Buildings & Cities

Francart, N., *et al.* (2020). Sharing indoor space: stakeholders' perspectives and energy metrics. *Buildings and Cities*, 1(1), pp. 70–85. DOI: https://doi.org/10.5334/bc.34

RESEARCH

Sharing indoor space: stakeholders' perspectives and energy metrics

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Abstract

The sharing of indoor space can improve space and energy efficiency. The drivers and barriers to space-sharing initiatives are investigated from the perspectives of building users and building sector practitioners, based on interviews and a workshop. The role of energy performance metrics in promoting space efficiency is further analysed through a literature review. From the users' perspective, space sharing can be understood through the interplay between tangible aspects (*e.g.* concrete benefits derived from sharing), organisational aspects (*e.g.* common decision processes and conflict resolution) and social aspects (*e.g.* group identity and consensus on appropriate behaviours). From the perspective of architects and property owners, shareable spaces require features such as flexibility and multifunctionality. The design of such spaces is limited by regulatory issues (*e.g.* building regulations poorly accommodate shared facilities) and business-related issues. One such issue is that building performance metrics normalised based on floor area do not incentivise the efficient use of space. A review of complementary metrics is provided, covering parameters such as number of users, layout, time of use, *etc.* Each metric serves a particular purpose; therefore, a set of complementary metrics can be used to support decisions at different phases of the building's life cycle.

Practice relevance

Improving space efficiency (*e.g.* by sharing indoor space) is a key strategy to meet simultaneously the future demand for facilities in cities and fulfil environmental objectives such as a reduction of climate change impact in the building sector. A clearer understanding of the specificities of space sharing is provided from the perspectives of building users and practitioners. This will assist practitioners to understand the needs of other stakeholders. Regulatory and business-related barriers to space-sharing initiatives are highlighted as a first step towards overcoming these barriers. Guidance is provided on complementary energy performance metrics appropriate for space efficiency. These metrics can be used to support various decisions during the different stages of a building's life cycle.

Keywords: co-housing; coworking; energy; indicator; metric; sharing; space efficiency

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1. Introduction

Rapid urbanisation and population growth create a high demand for housing and facilities in urban areas (United Nations Population Division 2018). The building sector is responsible for about one-third of global final energy use and between one-fifth and one-third of greenhouse gases (GHG) emissions (IEA 2013; Lucon *et al.* 2014).[1] Meeting the future demand for indoor space could therefore cause significant energy use and environmental impacts. One strategy to address this issue is to use indoor space more efficiently. Francart, Malmqvist & Hagbert (2018) highlight indoor space efficiency as a strategy to meet climate targets in the building sector, as it reduces the amount of new construction and operational energy demand. Similarly, Höjer & Mjörnell (2018) suggest a 'four-step principle' for a more efficient use of buildings. According to the principle, the first priority should be to adjust activities to require less space (*e.g.* through digitisation), the second to intensify the use of existing buildings, and the third to adapt buildings to new uses, constructing new buildings only as a last resort.

In Sweden, the floor area per person is among the highest in Europe (about 42 m^2 per person for housing and 16 m^2 per person for services), and many buildings are underused (Entranze 2008; Statistics Sweden 2019; Swedish Energy Agency 2012). The potential exists to intensify the use of indoor space. One solution is sharing indoor space between several users. Sharing can mean that several users occupy the premises at the same time (as in a shared kitchen or office space), or at different times (*e.g.* by using school premises for other activities during evenings and weekends). Space sharing could reduce the operational and embodied energy demand of buildings. There is a need to understand better the particularities of space-sharing initiatives in order to implement them successfully.

2. Background

The sharing of indoor spaces covers diverse types of initiatives. Examples of space sharing initiatives can be found in Brinkø & Nielsen (2018) and Höjer & Mjörnell (2018), and include:

- Co-housing, including co-living initiatives where inhabitants share a house or apartment, collective apartment buildings with communal rooms and eco-villages with common facilities (Vestbro 2014; Williams 2008).
- Student housing with small rooms and shared facilities such as laundry rooms and a kitchen.
- Coworking and flexible office spaces (Bouncken & Reuschl 2018).
- Premises such as gymnasiums and reception halls shared between several organisations (*e.g.* schools and retirement homes).

Space sharing is a complex topic, and has been investigated from a variety of perspectives. Several studies have investigated the advantages and drawbacks of space sharing from the users' perspective. The advantages of space sharing include access to affordable high-quality premises, reduced isolation and strong social networks (Lietaert 2010; Lubik & Kosatsky 2019; Wang & Hadjri 2018; Williams 2005b). Drawbacks can include overcrowding, stress and psychological distress (Evans 2003; Fuller *et al.* 1996; Marsh *et al.* 2019; Solari & Mare 2012). There is also a risk that space sharing leads to homogeneous communities in terms of affluence, ethnicity, opinions, *etc.* (Chiodelli & Baglione 2014; Williams 2008). User involvement has also been investigated. Brinkø & Nielsen (2018) consider user involvement as an important factor to avoid territoriality in shared spaces. Williams (2005a) notes that user involvement is usually seen as positive, but that too much user involvement can result in 'meeting fatigue' and increased conflicts.

Another strand of the literature focuses more on the physical design of shared spaces. Previous literature has stressed the relationship between physical characteristics of shared spaces and the social characteristics of the user group. In the case of co-housing, Torres Antonini (2001) and Williams (2005a) emphasised that the quality of social interactions and the feeling of safety can be improved through design for social interaction. This entails a layout that allows users to see and hear each other, shared pathways and buffer zones between private and public spaces, as well as common facilities that are easily accessible and fulfil the users' needs. Kim (2006) studied the design of common houses and concluded that there is no one-size-fits-all optimal design, and that the design of a common house must consider the group dynamics of the community. Brinkø & Nielsen (2017) studied the sharing of non-residential facilities and highlighted the distinction between sharing 'core' spaces versus 'support' spaces, as well as the importance of access, security and logistics.

A third perspective is that of facility managers and policy-makers. Brinkø & Nielsen (2017) developed a typology of shared facilities and a guide for municipalities to implement sharing in their premises. Höjer & Mjörnell (2018) and Huovila, Tuominen & Airaksinen (2017) also highlight the importance of using the right performance metrics for decision support, in particular for energy performance. Traditional operational energy metrics based on floor area (kWh/(m^2a)) have been widely studied (Abu Bakar *et al.* 2015) and are commonly used in certification and regulation, *e.g.* in the EU Energy Performance of Buildings Directive (EPBD) (European Council & European Parliament 2018). However, using buildings more intensively might lead to an increase in energy use per m^2 (but a decrease in energy use per user). Area-normalised energy metrics would therefore not fairly reflect the energy performance of shared spaces.

3. Aim and research questions

This paper explores two areas where a research need has been identified connected to space sharing. One aim is to improve the understanding of the processes involved in the implementation of space sharing and identifying aspects that deserve close attention when working with space sharing, as mentioned by Brinkø & Nielsen (2018) and Höjer & Mjörnell (2018). Another aim is to investigate the use of appropriate metrics for energy efficiency in shared spaces, as highlighted by Sekki, Airaksinen & Saari (2015). Specifically, the paper addresses these research questions:

- What aspects of space sharing initiatives deserve particular attention to make them suitable from the perspective of building users (*i.e.* residents and office workers)?
- What are the particular barriers that limit the adoption of space sharing practices, from the perspectives of building providers (*i.e.* property owners, managers and architects)?
- What complementary metrics for operational energy performance could be used to incentivise higher occupancy and efficient use of indoor space?

4. Methods

4.1 Perspectives of building users and providers

The perspectives of building users and providers on space sharing were investigated using interviews and a workshop with practitioners. Notes were taken in both cases, and analysed together to identify relevant common themes. The main ideas in each interview and in the workshop were written on index cards and arranged in an affinity diagram, where similar ideas were grouped together to identify common themes. These themes were structured to depict the specificities of space sharing initiatives from the perspective of building users and providers.

4.1.1 Semi-structured interviews

Semi-structured interviews were carried out with building users and providers involved in space sharing initiatives. The cases and respondents are presented in **Table 1**.

The research process started with an initial reflection about the types of cases and interviewees that should be investigated, following the guidelines on case study research in Bryman (2012) and Flyvbjerg (2006). The overall sampling strategy was to maximise variation and cover a broad diversity of cases in a small number of interviews. An overview of relevant initiatives was obtained from the literature and by asking researchers and property managers who had worked with space sharing.

Table 1: The shared spaces explored and interviewees.

Case	Location	Interviewees	Characteristics
StoCol	Stockholm, city centre	StoCol-Tenant (tenant, female, 30s) StoCol-Manager (project leader at a co-living company, female, 30s)	Co-living community with about 40 tenants. Very extensive sharing (nearly all rooms are shared, including most bedrooms). Convenient location, high-quality premises and high rent. Created by a small co-living company emphasising personal growth, community and social change
BerCol	Berlin, city centre	BerCol-Designer (architect, co-designed BerCol, male, 40s) BerCol-ArchTenant (lives at BerCol, works as an architect specialising in co-housing, male, 40s)	Community comprising three multifamily buildings managed by a cooperative owned by the residents. Includes conventional and shared apartments, common facilities and rooms that can be used by the tenants or rented out. Designed with a focus on sustainability, social diversity and openness to the neighbourhood
Lab	Gothenburg	Lab-Manager (project leader at facility manager, female, 40s)	Cluster of adaptable apartments designed with space efficiency and research in mind. Most tenants are students. Used for several ongoing research projects. A few apartments are independent, but most have a shared kitchen, living room and showers. Operated by a large housing company
Cowork	Gothenburg	Cowork-Founder (co-founded Cowork, now operates it full time, male, 30s)	Coworking space in a repurposed factory primarily used by artists, designers and entrepreneurs
Inno1	Unspecified	Inno1-Arch (architect, female, 40s)	Innovative Swedish architecture project dealing with sharing, integrating space sharing and mobility services in a future prototype building
Inno2	Unspecified	Inno2-Arch (architect, female, 50s)	Innovative Swedish architecture project focusing on new solutions for housing and circular economy at the neighbourhood scale

Note: Codenames are used for reasons of anonymity.

StoCol-Manager, Lab-Manager and Cowork-Founder were then contacted by email and interviewed in November–December 2018. This initial sample included only the perspective of facility managers. Further interviews with Inno1-Arch, Inno2-Arch and BerCol-Designer were conducted in January 2019 to cover the perspective of architects. Snowball sampling was employed to interview building users: StoCol-Tenant was suggested by StoCol-Manager, and BerCol-ArchTenant by BerCol-Designer. They were interviewed in February–March 2019.

Overall, the sample includes co-living and coworking initiatives, user-driven initiatives and initiatives driven by an external company, currently operating projects and innovative pilot projects.

Inno2-Arch and StoCol-Tenant were interviewed in person (for the latter, the interview took place at StoCol). Other interviews were carried out over the phone or via a video link. Most interviews lasted for about one hour (BerCol-ArchTenant was interviewed for only 20 minutes). Notes were taken during the interviews and analysed together with workshop notes. All interviewees were given the chance to review the content of this paper before submission.

The interviews were conducted based on guidelines from Kvale (2007). The template is provided in Appendix A. The topics addressed include:

- The origin of the project and the people driving it.
- The organisation of the community (meetings, communication channels, decision processes, *etc.*).
- The identity and background of users.
- Conflicts and how they are resolved.
- Practical issues such as cleaning, security, insurance, *etc.*

4.1.2 Workshop with practitioners

A workshop with building sector practitioners was organised on 25 April 2019 in Stockholm. Its aim was to gather ideas regarding opportunities to use space more efficiently, the drivers and barriers for space sharing, and possible uses of novel metrics to develop business models based on space efficiency.

The workshop was first introduced with a presentation of the preliminary results from the interviews and literature review. The participants were then divided into three groups. The discussion in each group was facilitated and documented by one or two members of the research team. Among the other eight participants were a researcher specialised in sustainable buildings, two engineers from a real-estate company specialised in facilities for research and teaching, a manager working with quality and sustainability at another real estate company, and four architects. Two of the architects had worked with space-sharing initiatives and had been interviewed previously (Inno1-Arch and Inno2-Arch).

Each group discussed two themes over the course of two sessions, after which the groups joined to share and discuss their conclusions. The first session dealt with the topic of space efficiency in housing and was centred on the question: How could the use of space in housing be reduced? The discussion was oriented by follow-up questions, including:

- Should new buildings be constructed differently?
- Should existing buildings be used differently?
- What can be done to make it easier for more people to live in the same apartment?
- How do the different habits of various tenants become matched?

The second session dealt with the topic of performance metrics to promote space efficiency. The stated questions were:

- What metrics could be used in the public sector to support new policy instruments such as regulations and subsidies?
- What metrics could be used by private sector actors to develop new business models promoting efficient use of space?

4.2 Review of the energy metrics favouring space efficiency

The scientific literature was reviewed to provide an overview of operational energy performance metrics that consider occupancy and could favour a more efficient use of space. Searches were performed with the Scopus and Web of Science search engines, using the keywords (building OR housing OR residential OR office) AND ('energy performance' OR 'energy use') AND (metric OR index OR indicator) AND (occupancy OR capita). These keywords yielded 161 unique results. For particularly relevant papers, those citing or cited by the relevant paper were also examined. A total of 25 papers were retained for a more in-depth examination. The main purpose of this review was to identify the existing metrics discussed in the literature. Therefore, the main criterion for selecting papers is that they presented relevant energy metrics related to occupancy or space efficiency. Papers that discussed other issues related to occupancy or energy performance assessments but did not present relevant metrics were not analysed. The papers retained for in-depth analysis are presented in section 6.

4.3 Limitations

This exploratory study highlights aspects that deserve particular attention when studying or implementing measures related to space sharing. The scope is deliberately broad, covering both the sharing of residential and non-residential premises, the perspectives of building users, facility managers and architects, and topics ranging from the social dynamics of a sharing community to the assessment of energy performance. The chosen approach is meant to generate ideas and pinpoint knowledge gaps and topics of interest based on empirical material. The aim was not to perform in-depth case studies or generate conclusive, generalisable solutions. Only a small number of interviews were performed. Further research is needed to gain an in-depth understanding of the drivers and barriers of space-sharing initiatives, but the present study acts as a starting point. Similarly, the literature review was meant to provide an overview of existing occupancy-based energy performance metrics and the context of their utilisation. However, it does not provide a comprehensive review of other issues related to energy performance metering in shared spaces.

5. Stakeholders' perspectives on space sharing

5.1 Building users' perspectives

This section highlights the specificities of space sharing from the perspectives of tenants and office workers, based on results from the interviews and workshop. They are organised into three categories:

- Tangible aspects, representing what users get access to when participating in a sharing initiative.
- Organisational aspects, including communication, decision-making and conflict resolution.
- Social aspects, relating to the group's identity and cohesion.

The key characteristics of each case studied are summarised in **Table 2**.

Table 2: Main characteristics relevant to building users in the cases studied.

	Key information about the case	Key tangible aspects	Key organisational aspects	Key social aspects
StoCol	Co-living community; extensive sharing; about 40 tenants; upper-class neighbourhood; high rent; core values of personal growth, community and social change	High-quality facilities; convenient location; collaboration	Regular meetings; specific working groups; emphasis on consensus; appointed mediator; group chat; harder to involve introverted or less fluent members	Early user involvement; workshops to define common principles; sharing and consensus as core principles; self-selection of new members based on core principles; importance of collaboration and social interactions, 'family feeling'; majority of upper-middle-class men without children, diversity of age and opinion
BerCol	Housing cooperative with three buildings; conventional and shared apartments; common facilities for rent; affordable rents; ground floor open to the outside; focus on sustainability, social diversity and openness	Affordable rent; common facilities for rent; discount for non-profit organisations	Monthly meetings for the whole cooperative; specific working groups; informal organisation in shared apartments; users co-designed apartments	Early user involvement; emphasis on learning and building trust early on; broad diversity achieved by affordable rents and a layout open to the outside
Lab	Primarily shared student apartments; clusters of six apartments sharing a kitchen, living room and showers; focus on space efficiency and research; operated by a major housing company	Affordable student housing	Top-down management by a housing company; unsuccessful attempts at involving tenants; each cluster of apartments self-regulates	Attempts at organising common meals; informal organisation and decision-making in each cluster; vast majority of tenants are students
Cowork	Coworking space; artists, designers and entrepreneurs; well-connected area near other workshops; operated by a single manager	Professional collaboration; shared studio equipment; convenient location	Administration by the manager as a full-time occupation; users are consulted informally	Importance of daily social interactions, in particular common meals; 'family feeling'; collaboration among users

Note: Inno1 and Inno2 were excluded because they refer to buildings that have yet to be built.

5.1.1 Tangible aspects of sharing

Workshop participants and interviewees (most particularly BerCol-Designer) emphasised that a successful space-sharing initiative must provide users with opportunities and tangible benefits. The main benefits identified in the cases studied were the following:

- Access to high quality *facilities* (StoCol includes spacious, well-furnished living rooms).
- Access to other shared *assets* (mobility services at Inno1, studio equipment at Cowork).
- Access to *people* (professional collaboration is prominent at StoCol and Cowork).
- Affordable *rents* (the rents at BerCol are below the market rate; Lab is an affordable alternative for students).
- Convenient *location* (StoCol is located in a central, upper-class neighbourhood of Stockholm; Cowork in a well-connected area near other small workshops).

Maintaining these tangible benefits, including, for example, cleaning and taking care of common facilities, was seen as particularly important. At StoCol and Cowork, a third-party company was contracted to clean common spaces.

5.1.2 Organisational aspects

Three different forms of *organisation and decision-making* were identified in the cases studied. First, StoCol and BerCol are user-driven initiatives where tenants developed their own structured collective decision processes. Collective decision processes at StoCol are structured around regular meetings and working groups for specific issues. StoCol-Tenant mentioned that the group always strives for consensus regarding important decisions, even though this results in lengthy processes. Similarly, BerCol has structured multilevel decision processes. BerCol includes three apartment buildings and common facilities managed by a non-profit cooperative co-owned by residents. Decisions at the neighbourhood level are taken during monthly meetings, but tenants are also involved in smaller working groups to manage common spaces. Some shared apartments also have their own smaller, more informal organisation, according to BerCol-ArchTenant. Second, Cowork is an initiative where a full-time service provider takes all decisions, but consults users informally by interacting with them on a daily basis. The organisation of Cowork seemed to rely exclusively on decisions taken by Cowork-Founder. He described his full-time occupation as 'going around Cowork, asking people what they need and taking care of everything'. The 30 members, some of whom are friends of Cowork-Founder, interact informally with him and trust him with important decisions. Third, Lab is an example where the facility manager is more impersonal (a large external company rather than an individual). Lab includes clusters of six rooms sharing a common kitchen, living room and showers. Lab-Manager considered that the clusters are small enough to self-regulate informally without major issues. There have been attempts to involve tenants in a 'tenant council', but they never gathered enough participants.

One workshop participant commented that intensifying space sharing could lead to an increase in *conflicts* within a group. The way conflicts are handled in the communities investigated reflects the way they are organised. At StoCol, the focus is on consensus. Hiring a third party to clean common spaces every day was described as a way of ensuring that the maintenance of shared facilities remains a collective responsibility. Additionally, a member was appointed as a mediator to help solve conflicts between members. In one case, a person moved away from StoCol because of an unresolved conflict. Conversely, the organisation of Cowork relies on its founder. Cowork-Founder claimed that he maintains a friendly and familial atmosphere, and did not recall any serious conflict at Cowork. Finally, Lab-Manager mentioned that conflicts can happen between student tenants at Lab, but tenants self-regulate: the property manager only intervenes in case there is a breach of contract.

The initiatives studied also used different tools for *internal communication* (*e.g.* group chats at StoCol and a pinboard at Cowork) and to book rooms and services (*e.g.* a common calendar at Cowork, a laundry booking system at Lab, mobility services at Inno1). However, successful communication is difficult to achieve. There can be a mismatch between the intended purpose of these tools and their actual use. For instance, the pinboard at Cowork and the laundry system at Lab are neglected by users. The interviewee at StoCol also mentioned difficulties with involving members who are not fluent in English or are more introverted.

5.1.3 Social aspects

The interviews indicate that social aspects related to space sharing are important to understand the appeal of these initiatives as well as the experience of tenants and the cohesion of the user group. In several of the cases studied, a shared *group identity* was built over time and maintained through various processes, including the following:

- Deliberate processes to define common values and learn appropriate behaviour. At StoCol, the community held workshops to establish common principles and rules. BerCol-ArchTenant also emphasised the importance of communicating, building trust, learning and developing a common understanding by involving tenants early in the process. Other initiatives (Cowork, Inno1, Lab) had no early involvement of users.
- Daily interactions and sociability. StoCol and Cowork were described as 'families' by interviewees. Cowork-Founder and Lab-Manager highlighted the importance of common meals in improving interaction and involvement.

- Collaboration. Members of Cowork, as well as several tenants at StoCol, collaborated on professional projects. Achieving common goals can also cement the community: StoCol-Tenant mentioned that the resolution of a past crisis brought members closer together.
- Recruitment criteria for new members. Members at StoCol must adhere to the community's list of core principles. Cowork-Founder mentioned that he finds new members by looking for people he likes and have compatible interests with other members. Thus, the criteria can be either explicit and deliberate, or implicit.

Group identity manifests, for instance, by the emergence of *consensus regarding appropriate behaviour and the boundaries between private and shared spaces*. In some cases, this means delimiting clear boundaries between private, shared and public spaces, as emphasised by Inno2-Arch and BerCol-Designer. In other cases such as StoCol, almost all rooms are shared. StoCol's group identity was deliberately built around sharing as a core value. Tenants embrace this lack of private space, and early members have established rules addressing appropriate behaviour ('leave no personal item in common spaces') and the respect of boundaries ('always knock before entering the silent room'). This consensus on appropriate behaviour is now reproduced through meetings, informal socialisation and the recruitment of new members who value similar principles. However, consensus also changes over time. StoCol-Tenant mentioned that despite the established rule, leaving personal items in common spaces is often tolerated.

5.2 Building providers' perspectives

This section focuses on the perspectives of architects, property owners and managers. It addresses three aspects based on results from the interviews and workshop: Building design, regulation, and the assessment of performance and viability.

5.2.1 Building design

Several workshop participants expressed scepticism regarding space efficiency and commented on the *detrimental impact of overcrowding* on physical and mental well-being, including poor air quality, humidity, stress and inappropriate conditions for children. Space-efficient buildings must therefore be designed with a particular focus on aspects of indoor environmental quality such as ventilation, daylight and privacy. At Lab, one solution to avoid a feeling of overcrowding has been to design rooms with small floor areas but high ceilings.

The architects who took part in the interviews and workshop mentioned several design criteria for space efficiency. A common notion is focusing on *function* (*i.e.* the needs of users and the value provided by the building) during the design process. However, BerCol-Designer remarked on the difficulty of predicting user needs. He gave the example of a shared leisure room at BerCol that was almost never used because it did not fulfil any specific need. Four possible approaches were mentioned during the workshop and interviews:

- BerCol-Designer mentioned that future tenants at BerCol were given the opportunity to co-design their apartments with the architects.
- A workshop participant brought up the idea of overlapping functions and multifunctional rooms, such as a combined café, library and laundry room.
- Another workshop participant suggested a higher focus on sharing services (*e.g.* storage, entertainment or cooking) rather than physical space, and integrating these shared services in a broader sharing economy supported by information and communication technology services.
- Inno2-Arch emphasised the importance of flexible, elastic and adaptable spaces, that is, spaces whose function can easily be modified in both the short term (*i.e.* a room used as a working space during the day and a living room in the evening) and in the long term (*i.e.* adapting an office space to the demands of a new user).

Another recurring theme was *physical boundaries* between private, communal and public spaces. A space that is supposed to be available to all users should be appropriately open and accessible. BerCol is thus characterised by an absence of boundaries between the ground floor and the outside: the ground floor is not just shared within BerCol, but becomes a welcoming space for every passer-by. On the contrary, private spaces should enable some level of separation. Inno2-Arch and BerCol-Designer argued that sharing space requires smaller but clearly separate private areas. StoCol has almost no private spaces, but has clear boundaries between different types of rooms: the living room is large and open to the kitchen and entry hall, but silent rooms are closed, and tenants always knock before entering. One shared bedroom was designed so that each bed is in a separate alcove behind a curtain, defining parts of a shared room as private.

5.2.2 Regulation

Regulatory barriers to space sharing were addressed primarily during the workshop. *Building regulations* based on norms of ownership and private space poorly integrate shared spaces. For instance, housing regulations regarding rent, contracts, taxation and tenants' rights do not easily apply to co-living communities with a large amount of shared space. Is it legal to rent out very small rooms if spacious common areas are available? Can the property owner modify

common areas without the tenants' consent? Do tenants need a home insurance covering only their room or common areas as well? StoCol also faced issues regarding the need to write individual contracts for each tenant, and part of the building had to be classified as a hotel. Sto-Manager argues that regulations should change to better accommodate co-living communities.

Moreover, in Sweden, different types of buildings are associated with differences regarding land use, prices, taxes, insurance policies and regulations for acoustics, ventilation, daylight, fire safety, parking spaces and accessibility. A workshop participant mentioned that this complicates measures to increase multifunctionality and flexibility, as there is a risk that a building fit for one purpose would not fulfil requirements for another purpose. This functional lock-in is reinforced by physical planning in Swedish municipalities. Detailed development plans specify the intended function of each building in advance. Designing a building with other functions than those specified might require a regulatory exception.

An architect also mentioned that space optimisation at the municipal level might blur the boundary between public and private spaces. If different functions are integrated in the same building, such as a mall including a subway entrance and private apartments, it can be difficult to define exactly what space is private, shared and public, and what the responsibilities of public authorities, the mall owner and residents are in different areas.

5.2.3 Performance and viability

One challenge to the adoption of space sharing is the need for property owners to assess whether it is a viable alternative. Space sharing will only be seen as worthwhile by developers if it is coupled with a viable *business model*. Workshop participants emphasised that the business model of property owners is based primarily on maximising two variables: rentable heated area and rent per m^2. Shared spaces reduce the demand for rentable heated area, but workshop participants discussed possible sharing-oriented business models that could increase rent per m^2. Ideas included renting out services rather than rooms (*e.g.* 'apartment with access to cooking equipment' rather than 'apartment with a kitchen'), renting out on an hourly basis, dynamically adapting prices to occupancy so that rents are cheaper for buildings with low occupancy, *etc.* Design for flexibility could also decrease reconstruction costs in the long term.

The workshop also included a discussion of indicators used to assess building performance. An architect working with space sharing expressed frustration about the fact that many decisions rely on quantitative performance metrics that can make shared buildings appear suboptimal. The architect claimed that flexibility and multifunctionality cannot be described with numbers, but also mentioned the need for appropriate metrics to prove the value of space sharing to investors and other stakeholders. Conventional performance metrics normalised per unit floor area should be complemented with other metrics to reflect the potential benefits of space sharing in terms of higher occupancy. Accordingly, the following section includes a review of complementary energy performance metrics that could encourage a more efficient use of space.

6. Energy metrics for the efficient use of space

A review and categorisation of operational energy metrics found in the scientific literature is presented. This can be used to complement existing metrics based on floor area, and encourage efficient use of space.

One approach to operational energy metrics promoting space efficiency is simply to *normalise operational energy use by another variable than floor area*. Such activity-based metrics include:

- Energy use per person (Ghajarkhosravi *et al.* 2020; Kampel *et al.* 2016; O'Brien *et al.* 2017; Sekki *et al.* 2015; Sekki, Airaksinen, & Saari 2017).
- Energy use per person-hour (the total number of hours spent by all people in the building) (Dooley 2011; Fokaides, Polycarpou, & Kalogirou 2017; Lindberg *et al.* 2018; Sekki *et al.* 2015, 2017).
- Energy use per euro of market value (Forsström *et al.* 2011).

A similar normalisation issue is encountered when defining a functional unit in building life cycle assessment (LCA). Chau, Leung & Ng (2015) provide examples of functional units used in building LCA. Normalisation based on heated floor area is the most common, but some LCA studies have assessed building life cycle energy use per person instead (Bastos, Batterman, & Freire 2014; Stephan, Crawford, & de Myttenaere 2013).

Another approach is to develop a comprehensive metric including both occupancy and floor area by *adjusting the area-based metric*, usually by dividing it by another variable (Dooley 2011; Escrivá-Escrivá, Álvarez-Bel, & Peñalvo-López 2011; Huovila *et al.* 2017; Lindberg *et al.* 2018; Sekki *et al.* 2015, 2017). Escrivá-Escrivá *et al.* (2011) use metrics normalised per floor area and time of use or vacancy, respectively. They also introduce a single-score indicator as a weighted sum of several other metrics. Dooley (2011) and Huovila *et al.* (2017) investigate energy use per m^2 and person-hour, but Huovila *et al.* argue that this overestimates the benefits of space efficiency. Huovila *et al.* and Sekki *et al.* (2015, 2017) adjust energy use for relative occupancy, that is, the time spent by users in the building compared with the maximum possible time they could spend there. They also introduce a more complex metric adjusted for occupancy and space efficiency of the layout (**Table 3**).

Table 3: Examples of energy metrics found in the literature and their stated purpose.

Purpose	Examples of metrics	References
Assessing the technical properties of the building	Asset rating: $\frac{E_{modeled\ building,standard\ conditions}}{E_{baseline\ building,standard\ contitions}}$	Goldstein & Eley (2014)
	Specific energy use (kWh/m^2)	Most common metric, *e.g.* Abu Bakar *et al.* (2015)
Assessing energy performance in a context of changing occupancy	Energy use per person-hour	Fokaides *et al.* (2017)
	Operational rating: $\frac{E_{modeled\ building,actual\ conditions}}{E_{baseline\ building,actual\ contitions}}$	Goldstein & Eley (2014)
	Energy use per person	O'Brien *et al.* (2017)
Assessing how well a building is operated	Energy use per guest night or per guest room night in hotels	Priyadarsini *et al.* (2009), Wang (2012)
	Operation and management index: $\frac{E_{measured\ (energy\ bills)}}{E_{modeled\ building,actual\ conditions}}$	Goldstein & Eley (2014)
	Metrics to optimise the use of schools in a municipality: (1) Energy use per user or user hour (2) Specific energy use adjusted for the number of users, person-hours or rate of occupancy (3) Specific energy use adjusted for occupancy and space efficiency: $SEC_{u,s} = \frac{E}{A.u}$, where $u = \frac{n.t}{t_{ref}.A/A_{ref}}$, where t is the average time spent by users in the building; and t_{ref} and A_{ref} are the reference values for occupancy time and area per user for this type of building, respectively	Huovila *et al.* (2017), Sekki *et al.* (2015, 2017)
Assessing a subsystem that depends on occupancy	Number of occupants at the 99th percentile of occupancy (to assess ventilation rates)	O'Brien *et al.* (2017)
	Energy use for heating, ventilation and air-conditioning divided by volume and operation time	Escrivá-Escrivá *et al.* (2011)
Identifying concrete opportunities to optimise operation	Ratio of workstations per employee so that employees can find a place to sit 99% of the time	O'Brien *et al.* (2017)
	Energy use per person-hour for different zoning solutions	Lindberg *et al.* (2018)
Identifying issues causing abnormal energy use	Ratio of time with the lights on to the total use time Ratio of office equipment energy use during use time to the total office equipment energy use	O'Brien *et al.* (2017)
	Ratio of energy use during vacant time to vacancy-hours	Escrivá-Escrivá *et al.* (2011)
Comparing buildings using a single score	Benchmark considering, for example, building age, size, location, number of users and operating time	Chung (2011), Goldstein & Eley (2014), González *et al.* (2011), Kontokosta (2015)
	Weighted average of several other metrics, with weights aiming at penalising high energy use during low occupation and poor heating, ventilation and air-conditioning (HVAC) performance	Escrivá-Escrivá *et al.* (2011)
	Energy use per visitor in swimming pools	Kampel *et al.* (2016)
	Life cycle energy use per person Life cycle energy use per guest night in hotels	Bastos *et al.* (2014), Filimonau *et al.* (2011), Stephan *et al.* (2013)
Emphasising fairness in access to space	Per capita building energy consumption occupied space (PCEOS) = $\frac{A^2}{E.n}$	Yuan & Long (2009)
Informing users about their energy use	Energy use per person	Dooley (2011)

Note: E is the building's total energy use in kWh, n is the number of users, and A is the heated floor area in m^2.

Yet another solution is to *compare operational energy use for the studied building with similar buildings* (Chung 2011; Goldstein & Eley 2014; González *et al.* 2011; Kontokosta 2015). This benchmarking can be based on a statistical analysis of a sample of existing buildings. Energy use for existing buildings is modelled as a function of, for example, floor area, occupancy, climate, *etc.* The assessed building's actual energy use is then compared with the expected energy use for similar buildings. For instance, Kontokosta (2015) describes how the Energy Star rating uses benchmarks considering, for example, user density and operating hours. Chung (2011) presents various mathematical methods used to derive such benchmarks. Goldstein & Eley (2014) describe the use of energy models to compare the assessed building with a fictitious baseline building (defined with the same floor area and operating conditions). They emphasise how different metrics can be used in combination to answer different questions. For instance, a model using standard operating conditions informs about the technical properties of the building, whereas using real operating conditions is appropriate to assess the building performance considering, for example, occupancy conditions.

Like Goldstein and Eley, others have emphasised the use of a *package of purpose-built complementary metrics* (Escrivá-Escrivá *et al.* 2011; O'Brien *et al.* 2017). O'Brien *et al.* (2017) argue that different purposes, actors and decision situations call for metrics with different variables, scope (*e.g.* total energy use or energy use for appliances only), spatial resolution (*e.g.* per room or for the entire building) and temporal resolution (*e.g.* per month or year). Detailed metering can be data intensive, but Escrivá-Escrivá *et al.* (2011) and O'Brien *et al.* (2017) point out that new integrated monitoring technologies in buildings allow for the collection of previously unavailable data.

Each metric serves a specific purpose, and different metrics can be used together to cover a variety of relevant issues. The review highlighted examples of occupancy-based metrics used for various purposes (see **Table 3** for details and references):

- Assessing energy performance in a context of changing occupancy.
- Assessing how well a building is operated.
- Assessing a subsystem that depends on occupancy (*e.g.* ventilation).
- Identifying concrete opportunities to optimise operation.
- Identifying issues causing abnormal energy use.
- Comparing buildings using a single score.
- Emphasising fairness in access to space.
- Informing users about their energy use.

The literature includes examples of metrics developed for a range of different stakeholders, including policy-makers (Fokaides *et al.* 2017), property owners and investors (Goldstein & Eley 2014), building managers (Escrivá-Escrivá *et al.* 2011; O'Brien *et al.* 2017) and municipalities (Sekki *et al.* 2017; Yuan & Long 2009). Most studies focused on *post-hoc* analysis of policies or existing buildings. There was little focus on metrics to consider occupancy proactively at the design stage, with the exception of Lindberg *et al.* (2018).

Different occupancy-based metrics have also been used for different types of buildings, for example, residential buildings (Dooley 2011; Fokaides *et al.* 2017; Stephan *et al.* 2013; Yuan & Long 2009), hotels (Filimonau *et al.* 2011; Priyadarsini, Xuchao, & Eang 2009; Wang 2012), hospitals (Salem Szklo, Borghetti Soares, & Tiomno Tolmasquim 2004), office buildings (O'Brien *et al.* 2017), schools (Escrivá-Escrivá *et al.* 2011; Sekki *et al.* 2015, 2017) and swimming pools (Kampel *et al.* 2016). However, Boemi & Tziogas (2016) mention a lack of studies about energy performance indicators for some types of buildings (*e.g.* shopping malls).

7 Discussion

Previous literature on shared spaces has highlighted the importance of a holistic perspective considering the interplay between physical and social elements (Balakrishnan, Muthaly, & Leenders 2016; Brinkø & Nielsen 2017, 2018; Kim 2006). The present results support this holistic view and point to the importance of considering both tangible properties of shared spaces (*e.g.* cost and quality of facilities) and social interactions within the user group (*e.g.* group cohesion and identity). Beside tangible and social elements, this study considers a third aspect related to the internal organisation of space sharing communities (*e.g.* decision-making).

Regarding the physical properties of shared spaces, the workshop and interviews with practitioners highlighted the importance of design criteria such as overlapping functions, multifunctionality, flexibility and ease of adaptation. These notions have been previously studied in the architectural literature (Estaji 2017), and the present study confirms their relevance in the case of space-sharing initiatives. Other notions were mentioned in the literature but did not come up in the present study, such as design for social interaction (Torres Antonini 2001; Williams 2005a), or distinguishing between sharing 'core' and 'support' spaces (Brinkø & Nielsen 2017).

Tangible benefits of space sharing for building users include access to high-quality premises, equipment and services, as well as lower rents. This fits well within the framework of sharing economy, emphasising access to goods and services rather than ownership, as well as the emergence of collaborative lifestyles (Botsman & Rogers 2010; Boyer & Leland 2018). On the other hand, using space more intensively could lead to significant drawbacks. Issues related to

overcrowding have been investigated in the previous literature (Evans 2003; Fuller *et al.* 1996; Marsh *et al.* 2019; Solari & Mare 2012), but overcrowding was never mentioned as a problem in the cases we studied.

Regarding social aspects, the importance of a cohesive user group was emphasised several times during the interviews. This indicates that close attention should be paid to the various processes that contribute to group cohesion, including those that establish trust and a consensus on appropriate behaviour, recruitment of members, internal communication channels, formal meetings and informal social activities (*e.g.* common meals). Cohesion and socialisation among residents has been previously studied in the case of co-housing (Ruiu 2016; Williams 2005a). The present results indicate that these processes can play an important role in other forms of space sharing as well, since socialisation and 'belonging to a family' were prominent topics mentioned by Cowork-Founder.

Previous studies have pointed out that a cohesive sharing community may also lead to homogeneity in terms of, for example, age, affluence, ethnicity and/or gender (Chiodelli & Baglione 2014; Williams 2008). The present study included cases with varying levels of diversity. At StoCol, most members are upper-middle-class men without children. Possible factors that might reinforce homogeneity at StoCol include high rents and the selection of new tenants by the users. On the other hand, BerCol was more heterogeneous and several aspects of its design and organisation aimed at improving diversity, including an open ground floor, moderate rents and discounts for non-profit organisations renting facilities. However, there is insufficient evidence to find a causal relationship between space sharing and higher or lower levels of diversity in user groups.

Regarding organisational aspects, three ways of organising space sharing communities were observed:

- *User-driven communities* such as StoCol and BerCol, where structured consensual decision processes, explicit user involvement and consensus-building are particularly important (especially when sharing is extensive).
- *Individually led communities* where an individual acts as a full-time manager. At Cowork, users rarely have formal input into decisions, but they contribute through daily socialisation and informal communication with the manager.
- *Top-down communities* with minimal intervention from the property manager. At Lab, most decisions are taken by the real-estate company. User involvement in these decisions remains limited, but each group self-regulates informally.

Ruiu (2014) and Williams (2008) emphasise the importance of grassroots models and user involvement for co-housing, but the present results suggest that different organisational forms can lead to viable space sharing practices. Brinkø & Nielsen (2017, 2018) provide further insights related to the sharing of non-residential facilities. They highlight the importance of user involvement to avoid conflicts, especially when sharing is extensive and users have no other alternative. In our case study of non-residential premises, Cowork, explicit user input was rare and conflicts appear to be limited by other factors. A possible explanation for this difference is that users are involved informally through daily interactions with the manager. Mutual help and socialisation are also both prominent at Cowork, which might reduce the risk of conflicts. Overall, the results indicate that various ways of organising space-sharing initiatives and involving users can lead to successful outcomes.

Regulatory issues are linked with shared spaces. Plans and regulations do not always include suitable categories for multifunctional buildings. It should be kept in mind that different regulatory barriers might exist in countries other than Sweden. Finally, issues were identified about the performance assessment of shared facilities. Common indicators of technical performance (*e.g.* energy performance) are sometimes inappropriate to assess the performance of shared spaces. Certification schemes such as Leadership in Energy and Environmental Design (LEED) (USGBC 2018) and Building Research Establishment Environmental Assessment Method (BREEAM) (BRE 2018) usually do not consider potential benefits from high occupancy. One recent exception is the Swedish CityLab certification scheme for neighbourhoods. It considers climate impact per user for residential buildings, in addition to conventional metrics (Sweden Green Building Council 2019). The Level(s) framework for environmental assessment of buildings also includes a reporting of measures taken to improve flexibility and adaptability (Dodd *et al.* 2017). The present review of complementary energy metrics could provide a basis through which to support a broader use of occupancy-based metrics.

8. Conclusions

The present study highlights some of the specificities of space-sharing initiatives from the perspectives of building users and providers, as well as barriers to their implementation. It also provides a review of complementary metrics that can be used alongside area-normalised metrics to take occupancy and space efficiency into account. It is part of an ongoing exploration of space sharing, and pinpoints aspects that deserve particular attention, rather than drawing conclusive results. From the perspective of building users, the aspects highlighted were:

- tangible benefits and drawbacks for users;
- modes of formal and informal organisation and user involvement; and
- social interactions and cohesion of the community.

From the perspective of building sector practitioners, the aspects highlighted were:

- design of the physical space;
- existing regulatory barriers in the building code and in development plans; and
- business viability and performance of space-sharing initiatives.

An in-depth understanding of the implementation of space-sharing initiatives will need to consider these aspects and their interplay. The results suggest that different forms of formal organisation and user involvement are viable for space-sharing initiatives (*e.g.* initiatives driven by the users, by a single entrepreneur or top-down by an external company). This aspect has not received much attention in previous literature, and more in-depth research is needed to understand whether these different forms of organisation face different challenges.

The alternative metrics for operational energy performance that were reviewed could be used to promote the efficient use of space. Future case studies can build upon this review to assess the energy performance of space-sharing initiatives. In particular, there is a lack of studies of occupancy-related metrics in design, as well as case studies for some types of non-residential buildings (*e.g.* shopping malls). In addition to the potential reductions in operational energy demand, space-sharing initiatives might also reduce embodied energy by avoiding the construction of new buildings. Future research is also needed to investigate how using such metrics could influence practices in the building sector (von Platten, Mangold, & Mjörnell 2020). In particular, second-order effects of space sharing should be investigated. Sharing might lead users to access more spacious facilities, and a more intensive use of a building might lead to a less intensive use of another building. Using occupancy-based metrics on a single building could therefore misrepresent the overall effects of a space-sharing measure.

These findings provide an overview of the specificities of space-sharing projects, including regulatory barriers that have not been the focus of previous research. Furthermore, the overview of metrics could provide a useful basis for practitioners who want to use such metrics to support investment, design and management decisions related to space-sharing projects.

Suggestions for future research include undertaking a more in-depth assessment of the various aspects highlighted in this paper, and broadening the scope of the analysis to include the perspectives of other relevant categories of stakeholders. In order to understand better the potential issues and risks of space-sharing initiatives, it would be relevant to include the perspective of users who are dissatisfied with space sharing. It would also be relevant to consider the perspective of public actors such as municipalities. Municipalities could help overcome regulatory barriers to space sharing at the local level. They are also large property owners themselves and could implement space sharing in their own premises, following, for example, the guidelines of Brinkø & Nielsen (2017).

Note

[1] Estimates vary depending on what is included under the denomination 'building sector' and on accounting conventions for indirect upstream emissions from energy use.

Acknowledgements

The authors thank their contacts within both academia and the private sector, who helped frame the project and identified relevant space-sharing initiatives. Comments from the reviewers and editor greatly helped to improve the paper, and are gratefully acknowledged.

Competing interests

The authors have no competing interests to declare.

Data availability

No supplementary data are available.

Ethics and consent

All interview participants were informed of the purpose of the study and gave their consent. They were given an opportunity to review this manuscript before submission, and their identity was anonymised. The research was conducted within the guidelines set by the Swedish Ethical Review Authority and the main author's institution.

Funding

Funding from the Swedish Energy Agency (grant numbers 46881-1 and 46067-1) and from the Strategic Innovation Program Viable Cities is gratefully acknowledged.

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A.1 Appendix A: Semi-structured interview template

The following template was used to structure conversation during the interviews. Owing to the semi-structured nature of the interviews, the template was meant as a guideline to the themes to be addressed rather than a list of questions that must be closely adhered to.

- Introduction of the purpose of the research project, clarifications about anonymity and any questions the interviewee might have.
- Generic information about the sharing initiative:
  - When did it start? Who launched it? Was sharing an integral part of the building's design from the start, or was sharing organised in a building that was already in operation?
  - What is being shared and what is kept private? Does it include shared equipment or services?
  - Logistics: What should a new participant expect? Are there fees to access shared facilities? Are participants present at the same time or different times?
  - Are there tools that facilitate sharing (*e.g.* booking system, pinboard, dedicated website)? Do they work well? Is any function of these tools lacking, or, on the contrary, present but barely used?
  - Off the top of your head, can you (the respondent) think of something that works well and something that doesn't regarding space sharing?

- The participants:
  - Who can participate in the sharing initiative? Can anyone join, is participation restricted to a predefined subgroup of people (*e.g.* students) or are new members approved on a case-by-case basis? In practice, do participants mostly belong to a particular social group?
  - What are the main reasons for participants to join? Are they sharing space by choice? Do they have a particular interest in community, social interactions or sustainability? Are they trying to save money?
  - What do participants need, logistically speaking? A particular resource, particular conditions (*e.g.* silence), or just a room?
  - Do participants have an active say in how the initiative works? Are they consulted? Do they co-own the facility, does one of them own it or does it belong to a third party?
  - Social aspects: Do participants have strong distinct identities? Is there a strong shared identity? Do some participants leave their mark or appropriate shared spaces?
  - How do participants communicate with each other? Does information and communication technology (ICT) play a role in solving/avoiding conflict? Is there a virtual community aspect (*e.g.* group on social media or chat)?

- Practicalities:
  - Does the group hold regular meetings? Do they include all members?
  - When internal issues arise, how are they solved? Is one person responsible or are decisions taken as a group? Who is legally responsible for, for example, damage to shared facilities?
  - Security: How is access to private and to shared spaces restricted (*e.g.* key, code, card)? Has there been any security issue in the past?
  - Material aspects: How is cleaning organised? How is damaged shared equipment replaced? Does shared equipment get damaged more/less often? How are common finances organised?

How to cite this article: Francart, N., Höjer, M., Mjörnell, K., Orahim, A. S., von Platten, J., & Malmqvist. T. (2020). Sharing indoor space: stakeholders' perspectives and energy metrics. *Buildings and Cities*, 1(1), pp. 70–85. DOI: https://doi.org/10.5334/bc.34

Submitted: 14 January 2020 **Accepted:** 15 April 2020 **Published:** 12 May 2020

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