White Paper

Task Force 1: Building-User interaction

Topic C: Responsive end-user

Revision: V3

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Executive summary

The SmartBuilt4EU project has set up four task forces investigating issues related to smart buildings: their objective is to identify the remaining challenges and barriers to smart building deployment, and the associated research and innovation gaps that should be addressed in the near future.

Task force 1 investigates how smart buildings can interact at best with their external environment. This topic C focuses on the responsive end user.

Occupant behaviour has proven to significantly impact the energy consumption and indoor environment of buildings. The uncertainty caused by occupant behaviour accounts for a significant discrepancy between predicted and actual energy consumption, that can often reach 30%[1]. Numerous smart building solutions have been developed with the aim of, among other, maintaining environmental indoor quality and reducing energy consumption. But comfort perception and building energy efficiency can be conflicting objectives: managing at best the related trade-offs and moving towards more energy-aware behaviours will require more interactions between occupants and the building. This will help both gather the necessary real-time data on user behaviours and building parameters and propose usable information and services to the end users towards more sustainable patterns.

This white paper therefore aims to provide an overview on what is known and what should be further investigated to answer the following questions:

- What are the occupants' expectations in terms of interaction with the building? What type of information are they interested in, through which medium, and to what end?
- What type of smart building functionalities can lead to actual occupants' behaviour change?
- How to tackle trust issues related to data privacy and usage?

In its first part, this paper proposes a brief literature review on the current state of the art to set a theoretical background and reviews the findings and ongoing developments of some key R&D projects, specific attention being paid to EC-funded projects.
A brainstorming process then enabled to identify some key barriers and drivers regarding the development of more interactive and influential smart building solutions. Figure 1 and Figure 3 provide an overview of the main barriers and drivers discussed.

[1] Van Dronkelaar Chris, Dowson Mark, Burman E., Spataru Catalina, Mumovic Dejan, A Review of the Energy Performance Gap and Its Underlying Causes in Non-Domestic Buildings, Frontiers in Mechanical Engineering, Volume 1, 2016, www.frontiersin.org/articles/10.3389/fmech.2015.00017

BARRIERS	
TECHNICAL	1. Difficulty to establish the exact relation between data collected, data retrieved to user, and impact of user response to this information
	2. Lack of mechanisms/ platforms and related governance models to consolidate data into actionable intelligence
	3. Existing legacy systems not compliant with standards
ECONOMIC	4. Data has become strategic and sharing it is seen as a risk or loss of opportunity
	5. High cost of data-driven solutions and lack of financial incentives
	6. Lack of information to occupants and building managers on long-term benefits of SB solutions
SOCIAL	7. Data privacy issues: lack of knwoledge by occupants about data privacy procedures in smart buildings (Who will do what with my data?)
	8. Lack of digital skills that can help occupants to use smart building technologies
	9. Limited data and feedback on/from vulnerable users (occupants with disability, the elderly)
VALUE CHAIN	10. Data ownership and governance issues: who owns the data and who captures its value?
	11. Lack of application by the industry of existing standards (ISO, CEN) related to interoperability, data models, product catalogues
	12. Lack of standardisation of novel occupant behaviour modelling - accounting for user diversities
REGULATION	13. Discrepancies between local and national regulations and legislations
	14. Lack of normative and technical regulations to support the mitigation of the energy performance gap between design and operation phases

Top barriers according to the Task Force (items 1, 4, 7, 14)

Figure 1: Overview of main barriers

DRIVERS	
SOCIAL	1. Users' need for user-friendly, clear, simple information related to their building
	2. Potential of behavioural change of building occupants though the provision of relevant feedback
	3. Integrated user-centric design and operation (by means of integrating social sciences and humanities disciplines into building design, construction and performance phases)
VALUE CHAIN	4. Shortness of housing stock, forcing to make a more efficient use of building stocks
	5. Energy flexibility potential from households and communities to support the power grid
	6. Optimisation potential of existing buildings/systems and future building designs through data collection, harmonisation and valorisation
TECHNICAL	7. Data aggregation potential (via interoperability, semantic models) to turn data in insightful information to users
	8. Multiple disciplines on data management and UX design towards user-friendliness, greater user-interaction, AI and machine-learning addressing user expectations
ECONOMIC	9. Total cost of ownership of smart solutions
	10. Need for one-stop-shop models (platforms) on data consolidation and sharing
	11. Transition to transparent and performance-based service provision
REGULATORY	12. Need to shift from footprint (CO^2) to handprint (positive impact in usage), involving total lifecycle understanding and management
	13. Trust related to GDPR implementation and model contracts

Top drivers according to the Task Force (items 1, 2, 12)

Figure 2: Overview of main drivers

Based on the State of the Art and the barriers and drivers, a number of research and innovation (R&I) gaps were identified. They are synthetised in the next diagrams (the darker ones are those that were identified as priorities with task force members).

These 'gaps will feed the elaboration of the Strategic Research and Innovation Agenda (SRIA) on smart buildings that will be produced by the SmartBuilt4EU consortium by mid-2023, together with some recommendations targeting policy makers.

R&D	1. Implement **participatory methods** involving end-users, to: - understand the conditions of adoption of smart solutions - understand and identify the data/information needs of different building users (occupants, owners, facility managers, etc.), for different building types (residential/ tertiary, with different levels of smartness) - identify occupants' behaviours that can be modified and those that cannot - design solutions providing pertinent and actionable information to users in line with their energy practices	
	2. Clarify **data ownership, usage and rights** when data is aggregated and used in integrated services (platforms)	
	3. Define how to **share openly and harmonise** the data: how to collect data from multiple sources? How to harmonise the data from different nature?	
	4. Apply AI, prediction, modelling, to help **fill the quality gap on real data** collected	
DEMO	5. **Deploy living labs** (permanent pilots) giving open access to real data on building's monitoring and user perspectives	*Top priorities according to the Task Force*
	6. **Implement large scale demonstrators** with emphasis on the active participation of end users, from the design phase. This implies engagement strategies relying on social science and humanities, and the use of techniques such as gamification.	*Top priorities according to the Task Force*
	7. Systematically integrate in demonstrators the monitoring of occupancy and weather data together with building parameters to ensure data quality	

Figure 3: R&I gaps

REGULATION	1. **Integrate the user-centric dimension into regulation,** i.e. the participation of users from the design phase and along the whole (smart) building life cycle	*Top priorities according to the Task Force*
	2. Design clear guidelines on data collection procedures: who can collect which data, whom should be informed the data collection and usage ('GDPR++')	*Top priorities according to the Task Force*
CERTIFICATION & STANDARDISATION	3. Develop **real-time certification on building performances** – not limited to energy – to provide users with actual building information	*Top priorities according to the Task Force*
	4. Enforce third-party **certification regarding privacy,** building on privacy metrics developed in SPHERE project and proposed to CEN442	
	5. Propose **KPIs and assessment framework to measure the level of engagement of users**	
SCALING UP & INDUSTRLIALISATION	6. Support the **integration/aggregation of services** (and products) into one-stop-shops. E.g. a service package focused on 'comfort & wellbeing' includes energy efficiency services as well	
	7. Demonstrate **business models** relying on new modes of collaboration/interaction with end-users	
AWARENESS RAISING	8. **Assist users in understanding the data privacy procedures** in smart buildings	

Figure 4: 'Go-to-market' gaps

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List of abbreviations

AI	Artificial Intelligence
BIM	Building Information Modelling
BDTE	Building Digital Twin Environment
EC	European Commission
EEB	Energy Efficient Building
GDPR	General Data Protection Regulation
HBI	Human Building Interaction
IAQ	Indoor Air Quality
IEQ	Indoor Environment Quality
ICT	Information and Communication Technologies
IoT	Internet of Things
ML	Machine Learning
MSI	Master System Integrator
OCC	Occupant Centric Control
R&D	Research and Development
R&I	Research and Innovation
SB	Smart Building
SRIA	Strategic Research & Innovation Agenda
SSH	Social Sciences and Humanities
TF	Task Force
UI	User Interface
UX	User Experience

1. Introduction

This white paper is produced in the context of the SmartBuilt4EU project, a coordination and support action funded by the European Commission to bring together the research and innovation community on smart buildings.

The SmartBuilt4EU project has set up four task forces with volunteers across Europe, investigating topics related to smart buildings. They respectively address the interaction between building and end-user, efficient building operation, interactions between the building and the external environment, and cross cutting issues.

Figure 5: The four Task forces set up by the SmartBuilt4EU project

SmartBuilt4EU task force 1 investigates how the interactions between any smart building and its users can be facilitated and improved, as a key success factor for the market uptake of smart building solutions. This investigation follows three main lines, so far defined as follows:

- **Topic A: Assessing and improving the acceptance and attractiveness of smart building solutions for the end users:** this topic aimed to evaluate our knowledge about building users' behaviours, expectations and concerns, and how this knowledge should drive the design and implementation of smart solutions.
- **Topic B: Occupant centric building for improved quality of life:** this topic aimed to investigate the question of integration of all smart technologies that can increase the quality of life of occupants (accessibility, comfort, health, real-time adaptation, etc…)
- **Topic C: Responsive end user:** this topic aims to investigate how smart building solutions can trigger behavioural changes among building occupants to serve purposes not limited to their own quality of life (building operation optimisation, resource efficiency, etc).

The present white paper focusses on the third topic, i.e. 'Responsive end-user' and presents the outcomes of a collective work, carried out with the members of the task force, in several steps:

- Agreement on the scope
- Review of the State of the Art and identification of the points to be investigated in particular
- Analysis of barriers and drivers
- Identification of R&I gaps
- Key conclusions on the topics and recommendations

2. Topic under investigation by the Task Force

2.1. Rationale

Occupant behaviour has proven to significantly impact the energy consumption and indoor environment of buildings. The uncertainty caused by occupant behaviour accounts for a significant discrepancy between predicted and actual energy consumption, a performance gap that often tops 30% as shown in several studies[2].

In recent years, numerous smart solutions have been developed with the aim of maintaining adequate Indoor Environmental Quality (IEQ) standards and of reducing energy consumption in the building. Energy management systems should be designed to both guarantee the required comfort level and to minimise the energy consumption. However, these two objectives might be conflicting in many cases, even more when considering that the perception of comfort remains very subjective.

Managing at best these trade-offs between occupant comfort and building efficiency will require a deeper involvement of occupants in the building management. As described by A. Franco et al[3]., this means that *"the pervasive supporting system will lead people towards energy-aware and comfort behaviours, considering the user feedback also on the perceived comfort in the surrounding environment. The user, along with the whole community of the building occupants, will (partly) be in charge of the IAQ control and energetic efficiency of the system that they daily live (work) in, and will feel more and more responsible for it. In practice, the user will be pushed towards wise behaviours as they will participate in the "control" of the system, via ordinary personal devices like smartphones, tablets, and desktops."*

Targeting such a level of occupant engagement implies to address several dimensions of the smart systems and services to be integrated to the building. They include, among other, the real-time data collection about building parameters and occupants' behaviour; the nature and efficiency of interaction between building and occupants; and the type of 'building intelligence' services proposed to occupants.

This white paper chose to focus more specifically on the following questions:

- What are the occupants' expectations in terms of interaction with the building? What type of information are they interested in, through which medium, and to what end?
- What type of smart building functionalities can lead to actual occupants' behaviour change?
- How to tackle trust issues related to data privacy and usage?

2.2. Scope

From the three questions introduced in the previous section, three 'blocks of knowledge' were identified to set the theoretical framework of the topic:

- Data integration for smart building services: overview of the data process from source to service provision
- Human-building interaction: definition and scoping of this emerging research area
- Data privacy and trust: definitions and requirements.

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[2] Van Dronkelaar Chris, Dowson Mark, Burman E., Spataru Catalina, Mumovic Dejan, A Review of the Energy Performance Gap and Its Underlying Causes in Non-Domestic Buildings, Frontiers in Mechanical Engineering, Volume 1, 2016, www.frontiersin.org/articles/10.3389/fmech.2015.00017

[3] Franco, A. Balancing User Comfort and Energy Efficiency in Public Buildings through Social Interaction by ICT Systems. *Systems* **2020**, *8*, 29. https://doi.org/10.3390/systems8030029

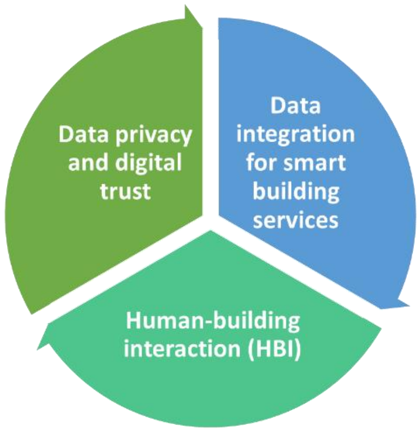

Figure 6: The three building blocks identified for the State of the Art

In this light, recent and ongoing projects were analysed by the task force members in terms of:

- analysis of occupants' behaviour and their expectations with regards to building interfaces
- user-centred development of smart building applications
- buildings' real-time data collection
- data privacy management

It should be noted that:

- the question of data security and governance is addressed in white paper TF4B 'Data governance and cybersecurity', including a synthetic review of regulations, certification frameworks and standards relevant to this topic
- the topic of interoperability, prerequisite for data integration, is covered in white paper TF2A 'Interoperability'.
- In relation to end-user engagement, the concepts of crowdsensing, gamification, and tangible devices are described in white paper TF1A 'end user acceptance and attractiveness'.

All white papers previously published are available at www.smartbuilt4eu.eu/publications/ .

3. State of the Art

3.1. Literature review

3.1.1. Data integration for smart building services

Currently in smart building management, data captured from sensors, actuators and multiple devices within a building can be analysed and used to provide information services.

According to Daissaoui et al. (2019), the most used architecture of IoT is a three-layer architecture, with:

- The perception layer that includes perception nodes and networks and is responsible for detection and data collection.
- The network layer that is responsible for data transport, a critical layer since it is the convergence of various devices and the communication infrastructure.
- The application layer is where end users interact. This top layer receives the transmitted data and deliver it to users for other services.

The acquisition, collection, transmission, integration, and analysis of IoT data is a complex process that requires integration of multiple technologies and computing platforms. Edge computing and big data technologies are some key computing approaches to address this complexity.

- Edge computing is the management of IoT data within the location of data acquisition from technologies and sensors
- Big data technologies enable to harness vast amount of data from smart building technologies. To facilitate this process, cloud computing is utilised to harness the seamless integration of technologies with high performance computing architectures.
- Analytical and machine learning (ML) algorithms are used to make sense out of the data captured.

Inibhunu and McGregor (2021) propose a privacy preserving smart building framework that segments the data process from source to service provisions. The framework, pictured below, comprises five computation layers: IoT infrastructure, IoT communication protocol, edge computing, cloud computing and services provision.

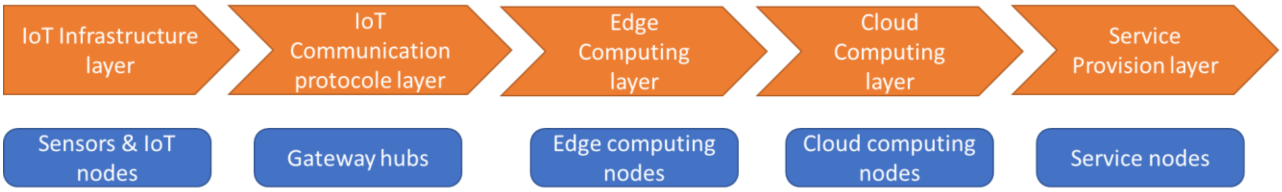

Figure 7: Privacy preserving smart building framework: five layers of data process flow

The Master System Integration (MSI) therefore becomes a critical role in the development of any complex smart building project where multiple vendor/supplier components or solutions are involved. While, in the past, the vendor doing the largest part of the work would take on the system integrator role and mainly focus on their solutions, the combined requirements of comfort and environmental performances (and their various associated solutions) do no longer allow this type of 'silo' management. The MSI's purpose is therefore to connect the building stakeholders to their systems and provide useful and meaningful information and control. Master System Integrators ensure that all systems communicate properly, collaborate with building owners to ensure systems information will be accessible and usable, and develop software layers responsible for integration, aggregation, and communication of the building systems.

Therefore, The Master System Integrator:

- needs to be engaged early (pre-construction phase) and on behalf of the client giving independent and impartial advice on the most appropriate solutions, integration, and delivery.
- needs to work closely with the main contractors and all mechanical/electrical systems, the applications and the myriad of vendors to create the required solutions and outcomes.

3.1.2. Human-building interaction and user interfaces

Human-computer interaction (HCI) is a multidisciplinary field of study focusing on the design of computer technology and, in particular, the interaction between humans (the users) and computers.

With the increasing incorporation of artificial intelligence and new forms of interactivity in buildings and urban spaces, a new research area is emerging, called **Human-Building Interaction (HBI)**, described as an interdisciplinary domain of research interfacing HCI with Architecture and Urban Design. H.S. Salavi et al. proposed a first definition of the field as follows:

"Briefly speaking, a building is a construction of physical elements that creates and protects a space. Each of these two aspects, the physical and the spatial, carry a social value: the former by the shaping and decoration of elements (with functional or cultural significance), and the latter by providing spatial patterning of activities and relationships. Designing Human-Building Interaction, in that perspective, consists of ***providing interactive opportunities for the people to shape the physical, spatial, and social impacts of their built environment****."*

In 2019, H.S. Alavi et al. proposed a mapping of some key research activities related to this new field, along the three above-mentioned dimensions (social, physical, spatial), as synthetised in the diagram in

Figure 8. In the diagram, the three concentric circles of "People," "Built Environment," and "Computing" reflect the three coordinates relevant to HBI questions. In addition, the classification comprising the interrelated dimensions of Physical, Social, and Spatial, specify the various but overlapping directions to which HBI research can contribute.

Figure 8 illustrates a few examples as how the various themes of research within HBI stretch their extent between the three dimensions.

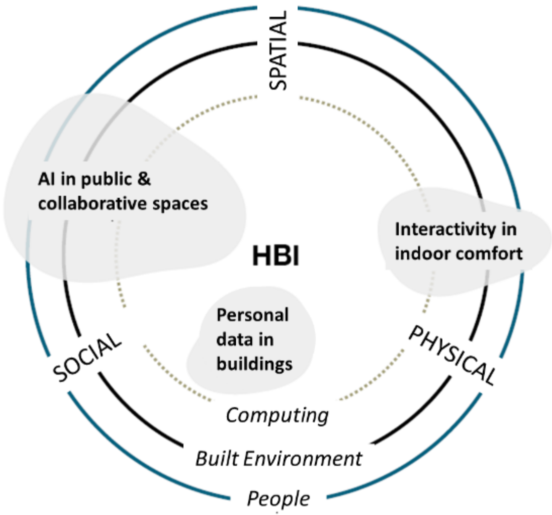

Figure 8: Mapping of some key research activities along within the HBI research scope
(H.S.Alavi et al. 2019)

3.1.3. Data privacy and trust

One of the key issues when considering the adoption of interactive solutions/services by building occupants is the potential distrust of occupants in the way data related to their life is collected and used. In the next paragraphs, some definitions are provided with regards to data privacy, digital trust, consumers trust in IoT, and trustworthiness of building digital twin environment.

Data privacy

There are many existing definitions of data privacy. In this context following definition is considered:

"Data privacy is the right of a citizen [building occupant] to have control over how their personal information is collected and used"[4]

The General Data Protection Regulation[5] sets six privacy principles:

- Lawfulness, Fairness, and Transparency
- Limitations on Purposes of Collection, Processing, and Storage
- Data Minimisation
- Accuracy of Data
- Data Storage Limits
- Integrity and Confidentiality.

Digital trust

The concept of trust in relation with the digitalisation process is not clearly defined yet. The World Economic Forum has launched a dedicated working group[6] seeking to establish a global consensus among key stakeholders around what digital trust means and what measurable steps we can take to improve the trustworthiness of digital technologies through security and responsible technology use. A cautious definition of **digital trust** could be, as proposed by Jeffrey Ritter, University of Oxford:

Digital trust is the confidence users have in the ability of people, technology and processes to create a secure digital world. Digital trust is given to companies who have shown their users they can provide safety, privacy, security, reliability, and data ethics with their online programs or devices[7].

Consumer trust in the IoT

While recent literature investigates the various dimensions of consumer trust, the concept of consumer trust in the IoT is rarely defined. Khan et al. (2019) proposes the following definition: *consumer trust in the IoT takes into account a holistic view of a consumer's behaviour; products that earn consumer trust must promise consumers that their devices are reasonably secure, and their data are protected; and consumers must have confidence that private data associated with identity are properly controlled.".* The authors propose a consumer trust model and derive a set of privacy requirements at different stages of a smart object working hierarchy.

[4] Converging definition proposed in various online sources, e.g. https://www.emotiv.com/glossary/data-privacy/
[5] https://gdpr-info.eu/
[6] See https://fr.weforum.org/global_future_councils/gfc-on-cybersecurity/projects/digital-trust
[7] Definition proposed by Jeffrey Ritter, University of Oxford

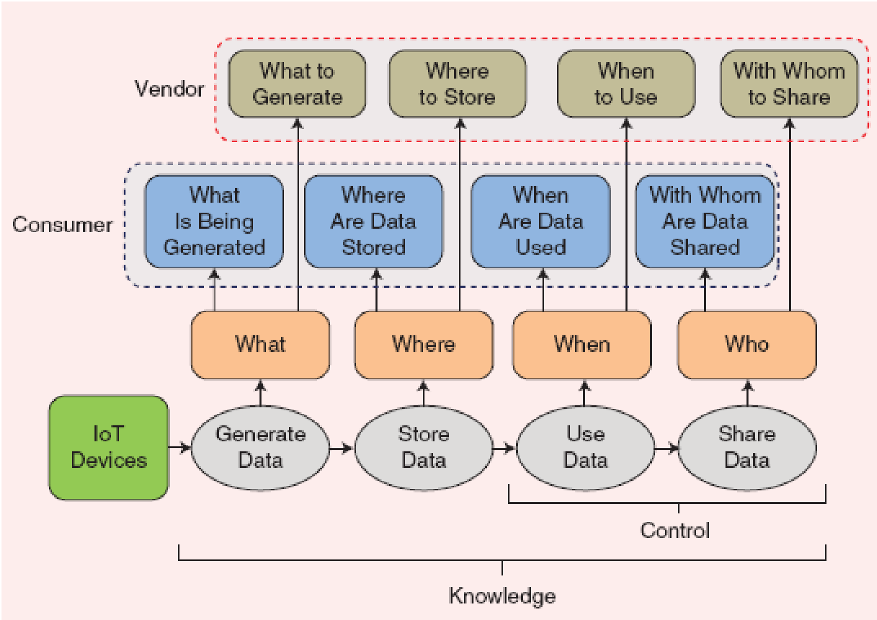

Figure 9: Privacy requirements for IoT devices (Khan et al. 2019)

Trustworthy Building Digital Twin Environment (BTDE)

The SPHERE project developed the concept of trustworthy Building Digital Twin Environment (BDTE), starting from the work performed by the high-level expert group on artificial intelligence about "guidelines for trustworthy AI systems". A trustworthy BDTE is thus defined as:

"incorporating lawful, ethical, and effective mechanisms that make it fair, transparent, accountable, safe, and robust to its users. It requires a design approach that make them trustworthy to its stakeholders from inception".

SPHERE also analyses how privacy-preserving computing can be applied to the context of IoT in buildings to tackle the technical challenges of data privacy.

3.2. Lessons learnt from Horizon 2020 and other R&D projects

Several H2020 projects were identified as addressing some aspects in the scope of this white paper, as depicted in Figure 10. They are clustered according to their respective focus (user behaviour, IT platform and interoperability, building performance indicators, and real-life performance measurement).

Figure 10: Relevant H2020 projects identified by the Task Force members

Among the ongoing projects directly contributing to Task Force 1, some were already able to provide some lessons learnt from their activities, as described in the next sections. These findings from EC-funded projects are also completed by valuable insights from national projects and private organisations.

3.2.1. Users' expectations on smart building interface: lessons learnt from the PHOENIX and BEYOND projects

The delivery of responsive applications is a point of examination in the **PHOENIX** project. A state-of-the-art analysis on existing solutions is performed but main emphasis for this white paper is on the feedback from the users (building consumers/prosumers). A survey took place at the very early phase of the project (end 2020) and feedback of over 100 participants was gathered considering the development of an intuitive and user-friendly UI.

- Overall, there is high interest about the visualisation of the information about smart energy systems and building performance (> 82% consider important or very important).
- The information should be accessible by different means (Web Portal: 50 %, Tablet: 13 %, Smartphone App: 72 %).
- There is interest for customisation of time period for data visualisation (> 60%), considering also the diversity on the feedback from building occupants about the updates on energy and environmental data {Real time: 22 %, Hourly: 7.5 %, Daily: 24 %, Weekly: 41 %, Monthly: 46 %} or smartness of the building reporting (KPIs about SRI, energy reporting, comfort levels: Real time: 28 %, Daily: 22 %, Weekly: 48 %, Monthly: 39 %).
- Regarding the information to be visualised through the applications for building occupants, the priority is balanced between: Comfort & Convenience 30 %, Energy Savings: 44 %, Smart Energy Management: 26 %.
- Building occupants are interested to get insights about different energy and non-energy metrics: (multiple answers): Total Energy Consumption: 63 %, Energy Consumption Savings: 46 %, Comfort

Level: 35 %, CO2 Emissions: 33 %, Historical Consumption: 28 %, Environmental Conditions: 28 %, Energy Consumption Waste: 26 %,

- Also, information about consumption of similar peers (neighbours, prosumer clusters etc.) show high interest (63 %); but even much higher is the interest about energy use compared to past behaviour (last week, last month etc...): 93 %.
- High interest for information about comfort levels (89%) and IAQ monitoring (91 %) in the COVID era.
- Practical information about updates for maintenance of building devices (80 %) is an interesting feature, or local generation and self-consumption insights (82 %) in case of Solar Panels installation.

The **BEYOND** project develops and offers a big data platform and an AI analytics toolkit that allows energy value chain actors to search, find and utilise data generated by buildings. By using the platform, these actors can run analytics and simulations during the real-time runtime of the buildings to optimise their operation and energy performance. To form the user requirements, a questionnaire was designed and distributed to building occupants. Some key outcomes are listed below:

- The participants seem to be willing to pay some money for installing some sensors for monitoring the indoor building conditions.
- The most common priorities for the establishment of the smart building were energy savings (45 %), comfort and convenience (33 %) and smart energy management (22 %). This appears in their preference on the indicators they would like to monitor (total energy consumption: 72 %, energy savings: 66 %, comfort level: 57 %, CO2 emissions: 54 %).
- The majority of respondents (76 %) would find a mobile interface useful for the monitoring of such indicators, while 40% of the respondents prefer to use the Web and 30% prefer a tablet.
- Most of the participants are interested in getting insights about their energy usage compared to similar neighbouring profiles (yes: 73 %, no: 10 %, not sure: 17 %). An even greater majority would like to monitor his energy usage compared to his past behaviour (93 %).
- This monitoring would be preferred to be provided via a mobile application in most cases (68 %), while the web and tablet applications would be utilised by 34 % and 27 % respectively.
- Also, there is a high interest in monitoring various indicators concerning the indoor conditions and comfort in their premises and specifically indoor temperature (somewhat important: 71 %, very important: 24 %), indoor air quality (somewhat important: 29.3%, very important: 61%), indoor humidity (somewhat important: 40 %, very important: 37 %) and luminance (somewhat important: 35.4%, very important: 29 %). They again think that it is more sensible to view these indicators mainly via a mobile application (77 %) and less via web or tablet applications (39 % and 27 % respectively).

3.2.2. Impact of water consumption monitoring on users' behaviours: lessons learnt from Decfon8

Defcon8, an organisation represented in this task force, developed a smart water monitoring app, demonstrated through a large demonstration in Zaragoza, Spain. Valuable experience was shared regarding occupants' feedback when provided information on their water consumption:

- Application in hotels: real time feedback of water usage during shower saved an average of 11% water even without providing any economic benefit to customers
- Application in tourist apartments: experiment showed that some members of the cleaning staff left the hot water tap running in the bathroom for 7 minutes to clean the mirror & tiles easily
- Application in eco bungalows requested to provide users their water footprint as a % of used water was recycled for garden
- Application in typical household: 15% water saved by changing behaviour daily habits

A more complete example is detailed here:

https://www.theguardian.com/lifeandstyle/2014/jul/30/zaragoza-smarter-urban-water-zaragoza-spain-learned-to-use-less

3.2.3. Real-time monitoring and data validation on demonstration sites: lessons learnt from SPHERE project

Return on experience about the demonstration sites: despite of a 4- year project duration (i.e. long time span), the problems encountered with the pilots during pandemic time made quite difficult to get good monitoring and results to be used with simulation models. We should be using dedicated installations for monitoring from the first day, to ensure validation at any time since the beginning of the project. Experimental building available in the EU could be more than interesting.

Return on experience on validation procedures: to get an idea of how good the real time simulation was compared to monitoring, one year of signal measurements were recorded. Several simulation software and models were used, and it is clear that a non-casual mathematical procedure gives a great flexibility and may be adapted to commissioning scenarios, where only part of the installation is available. In other words, mathematical solver is important to validate when signals are not perfect and when several scenarios need to be considered.

Regarding simulation standards: it is clear that if we want to get economic and reliable mathematical simulations, the use of standards is a must. These standards must consider equipment components (SIMBOTS) and ports as well. This was the matter of the simulation workshop at BDTIC 2022 in Barcelona, and the idea is to present a first standard (draft) at the end of 2022 at CEN442 WG9.

3.2.1. Data privacy: developments by the SPHERE project

Some of the delays were originally generated by a complicated and inefficient privacy protocol. A new privacy metric tool was developed which was presented at CEN 442 WG9 in Bratislava in September 2022 and was also presented at the BDTIC 2022 in Barcelona. This tool would have allowed a defined privacy estimation of each monitoring protocol.

3.2.0. Actual behaviours of residents in zero energy renovated homes: lessons learned from the Dutch project 'IEBB' (Energy transition in existing buildings)

The main objective of the Dutch IEBB project on energy transition in existing buildings is to arrive at acceptable, affordable, and scalable renovation solutions for residential and non-residential buildings in the Netherlands. For existing homes, this involves a significant cost reduction (20-40%) and the reduction of nuisance for the resident as the renovation process is limited to a maximum of 5 days. Thus, the project focuses on concepts for buildings that can be industrialised, based on usage typology and based on measured data. Lessons learnt are shared below regarding the performance monitoring of renovated homes, with a specific focus on the role of occupants' behaviour, interaction with the building technologies and satisfaction on building performance.

Analysis of existing renovation projects in the Netherlands showed the following:

- All publicly available cases studies reported positive results (e.g., energy neutrality in zero-energy projects). However Dutch statistical analysis has previously shown discrepancies between the predicted and actual energy consumption.

- In these case studies, we found that underconsumption in of final energy use in some categories like domestic electricity, compensates for the overconsumption in another final energy use like heating electricity.
- Energy neutrality (or overall energy performance) should best be analysed as a whole (i.e., neighbourhood level), not on an individual (i.e. per home) basis.
- Although data on occupants' satisfaction is collected, there is rarely data collected in relation to occupants' behaviour or interaction with the building technologies (i.e., thermostat settings and setbacks, opening windows, etc.).
- In the instances when energy consumption is higher than expected, or when occupants are dissatisfied with some system, the cause is rarely investigated.

Results from monitoring campaign in zero-energy renovated homes, where in line with the results of the published case studies:

- The actual behaviour of users differed from the behaviour expected by the housing association and installers.
- The behaviour of the residents depended on their personal preferences, needs, lifestyle and habits.
- Residents complained about the interaction with mechanical ventilation system, radiators, and thermostat. In many cases, they didn't received feedback from the device whether it was working or not.
- Some residents didn't fully understand how the systems in the house worked, for example a resident didn't know that the balance ventilation system also supplies fresh air.
- Some residents didn't know how to properly maintain the various systems in their homes.
- Indoor temperature provided by the systems (19-22oC) was not always satisfactory for the residents. For example, one household said to be too cold all the time, so they purchased additional electrical heaters. Two households complained on the bedrooms being too warm to sleep at night.
- Residents tend to open windows during the winter. They do it to get fresh air, or to regulate the temperature when they cannot do it via the radiators or thermostat.
- Residents tend to set the mechanical ventilation on the lower setting due to the noise it creates either for themselves or even for pets. This affects the indoor air quality.

3.2.1. Development of user-centred apps: ongoing activities of the Smart2B, Auto-DAN and domOS projects

Smart2B aims to enable smart buildings to interact with their occupants and the grid in real-time to untap energy efficiency and local flexibility. The project follows a user-centric approach that simplifies equipment and device control and delivers information about the total energy performance.
The user interface app is intended to make the bridge between the energy management system and the users, through the presentation of energy and comfort related dashboards, definition of user preferences, user feedback requests and a gamification component.

Related to the topic at hand, key lessons learnt include that producing a tool that ensure a continuous engagement of the users is difficult, and that it is essential to involve users from the initial stages of app development, even in the definition of its concept and the approach to be followed.

Auto-DAN aims to produce a cost-effective technological solution for the self-assessment of the actual energy performance of buildings and the products which use energy in buildings, by exploiting IoT and data technologies. Auto-DAN is working on the creation of an interactive dashboard which will be able to provide useful information to the building users and increase the user awareness of energy efficiency of both the building and appliances. This dashboard rests its foundation on a 'live' energy audit and the calculation of indicators related to four main types:

- Building-level performance indicators
- Appliance-level performance indicators
- Smart-readiness evaluation
- Financial indicators based on the implementation of Demand-Response strategies.

The interface of this dashboard with the user is intended to be as simple as possible to be used also by non-technical users and to introduce behavioural changes that would lead to a better quality of life, energy efficiency and money-saving. The dashboard has the function of providing building users with the awareness to proactively optimise their energy use.

domOS elaborates an ecosystem that allows multiple smart services to access multiple field appliances (if permitted) in a model-independent way. The approach enables a management of smart services inspired from the smartphone ecosystem: apps can be selected from an app store, deployed in the building if the infrastructure is appropriate, and privacy is controlled centrally. The domOS ecosystem requires that a common nomenclature is used to describe buildings and to provide a generic view of monitoring and control points within energy appliances inside building. This nomenclature – called "domOS Common Ontology (dCO) - should be generic enough to cover the broad spectrum of buildings in Europe and detailed enough to support the requirement of specific smart services.

3.3. Other relevant international initiatives

Other relevant other international initiatives include the IEA Annex 79 entitled 'Occupant-Centric Building Design and Operation', that is currently leading research on how to integrate and implement occupancy and occupant behaviour into the design process and building operation to improve both energy performance and occupant comfort. A specific activity is focused on providing guidance on occupant-centric controls (OCC) based on field observations, to close the gap between predicted and measured performance and user satisfaction. Among the main investigated success factors are occupants' acceptance of automated systems, usability of interfaces, communication and training of occupants and operators.[8].

4. Barriers and drivers

4.1. Barriers

Barriers to the development of more interactive and influential smart building solutions were listed and prioritised by the Task Force. The top barriers are highlighted in Figure 11.

[8] See Annex 79 newsletter from Nov. 2021

BARRIERS	
TECHNICAL	1. Difficulty to establish the exact relation between data collected, data retrieved to user, and impact of user response to this information
	2. Lack of mechanisms/ platforms and related governance models to consolidate data into actionable intelligence
	3. Existing legacy systems not compliant with standards
ECONOMIC	4. Data has become strategic and sharing it is seen as a risk or loss of opportunity
	5. High cost of data-driven solutions and lack of financial incentives
	6. Lack of information to occupants and building managers on long-term benefits of SB solutions
SOCIAL	7. Data privacy issues: lack of knwoledge by occupants about data privacy procedures in smart buildings (Who will do what with my data?)
	8. Lack of digital skills that can help occupants to use smart building technologies
	9. Limited data and feedback on/from vulnerable users (occupants with disability, the elderly)
VALUE CHAIN	10. Data ownership and governance issues: who owns the data and who captures its value?
	11. Lack of application by the industry of existing standards (ISO, CEN) related to interoperability, data models, product catalogues
	12. Lack of standardisation of novel occupant behaviour modelling - accounting for user diversities
REGULATION	13. Discrepancies between local and national regulations and legislations
	14. Lack of normative and technical regulations to support the mitigation of the energy performance gap between design and operation phases

Top barriers according to the Task Force

Figure 11: Overview of main barriers

4.2. Drivers

Drivers supporting the development of more interactive and influential smart building solutions that were identified by the task force are illustrated in Figure 12.

DRIVERS	
SOCIAL	1. Users' need for user-friendly, clear, simple information related to their building
	2. Potential of behavioural change of building occupants though the provision of relevant feedback
	3. Integrated user-centric design and operation (by means of integrating social sciences and humanities disciplines into building design, construction and performance phases)
VALUE CHAIN	4. Shortness of housing stock, forcing to make a more efficient use of building stocks
	5. Energy flexibility potential from households and communities to support the power grid
	6. Optimisation potential of existing buildings/systems and future building designs through data collection, harmonisation and valorisation
TECHNICAL	7. Data aggregation potential (via interoperability, semantic models) to turn data in insightful information to users
	8. Multiple disciplines on data management and UX design towards user-friendliness, greater user-interaction, AI and machine-learning addressing user expectations
ECONOMIC	9. Total cost of ownership of smart solutions
	10. Need for one-stop-shop models (platforms) on data consolidation and sharing
	11. Transition to transparent and performance-based service provision
REGULATORY	12. Need to shift from footprint (CO^2) to handprint (positive impact in usage), involving total lifecycle understanding and management
	13. Trust related to GDPR implementation and model contracts

Top drivers according to the Task Force

Figure 12: Overview of main drivers

As an outcome of the open consultation process, an additional driver was proposed: the potential reduction of household costs thanks to the building information received.

5. Gaps

Based on the detected barriers and drivers, the Task Force members identified some research and innovation gaps regarding the development of more interactive and influential smart building solutions.

There are presented in the next table. The priority ones according to the Task Force are in bold.

Table 1: Suggested research and innovation activities

Type of activity	Activities
Research	▪ Implement participatory methods involving end-users, to: - understand the conditions of adoption of smart solutions - understand and identify the data/information needs of different building users (occupants, owners, facility managers, etc.), for different building types (residential/ tertiary, with different levels of smartness) - identify occupants' behaviours that can be modified and those that cannot - design solutions providing pertinent and actionable information to users in line with their energy practices ▪ Clarify data ownership, usage, and rights when data is aggregated and used in integrated services (platforms) ▪ Define how to share openly and harmonise the data: how to collect data from multiple sources? how to harmonise the data from different nature? ▪ Apply Artificial Intelligence, prediction, and modelling, to help fill the quality gap on real data collected
Demonstration	▪ **Deploy living labs (permanent pilots) giving open access to real data on building's monitoring and user perspectives** ▪ **Implement large scale demonstrators with emphasis on the active participation of end users, from the design phase. This implies engagement strategies relying on social sciences and humanities, and the use of techniques such as gamification.** ▪ Systematically integrate in demonstrators the monitoring of occupancy and weather data together with building parameters to ensure data quality
Regulation & legal framework	▪ **Integrate the user-centric dimension into regulation, i.e., the participation of users from the design phase and along the whole (smart) building life cycle** ▪ Design clear guidelines on data collection procedures: who can collect which data, whom should be informed the data collection and usage ('GDPR++')
Certification & standardisation	▪ **Develop real-time certification on building performances – not limited to energy – to provide users with actual building information** ▪ Enforce third-party certification regarding privacy building up the privacy metrics developed in the SPHERE project and proposed to CEN442 ▪ Propose KPIs and assessment framework to measure the level of engagement of users

Scaling up & industrialisation	▪ Support the integration/aggregation of services (and products) into one-stop-shops. E.g., a service package focused on 'comfort & wellbeing' includes energy efficiency services as well ▪ Demonstrate business models relying on new modes of collaboration/interaction with end-users
Awareness raising	▪ Assist users in understanding the data privacy procedures in smart buildings

6. Conclusion

This document formalises the collaborative work performed on a voluntary basis by the members of SmartBuilt4EU task force 1 during the period May 2022 – October 2022. It also integrates the feedback collected during a peer review conducted by VITO and the open consultation process held during October-November 2022. Based on an analysis of the state of the art and the identification of barriers and drivers, the main objective of this paper is to detect some research and innovation gaps that still need to be addressed in the coming years to support the development of more interactive and influential smart building solutions towards more sustainable occupants' behaviours.

This white paper will feed the elaboration of the strategic research and innovation agenda that the SmartBuilt4EU consortium will present to the European Commission.
To receive the updates on the SmartBuil4EU task forces, white papers and events, please register here: https://smartbuilt4eu.eu/join-our-community/

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Annex 1: list of H2020 projects reviewed

Table 2: list of relevant EU projects

Project	Status	Contact in TF	Weblink	Relevant inputs
EXCESS LIVE IN POSITIVE ENERGY	ongoing	Ivan Luque Segura	**https://positive-energy-buildings.eu/**	FleXible user-CEntric Energy poSitive houseS – will showcase how nearly-zero energy buildings can be transformed into positive energy buildings.
ALDREN	completed	Graziano Salvalai (POLIMI) Marta Maria Sesana (UNIBS)	https://aldren.eu/	BRP+Renovation roadmap ALDREN introduces a new dedicated indicators for comfort named TAIL included in the Building Renovation Passport as a specific module to be evaluated considering the user perspection.
Auto-DAN	ongoing		https://www.autodan-project.eu/	The project will exploit the evolution of IoT and emerging technologies to capture data and create solutions enabling self-optimisation of building's energy consumption. Auto-DAN will also produce a new dynamic (and continuous) self-assessment methodology that takes into account the actual energy performance of a building, the quality and operation of appliances/systems installed, user operational habits and the smart readiness indicator (SRI) of a building.
BEYOND	ongoing	John Avramidis/ Louiza Kachrimani	https://beyond-h2020.eu	BEYOND introduces a reference big data platform implementation for collecting, processing and analyzing building data, while transforming them into a tradeable commodity through the development of appropriate data sharing mechanisms for data sharing between different stakeholders.
cultural E+	ongoing	EURAC + ADVANTICSYS	https://www.cultural-e.eu/	IoT+ML+cloud for positive energy buildings LCC tool
domOS	ongoing	Dominique Gabioud	http://www.domos-project.eu/	Operating System for smart building: Any in-building infrastructure available for any monitoring / control / optimisation application, if permitted
EPC RECAST ENERGY PERFORMANCE CERTIFICATE RECAST	ongoing	Graziano Salvalai (POLIMI) Marta Maria Sesana (UNIBS)	https://epcrecast.wordpress.com/ https://epc-recast.eu/	New generation of EPCs House owners' considerations about usefulness of the EPC are central as owners decide whether to implement energy conservation opportunities provided by the EPC. EPC RECAST is a decisive decision-supporting tool for tenants and potential buyers. It provides guidance on cost-optimal building renovation for building owners, covering as well wellbeing and smartness and user centric indicators. EPC RECAST project will develop a well-structured process and a toolbox that will support the development, performance and validation of

				new EPCs focusing on existing residential buildings.
PHOENIX	ongoing	Dimitra Georgakaki, Kostas Tsatsakis	https://eu-phoenix.eu/	The aspiration of PHOENIX project is to change the role of buildings from unorganized energy consumers to active agents orchestrating and optimizing their energy consumption, production and storage, with the goal of increasing energy performance, maximizing occupants' benefit, and facilitating grid operation.
Smart2B Smartness to existing Buildings	ongoing	Nuno Matteus	https://cordis.europa.eu/project/id/101023666	SMART2B project will upgrade the capacity of existing buildings by developing non-intrusive Internet of Things sensors and actuators to control equipment, while improving indoor comfort and energy efficiency. The project will allow for coordinated control of legacy equipment and smart appliances and integrate two existing cloud-based platforms into a single building management platform.
SPHERE BIM DIGITAL TWIN PLATFORM	Ongoing		https://sphere-project.eu	Digital Twins + ICT Systems of Systems infrastructure based on Platform as a Service (PaaS) service to allow large scale data, information and knowledge integration and synchronization, to improve energy efficiency across buildings' entire lifecycle
MEZeroE	Ongoing	Graziano Salvalai (POLIMI) Marta Maria Sesana (UNIBS)	https://www.mezeroe.eu	Development of an open innovation ecosystem for the development of ground-based solutions focused on carbon neutrality and a healthy indoor environment. Living Lab test and analysis will be a strong innovative way for the user engagement to validate also the real performance of new solutions for buildings and for comfort.
NUDGE Nudging consumers towards energy efficiency through behavioural science	Ongoing		https://www.nudgeproject.eu/	NUDGE aims to systematically assess and unleash the potential of behavioural interventions towards achieving higher energy efficiency; and to pave the way to the generalized use of behavioural interventions as a worthy addition to the policy-making toolbox.
EVIDENT	Ongoing		https://evident-h2020.eu/	EVIDENT envisions the formulation of a framework to define the main drivers of individuals' decision making and to establish new relationships between energy consumption.
ENCHANT	Ongoing		https://enchant-project.eu/	Energy Efficiency through behaviour Change Transition – will test the impact of interventions affecting energy consumption behaviour on a large-scale across Europe.
WHY Climbing the causality ladder to understand and project the energy demand of the residential sector	Ongoing		https://www.why-h2020.eu/	WHY develops a new Causal Model combined with an innovative profiling approach to analyse human decision making in energy consumption and human reactions to energy policy changes.

syn.ikia	Ongoing		https://www.synikia.eu/	syn.ikia aims at achieving sustainable plus energy neighbourhoods. The concept is deployed on four demonstrators.
eTEACHER	Completed		http://www.eteacher-project.eu/about-the-project/	Performed a SoA on ICT-based engagement for EE; evidence-based approach for developing behaviour change interventions; Case studies of end-user behaviours in buildings