective housing models in different social forms would be valuable.

8.7 Summary

The knowledge gained from literature and fieldwork are summarized in the following table:

	Literature Review Findings	**Fieldwork Findings**
Concepts	There are various types of definitions for collective housing development. Main concepts include co-housing, collaborative housing, collective housing, co-living, communal housing, and cooperative housing (concepts comparison see section 2.2.5)	Many residents have limited knowledge of shared housing prior to moving in.
Building and community	Physical building design and site design need to deal with private unit, common spaces,	Different types of collective housing have different design priorities. Co-living focusing

design	and outdoor spaces, as well as organize traffic and resident activity.	more on the design and resilient of how to make better use of space to enhance the living experience in high-density a residential community.
Community organisational structure	Organisational structure of collective housing communities varies. Co-housing communities is based on democracy, where each household has an equal voice. Decisions made for the community were usually discussed through community meetings by residents, whereas, co-living community don't.	Co-living community residents don't directly participate community decisions; however, community management team would consult the residents and residents could make suggestions.
Resident participation	Resident participation in co-housing communities begins at the design stage. Participate some community activities and attend community meetings are residents' responsibility. And these are some of the ways to keep the community alive.	Though co-living residents don't participate in the design stage, they have an impact on community building through involve in community event or organize their own.
Sharing	Sharing in many forms,	Sharing of household goods

practice	including time, meal, spaces, facilities and household goods are commonly found in co-housing communities. Co-living community has large common to private space ratio and amenity spaces.	and recycling are also exist in co-living community. The use of common spaces and sharing practices are less common in sustainable community than other two collective housing types.

Table 8. 3 Knowledge gained from literature and fieldwork.

Chapter 9 Conclusion

9.1 Introduction

The conclusion chapter has the following purposes. The research questions are restated, key findings of this research are summarized and suggestions for collective housing regarding social and environmental sustainability are listed. These are followed by a critical review of research methodology and limitations of the study. Lastly, ideas for further studies are presented.

9.2 Summarize and reflect on the research

Based on the hypothesis and the two main research questions of this study, as presented in Section 1.3.2:

Research hypothesis:

- Collective housing has potential for energy savings over equivalent individual dwellings.

Research questions:

- What, if any, are the features of collective housing that affect energy consumption and energy-related behaviour of collective housing in design and in-use stages?
- What lessons can be learned from existing collective housing projects' challenges and experiences to provide sustainable guidance for future projects?

And the aims of this research presented in Chapter 1:

- to investigate different types of collective housing;

- to explore the sustainable features of collective housing in both design process and in-use stage;
- to find out the challenges in collective housing communities in the UK; and
- to explore what lessons could be learnt from existing experiences to guide future collective housing projects.

Five objectives are presented to explore the research aims:

- To review the definitions, development, and sustainable features of various types of collective living housing.
- To explore the impact of building design configurations and occupant behaviours on collective housing's energy consumption.
- To find out the sustainable strategies and main challenges in existing collective housing developments in both design stage and in-use stage.
- To investigate the energy-related occupant behaviours in private and common spaces in collective housing.
- To discuss research findings from social and environmental aspects to explore benefits and provide suggestions for collective housing developments aiming to achieve better living environments and sustainable outcomes.

Findings are summarized according to the five objectives as follows:

9.2.1 Definition, development and sustainable features of collective housing

Findings from the literature review on collective housing (Chapter 2) are, firstly, the development of collective living can be traced back in early years in various locations and cultures. Secondly, the definitions for collective housing are various and not unified. Similar housing types are described using different terms worldwide. Co-housing, as one of the collective housing typologies, emerged in the 1960s in Denmark and is still developing in Europe, the UK, North America and elsewhere.

More sustainable features, including sustainable technologies, and environmental behaviours were found in co-housing communities than in ordinary residential developments.

It was noted that most collective housing is owned by the community and has been designed, constructed and used by its residents.　There are also collective housing companies which work between residents and landlords managing the property and providing co-living services. Collective housing companies either own the buildings themself or rent from existing property owners.

9.2.2 How occupant behaviours and design configurations affect collective housing energy consumption

One of the collective housing typologies was selected to test as a prototype to explore the impact of design parameters on building energy consumption. Five geometry design parameters were studied: building height, orientation, window-to-wall ratio, common to private space ratio and floor-to-floor height, were tested through prototypes in DesignBuilder software. The result of the mass modelling test of co-housing building type showed that floor-to-floor height, common to private space ratio and window-to-wall ratio are the three top design factors that influence energy performance in medium to high rise co-housing buildings. However, this study only examined the physical characteristics of the building. Therefore, the role of common spaces and how people use spaces in collective housing became the focus of the following fieldwork.

9.2.3 Sustainable strategies and main challenges in existing collective housing development

Through the literature and case studies of three collective housing projects in Chapter 6 and field research of collective housing projects in Chapter 7, the sustainable strategies in existing collective housing development are:

The scale of the collective housing developments supports the use of sustainable technologies that would not be feasible for individual homes. Sustainable technologies used in collective housing communities include photovoltaics, solar thermal systems, and wind turbines.

Social spaces and equipment are designed in collective housing communities. Together with regular and well-organized community events, they contribute to the community working towards a place to provide residents with a fulfilled and high-quality living environment.

The main challenges in existing collective housing developments are:

Risk exists in the type of co-living which the co-living company rent properties from landlords to operate co-living community. If the contract with landlords go wrong then the co-living residents' living experience would be affected. For example, if the landlord breaks the contract and wants to take back the property early, then the co-living company is forced to break the contract with the residents.

Dealing with conflict among the community in design and post-occupancy stage are important to community's social sustainability. In the design stage, not all residents' requests can be met and the discussion and compromises process can be long and hard. Post-occupancy conflicts are also challenging, as whether it is properly addressed has a direct impact on the long-term living experience.

The onboarding of new residents can be challenging, especially when the residents are from multiple backgrounds. This requires the management team to embrace changes and adapt their approaches to extend community inclusiveness.

9.2.4 Usage of private and common spaces

The findings from field study show that occupant energy-related behaviours are different in private and common spaces. Occupants tend to adapt to the room environment in their private spaces by opening/closing windows, adjusting radiators and changing their own clothes. Whereas in public spaces, the most common behaviours are adjusting clothes, changing places and opening/closing windows.

9.3 Suggestions for collective housing development

The findings are drawn from the literature review and case studies of existing collective housing developments, as well as from interviews and observations during the field studies. It was found that collective housing development relies on the contribution of professionals, residents, as well as support from government. The suggestions for collective housing development are listed as follow:

Themes	Suggestions
Designers	• Instead of 'designing homes for people', architects should 'help people to get their ideal home built', to learn and adapt to work with a group of people as clients who have visions for the kind of houses that they want to live in. • The design stage usually involves residents' participation. It is recommended to build long-term relationship with collective housing clients. • Consider resilient design for growing families to increase flexibility in the house space using. • The common house should be designed with focus on boosting community connection, flexible spaces for all kinds of events, and comfortable for daily use.

Community Group	• Uphold consistent and open communication throughout the entirety of the project, extending this practice into the post-move-in phase to foster a sense of community. It is crucial to ensure that all residents are kept abreast of design decisions, promoting a transparent and inclusive environment that values the input of every community member. • Collaboratively manage risks as a group, proactively address challenges and enhance the resilience of the community. • Establish a decision-making framework that ensuring the voices of all individuals within the community are not only acknowledged but also integrated into the decision-making process. • Keep it simple and clear when engaging with external experts.
Developers	• The relationship between co-living company and landlord should be handled carefully. Establishing clear contractual agreements and well-defined rules is essential to address potential conflicts. This strategic approach helps to cultivate a stable and harmonious living environment. • When developers are constructing their own co-living buildings, understanding the potential residents is crucial. Factors such as residents' utilization of amenity spaces, their preferences for private spaces, the types of events and activities they may organize, and their interactions with building facilities all have a substantial impact on the design concept.
Resident	• It is needed to be well informed before joining a collective housing community, ensuring a

	comprehensive understanding of the fundamental rules and responsibilities as a resident. • Participating in community events, active engagement in community events and further contributes to fostering a sense of belonging.
Policy Maker	• Establish policies and regulations for collective housing specifically, as due to its unique layout and usage, it doesn't fit any current housing types. • Enhance support by offering a variety of policies, engaging professionals, and providing additional funding for collective housing projects.

Table 9. 1 Suggestions for collective housing development.

9.4 Limitations

This section discusses limitations of the research, together with suggestions for future research. Detailed limitations of the methodology used in this research are discussed in Chapter 4.

Firstly, this work was carried out under the restricted conditions imposed by the Covid-19 pandemic in the UK. The part of the planned fieldwork on a co-housing project had to be cancelled as it was not possible to visit the site. Alternatively, a desk-based literature study of co-housing projects explored gaps in the fieldwork findings. Social and sharing practices in co-housing community are distinguished from co-living and sustainable community, as it is intentional community highly dependent on its residents and self-driven. While in co-living and sustainable community, the community forming rely on some degree of third-party co-management. To better address this, research which study mid to high-rise co-housing building communities with more case studies and discover how their social and sharing practice differ from other types of collective housing communities would provide valuable findings for future research.

Secondly, detailed energy consumption data for the case studies in this study were not available. Such data would have helped to quantify occupants' energy-using behaviour by looking at energy use at home breakdowns at different times of the day and throughout the year. It is also helpful to compare real monitoring data with the design estimated data, which helps to optimize building design and reduce energy consumption gap. Despite the lack of data, the fieldwork completed reveals important insights into how residents use their facilities.

Thirdly, field study case studies are carried out in the UK only. The design and operation of collective housing in other countries may differ from the UK context. Hence, the research outcomes might not be applicable to other contexts. Further study might explore collective living models in different social forms. Different kinds of collective living communities of similar social form can be compared in order to discuss the impact of the spatial organization of collective living communities on community sustainability.

Lastly, the co-housing model analysed in this study used a prototype generated from mid to high-rise co-housing project layout features. It indicated key design factors that influence the energy consumption of co-housing model; however, it did not reflect the energy use of any actual projects. It must be recognised that the layout of co-housing project is diverse and the key factors that affect their energy consumption may vary. The key design factors on energy consumption in a co-housing project need to be analysed on a case-by-case basis. It would be meaningful to study a project with detailed building information, its monitoring data and qualitative research on resident practices at the same time. This would provide a more comprehensive view on how collective buildings are used differently with design intentions and which aspects as designers could work on to help with community sustainable.

9.5 Ideas for further studies

The findings of this study provide several potential areas for further work.

Firstly, more case studies are required to fully understand the ability of collective housing to lead to more sustainable outcomes.

Secondly, further study could assess the long-term effects of resident participated sustainable design on its effectiveness and continuity.

Thirdly, further study might explore more collective living models in various social forms. Different kinds of collective living communities of similar social form can be compared in order to discuss the impact of the spatial organization of collective living communities on community sustainability.

Finally, it is worth getting access to real monitoring data on the energy consumption in collective housing buildings. It helps to better understand occupants' energy-using behaviour by looking at energy use at home breakdowns at different times of the day and throughout the year. It is also helpful to compare real monitoring data with the design estimated data, which helps to optimize building design and reduce energy consumption gap.

9.6 Summary

Collective housing is different from ordinary housing in many ways, including design layout, occupant energy consumption behaviours, and use of spaces. It provides an alternative housing choose for people who are looking for extra or alternative features in living from traditional housing market. Moreover, it shows potential to shape social sustainable community and reduce building energy consumption. Co-housing provides residents opportunities to participate in the early design of their own home, and create community from the whole design, build and maintain stages. Co-living apartments satisfy people's needs of convenient and low maintenance living environment, living within a community, and access to amenity facilities. Sustainable communities are designed with environmental and social sustainability concepts, which provide different types of community spaces and reduce energy bill significantly through sustainable building design.

A successful collective housing project requires input from various parties, including developers, residents, policy makers and professionals like architects, sustainable consultants, and engineers.

For designers, instead design houses for people, architects need to help a group of residents to bring their dream homes to life. This means working closely with a group of people who all have their own ideas about what kinds of houses they want, which can be challenging. When it comes to designing homes for growing families, it's better to create spaces that can adapt easily to family's needs. And for the shared spaces in community, it's important to design a space that brings people together. This includes creating spaces that can be used for various events and everyday use.

For developers, depending on co-living developers' business model, if they rent dwellings from landlords rather than building their own building, ensuring a smooth relationship between co-living developers and landlords requires clear contracts and rules to prevent conflicts. If developers are building their own co-living buildings, then understand their potential residents is the key. As residents' usage of amenity spaces and requirement of private spaces, what events and activities residents will be hold, and how residents interact with building facilities, would impact on the design concept.

For policy maker and housing associations, more policies and regulations should be established for collective housing building type, as it doesn’t fit in any current housing guides. More support is needed from professionals and fundings are need from local councils or housing associations for collective housing projects to be build.

For residents, as collective housing project is different from ordinary housing schemes, before joining a collective housing community, residents should be well informed of what to expect and ensure a comprehensive understanding of the fundamental rules and responsibilities as a resident. Moreover, participating in community events, active engagement in community events and further contributes to fostering a sense of belonging.

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Appendix

Appendix a. Sustainable communities

Types

Sustainable communities vary by size (community scale), location (urban and rural), type of residents. There are four types of low carbon community:

- Government and developer lead (case study: Hammarby Sjostad in Srockholm, Sweden). Known as Hamarby Model, the development of the district was inspired by Agenda 21 and initiated in 1996, it accommodate 35,000 people with 11,000 apartments.

- Government and building owners' cooperation (case study figure 4.: Vauban District in Freiburg, Germany). The construction began in the mid-1990s and was finished in 2000, located 5km South of Freiburg's town centre. Now it has 5,000 inhabitants with over 600 jobs. The district is also designed to green transportation that parking lot only available on the edge of the district. Living essentials are located within walking distance in Vauban District, this result in over 70% of the inhabitants live without a car (57% of the households who previously owned a car decided to stop using cars). However, this stargate's applicability depended on community size and building layout, distance to town centre, residents' living preference etc.

Figure A. 1Vauban Distrcit (Ellen Macarthur Foundation, 2010)

- Non-government organization (case study: BedZED and ReGen Village see figure 5 & 6.). Become viral since their announcement at the Venice Biennale for Architecture in 2016. It’s the first Tech-integrated and regenerative residential real estate development. The first pilot community is in Almere, Netherlands and planning to develop projects across Northern Europe, USA and Asia. There are five design principles of ReGen Villages, they are energy positive homes, door-step high-yield organic food production, mixed renewable energy and storage, water and waste recycling, and empowerment of local communities.

Figure A. 2 ReGen Village Rendering (effekt, 2018)

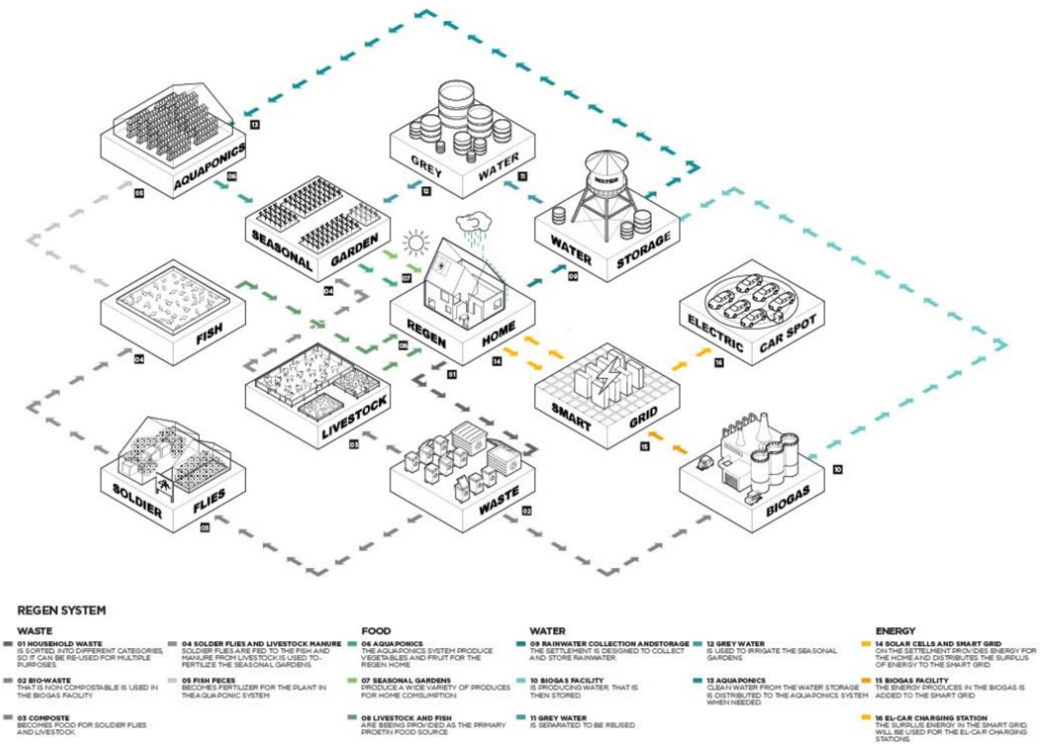

Figure A. 3 ReGen system (Dana Varinsky, 2016)

- Intentional residents lead – cohousing projects

Low Carbon Building

All new public buildings should be 'nearly zero energy buildings' (nZEB) from 2018 and all other buildings in 2020 according to EU EPBD legislation. UK defined nZEB as 'zero carbon' buildings and plan to meet the requirement by 2020. The sustainable strategies for buildings are fabric first and then consider suitable renewables.

Zero carbon standards: There are three layers of zero carbon standard and they are applied as an hierarchy, fabric energy efficiency standards (FEES), on site low carbon technologies, and allowable solutions. Minimum Fabric Energy Efficiency Standards (FEES) are set to determine yearly maximum space heating demand (per m2 floor area), 39 kWh/m2 per year for flats and terraced houses and 46 kWh/m2 per year for detached houses.

Passivhaus and EnerPHit standards for all buildings: Passivhaus standard (see Table 3.) was developed in Germany in 1991 and it specifically targets to reduce space heating and cooling demand, and primary energy consumption for new built (EnerPHit is mainly for retrofit schemes). It can be applied to both residential and public buildings.

	Passivhaus	**EnerPHit**
Primary energy demand	≤ 120 kWh/m^2.yr	≤ 120 kWh/m^2.yr + [(Space heat demand - 15 kWh/ m^2.yr) x1.2] (Baeli, 2013)
Space heating demand	≤ 15 kWh/m^2.yr	≤ 25 kWh/m^2.yr
Space cooling demand	≤ 15 kWh/m^2.yr	≤ 25 kWh/m^2.yr
Space cooling load	≤ 10 W/m^2	
Airtightness	≤ 0.6 ACH @ 50 pa	≤ 1 ACH @ 50 pa

Table A. 1 Passivhaus and EnerPHit standard.

AECB standards: AECB formed several different energy standards to achieve different energy goals. AECB Silver Standard is a low-cost, low-risk and easily achieved goal to achieve high performance building. While AECB Gold Standard and Platinum Standard (see Table 4.) are required to achieve higher carbon reduction. They were all voluntary followed by industry from 2006 and became and will become building regulation from 2015, 2020 and 2025 respectively (Duan, 2016).

	AECB Silver	AECB Gold
CO_2 reduction target	70%	85% - 95%
Delivered heat and cooling	40 $kWh/m^2.yr$	15 $kWh/m^2.yr$
Primary energy demand	120 $kWh/m^2.yr$	58 $kWh/m^2.yr$
Air tightness (50 pa)	$\leq$ 1.5 h^{-1}	/
Summer overheating	< 10%	/

Table A. 2 AECB Gold and Silver standard.

Appendix b. Interview outline

About the project:

- What are the key design concept of The Collective Old Oak project?
- What make The Collective Old Oak project unique and different from other residential projects?
- What are the key referencing materials (papers, projects, theories, etc.) on designing co-living community project that the design team use for The Collective Old Oak project?
- How do you define ‘co-living’ and ‘cohousing’ models? What are the similarities and differences between these two housing models?
- In your opinion, would the co-living building model have impact on residents’ way of living? If yes, what kinds of impact it may have?

About shared spaces VS private spaces:

In the design process, how do you make decisions about:

- How much spaces are using as common spaces and how much spaces are using as private living units?
- What functions are included and activities are designed for the common spaces? How to decide their space areas, and reason?
- What are the priorities for you to consider which spaces are ‘a must’ for private units (like bathroom), and which spaces are less of a must for private units (like living room)?
- Why there aren’t two-beds, three-beds apartments designed in Old Oak project?
- How did the design team generate the layout and space area of private units in design stage? As shown from residents’ feedback that the private units are a bit small for long-term living, what would be the reason for causing this

as-design and in-use gap?

About sustainable and energy efficiency:

- What are the sustainable design strategies or energy efficiency considerations in The Collective Old Oak project? E.g. installing PV, water recycle system, heat recovery system?
- Are there any strategies specifically aiming to save energy in the community?
- Do you think the co-living model is more environmentally sustainable than regular residential communities, in both community scale and individual?
- Did the design team do any energy prediction calculation during design process?
- What standard did you use? Or what kinds of simulation tools/data did you use, how did you get these data?
- (If you know the data or what's the design target) What are the energy consumption segment in the community? As in, how much are for building service, energy using in each common spaces, energy using for private spaces (in percentage)?

About cooking facilities and spaces:

When I walked through Old Oak, I found there are several areas that contains cooking facilities. In the twin studio, there's a small cooking space; there are common kitchens in each floor; there's a large kitchen at the ground floor. These are some questions about the design decisions of cooking facilities and spaces in Old Oak:

- What are the differences among these cooking spaces?
- What's the reasons or considerations to design this way?
- What are the targeted users of these spaces?

About the co-living model:

- What do you think are the pros and cons of co-living building model?
- What are the challenges and opportunities for co-living model to spread in the UK?
- Are there other co-living projects in other countries?
- In China, there's company (founded in 2012) developed with co-living concept as well – You+ (International Youth Community), have developed 23 communities in 10 cities in mainland China. Do you familiar with this scheme and what do you think are the similarities and differences between You+ and The Collective?
- What do you think are the top five key words for The Collective Old Oak project or co-living model?